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CONCEPTUAL DESIGN METHODOLOGIES FOR WATERBORNE AND AMPHIBIOUS AIRCRAFT

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ABSTRACT

This study is laid out in 8 self-explanatory sections. The Introduction sets the scene for the thesis by describing the reasoning behind the study, defines terms and introduces the reader to the markets for amphibious aircraft which drive the design requirements.

An overall floatplane design methodology is developed. The advantages and disadvantages of the 2 practical float configurations are identified, which result in a basic configuration choice methodology. A method of initially estimating float dimensions and mass for a required displacement is developed from existing references and the aircraft and float databases. Initial float support structure design solutions are proposed based, again, on the information from the databases. A method of positioning the resultant float and structure configuration relative to the existing land-based aircraft centre of gravity is then developed using existing guidance on lateral and longitudinal water-borne static stability and the aircraft database. Guidance on the initial purchase price of floats is gained from a study of commercially available items. The changes in performance due to fitting floats to a conventional aircraft are studied along with a drag comparison study of the main configurations.

The work on flyingboats develops an overall flyingboat design methodology which identifies key areas where design methods are required. These methods are developed leading to initial configuration choice methodologies based on a series of generalised mass, configuration and role classifications. Having decided on the overall configuration, tools are developed to choose the method of providing on-water lateral stability and to complete the initial sizing of that choice. A method of estimating initial planing bottom dimensions is developed along with step position and configuration. Tools to estimate the mass of flyingboat-specific items are developed including planing bottom structure and the choice of lateral stability method. Knowing the mass and configuration of the flyingboat allows spray estimation and detailed on-water static stability calculations to be completed to check the acceptability of the initial configuration and dimensions. Performance estimation methods including take-off and landing, aerodynamic drag and on-water dynamic stability are proposed.

Logistic support infrastructure, safety and water loading are common to both floatplanes and flyingboats and these are discussed in a separate section, along with a method of allocating values to amphibious aircraft design attributes to measure the success of the design.

The methodologies are then used to design 5 floatplanes and 5 flyingboats based on a cross-section of relevant aircraft specification types. This use of the methodologies illustrates that the concept of a linked series of tools to complete the rapid conceptual design of an amphibious aircraft has been successfully achieved.

A discussion chapter summarises the key discoveries in each of then former chapters and a conclusion details how the study's aim to develop integrated conceptual design methodologies for waterborne and amphibious aircraft has been successfully achieved. The study's contribution to knowledge, which includes mass, sizing, performance and cost equations for both floatplanes and flyingboats, are also detailed. A list of further work is included which concentrates on the need for further empirical information to increase confidence in the methodologies.

A comprehensive bibliography of relevant texts is included.

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List of Tables

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NOTATION AND UNITS

The notation used throughout this study is either drawn from the relevant reference or is defined in the text itself. A summary of frequently-used notation is presented below. Many of the references used in the study were of the age or geographical background that Imperial rather than SI units were used. If this occurs in the text this is always highlighted.

A = area (m^2)
AUM = all up mass (kg)
a = moment arm (m)
b = beam (m)
B = tail uplift (N)
C_D = drag coefficient
C_L = lift coefficient
C_z = spray coefficient
C_Δ = beam loading coefficient
D = diameter (m)
d = distance (m)
g = gravitational acceleration (m/sec^2)
h = height (m)
L = lift (N)
l = length (m)
M = mass (kg)
S = wing area (m^2)
s = float lateral spacing (m)
T = thrust (N)
t = thickness (m)
V = velocity (m/sec)
v = volume (m^3)
w = weight (N)
y = lateral distance (m)
z = spray height (m)

β = deadrise angle (°)
λ = length to diameter ratio
Δ = displacement (kg)
ρ = density (kg/m^3)

Subscripts

ab = afterbody
b = bow
f = fuselage
fb = forebody
h = horizontal plane
n = nose
pb = planing bottom
w = wetted
x = cross-sectional
TO = take-off

Special Lateral Stability Notation (see Figure 2.5)

GM = metacentric height
KG = vertical position of centre of gravity
KB = vertical position of centre of buoyancy
BM = height of metacentre above centre of buoyancy

1. INTRODUCTION

1.1 LAYOUT OF THESIS

The thesis is laid out in 8 main self-explanatory sections: Introduction, Floatplanes, Flyingboats, Common Items, Using the Methodologies, Discussion, Conclusions and Recommendations. The Introduction sets the scene for the thesis by describing the reasoning behind the study, defines terms and introduces the reader to the markets for amphibious aircraft which drive the design requirements. The 2 main core sections cover the development of conceptual design tools for floatplanes and then flyingboats. These sections are configured to stand alone if the reader is only interested in one of the two topics. The sections are laid out logically following the path that a designer would use when designing such aircraft. Tables, graphs, figures and plates are located immediately after the relevant section's text. For example, Table A4.1 is the first table in Appendix 4. Similarly, equations are numbered relative to the section to which they refer. For example, Eqn 2.4 is the 4^{th} equation in Section 2. Certain aspects of design are clearly relevant to both types of aircraft but those which identify strongly with one or the other are included in that particular section. For example, spray height is relevant to both types of aircraft but is a more important design parameter for flyingboats than floatplanes and is therefore studied in detail in Section 3. Conversely, aerodynamic stability is primarily a significant concern when floats are added to existing aircraft and is therefore discussed in Section 2. Areas of interest which are not particularly tied to floatplanes or flyingboats are included in Section 4. Section 5 uses all the tools to design floatplanes and flyingboats to fill the key markets identified in the Introduction. The Discussion summarises and links the main points of the previous sections and the Conclusion details how the thesis fulfils its objectives. The Recommendations detail further work required. For clarity and ease of progress, appendices are used to derive the more long-winded calculations and relationships used in the main text.

1.2 REASONS FOR STUDY.

In late 1993, as part of a MSc in Aerospace Vehicle Design at Cranfield University, the author undertook a conceptual design investigation into the RAF Nimrod replacement $_{(1)}$. As part of this study consideration was given as to whether a modern amphibious flyingboat could practically fulfil the specification, bearing in mind that at that time the Beriev Be42 Mermaid jet amphibian was being considered as a possible contender (see Plate 1.1). During the investigations it was discovered that there were very few modern guides to the conceptual design of such aircraft. The design tools available in the open press were either from the 1930s, 40s and 50s, were extremely generalistic or conformed with particular company's views. In some cases guidance was contradictory. It was therefore concluded that there was a requirement to produce a series of up-to-date conceptual design tools for amphibious aircraft. This need was underlined by the continued interest in float-equipped and flyingboat type aircraft in utility, sport, commuter, firebombing and large cargo transport roles. An examination of any recent Janes All The World's Aircraft reveals that float-equipped versions are available for almost every size of utility aircraft, up to and including the C130J Hercules (see Plate 1.2) and new flyingboat designs appear each year. The expansion of the economic power of developing countries of the world, in particular those of the Pacific Rim, has caused renewed interest in amphibious aircraft. These regions are not equipped with the existing airport infrastructure, often dating back to World War 2, which in essence subsidises conventional land-based aircraft operations in North America and Western Europe. This requirement for design tools for amphibious and waterborne aircraft forms the basis of these studies towards a PhD in Aerospace Vehicle Design.

1.3 OBJECTIVE.

The objective of these studies is to develop an integrated waterborne and amphibious aircraft design methodology capable of producing floatplane and flyingboat designs to fulfil any relevant current or future subsonic specification.

1.4 DEFINITIONS.

1.4.1 Conceptual Design. Various definitions of conceptual design exist, but the author has chosen a development of that provided by Moore (2) and Raymer (3) as follows:

> Conceptual design extends from the development of requirements through the determination of a vehicle concept and size estimation to a point where there is a confident geometric definition of the vehicle which will support the detailed design of the actual hardware.

To this the author has added the requirement to identify and quantify other data which will enable the designer to fulfil a likely specification, for example performance and cost of ownership. Note that this definition includes the process of embodiment design defined in BS 7000 (4).

1.4.2 Amphibious Aircraft. An amphibious aircraft is defined as an aircraft which can take-off from and land onto a water surface. Within this general definition the following specific definitions are included. These will be used throughout this study:

a. Pure Floatplane. A pure floatplane is defined as an aircraft which can only take off/land from/on water and derives its flotation from discrete floats (see Plate 1.3).

b. Amphibious Floatplane. An amphibious floatplane is defined as in 'a' above but is equipped with wheels to enable it to take off/land from/on land in addition to water (see Plate 1.4).

c. Pure Flyingboat. A pure flyingboat is defined as an aircraft which can only take off/land from/on water and derives its flotation from a specially configured fuselage (see Plate 1.5).

d. Amphibious Flyingboat. An amphibious flyingboat is defined as in 'c' above but is equipped with wheels to enable it to take off/land from/on land in addition to water (see Plate 1.6).

Not included in this study's definition of amphibious aircraft are wing-in-ground effect (WIGE) aircraft, hydrofoils or hovercraft.

1.4.3 Flyingboat Hull Form. The form of a flyingboat is different from that of a land-based aircraft to reflect the design compromises enabling it to operate from water as well as the air (see Figure 1.1). In particular, the bottom of the fuselage is, ideally, flat to allow it to plane across the water surface on take-off and landing. To reduce the effect of water impact loads this planing bottom is usually set at a symmetric angle to the horizontal when viewed from the front elevation: the deadrise angle. There is usually a sharp discontinuity between the planing bottom and the rest of the fuselage. This is known as the chine and ensures that the water surface breaks cleanly away from the fuselage avoiding the Coanda effect holding the flyingboat to the water. Viewing the flyingboat from the side elevation illustrates the bow angle, necessary to help the flyingboat break through waves, and the step. The purpose of the step is, like the chines, to act as a discontinuity to the water flow during planing. This limits planing to the area forward of the step, around the centre of gravity, where the pitching moment changes are more controllable and stops the aft portion of the hull generating Coanda drag. The final point of note is that the flyingboat must be stable when at rest on the water. This is achieved by providing buoyancy away from the centreline in the form of tip floats, stubs or parts of the wing.

1.4.4 Float Form. The form of the floats used on floatplanes are similar to flyingboat hulls with some additional points of interest (see Figure 1.1).The float sternpost angle must be at least equal to the take-off trim angle for the original landplane. If the angle is lower the stern of the float will trail in the water on take-off, significantly increasing take-off distance. The planing bottom of an inflatable float does not require deadrise to lessen the water-impact as it relies more upon the flexibility of inflatable airbags to absorb the force. The float main body must not only transfer the landing loads to the struts and thence to the main airframe structure, but must also displace the required volume of water. The float structure should also be able to support the weight of passengers or maintenance staff moving on the upper surface. The internal volume of the float can be used to transport fuel or cargo. Main undercarriages are usually located behind the step in the less-heavily loaded afterbody. Nose undercarriages are frequently semi-retractable to allow the tyre to form a bow bumper. On pure floats a rubber bumper is often used for this purpose. Water rudders are attached to the rear of the float and must be able to be retracted when the floatplane is above a certain speed when taking-off and landing. Float support struts follow the same construction rules as similar wing support structures.

1.5 THE MARKETS FOR AMPHIBIOUS AIRCRAFT.

1.5.1 Introduction. There are 3 main potential markets for flyingboats and floatplanes: commercial, military and private. Although each relies upon the amphibious aircraft's unique ability to operate from water, each also imposes priorities which must be considered during the conceptual design process. The tools developed in this thesis allow a designer to fulfil these requirements with confidence.

1.5.2 Commercial Markets. Amphibious aircraft currently targeted at commercial operators usually rely on their ability to operate from water surfaces very close to the customer's start point or destination to differentiate themselves from conventional landplanes. Thus, floatplanes or flyingboats targeted at business travel operators stress their ability to land close to city centres on river or lake locations, therefore significantly reducing journey time by cutting the conventional aircraft's door-to-airport land transport time. In this way the usual performance disadvantage of an amphibious aircraft can be offset. An example is the PanAm (ex Chalks) Turbo-Mallards operating on the Fort Lauderdale to the Bahamas route (see Plate 1.7). However, this type of operation requires some form of specialised seaplane base close to city centres and environmental and safety problems with aircraft in close proximity to densely populated areas must be considered. The latter requirement means that noise reduction on take-off, approach and taxiing must be a large consideration when designing aircraft for this market area. As the competing transport types are usually ground-based, the business-targeted amphibious aircraft must attempt to be equally comfortable and have easy boarding systems - clambering around wet, slippery docks or using boats is not acceptable. In almost every case a business traveller-targeted flyingboat or floatplane should be amphibious to allow it to operate into and from conventional airports, for example in Alaska $_{(5)}$, although in well proven harbour-to-harbour routes, such as the Canadian west coast, pure floatplanes and flyingboats are practical. Another commercial target for amphibious aircraft is the customer whose destination is in an island, wilderness or outback region far from conventional airports or even dirt strips. Examples include logging or mining operations and tourist (usually fishing) transport. The main competition to amphibious aircraft in this area are STOL utility aircraft and helicopters, and therefore a flyingboat or floatplane must seek to match these aircraft's' load carrying ability (both mass and volume) and ease of loading awkward freight. This not only defines float configuration but also puts a high value on large door sizes. Low cost of ownership is a key advantage over helicopters. The transport of ultra-high volume freight has been an oft quoted, although seldom realised, commercial target market for very large flyingboats. Advantages include the savings of mass due to the lack of an extensive undercarriage - the projected super Jumbos may require 24-wheeled undercarriages - and good design synergy, with the bulky freighter fuselage automatically providing engine/wing spray height and good provision for planing bottoms. Large beam freighter flyingboats may be sufficiently laterally stable not to require additional features such as tip floats or stubs giving further mass and performance advantages. A further advantage may be the use of existing ship-based freight handling systems, especially if standard freight containers are used. Studies have included Dornier's flying ships of the 1980s (6) (see Figure 1.2) and the more recent Hydro 2000 project from France (see Appendix 1).

1.5.3 Government Agencies. Government or pseudo-official uses of amphibious aircraft are largely confined to active military or more passive coastguard/environmental patrol/survey functions along with firebombing. Active military uses include anti-submarine/anti-surface unit operations, combat search and rescue and overt/covert troop insertion. All roles tend to demand long range and a high payload along with good crew comfort to increase effective endurance (7). To maximise the aircraft's flexibility to operate from unprepared, dispersed locations a high degree of maintainability and autonomous support is required. Similarly, to ensure that military operations are not limited by weather conditions, a good standard of seaworthiness is needed. High dash speeds to the area of operation may be an advantage. Rapid deplaning, either into assault boats or directly onto a beach, requires large, low-mounted freight doors such as those seen on the Thai Air Force CL215 aircraft (see Plate 1.8). A more optimised freighter is the float-equipped C130 Hercules which is primarily marketed at the covert insertion of Special Forces' boats and other heavy equipment from the rear ramp (see Plate 1.2). The use of amphibious aircraft in this type of operation was successfully demonstrated during the German invasion of Holland in 1940, when floatplanes landed storm-troopers onto Dutch rivers and canals to capture key bridges. Equally, during peace-time exercises, the Convair Tradewind demonstrated its assault capability by landing US Marines and their heavy equipment directly onto a beach (see Plate 1.9). Managing the risk of loosing such an expensive asset would ensure that the beach was not actively defended by the enemy and the relevant sea-bed was well reconnoitred. More passive coastguard-type patrolling again requires a long range and comfortable crew conditions, and a high payload may be required to enable the aircraft to carry droppable rescue stores if a water landing is impractical. In some cases small, simple amphibious aircraft can make cost-effective patrol aircraft in civil, police or low-intensity operations where a conventional airfield is not available. The US Navy trialed a Pereira Osprey in SE Asia for this role in 1971 (8) and the French currently use Petral aircraft to patrol the Ariane rocket launch zone in French Guyana. However, patrol operations more often require a powerful radar and the design compromises necessary to interface a radome into a flyingboat configuration can be challenging. Bow chines necessary for good wave penetration require careful integration into a nose radome geometry and the provision of mooring fixtures must be carefully examined. The complexities of this exercise for relatively small flyingboats can be seen in the form of the Dornier Seastar nose radome (see Figure 1.3a). Roof-mounted radar such as that fitted to the Martin Mariner (see Figure 1.3b) results in high drag and retractable radomes are complex and, again, cause drag when deployed. Smaller aircraft with single, high mounted pusher engines such as the Lake Renegade-based Seawolf have a natural mount for a radar in the nacelle front, although vibration needs to be carefully damped. Anti-submarine warfare operations using flyingboats floating on, rather than merely based from, the water were trialed by the US Navy in the late 1950s, when a modified Martin Marlin was equipped with a dipping sonar (9). Along a similar vein, vertical floats were experimented with to improve the sea-sitting capabilities of such aircraft (see Section 4.6). These trials had a variety of success but take-off and landing in high sea states remained a problem and the development of efficient sonobuoys killed off the idea for military purposes. The idea of a dipping sonar has, however, been recently re-activated for ecological and survey work as an option on the Beriev Be200 flyingboat (10).

1.5.4 Firebombers. Firebombing has been the most successful government-related role for recent flyingboats, with ex-military Mars and Catalina-based aircraft operating alongside purpose-designed Canadair CL215, CL215T and CL415 aircraft all over the world. The Beriev Be200 jet flyingboat is also primarily aimed at the firebombing market (see Plate 1.10). The amphibian's advantage over a land-based water bomber is primarily its ability to re-load water while skimming a suitable water surface, although flexible basing close to potential fire risk areas and safe emergency landing in forested country are also positive factors. However, this flexibility is also available to underslung bucket-equipped helicopters (11), and therefore the range, shorter time-to-fire and cost of ownership advantage of the flyingboat must be carefully exploited if such an aircraft is to succeed. The firebombing role favours high fuselages, as the water or foam tanks can be more easily grouped close to the centre of gravity to avoid rapid pitch changes during the drop. The ability to take on large masses of water while planing on rough water demands a rugged structure, illustrated by the Be200 requiring extra wing root reinforcement in the firebomber version (10). Retractable floats allow a firebomber flyingboat more bank angle safety when planing on the step to pick up water. The speed/drop weight ratio for firebomber flyingboats is a contentious issue (12). The Be200 flyingboat is jet-engined and is optimised towards more distant basing from the fire. Thus fast dash to the fire location is important. This reflects the topography of the aircraft's prime market: Russia. On the other hand, Canadair's CL215/415 aircraft designs and the AAA are propeller powered and rely on closer basing to the fire with a lesser reliance on dash speed. Similarly, aircraft size (and therefore drop mass) is a variable, the ratio of water load to AUM noticeably increasing with AUM. Data for 4 relevant aircraft is summarised below.

Aircraft	AUM (kg)	Water load (kg)	Load ratio	Max speed (kts)	Endurance (hrs)
Mars	74910	27180	0.36	207	5.5
Be200	36000	12000	0.33	?	3
CL415	19731	6130	0.31	203	4.2
CL215	19278	4500	0.23	164	2.9

1.5.5 Private Aircraft. The flyingboat or floatplane as a personal, private aircraft relies primarily on its freedom from normal airports to differentiate itself from other light aircraft. In a similar manner to commercial operations, the ability to base the aircraft close to home and land close to the destination is also an advantage. There is also a considerable element of additional romance and excitement to water landings and take-offs which is frequently used in the marketing of this type of aircraft (13). However, this must be balanced by an understanding of the limited maintenance resources available to private owners and such flyingboats and floatplanes should be extremely simple to maintain in an environment which is potentially much more hostile to the aircraft than a conventional airport. The private operator is, on average, with the aircraft for far fewer hours than the commercial or government operator and may only have received minimal training. Safety must therefore be a strong recurring element in aircraft targeted at this market. For example, keeping the propeller away from entrance/exit area is a useful configuration input.

1.6 SOURCES OF DATA.

1.6.1 Introduction. A literature search was initiated at the Ministry of Defence (London), Royal Aeronautical Society (London), Royal Air Force College (Cranwell), Italian Air Force (Florence) and Cranfield University libraries, the Southampton Flyingboat Museum archive and the UK Public Records Office (London). This identified 3 main sources of information: specific aircraft and float data, research findings and general information.

1.6.2 Specific Aircraft and Float Data. Specific aircraft data was used to compile a floatplane and flyingboat database (see Appendix 1). To ensure that a sufficiently large statistical sample of this niche of aircraft design was available for analysis the database covered as much information as possible on monoplane flyingboats from 1934 to date with primarily metal construction and as many floatplanes as possible in the same period. This admittedly long period was chosen as it represented the life of what may be considered as "modern" aircraft. Certain aircraft which were considered to represent significant data points, but which were outside this capture envelope, were also included. For example, stub-equipped aircraft from 1930-34 were included to ensure a statistically relevant sample of such aircraft. Biplane flyingboats were not included as it was felt that the biplane layout had too great an effect on the fuselage/wing configuration to draw relevant conclusions for modern aircraft. However, biplane floatplanes were included as the study's work on adding floats to existing land-based aircraft was largely independent of the lifting surface configuration. In addition to the floatplane database a modern float database was compiled using details gained from float manufacturers. Wherever possible, a variety of aircraft manufacturing firms and countries were used to avoid a single style unbalancing the results. Much dimensional information was gained by scaling drawings from Janes All The World's Aircraft and similar sources, but due to the potential inaccuracies implicit in this technique dimensions quoted in text were used in preference. There is a potentially large number of light floatplane data points available from references such as Janes. However, relatively few were used for, say, the mass and sizing exercises as such high quality data was available from the float manufacturers' information. Note that a complete set of information was not available for each aircraft in the database; in some cases only the configuration of the flyingboat or floatplane was available whilst in others the aircraft was described in minute detail with a full set of specifications, dimensions and in some cases build drawings. The databases contain the following information:

flyingboats: 132 aircraft (and an additional 30 project designs)
floatplanes: 90 aircraft
floats: 76 pure and amphibious floats

Note that project designs are defined as those produced by aircraft manufacturers or research organisations (such as NACA) for which good quality information was available but no actual aircraft was or has yet to be produced. Student projects are not included. Aircraft which were included in the most up-to-date issue of Janes All the World's Aircraft at the time of writing and for which a full-scale mock-up had been constructed or indication of prototype manufacture was present were included in the full database.

1.6.3 Research Data. Research data such as NACA, ARC and MAEE reports were in many cases used as the start-point for developing more up-to-date design tools. To account for the time lapse before the results of basic research are reflected in actual design practice the period 1930 to date was chosen to match with the specific aircraft database. If not specifically referred to in the text, details of these reports are included in the bibliography.

1.6.4 General Data. General data from books and articles was used to verify and/or weight the information derived from the specific aircraft database and the research data. Similarly, on-site visits to relevant organisations with amphibious aircraft connections enabled first hand data to be gathered from actual aircraft and their designers and operators. Visits to operators have included private bases at Oslo (Norway), Vancouver (Canada), Florida (Jack Brown's Seaplane Base – US) and Australia (Pacific Seaplanes). Also visited were the Canadian water-bombing organisation, Forest Industries Flying Tankers, and the Miami-based commercial service run by Pan Am Air Bridge. Visits to manufacturers included Canadair (Canada), Progressive Aerodyne (US), Lake (US), Dornier (Germany), Warrior Aeromarine (UK) and Aerocomp (US). Visits to museums and collections have included the Hendon (UK), Southampton (UK), Duxford (UK), Cosford (UK), Pensacola (US) and Soesterberg (Netherlands) aerospace museums. In addition, the author has become a member of the Seaplane Pilots Association (SPA). Aspects of this study were successfully presented at ICAS 96 (14) and IAC 97 (15).

1.6.5 Acknowledgements. The author gratefully acknowledges the open, constructive and helpful assistance of all the personnel at the above organisations. Names are too numerous to mention, but the level of enthusiasm shown both by those visited and those who helped via written communications has been unparalleled in the author's 20 years in the aircraft industry. The challenges of air, land and water bring out the best in the aerospace professional.

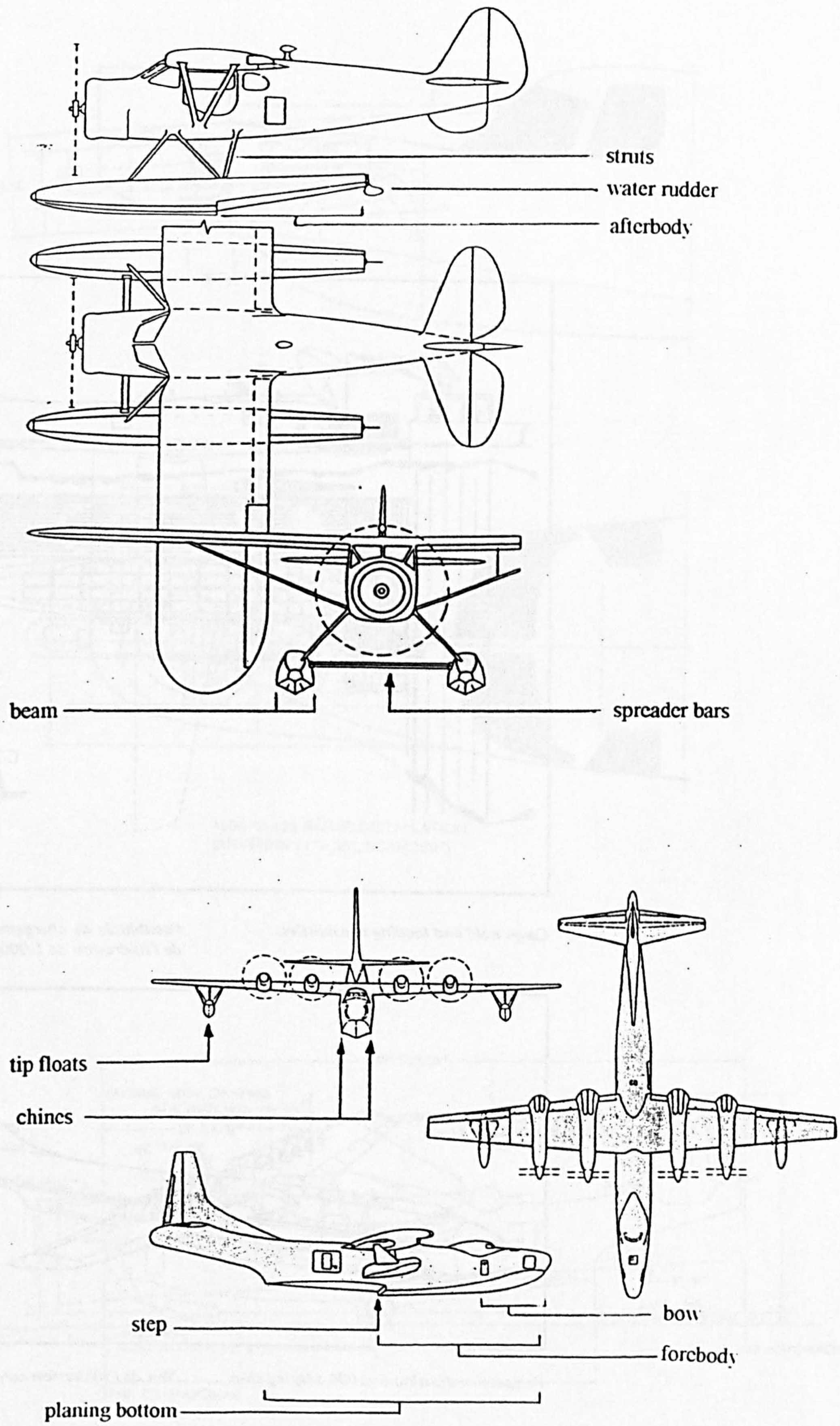
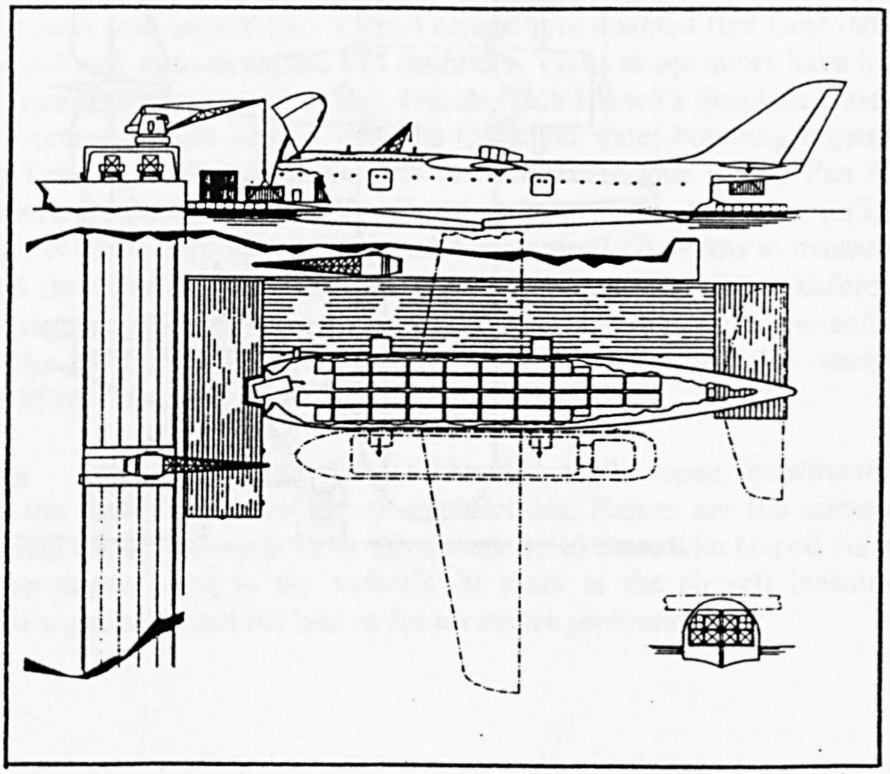
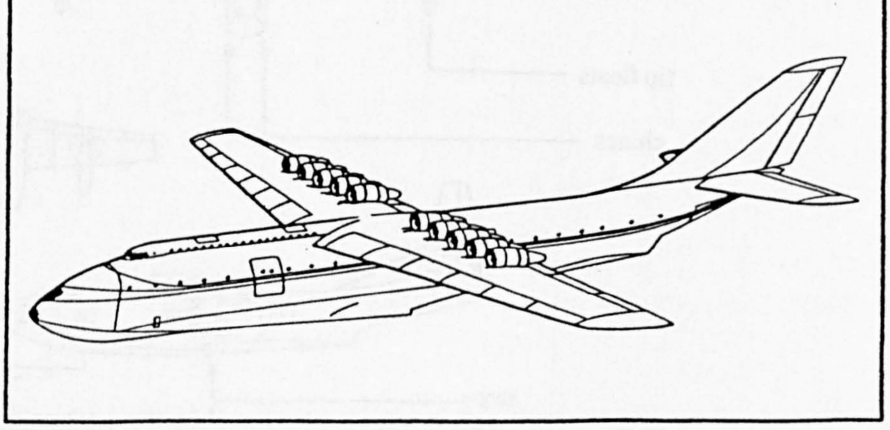


FIGURE 1.1. FLOATPLANE AND FLYINGBOAT TERMINOLOGY



Cargo hold and loading capabilities.

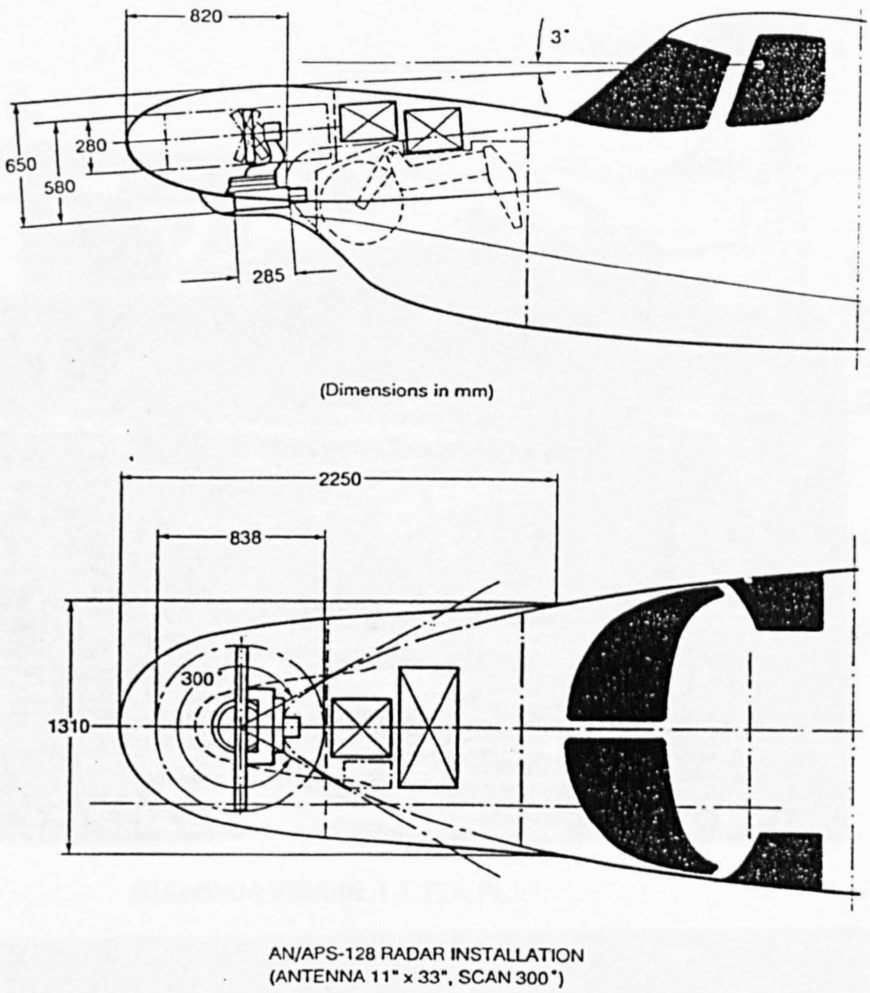
Possibilités de chargement et déchargement de l'hydravion de 1.000 tonnes.



Perspective drawing of 1000 t flying ship.

Vue de l'hydravion cargo de 1.000 tonnes.

FIGURE I.2. DORNIER FLYINGSHIP



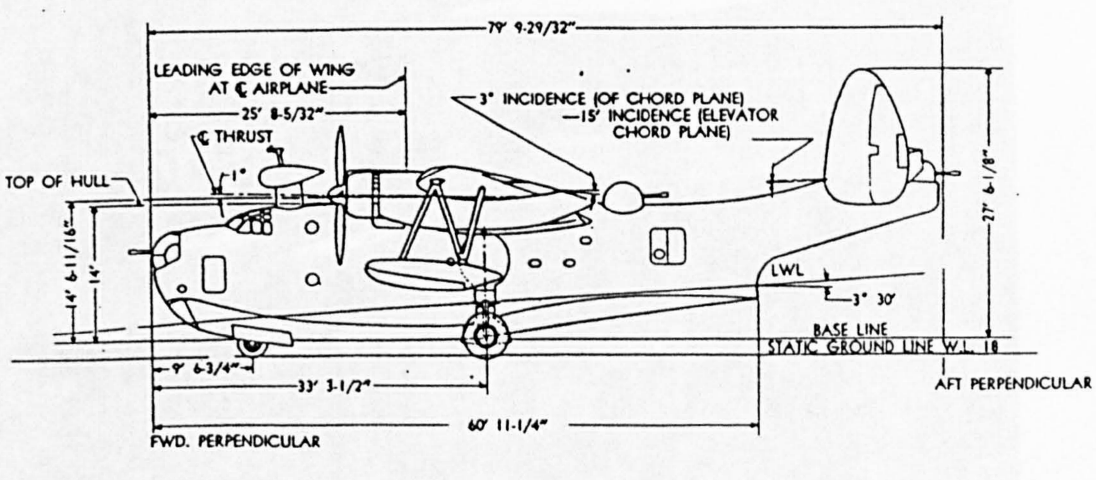


FIGURE 1.3a-b. FLYINGBOAT RADAR INSTALLATIONS

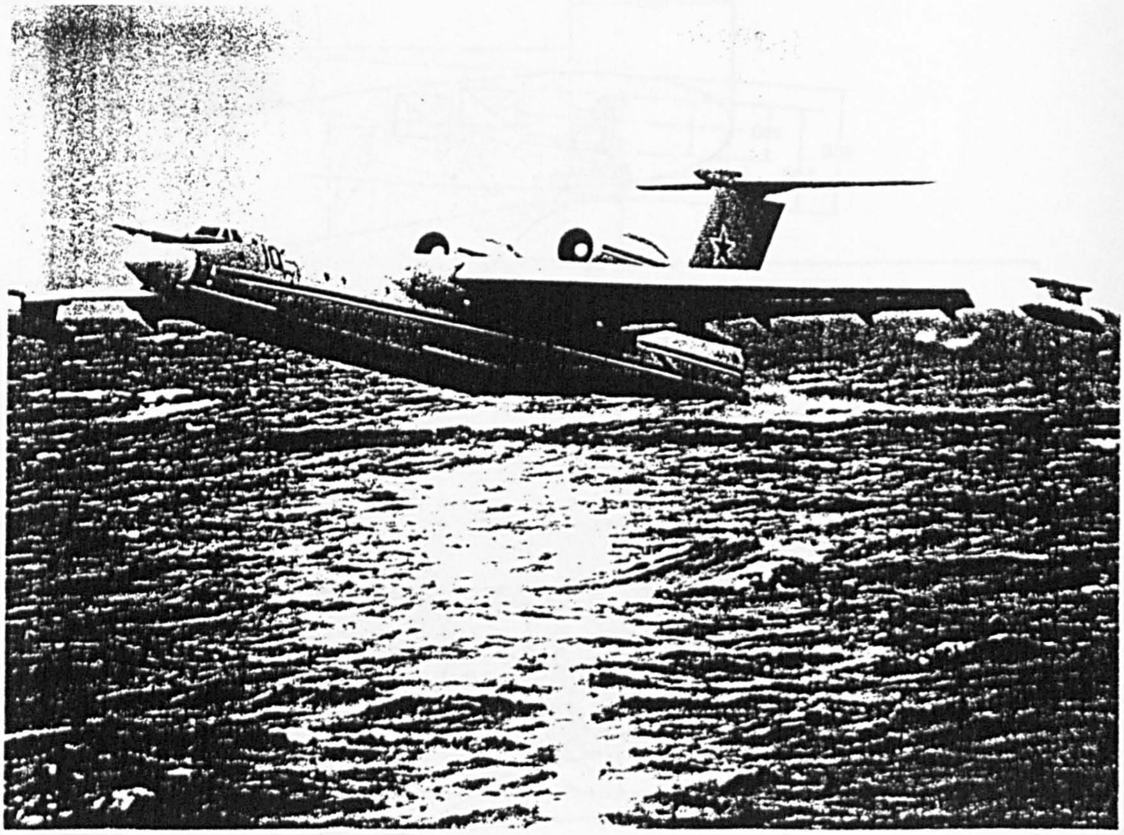


PLATE 1.1. BERIEV MERMAID

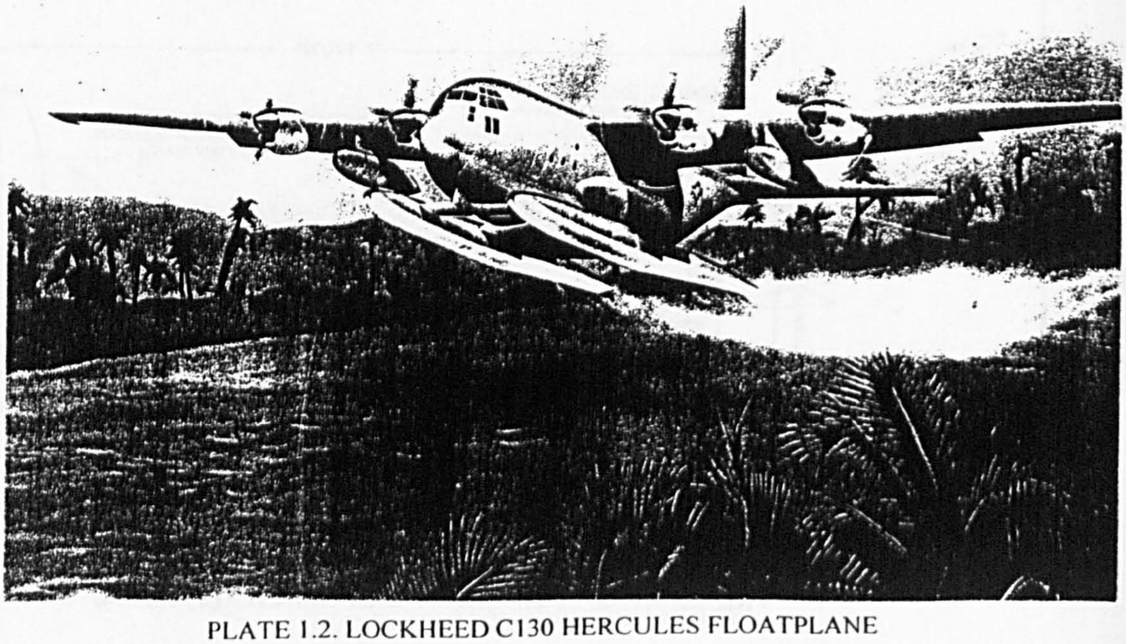


PLATE 1.2. LOCKHEED C130 HERCULES FLOATPLANE

PLATE 1.3. TURBO-BEAVER AMPHIBIOUS FLOATPLANE

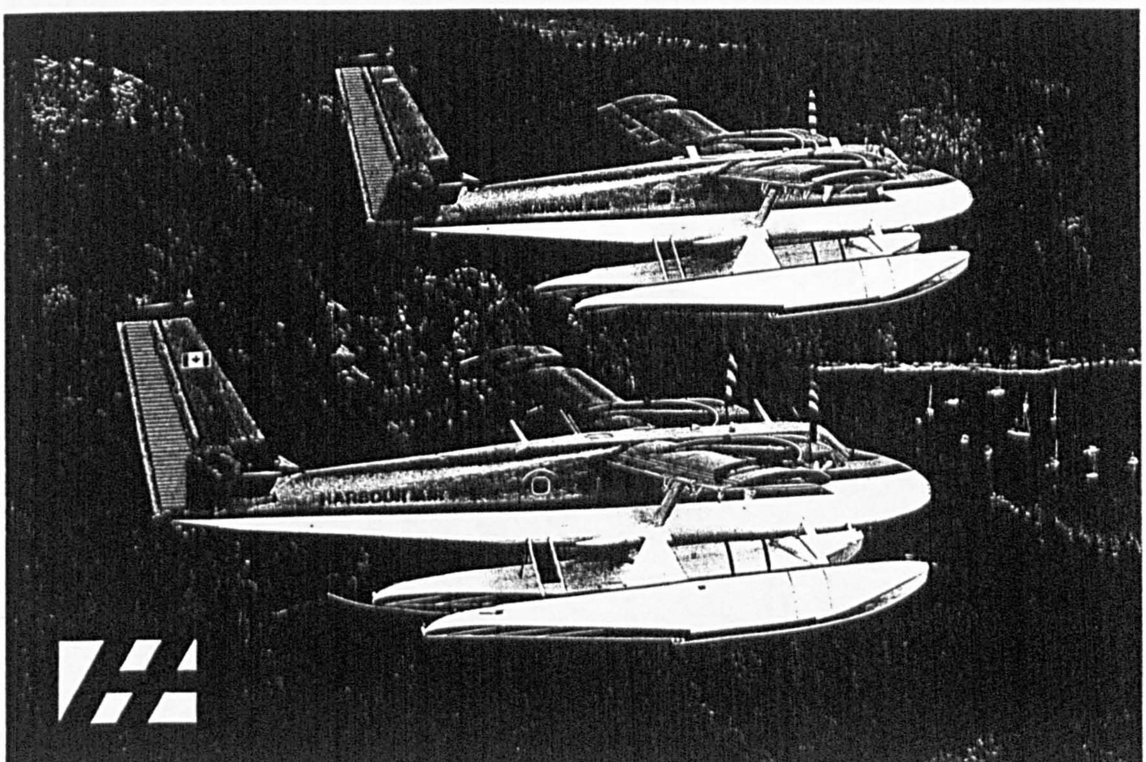


PLATE 1.4. TWIN OTTER PURE FLOATPLANE

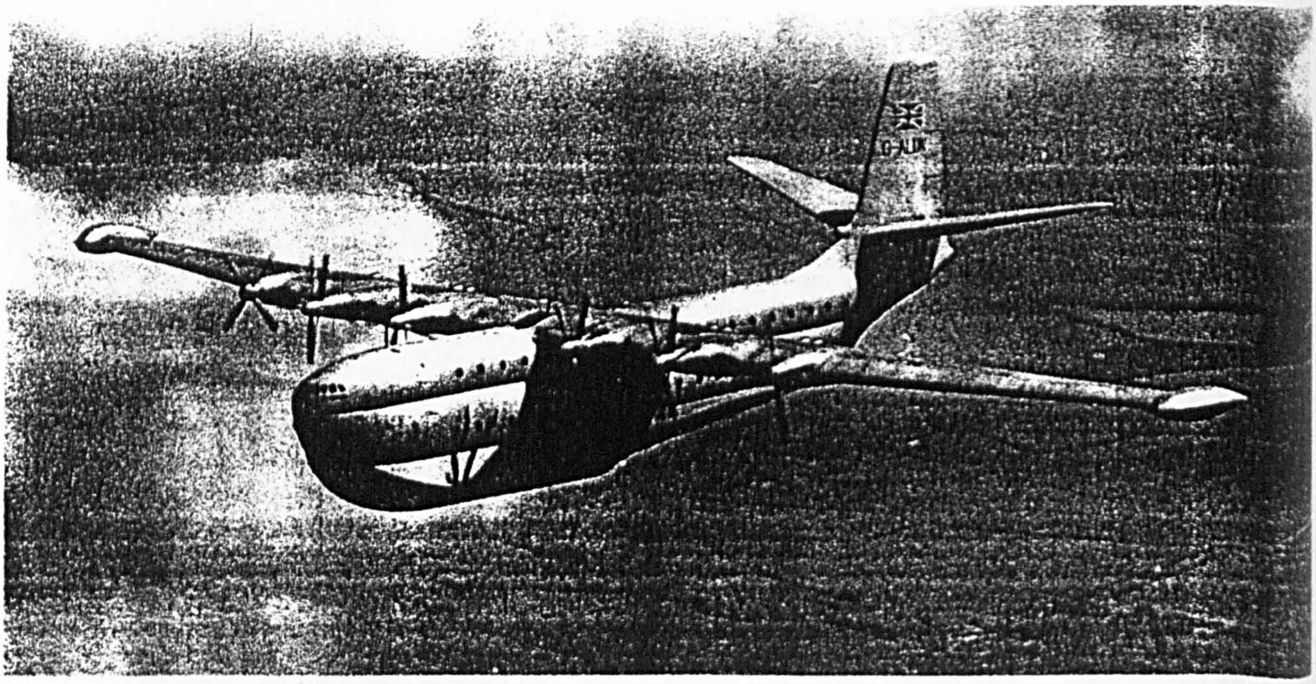


PLATE 1.5. SARO PRINCESS PURE FLYINGBOAT

PLATE 1.6. BERIEV MERMAID AMPHIBIOUS FLYINGBOAT

PLATE 1.7. PAN-AM AIRBRIDGE TURBO-MALLARD

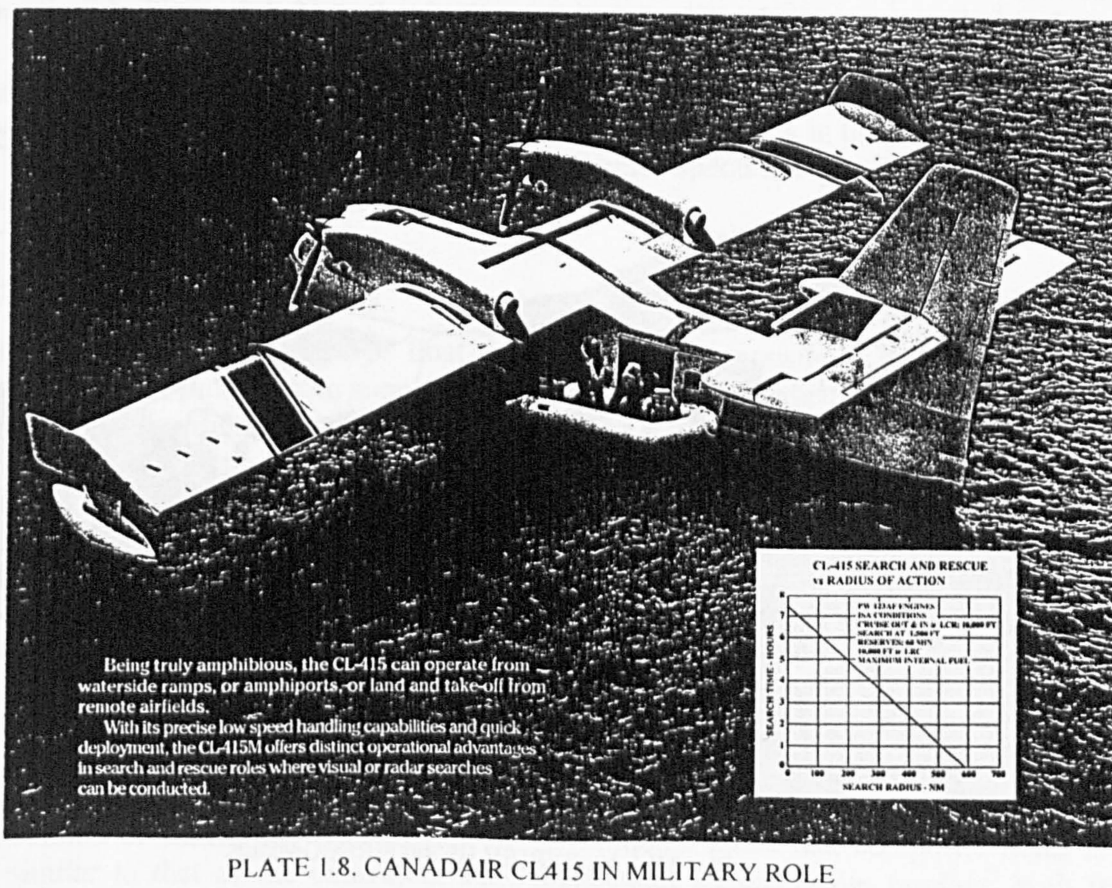


PLATE 1.8. CANADAIR CL415 IN MILITARY ROLE

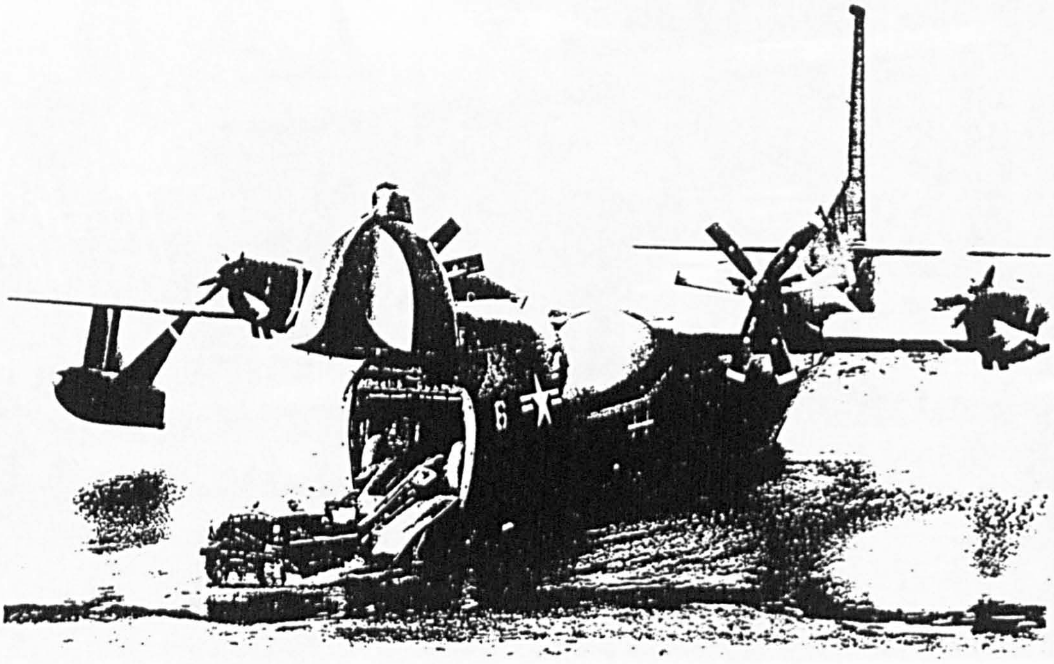


PLATE 1.9. CONVAIR TRADEWIND

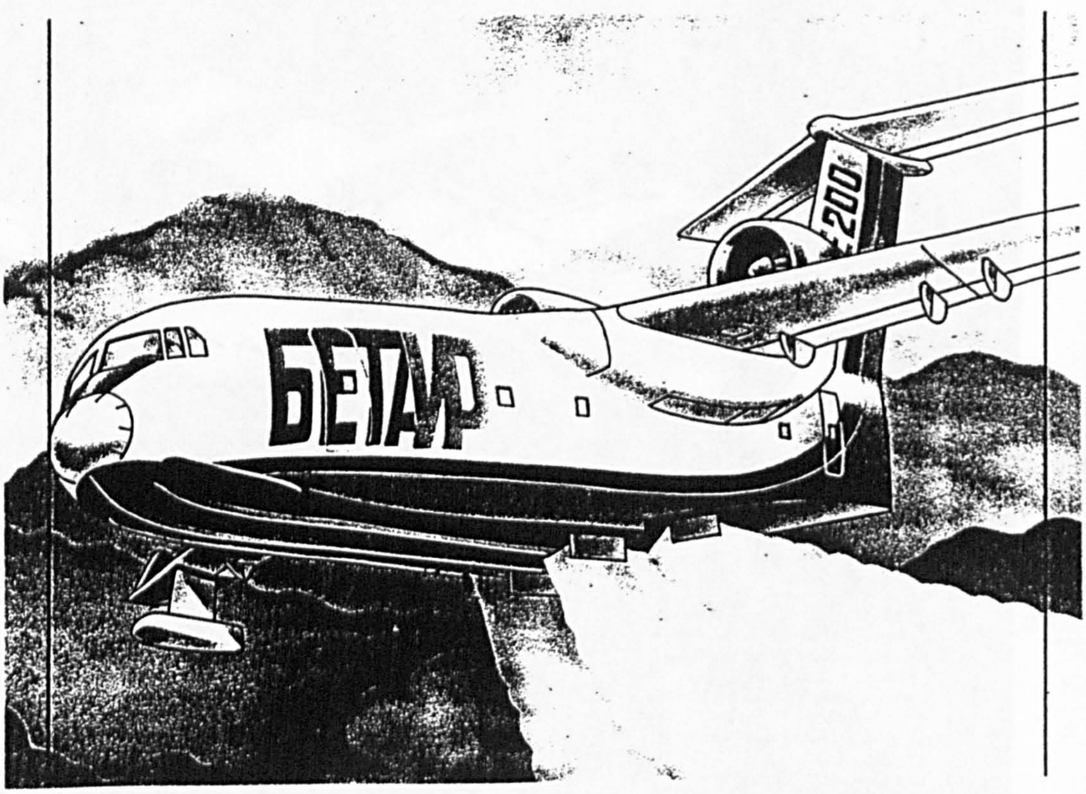


PLATE 1.10. BERIEV BE200 FIREBOMBER

2. FLOATPLANES

2.1 INTRODUCTION.

2.1.1 Adding Floats to a Landplane. In the vast majority of cases a single or twin float installation on an aircraft will only be required when there is a need to make an existing, land-based aircraft into a pure or amphibious floatplane. Thus in the majority of cases the design information required can be simplified into 2 distinct but related groupings as follows:

Float Configuration. This can be further subdivided into:

Basic Configuration.
Float Dimensions.
Float Mass.
Support Structure.
Relation to Base Aircraft Structure.
Initial Purchase Price.

Change in Original Aircraft Specification. This can be further subdivided into:

Air Performance.
Water Performance (see 3.13 and 3.15).
Cost of Ownership (see 4.3).

The design process to gain all the information to fit floats to an existing land-based aircraft is summarised in Figure 2.1. Note that in the past it was relatively common to design floatplanes such as the Northrop N-3PB (see Plate 2.1) from scratch. However, since the late 1940s only conceptual designs have examined floats as the initial, prime landing method; none have ever been produced. Some aircraft will require additional strengthening in the form of structures such as V-braces for windshield/fuselage integrity $_{(16)}$. These aspects are specific to individual aircraft types but are discussed further in 2.10.5.

2.1.2 Float System Construction.

The construction of every type of float, be it of metal, composite or inflatable construction, reflects its 3 main functions: to support the mass of the aircraft when floating, to plane over the water allowing the aircraft to take-off and land and to transmit water loads to the main airframe structure. Secondary construction details may include the addition of a wheeled undercarriage if land based operations are required and a water rudder for low speed on-water manoeuvrability. The ability to use the float for internal and external stowage is also useful.

a. Planing Bottom. The form of the planing bottom of a conventional metal or composite float is influenced by the same factors as that of a flyingboat (see Sections 3.5 and 3.6).

b. Float Body. The float main body must not only transfer the water landing loads to the struts and thence to the main airframe structure, but must also displace the required volume of water. The construction of conventional metal and composite floats is very similar to that of the equivalent semi-monocoque or composite fuselage, with frames transferring the water loads from the planing bottom to the strut attachment points and the stringers stiffening the thin outer skin (see Figure 2.2). Increasing numbers of plies in composite float skins can match water pressure and other local loads. Internal frames can be open or closed to form water-tight bulkheads which divide the float into the minimum of 4 approximately equal compartments required by FAR 23.751. The number of compartments can increase almost linearly with displacement, with Brimm (16) recommending 4 at displacements of 1000lb rising to 7 compartments at 62000lb. The effect of the structural discontinuity caused by the step can be minimised by placing a frame at this point. The float structure should be able to support the weight of passengers or maintenance staff moving on the upper surface. Stiffening the upper float surface can also provide extra flexibility of use by allowing a variety of strut fixing points and thus a variety of aircraft types' attachments (see Figure 2.3). Although a well-rounded float top is aerodynamically sound and allows water to run off the float, a flat top and slab sides makes passenger use safer and eases manufacture and the lashing of external loads. Access to the inside of the float is required to check the structural integrity and to bail out any water leaks. The internal volume of the float can be used to transport fuel, weapons (see Plate 2.2) or cargo, although adequately sized and waterproof access doors are required. Internal volume can also be used for water or foam in the firebomber role.

c. Amphibious Float Undercarriages. Amphibious undercarriages can be either of the nose or tail (ie the stern of the float) wheeled variety (see Plates 2.3, 2.4 and 2.5). The most common is the nose wheeled type. Advantages and disadvantages of nose and tail wheeled floats are similar to those for the relevant undercarriage configuration for flyingboats (see Section 3.16). Main undercarriages are usually located behind the step in the less heavily loaded afterbody (see Plate 2.4). The hydrodynamics of the afterbody are also less important than those of the forebody, so discontinuities such as doors or semi-retractable wheels cause fewer problems. The location of the main undercarriage immediately aft or forward of the step allows the step frame to be used as an attachment point. Nose undercarriages are frequently semi-retractable to allow the tyre to form a bow bumper (see Plate 2.4). On pure floats a rubber bumper are often used for this purpose. Tail wheels can be used as water rudders or to support water rudder mechanisms.

d. Water Rudders. Water rudders are attached to the rear of the float and must be able to be retracted when the floatplane is above a certain speed when taking-off and landing (see Figure 2.2). The water rudder actuation method is usually wire routed either externally or internally. Although external routing increases drag, exposes the mechanism to the elements and can be a trip hazard for passengers, inspectability is good and the mechanism can be readily cleaned and, if operating in salt water, washed down after every flight. Internal routing decreases drag and clears the float top of trip hazards. However, internally routed wires must pass through the float's water-tight frames adding complexity, maintenance costs and decreasing inspectability. An overview of maintaining water rudders is at Reference 17. The ability to clear unwelcome aquatic animals and plants off water rudders and their actuation mechanism before flying to another water area is becoming an increasingly important environmental issue (18).

e. Struts. Struts may follow the same construction rules as similar, wing support structures. However, a point to note is that any cross-float member or spreader strut should be stressed to support the floatplane when used as lifting points for fork lift trucks. Streamlined struts with an internal spar are commonly used in this role. In addition to supporting the floats, struts are also often used as fixing points for passenger steps and water rudder actuation wire pulleys (Plate 2.6).

f. Setting Angle. Although the setting angle between the float and the wing will be individual to each aircraft type, the usual angle is approximately 4° down (19). If the setting angle is decreased from the optimum (ie made more negative) the take-off time will improve due to increased angle of attack, but cruise performance will decrease due to greater drag. An extreme example is the Schneider racing floatplanes which sacrificed take-off performance for cruise speed by having a positive setting angle. The result was often a take-off run of over 5 miles.

2.1.3 Construction Materials. There are 3 main float construction materials: aluminium alloy (henceforward referred to as metal), composites and synthetic textile fibre (henceforward referred to as inflatable). All have their own particular advantages and disadvantages.

a. Metal Floats. Metal floats, using mechanically fasteners (eg rivets), have the advantage of being an accepted and well-known technology. They are easy to manufacture and repair (as long as complex curvatures are avoided), often using the same facilities as the parent aircraft. Metal floats do not suffer from UV light degradation, but are subject to corrosion. Therefore, aluminium corrosion protection measures such as anodising and zinc chromate priming before assembly and sealing all seams with plastic sealant during manufacture are vital. In the past, steel parts have been cadmium plated, although environmental concerns are making this process increasingly unacceptable. A more detailed description of corrosion control measures is at Section 4.3. Post-manufacture leak testing, either by filling the float with water or immersing the float to a depth up to twice the normal displacement pressure are accepted ways of testing for leaks (20). However, even slight impacts can loosen rivets and cause leaks and therefore minimising fasteners by using integrally machined stiffeners can significantly reduce cost of maintenance, although manufacturing infrastructure costs are initially higher. Some load optimisation can be achieved by using different skin thicknesses for the planing bottom, sides and afterbody, although the desire to use countersunk rivets may define skin thicknesses more than loading.

b. Composite Floats. Composite floats are usually constructed from glass fibre, although Kevlar can be used to improve impact resistance in particularly prone areas such as the bow and keel. Composite floats can be constructed in complex, double curvature shapes and use well established construction methods. Manufacture is more efficient if paired with composite aircraft manufacture. As composite floats have no fastener holes, leak problems are less significant than for metal floats, although protection is still required to ensure that the adhesives and resins do not absorb water and disbond or gain in mass. Repair of composite floats can be problematic in remote locations, especially if materials other than glass fibre are involved. The design of composite floats can be more optimal, and therefore lighter, than the equivalent metal float as the lay-up can be more closely matched to the load, although this has manufacturing and repair cost implications.

c. Inflatable Floats. In the context of this study the term inflatable float only refers to that form of inflatable structure which mirrors the hydrodynamic performance of conventional floats. Thus the streamlined, stepless inflatable bodies used to support helicopters on water are not included. Within this definition only one firm, Full Lotus, manufactures inflatable floats (see Plate 2.7). These are constructed from a number of air bags, usually 8, inflated to 1.5 psi. The bags are contained in a fabric, float-shaped bag.

The bow and forebody of the float is encased in a rigid plastic glove which zips onto the float. Float form is maintained by drawn aluminium alloy stiffeners running along the top of the float which also act as strut attachment points. If an air bag is punctured the remaining bags migrate into the area. Clearly, inflatable floats are not possible to manufacture without specialist machinery, yet their fabric construction and multi-air bag construction make them relatively easy to repair.

2.2 FLOAT CONFIGURATIONS.

2.2.1 Introduction. There are 2 main configurations of floatplanes: single and twin. The single float configuration was popular in World War 2, primarily in the US and Japanese Navies. The twin configuration is now accepted as standard for all civilian floatplanes, although each configuration has particular advantages and disadvantages (see Table 2.1).

2.2.2 Single Float Configuration. The main reason for favouring a single float configuration was the ease with which the aircraft could be catapulted from a naval vessel, as the float structure passed both the water landing loads and the catapult loads straight into the main fuselage structure through a single robust path (see Plate 2.8). A further advantage was that the single float could contain more useable volume for stores than the equivalent twin floats. This volume was close to both the lateral and longitudinal centre of gravity and therefore stores could be dropped with little change in trim (see Plate 2.2). However, single float floatplanes require some form of additional lateral stability and therefore tip floats are usually fitted, not only counteracting the robust nature of the main float, but also adding drag. Note that most single float floatplanes were designed as floatplanes rather than modifications of existing landplanes. A single float configuration may be advantageous if the existing landplane's uses a single, fuselage-mounted undercarriage such as the Europa light aircraft.

2.2.3 Twin Float Configuration. The twin float configuration was also used during World War 2 but has continued to be popular due to its significantly easier passenger and freight loading and unloading characteristics; these factors are important in peace-time commercial operations. When adding floats to an existing landplane the twin float configuration only requires structural modifications to the fuselage, whilst the single float configuration requires both wing and fuselage modifications. A twin float configuration provides a more stable basis for an amphibious undercarriage as the wheels can be more easily placed apart laterally (see Plate 1.3).

2.2.4 Unusual Float Configurations. A development of the single float configuration which includes the advantages of the twin configuration was investigated by SE Saunders in 1926 $_{(21)}$. This concept involved a single large, wide, centrally-mounted float which could split along its length and separate laterally for waterborne use (see Figure 2.4). The lateral separation was sufficient to provide lateral on-water stability but, when retracted into a single float, resulted in a surface area less than the 2 floats and no requirement for tip floats. The disadvantage of the system, which never got off the drawing board, was its complexity and therefore manufacturing, mass and maintenance costs.

2.3 MASS ESTIMATION.

2.3.1 Twin Float Configuration - Pure Floats. A method of estimating the extra mass required to provide land-based aircraft with pure floats was required. The modern float database was used to provide information of float displacement and additional float mass. FAR 23.751 requires that the two floats of a twin float floatplane provide 180% fresh water buoyancy. Thus the maximum possible aircraft all-up mass (AUM) legally supportable on a twin float system was calculated by taking the single float displacement, multiplying this by 2 to reflect the twin float configuration and then dividing by 1.8 to reflect the 180% buoyancy (22). Assuming that the 180% buoyancy requirement also applies to the lighter "experimental" category of aircraft a relationship between floatplane AUM and additional float mass can be derived knowing float data (see Table 2.2 and Graph 2.1). The resulting relationship is approximately linear, but shows significant scatter for light floatplanes and few data points for aircraft with high AUM. A relationship is therefore developed for aircraft with AUM greater than 1500kg as follows, with low and high AUM floatplanes considered in more detail.

for AUM>1500kg: $M_{floats} = (0.1xAUM) + 33$ Eqn 2.1

2.3.2 Overfloating. The above technique assumes that the manufacturer only provides the legal minimum displacement. However, a degree of "overfloating" is sometimes recommended to give better on-water performance (23). A selection of 19 floatplane AUMs were compared with the theoretical float displacement. This indicated an average overfloat factor of 11% (see Table 2.3). Many of the more extreme examples of overfloating were possibly due to the floats being originally designed for a heavier aircraft. Similarly, a float may have been designed for an amphibious floatplane and then cheaply converted to a pure float; the inclusion of the previously "wet" undercarriage stowage into the "dry" volume of the pure float adds buoyancy and results in overfloating when the pure float is added to the same aircraft as the original amphibious float was designed to support. It was therefore decided not to include an overfloating factor in any further calculations.

2.3.3 High AUM Floatplanes. Whilst the number of data points ensured that the float database technique was able to confidently estimate float masses for aircraft up to approximately 5500kg, it would be naive to carry the estimation much above this figure. A method was therefore required to estimate float mass data beyond this point. The floatplane database was examined and data on 7 floatplanes having an AUM above 5500kg and sufficient additional information (ie floatplane and original landplane empty mass) extracted. The mass of the undercarriage of the landplane was estimated based on the AUM (24) and this estimate was then subtracted from the empty mass to gain the empty mass of the aircraft less the undercarriage. This mass was then subtracted from the empty mass of the floatplane to gain the float system mass. The results are detailed in Table 2.4 which shows quite considerable deviation from the estimation technique of Eqn 2.1. An attempt was made to validate the method using data for aircraft with an AUM under 5500kg and this too showed considerable scatter. These deviations are likely to be due to the assumptions inherent in the undercarriage mass estimation method. This view is supported by the only 2 examples where the actual float mass is known; these tend to support the estimation technique result of Eqn 2.1. It was therefore decided that the relationship of float mass to aircraft AUM as stated in Eqn 2.1 could be applied to aircraft with an AUM greater than 5500kg, but with care due to the small statistical sample.

2.3.4 Low AUM Floatplanes. Examining the data points for the floats fitted to the aircraft with AUMs below 1500kg showed quite a significant amount of scatter from the linear estimation. In particular there was a significant difference between those floats fitted to FAR 23 aircraft and those considered as ultra-light, experimental or home-build. When considering floats for these very light aircraft the float material has a large effect on mass (see Graph 2.2). Due to the scale of this discrepancy between material types a generalised float mass to AUM relationship is difficult to support for ultra-light aircraft. Therefore, for aircraft under 1500kg a series of material-based relationships is proposed as follows:

$$\text{for AUM<1500kg:} \quad \left.\begin{aligned} (M_{floats})_{metal} &= (0.14\text{xAUM}) - 24 \\ (M_{floats})_{composite} &= (0.038\text{xAUM}) + 4 \\ (M_{floats})_{inflatable} &= (0.063\text{xAUM}) + 3 \end{aligned}\right\} \text{Eqn 2.2}$$

2.3.5 Other Factors Affecting Float Mass. The large discrepancy between the relationships regarding those aircraft with AUM above and below 1500kg indicated that factors other than aircraft AUM were involved. On examining the performance of the aircraft which were fitted with the lightweight floats it became clear that their landing speeds were significantly less than the more conventional aircraft. This factor has a great effect on the force acting on the floats (see Section 4.5) and therefore their structural strength and mass. The relatively small number of real data points for the ultra-light aircraft (as opposed to float data) was augmented by calculating the optimum lightweight metal, composite and inflatable float for a variety of relevant aircraft thus producing theoretical float/aircraft combinations. It was initially assumed that an energy-related $(v_{landing})^2$ function could relate the aircraft to the float mass, but when plotted this still did not group the lightweight and inflatable floats with the more conventional designs. A $(v_{landing})$ function produced a slightly more acceptable data point grouping, as did the $(AUM^{2/3})$ term derived from theoretical flyingboat hull loading equations discussed in Section 4.5. These relationships produced data which is summarised in Table 2.5 and Graphs 2.3a-c. However, the scatter was still such that no additional confidence could be placed in this method over the simple AUM relationships and therefore the methods of Eqns 2.1 and 2.2 are henceforth used alone.

2.3.6 Twin Float Configuration - Amphibious Floats. The above methods were then repeated for amphibious floats (see Table 2.2 and Graphs 2.4 and 2.5) and the following equations deduced:

$$\left.\begin{aligned} \text{for AUM} < 1500\text{kg} \quad M_{float} &= (0.056\text{xAUM}) + 13 \\ \text{for AUM} > 1500\text{kg} \quad M_{float} &= (0.13\text{xAUM}) + 105 \end{aligned}\right\} \text{Eqn 2.3}$$

Note that the datapoints for light floats were sufficiently close together that it was not felt necessary to separate them into separate construction materials.

2.3.7 Single Float Configuration. Estimating the additional mass of single-float floatplanes was more problematical than that for the twin float configuration, as not only must any initial estimate include tip floats, but also all but 2 examples in the database were military aircraft from World War 2. The 2 non-military aircraft were an inflatable single float ultra-light and an experimental adaptation of an existing twin float floatplane; neither were good data points. These factors add an element of doubt to the data, not only due to age, but also as to how modern certifying authorities would view any extra displacement required of a single float. An initial assumption could be that the single float should have the same 180% buoyancy of the twin configuration if used for passenger carrying. However, this is an unlikely role for a single float floatplane. More likely is that a relaxed buoyancy requirement would be imposed for, as an example, firebombing. An example of this is the Sea Thrush amphibious crop spraying aircraft which has an AUM of 3859kg when operating in the "restricted" category. This mass would normally generate the requirement for 6946kg displacement, but the Sea Thrush is actually fitted with 2xEdo4930 floats with a displacement of 4476kg, a reserve buoyancy factor of 116% (25). The FAA and SPA were approached for guidance, but in the absence of an answer, it is conservatively assumed that the single float would have to follow the 180% buoyancy rule of twin floats. A further complicating factor is that most single float floatplanes were purpose-designed rather than adoptions of conventional land-based aircraft. Thus little data was available to estimate the float mass in the absence of actual float masses. The following method was therefore used to estimate the additional mass of a single float configuration. First, an assumed aircraft AUM was multiplied by 1.8 to reflect the 180% buoyancy requirement. Next a graph of existing float displacement to mass was produced using the modern float database (see Table 2.6). The relationship between these 2 variables was estimated as 0.064xAUM (see Graph 2.6). Therefore, without the x2 floats factor the mass of a single float bearing all the required displacement could be gained for that assumed aircraft. The additional mass of the tip floats was estimated using the flyingboat technique described in paragraph 3.8.4. The results are summarised in Table 2.7 and Graph 2.7 and the relationship is estimated as follows:

$$(M_{floats})_{single} = 0.11AUM \qquad \text{Eqn 2.4}$$

An attempt to validate this was made using the only example in the database where landplane and single float floatplane data was available (26), the World War 2 Vought Kingfisher (see Plate 2.8). A relationship of 0.08AUM was gained as follows:

$(M_{empty})_{floatplane} = 1957kg$ $\qquad$ $(M_{empty})_{landplane} = 1872kg$

$(AUM)_{landplane} = 2542kg$ therefore $M_{undercarriage} = 122kg$ (24)

therefore $(M_{empty})_{landplane}$ less undercarriage = 1872 - 122 = 1750kg

therefore $M_{float} = 1957 - 1750 = 207kg$

therefore float mass to landplane AUM relationship = 207/2542 = 0.08

It is therefore concluded that the mass of a single float system can be between 0.11AUM and 0.08 AUM depending on initial assumptions ranging from conservative civilian to wartime military. However, due to the tiny data sample, the lower figure must be treated with great care. However, an important conclusion to be drawn from this relationship is that there is little difference in mass between the single and twin float configuration.

2.3.8 Methods from References. Five references gave methods of calculating float mass knowing landplane AUM. None of these techniques made allowances for landing speed, but all generally support the author's methods. The data is summarised in Table 2.8.

a. Seaplanes - Manufacture, Maintenance and Operation (16). A number of examples are provided of landplane mass and associated float mass for a seaplane version. These vary from 12.5% to 7% of AUM. As the data was empirical it is not surprising that it closely matches the database estimations. Although the Reference's data stops at AUM = 2815 kg it is interesting to note that the data line gradient lessens as AUM rises.

b. Seaplane Float and Hull Design (27). Langley calculates float mass using the following equation:

$$M_{floats} = 2\,[0.0365\ AUM + 43.5]\ lb$$ Strut mass is quoted as 3% of AUM.

With the exception of very light aircraft Langley's system consistently under-estimates float mass.

c. Seaplane Design (28). Nelson gives the following generalisations which make no allowances for increasing AUM:

Landplane to seaplane (single float) = +5% to +7%.

(twin float) = +10%.
(amphibian) = +15%.

The method does not include any strut mass and therefore this has been added using Langley's method. The method for twin floats closely matches the lower AUM database output but over-estimates float mass for aircraft AUM above 3000 kg.

d. The Weight of Seaplane Floats (29). Rosenthal proposes the following equation for float mass:

$$M_{floats} = 0.134\,(AUM)^{0.8812}$$

Again, no mention is made of strut mass so this was assumed not to be included and was added separately. The resultant data points significantly underestimated the float system mass over the majority of the data environment. At low AUMs the estimation method matched the light-weight floats but only approached the empirical figure again at AUM = 10000 kg.

e. Aircraft Landing Gear (30). Currey quotes a float undercarriage as having a mass of 10% AUM for pure and 17% for amphibious floats. This estimate includes struts.

2.4 FLOAT DIMENSIONS.

2.4.1 Length. Inspection of the float database quickly revealed a close relationship between floatplane AUM and float length (see Table 2.9 and Graphs 2.8 and 2.9). Note that where manufacturers' float dimensions are used the aircraft AUM is derived from the float displacement. As has already been discussed under float mass there is a 'dog-leg' in the graph of float length against floatplane AUM. Thus 2 equations are proposed as follows:

For AUM < 2500 kg	$l_{float} = (0.0018xAUM) + 3$	}Eqn 2.5
For AUM > 2500 kg	$l_{float} = (0.0002xAUM) + 8$	}

As already noted under float mass there are only 2 data points for civilian single float floatplanes, one of which has no AUM data. It was therefore decided to check the relationship between the float length of military and civilian twin float floatplanes and assume the same relationship held for military to civilian single float floatplanes. The 2 data points could then be used as validation. Thus from Graph 2.8 for military twin floats:

$$l_{float} = (0.00048xAUM) + 6$$

and from Graph 2.9 for military single float floatplanes:

$$l_{float} = (0.00074xAUM) + 6$$

Therefore assume AUM factor between the two is approximately 1.5. When applied to Eqn 2.5, to model a projected civilian single float floatplane, the result is as follows:

For AUM < 2500 kg	$l_{float} = (0.0027xAUM) + 3$	}Eqn 2.6
For AUM > 2500 kg	$l_{float} = (0.0003xAUM) + 8$	}

Validation occurs in Section 2.14.

2.4.2 Beam. A number of variables were plotted against float beam but, as expected, only float length presented a close relationship. The average ratios for the relevant data sets are as follows:

civil twin floats:	l/b = 8.4	military twin floats:	l/b = 7.3
individual floats:	l/b = 7.4	military single floats:	l/b = 6.9

The discrepancy between the civil twin float value and that of the individual floats can be partially explained by the pattern of length to beam ratios against AUM; there is a reduction in the ratio at the lower masses represented in the table by the individual floats. However, the scatter at low AUM is too great to confidently develop a relationship. The average of the 2 data sets together is 7.7 which corresponds well with the military twin floats. The average of all 3 twin float results is therefore used as the basis of the relationship for twin floats and no differentiation is made between military and civil. The single float data shows some statistical scatter and therefore any relationship should be used with care. The following relationships are therefore proposed:

twin float l/b = 7.5	}Eqn 2.7
single float l/b = 6.9	}

It should be noted that there is a drift towards higher l/b ratios at higher AUM values.

2.4.3 Height. A number of variables were plotted against float height but only float length presented a close relationship. Note that the inflatable Full Lotus floats gave uniformly high l/h ratios. Inspection of the floats reveals lower than normal heights for all such floats due to their inflatable bag construction (see Plate 2.7). The average l/h ratios for the data sets are as follows:

civil twin float	9.8
floats	9.2 (8.3)
military twin floats	8.8
military single floats	8.5

However, if the Full Lotus floats are removed the average ratios for floats becomes that in brackets. As all the averages are relatively similar a single relationship is proposed as follows:

float l/h ratio = 8.8 Eqn 2.8

2.4.3 Forebody Length. As expected, the closest relationships with forebody length was that with total length. The average ratios for all data sets were closely grouped as follows:

civil twin floats = 2.0
individual floats = 2.0
military twin floats = 1.9
military single floats = 1.8

Although not particularly significant, the smaller average for single floats is probably due to the same forebody planing area as twin floats being achieved by the larger beam dimensions of the single float aircraft. It is therefore proposed that the following relationships be used:

twin float $l/l_{fb} = 2.0$ }Eqn 2.9
single float $l/l_{fb} = 1.8$ }

Note that this initial method of placing the step in a float design is very crude and should be confirmed by the more rigorous centre of gravity method described in Section 2.7 and 2.8.

2.5 HEIGHT ABOVE WATERLINE.

The distance of the floatplane fuselage or propeller above the waterline is dependent on spray height. This subject has been studied in many references with regard to flyingboats (see Section 3.10), but no information could be found regarding floatplanes. Therefore, a simple statistical method based on the database was derived. The vertical height from the top of the float to the nearest piece of major structure (eg fuselage/wing) was plotted from the available data (see Table 2.10). The data was plotted against AUM (see Graph 2.10) and, as could be expected, the statistical scatter was considerable as many other floatplane configuration factors influence the position of the float relative to the nearest structure. Scatter was also present when the data was plotted against aircraft span in an attempt to add a configuration-related factor (see Graph 2.11). The data was then separated into 3 categories of single engined twin float, single engined single float and multi-engined twin float to examine configuration effects. None gave results from which a relationship could be confidently developed, yet the scatter was less than when no configuration breakdown was included. Three separate but very approximate relationships are therefore postulated as follows:

single engined twin float: $z = 0.54 + (1.2\text{x}10^{-4}\ \text{AUM})$ }
single engined single float: $z = 0.35 + (2.0\text{x}10^{-4}\ \text{AUM})$ }Eqn 2.10
multi-engined twin float: $z = 0.9 + (4.4\text{x}10^{-5}\ \text{AUM})$ }

2.6 STATIC STABILITY.

2.6.1 Introduction. Both longitudinal and lateral stability of seaplanes can be accurately calculated once the exact form of the floats is known. However, until that stage is reached approximate methods are required. Such methods are developed for firstly, longitudinal and secondly, lateral stability using the theory of metacentric heights (27) and dimensions from the floatplane database.

2.6.2 Longitudinal Static Stability. From the theory of metacentric heights (see Figure 2.5) the following equations can be derived (detailed derivation in Appendix 2 and data in Table 2.11):

single floats: $h_{max} = [\{85.4\, b\, (0.9\, l)^3\}/AUM] - [0.59(AUM/0.454)^{1/3}]$ }Eqn 2.11
twin floats: $h_{max} = [\{170.8\, b\, (0.9\, l)^3\}/AUM] - [0.6(AUM/0.454)^{1/3}]$ }

2.6.3 Lateral Static Stability. Using the same method as above but in a lateral sense and using safe metacentric heights quoted in numerous references (27, 31) the following equation can be derived (detailed derivation in Appendix 2 and data in Table 2.12):

$s_{min} = [\{[0.43\, (AUM/0.454)^{1/3} + h]\, [12AUM/1025l] - 2b^3\}/6b]^{1/2}$ Eqn 2.12

Note that for single float floatplanes lateral stability is calculated using the flyingboat method described in Section 3.12.

2.7 AIRCRAFT/FLOAT RELATIVE POSITIONS

Having established the dimensions of the float, along with minimum spacing, maximum height and an approximation of the spray height between the float and the fuselage, the next task is to finalise the exact position of the floats relevant to the aircraft. The process is as follows (32, 33) and is best achieved using separate side elevation drawings of the aircraft and the float:

a. Identify the longitudinal and vertical centre of gravity position of the float installation (including spreader bars and attachment fittings). If these are not available from the manufacturer or the float is a new design assume the position as detailed in Appendix 3.

b. Identify aircraft longitudinal and vertical centre of gravity positions. If these are not available from the manufacturer, estimation methods can be used. Methods of estimating the longitudinal position are common in aircraft design references (24) and a method of estimating the vertical position is described in Appendix 4.

c. Identify the longitudinal and vertical centre of buoyancy of the float in the fully immersed "at rest" position. If these are not available from the manufacturer or the float is a new design assume the positions as detailed in Appendix 3. Remember that the position will change with aircraft attitude, speed and mass.

d. Draw a line from the float centre of buoyancy perpendicular to the float water line. Mark off on the line the spray height estimated in Section 2.5 and verified in paragraph 2.6.2.

e. Position the float so that the line passes through the forwardmost point of the aircraft's centre of gravity travel when the aircraft is at maximum AUM.

f. Keeping the line through this point, rotate the float drawing about the aircraft's forwardmost centre of gravity travel until the float angle of incidence is 3° - 5° bow down to the aircraft horizontal reference line. The advantages of the relative angles of attack are detailed in paragraph 2.1.2f.

g. Move the float drawing parallel to the line drawn at paragraph d until the marked-off spray height correctly spaces the float waterline to the fuselage bottom.

h. Check that the floatplane longitudinal centre of gravity travel does not exceed that of the original landplane. This is best achieved by assuring that the float installation centre of gravity is directly under the midpoint of the aircraft's centre of gravity travel.

2.8 STEP POSITION

A check of the position of the float can be made by comparing the position of the step with the aircraft centre of gravity. In a method similar to that developed for flyingboats the database was examined and the angle between a line dropped vertically from an assumed centre of gravity and a line between the centre of gravity and the step centroid measured. The results are summarised in Table 2.13. The results for both twin and single floats indicate that an angle of between 14° and 15° should be expected. More details on steps can be found in Section 3.5.

2.9 STRUT DESIGN SYNERGY.

Once floats have been positioned in space adjacent to the existing aircraft, decisions have to be made as to how exactly they are to be attached to allow the landing loads to be transmitted from the floats to the aircraft structure. Indeed, this decision may require a further iteration of the former process if the configuration is not possible. An exact method to produce a strut configuration to best transfer this load is not possible without detailed knowledge of the receiving aircraft structure. However, general configuration guidance can be given by examining the floatplane database. This data is presented in Table 2.14 and is split into 3 major categories driven by the float configuration (single or twin) and the receiving aircraft configuration (single or multi-engined). The configurations are summarised in Figure 2.6. Note that the single most common factor in float strut configuration was, understandably, the use of existing land undercarriage attachment points.

2.10 PURCHASE PRICE.

2.10.1 Introduction. Price lists were obtained from the float manufacturers. This data is presented in Tables 2.15 and 2.16 for pure and amphibian floats respectively with strut and fitting costs included. If a variety of fitting prices were quoted for a single float type for a number of aircraft the average was used. To aid in costing newly designed floats the existing float costs were also estimated as a function of displacement. Note all costs are in 1994 $US.

2.10.2 Pure Floats. In a similar manner to float mass, the cost relationship changed significantly between aircraft masses and float construction materials. There was also a marked difference in price between floats having a Specific Type Certification (STC) and those not, clearly illustrating the additional costs implied in the certification process (see Graph 2.12a). For metal floats with STC a relationship was defined as below. Note that the Wipline 13000 float is only fitted to a single floatplane type, the Twin Otter (see Plate 1.4) and therefore only a very small number of floats have been made. It is therefore likely that production volume considerations are a significant factor in its price. In the lightweight, non-STC area the pattern of the float mass relationship reoccurs, but with the metal floats' cost gradient being significantly steeper than that of the equivalent inflatable or composite floats. It is suspected that parts count cost considerations cause this effect. Unlike the float mass the difference in metal float gradient is such that relationships are postulated for material types within the lightweight float category as below:

metal pure floats (STC): $cost = 2.75AUM^{1.275}$ }
metal pure floats (non-STC, AUM < 1500kg): cost = (17xAUM) - 2700 }Eqn 2.13
composite/inflatable pure floats (AUM < 1500kg):cost = (4.5xAUM) +1000 }

2.10.3 Amphibious Floats. For amphibious floats, again noting the Wipline 13000 float data point, the relationship for metal floats with STC is as below (see Table 2.16 and Graph 2.13a). For lightweight amphibious floats the metal, inflatable and composite constructions are significantly closer together than pure floats (although still in the same ranking and with metal floats having almost double the gradient) and therefore the relationship for amphibious floats with displacements below 1500kg are as below (see Graph 2.13b):

metal amph floats (STC): cost = (72xAUM) - 73000 }
metal amph floats (non-STC, AUM < 1500kg): cost = (5xAUM) + 2000 }Eqn 2.14
composite/inflatable amph floats (AUM < 1500kg):cost = (10xAUM) + 2000 }

2.10.4 Float Kits. Many of the smaller displacement floats can be purchased in kit format (34) at a reduced price from pre-constructed floats. The average price of a float kit is 53% for pure and 70% for amphibious floats. This data is presented in Table 2.17. Note that the Avid 1100 amphibious float is fibreglass and the Zenair floats are aluminium alloy yet both materials give similar kit-to-assembled cost ratios.

2.10.5. Floatplane Modifications. Included in the price of the landplane to floatplane conversion are the structural modification items needed. For example, the Cessna 206 modification kit includes the following items in addition to flap, elevator and rudder trim adjustments and anti-corrosion treatments (13):

Strut attachment hardpoints for fuselage.
V-brace between the upper corners of the windshield and the cowl deck adding torsional stiffness to the fuselage.
Panels to cover nosewheel opening.
Kit to relocation of stall sensor so that it is not affected by the flow from the floats.
Kit to blank off port, forward static source.
Larger rudder and ventral fin to offset greater side area forward.
Modified nose cap and air intake structure and controls to improve cooling.
Hoisting rings on wing upper surface.
Steps and assist handles on forward fuselage to aid in refuelling.
Replacement stainless steel control cables.

Many aircraft also have strengthened engine mountings and, in the case of fixed pitch propellers, a replacement, longer propeller with a flatter pitch to gain maximum power at take-off.

2.11 CHANGES IN PERFORMANCE

2.11.1 Introduction. Having established the physical dimensions and installation details of floats on existing aircraft there was the need to develop a method of predicting the changes in performance due to these floats. The major changes in aircraft specified performance are range at a set payload, rate of climb and speed.

2.11.2 Theoretical Methodology. The prime factor of a float installation which affects these aspects is C_{D0}. This assumes that the AUM of the land and floatplane remain equal and that lift, and therefore lift-induced drag, due to float form is negligible. The additional parasite drag of a float is caused by a combination of the floats themselves and the supporting struts. Hoerner $_{(35)}$ provides some float drag data and estimates that a normal, as opposed to heavily streamlined, float has a C_{D0} of 0.22 based on the float cross-sectional area. Stinton $_{(36)}$ provides an estimate of 0.2, again based on cross-sectional area. These estimates are supported by the results of NACA Report 236 $_{(37)}$ which, although including a spread of values from 0.097 to 0.510 gave an average of 0.22 (see Table 2.18). As float height and beam could be estimated from earlier work, an approximation of float cross-sectional area can be estimated. Hoerner also includes data on the drag of undercarriage struts, a good approximation of float struts, with a C_{D0} of 0.3 based on the cross-sectional area of the related wheel ($0.14m^2$). This equates to a C_{D0} of 0.0182 based on a $1m^2$ cross-section. Thus an estimate of a complete float installation can be gained (for an example calculation see Appendix 5). Using this method and examples from Roskam $_{(38)}$ and Smith $_{(39)}$ ratios of landplane to floatplane C_{D0} were estimated for 9 floatplanes based on fixed undercarriage landplanes and 2 with retractable undercarriages (see Table 2.19). The average ratio for fixed undercarriage landplanes was 0.87 and that for retractable undercarriage aircraft was 0.78. However, the small data set and statistical scatter makes this method unreliable without validation. A method using the greater amount of information from the database was therefore used to provide this validation.

2.11.3 Empirical Method. The effect of the floats on aircraft range was examined by comparing landplane and floatplane performance, in particular by considering the Breguet range equation:

$$\text{range (miles)} = 375\,(\zeta_p/BSFC)(C_L/C_D)(\ln w_o/w_1)$$

and expressing the range of a floatplane over the range of the landplane from which it was derived and assuming that w_o/w_1 is constant in both cases gives:

$$(\text{range}_{\text{floatplane}})/(\text{range}_{\text{landplane}}) = (C_{D0\ \text{landplane}})/(C_{D0\ \text{floatplane}})$$

The floatplane database was examined and, where present, the landplane and equivalent floatplane performance figures extracted. A total of 33 data points were extracted (see Table 2.20). The average range ratio for fixed and retractable undercarriage aircraft was 0.91 and 0.66 respectively. The fixed undercarriage ratio was sufficiently close to the figures calculated in paragraph 2.11.2 to confidently use the average ratio method for estimation floatplane performance. However, for retractable undercarriage aircraft the small, largely military data sample along with the discrepancy between results from the methods and the scatter within the sample indicated that this method should only be used with care. As the average empirical method produced more conservative results than the range comparison method the former was recommended for retractable undercarriage aircraft. Considering the speed and range performance comparisons and the theoretical methodology gives:

fixed undercarriage speed and range C_{D0} ratio = 0.87 } Eqn 2.15
retractable undercarriage speed and range C_{D0} ratio = 0.78 }

Additionally, from Table 2.20:

floatplane (fixed undercarriage) rate of climb reduction factor = 0.85 } Eqn 2.16
floatplane (retractable undercarriage) rate of climb reduction factor = 0.76 }

2.11.4 Information from References.

a. NACA TN 525 (41). Drag is greatly influenced by the form of the bow. The angle of afterbody keel effects the angle of minimum drag.

Step type	0° trim		5° trim	
	C_D	order	C_D	order
transverse	0.038	3	0.046	1
pointed	0.036	2	0.051	3
faired	0.034	1	0.05	2
faired *	0.045	-	0.078	-

Note: * designates faired step with "good" sea-worthy nose form. Note change in order.

b. Reference: NACA TN 716 (42). Non-dimensional drag coefficient for floats can be:

$$C_D = D/q\ (\text{volume})^{2/3} \quad \text{(where D = drag force)}$$

as volume is a common design variable. Using this definition for twin float form:

dead rise	C_D
20	0.046
25	0.0475
30	0.049

Note: all data is with spray strips fitted and at 0° pitch angle. Spray strips have the following effect:

$C_{D\,none} = 0.041$ $\qquad C_{D\,strips} = 0.046$

c. Reference: NACA TN 656 (43). High, wide chines at bow increase drag but improve sea-keeping performance. Keep chine line parallel with streamline at economic cruise attitude. In this case the difference in drag between sharp or rounded chines is negligible, yet the sea-keeping of the former is significantly better. A pointed (in plan form) step has lower drag.

2.11.5 Drag of Single Float Configuration. There was no relevant data to derive the performance modification due to the attachment of a single float system to a landplane. Although it was possible to estimate the drag of the single main float and the twin tip floats using the C_{D0} estimations from 2.11.2 a more simple method of comparing the drag of twin and single float configuration drags was required. It was decided to compare the wetted and cross sectional area of each configuration with identical displacements. It is assumed that drag due to fittings, struts and interference is the same for both configurations.

a. Wetted Area. The wetted area of each configuration was estimated using the fuselage method of Torenbeek(44). The resulting equations are as follows (full derivation in Appendix 6):

wetted area of twin float configuration: $A_w = 0.6l^2$
wetted area of single float configuration: $A_w = 0.4l^2$

b. Cross Sectional Area. The cross-sectional area of each configuration was estimated as follows (full derivation in Appendix 6):

cross-sectional area for twin float configuration: $A_x = 0.03l^2$
cross-sectional area for single float configuration: $A_x = 0.041l^2$

It can be seen that the single float configuration is approximately 0.66 times the wetted area of the equivalent twin float configured floatplane. In terms of cross-sectional area the twin float configuration is approximately 0.75 the area of the single float configuration. Substituting into the AUM to float length equations (Eqn 2.5) gives the data of Table 2.21 and Graph 2.14. At low speed, cross-sectional area is likely to be a greater drag factor than wetted area and therefore a twin float configuration will have a lesser drag than a single float configuration of the same displacement. However, if the single float need have a lesser displacement than the twin, the equivalent drag will be lower. Taking the theoretical example of the Sea Thrush discussed in paragraph 2.3.7 the displaced mass of the floats was 0.64 times that expected. Transferring this onto Graph 2.14 results in a single float cross-sectional area approximately equal to that of the equivalent twin configuration. It is therefore unlikely that there will be a significant, practical difference in drag between configurations.

2.12 AERODYNAMIC STABILITY

2.12.1 Introduction. Several amphibious aircraft design features make the aerodynamic stability of the resulting design different from similar landplanes. In particular, the addition of floats to existing landplanes creates significant additional mass, side area and lift and drag producing structures well below the existing centre of gravity. Flyingboat design features such as forward mounted air intakes for jet engines, high slab-sided fuselages and high mounted tail surfaces and engines also ensure that aerodynamic stability derivatives require additional examination from an amphibious aircraft design viewpoint.

2.12.2 Yawing Stability. In yawing flight the aircraft must have adequate static directional (weathercock) stability and be able to trim in a cross wind and, if multi-engined, an engine failure. An aircraft should be designed so that it recovers automatically from a skid or yaw deviation from straight and level flight. This is usually achieved by the fin surface increasing angle of attack, thus producing a restoring moment. The principle measure of this stability is N_v (yawing moment derivative due to sideslip). N_v is affected by any structure with a side area and therefore floats, fuselage mounted engines and their support structures, large water rudders or deep flyingboat hulls can have an effect. The greater the distance the unbalanced area is ahead of the centre of gravity the worse the effect. Another amphibious aircraft-related effect is the presence of forward mounted jet air intakes (necessary for spray clearance), the inward mass flow of which may induce sideforce and therefore moment tending to increase the yaw and making the aircraft directionally unstable. Pusher propellers aft of the centre of gravity are stabilising but propellers forward are destabilising $_{(36)}$. The most simple method of ensuring that the addition of floats to an existing landplane does not reduce directional stability is to ensure that the side area forward of the centre of gravity is equalled by that aft. Other derivatives relevant to yawing flight are as follows:

a. N_ξ = yawing moment due to aileron (aileron drag) - no amphibious aircraft related effects.

b. N_ζ = yawing moment due to rudder - should have little effect as longitudinal moment arm from rudder to centre of gravity is largely unaffected by amphibious aircraft related design parameters.

c. N_p = yawing moment due to rate of roll - no amphibious aircraft related effects.

d. N_r = yawing moment due to rate of yaw (yaw damping) - as fuselages, especially sharp edged ones, have a negative (stabilising) effect on yaw damping $_{(30)}$ it is likely that floats and flying boat hulls will have a similar effect. Flyingboat planing bottoms with spray dams may have positive anti-spin characteristics, as may flat topped floats.

2.12.3 Directional Stability Database Work It was noted from the floatplane database that many floatplanes used additional ventral, dorsal or tailplane-mounted fins to add side area to the rear of the aircraft (see Plates 2.9 and 2.10). This is to offset the greater side area of that part of the floats forward of the centre of gravity (compared to the side area aft) and thus maintain the same directional stability performance as the original land-based aircraft. To establish a pattern for extra area those floatplanes with side elevation drawings available were extracted from the database. An assumed centre of gravity position of 20% mean root chord was drawn on the elevation and a vertical line dropped from this point through the float. The side area of the float was calculated forward and aft of this line and presented as a ratio. The extra fin area was also calculated and a new ratio calculated. Not surprisingly, considering the geometry of a standard float, a large proportion of the floatplanes indicated an unfavourable ratio (ie greater than 1). To retain the directional stability of the land-based aircraft following the addition of the float, the area forward of the centre of gravity should be the same as that aft. If a ratio of exactly 1:1 is not possible then the area aft should be greater than that forward to improve rather than reduce stability; thus a ratio less than one is desirable. The data is presented in Table 2.22. Note that both of the unstable aircraft in the Table which did not have fins added were project aircraft only; it will be interesting to note if fins are added later in the design stage. The only aircraft which remained unstable following the addition of a fin was only unstable to the second decimal place. Of the aircraft whose ratios indicated that they were stable, 4 had fins added seemingly making them more stable. Assuming that the designer would not add unnecessary items, this suggests that either the area estimation method or the centre of gravity position is at fault. In addition to the detailed dimensional output from the database a more general output was taken of the number of floatplanes which had additional fins and what form the fins took. A ventral location was the most favoured for an additional fin, despite this position being awkward for manoeuvring the rear fuselage over docks and jetties. It is assumed that this is the most convenient position from the point of view of the structure. The stability effects of ventral fins are quantified in Reference 45. Finlets fitted to horizontal tailplanes were the next most popular method, but are structurally complex despite clearing the jetty problem. Dorsal fins were unpopular. Dorsal fins are efficient at keeping flow effectiveness at high angles of sideslip due to vortex formation over the fin when otherwise flow would be separated. Thus they have little effect on lateral stability (46). Some aircraft use design synergy to gain additional side area aft of the aerodynamic centre. For example, the single float Vought OS2U Kingfisher's aft float support is not a minimal strut like the forward supports, but is a wide chord aerodynamic surface (see Plate 2.8). However, there was a surprisingly even split between the number of floatplanes requiring some form of extra area and those not. This indicates that no general pattern can be confidently drawn and each case must be considered individually.

2.12.4 Rolling Stability. In rolling flight the aircraft should have adequate control to perform the desired rolling manoeuvres and there should be adequate control in a steady sideslip. Considering the rolling aerodynamic derivatives:

a. L_ζ = rolling moment derivative due to rudder - should be affected by generally lower centre of gravity of both floatplanes and flyingboats, that is the rudder-generated force is acting over a larger moment arm therefore causing greater roll. However, this is not likely to be significant.

b. L_ξ = rolling moment derivative due to aileron - amphibious aircraft design features should have negligible effects as this derivative is more a function of aileron span and position rather than a change in centre of gravity position. The effects of a cross wind on large float or hull side areas may have a stabilising input. However, this is not thought to be significant.

c. L_p = rolling moment derivative due to rate of roll - no related effects.

d. L_r = rolling moment derivative due to rate of yaw - floats may have a slight effect if they generate lift. This effect is caused as the outer float in yaw will generate more lift and will add to the additional wing lift. However, this is not thought to be significant.

e. L_v = rolling moment due to sideslip (dihedral effect) - if floats are well away from the fuselage this should not be a problem. However, if the floats are close to the wings, for example on a twin engined low wing aircraft, an effect may occur. Reference 47 discusses this effect in relation to underwing nacelles, and although the float shape (especially length) puts it well out of the geometric parameters covered by the experimental range of the method, the indication is that the negative (stabilising) effect is the order of -0.007. As values of L_v should be around 0 to -0.1 (36) this effect is not considered to be significant. However, when too much dihedral stability is combined with insufficient directional stability serious Dutch roll problems can be caused (48).

2.12.5 Lateral-Directional Stability. The aircraft must have adequate response in terms of spiral stability, roll subsidence and lateral oscillations. In some cases the latter may develop into a Dutch Roll which must be kept within reasonable limits. Spiral instability is caused by an aircraft having too much directional stability (N_v) and too little lateral stability ($-L_v$). Floatplanes tend not to suffer from this effect as it is mitigated by low centres of gravity. However, the effect should be avoided by not over-compensating for the addition of floats to an existing aircraft with too much additional aft side area.

2.12.6 Sideforce Derivatives. Amphibious aircraft design parameters have the following effects on sideforce derivatives:

a. Y_ζ = sideforce due to rudder - no amphibious aircraft related effects

b. Y_p = sideforce due to rate of roll - usually insignificant but is influenced by any additional side area vertically away from the centre of gravity and therefore floats may have some effect.

c. Y_r = sideforce due to rate of yaw - a very small effect, but side surfaces forward of the centre of gravity have a negative effect and those aft a positive effect. A balanced fore/aft float system side area is therefore required.

d. Y_v = sideforce due to sideslip - the lateral resistance to sideways motion is similar in effects to N_r, in that the additional sideways drag of the floats adds to stability. In a similar way to L_v, Reference 49 gives guidance on the effect of underwing nacelles which have similarities to floats. Although, again, the effect of the float shape puts it well out of the geometric parameters covered by the experimental range of the method, the size of the effect at -0.1 onto a coefficient of -0.03 to -0.5 indicates that the stabilising effect can be significant.

2.12.7 Pitch and Speed Stability. As the float centre of gravity should generally be directly below that of the aircraft this parameter should have no effect on pitch stability. However, lift from the float bow form could be destabilising in pitch. Similarly, floats should balance fore/aft in a plan form view as well as side elevation. The usual plan form of a float does not lend itself to such a balance and therefore a larger horizontal tail surface may be required. This, in turn will require more powerful capability to retrim. However, as the floats act as a pendulum in the pitch sense, this effect should be self cancelling. The high thrust lines popular with amphibious aircraft for spray avoidance add pitch-related speed instability as an increase in thrust also serves to push the nose down, further increasing speed. Similarly, a drop in power due to, say, an engine failure brings nose up, potentially causing a stall. The high thrust line arrangement also results in a considerable download on the tailplane surfaces in level flight causing trim drag. This problem is often minimised by tilting the thrust line to reduce the download (36).

2.13 FLOAT CUSTOMER REQUIREMENTS.

During site visits amphibious and pure floatplane users were asked to detail their desirable requirements for floats in addition to the mandatory buoyancy and ever-present cost/performance points. The following list is a summary of their views with design-related notes in brackets. For more details of this market research exercise see Section 4.2.

a. High Impact Resistance of Float Bottom.
- position and number of internal or external longitudinal and lateral stiffeners (cost of manufacture, mass, hydro-boosters, skegs, watertight bulkheads).
- choice of materials and skin thickness (aluminium, inflatable or composites, cost of manufacture mass and repairability).
- deadrise (displacement/draft effects and landing force vector resolution).

b. Maintainability of Floats.
- internal access (bilge pumps and repair access).
- choice of materials (repair following damage and cost).
- joints (bonded or riveted for cost of manufacture and leak sealing processes).
- access to strut joints/rudder mechanism for maintenance (aerodynamic effects).

c. Passenger Safety.
- high rearwards buoyancy and flat top enables passengers and maintainers to move along rear of float safely (performance effects).

d. Constructive Use of Float Internal Volume.
- access panel size and water tightness of volumes used for baggage or fuel (cost of manufacture, loading of cut-outs).

e. Water Performance.
- conflicting requirement of rapid take-off (ie `slippery' float) and rapid deceleration (for aircraft without variable pitch propellers).

2.14 VALIDATION EXAMPLES.

2.14.1 Introduction. Three examples are used to validate the majority of the methodologies proposed in the floatplane section of the study. The examples use floats and aircraft at the light and heavy ends of the twin floatplane spectrum and one single float floatplane. None of the validation floats or aircraft data have been used in developing the methods. Not every methodology could be validated by all examples due to a lack of information and data priority being placed on gaining the methodologies, but at least one example validates each methodology.

	Example 1	Example 2	Example 3
mass	✓	✓	✗
length	✓	✓	✓
beam	✓	✓	✓
forebody length	✓	✓	✓
height	✓	✗	✓
spray height	✓	✗	✓
cost	✓	✗	✗
longitudinal stability	✓	✗	✓
lateral stability	✓	✗	✓
performance	✗	✗	✓

A summary of the results are as follows, detailed calculations are in Appendix 7.

2.14.2 Example 1 - Twin Float, Single Engined Aircraft. The Baumann BF2100 float fitted to the Piper PA18 Super Cub was not included in the development of the float methodologies and can therefore be used for validation purposes.

	calculated	actual	error
mass	124 kg	112kg	+10%
length	4.91m	5.14m	-4%
beam	0.65m	0.72m	-9%
height	0.56m	0.55m	+2%
Forebody length	2.45m	2.55m	-4%
spray height (empirical)	0.65m	0.65m	0%
spray height (calculated)	1.11m	1.2m	+7%
Float separation	2.1m	2.1m	0%
cost	$19773	$18500	+7%

2.14.3 Example 2 - Single Float, Multi-engined Aircraft. In 1939 a Short Scion Senior transport aircraft was fitted with a half-scale representation of a Sunderland hull under its fuselage for experimental work (see Plate 2.11) $_{(50)}$. This is the closest to a large single float civilian floatplane available for validation work, although some care must be taken in using the figures as the dimensions would have been driven more by the requirement to represent the Sunderland rather than by efficiently supporting the Scion. However, the design still had to be safe to operate.

	calculated	actual	error
length	8.8m	9.0m	-5%
beam	1.3m	1.49m	-8%
height	1.0m	0.95m	+5%
forebody length	4.9m	5.1m	-4%

2.14.4 Example 3 - Large Twin Float Multi-engined Aircraft. The DC3 Dakota aircraft was modified to become an amphibious floatplane primarily to serve the Pacific theatre during World War 2 (see Plate 2.12). The floatplane DC3 had additional fuel tanks in the floats and therefore a range comparison with the landplane is not valid.

	calculated	Actual	error
length	10.4m	13m	-20%
beam	1.4m	1.5m	-7%
height	1.22m	1.31m	-7%
forebody length	5.2m	4.8m	+8%
spray height (empirical)	1.4m	1.4m	0%
spray height (calculated)	-1.11m	3.24m	-
float separation	5.8m	5.8m	0%
speed	289km/hr	309km/hr	-6%
ROC	278m/min	228m/min	-18%

2.14.5 Discussion of Validation.

a. Twin Floats. The validation results well illustrate both the strengths and weaknesses of the float methodologies. The Baumann float represent a place in the methodologies where there are many data points to support the equations. The errors are therefore small and generally acceptable. There is also very little variance in configuration input with these small sized floats and floatplanes. A large degree of confidence can therefore be placed in the methodologies. The opposite is true for the DC3-sized floats. Here, there are few data points to support the methodologies and some of the old empirical relationships built into the equations cannot be sensibly extrapolated. This is vividly illustrated in the results of the centre of gravity to centre of buoyancy method. Similarly, any error in the length estimate moves through all the other dimension estimations. This is an important factor to consider in the larger floats, as configuration inputs play a more significant role than with small floatplanes. Care must therefore be taken when using the methodologies for large floatplanes.

b. Single Floats. The lack of data regarding the single float configuration is not only illustrated by the size of the errors in the validation examples, but also in the fact that only a few parameters could be validated. The Scion was chosen as a validation example to show a possible, practically-sized civilian application of this type of arrangement. However, it also illustrates the difficulty in using data from the largely small, military floatplanes in this different area. As stated in the text, the methodologies for single float floatplanes must be used with care.

TABLE 2.1

ADVANTAGES OF SINGLE AND TWIN FLOAT CONFIGURATIONS

Single Float	Twin Float
In some cases lighter float for same aircraft AUM.	More robust (no tip float to break off).
More manoeuvreable in water due to use of tip float as pivot.	Easy to taxi to piers etc (no tip floats).
In some cases smaller frontal/wetted area and therefore less drag.	Main floats ease disembarkation.
Easy to catapult (obsolete military reason).	Only requires fuselage mods (no wing mods for tip floats).
No lateral or longitudinal c of g change if used for water bomber.	Easy to make amphibious due to wide track of floats.
More robust for landings as loads go straight vertically into fuselage frames.	Easier to emergency land on land due to robust floats (no tips).
Greater useable internal volume.	In case of single prop, struts can be shorter as the prop fits between the floats.
	More potential useable volume in floats near to longitudinal c of g.
	No requirement to fit tip floats on high wing (long struts).

TABLE 2.2a

MODERN PURE FLOAT MASS DATA

Name	Mass of Float System (kg)	Theoretical Aircraft AUM (kg)
Superfloat 500	13	252
Superfloat 800	14	404
Superfloat 1000	26	504
Superfloat 1200	27	605
Superfloat 1400	30	706
Superfloat 1600	40	807
Superfloat 1800	42	908
Superfloat 2000	42	1009
Superfloat 2300	43	1160
Zenair 550	16	277
Zenair 750	25	378
Zenair 950	38	479
Zenair 1150	53	580
Zenair 1400	64	706
Zenair 1650	71	832
Zenair 1900	77	958
Full Lotus 1220	43	615
Full Lotus 1260	45	636
Full Lotus 1650	49	832
Full Lotus 2150	69	1085
Full Lotus 2250	78	1135
Aqua	113	757
Murphy	77	762
Edo 1650	100	832
Edo 2000	109	1009
Edo 2130	114	1074
Edo 2440B	154	1261
Edo 2960	193	1507
Edo 3430	213	1730
Edo 4930	275	2487
Edo 62-6560	341	3309
Edo 61-5870	309	2961
Edo 59-5250	286	2431
Edo 58-4560	259	2109
Edo 45-2660	171	1342
Edo 44-2425	153	1223
Edo 47-1965	125	991
Edo 46-1620	107	817
Edo 60-1320	74	666
Edo 54-1140	68	575
Edo D-1070	48	540
PK 3000	192	1567
PK C3500	201	1776
PK B2300	138	1158
Honn	190	1556
Aeroset	216	1970
Wipline 4000	239	1918
Wipline 6000	344	2857
Wipline 8000	524	3939
Wipline 13000	672	6479

TABLE 2.2b

MODERN AMPHIBIOUS FLOAT MASS DATA

Name	Mass of Float System (kg)	Theoretical Aircraft AUM (kg)
Superfloat 500	19	252
Superfloat 800	20	404
Superfloat 1000	33	504
Superfloat 1200	34	605
Superfloat 1400	37	706
Superfloat 1600	52	807
Superfloat 1800	54	908
Superfloat 2000	57	1009
Superfloat 2300	59	1160
Zenair 550	30	277
Zenair 750	39	378
Zenair 950	52	479
Zenair 1150	66	580
Full Lotus 1220	60	615
Full Lotus 1260	62	636
Full Lotus 1650	63	832
Full Lotus 2150	86	1085
Full Lotus 2250	95	1135
Edo 2500	274	1261
Edo 2790	284	1408
Edo 3500	341	1766
PK D3500A	329	1725
Wipline 4000	341	1918
Wipline 6000	4722	2857
Wipline 8000	657	3939
Wipline 13000	939	6479

TABLE 2.3

OVERFLOATING DATA

Aircraft	AUM (kg)	Float	Theoretical Aircraft AUM (kg)	Overfloat Factor
Avid IV	522	Zenair 1150	580	1.11
Rebel	749	Murphy	762	1.02
Cessna 150	749	Edo 1650	832	1.11
Piper Super Cub	799	Zenair 1900	958	1.20
Piper Super Cub	799	Edo 2000	1009	1.26
Champion Scout	976	Edo 2130	1074	1.10
Cessna Hawk	1158	Edo 2440B	1261	1.09
Cessna 180	1339	Edo 2960	1507	1.10
Cessna 185	1521	Edo 3430	1730	1.14
Cessna 185	1521	Wipline 4000	1918	1.26
Pilatus Porter	2202	Edo 4930	2487	1.13
Beaver	2438	Wipline 6000	2857	1.17
Caravan	3632	Wipline 8000	3939	1.08
Twin Otter	5675	Wipline 13000	6479	1.14
Cessna 206	1634	PK D3500A	1725	1.06
Cessna 185	1521	PK D3500A	1725	1.13
Cessna 185	1521	PK 3000	1522	1.00
Cessna 172	1044	PK 2300	1158	1.11
Maule M5-210	1044	PK 2300	1158	1.11
			Average	1.11

TABLE 2.4

LARGE AIRCRAFT FLOAT MASS DATA

Aircraft	AUM (kg)	Landplane Empty Mass (kg)	Floatplane Empty Mass (kg)	Under-carriage Mass (kg)	Float Mass (kg)	% AUM	Float Mass (from Eqn 1) (kg)	Error %
Valetta	9940	6365	6605	477	717	7	1093	+52%
Ha 139	16575	11090	13532	796	3238	19	1823	-44%
Ca 312	5593	3428	3995	268	835	15	615	-26%
Tu TB1	8000	-	-	-	816	10	880	+8%
Ju 52	11041	6503	7116	530	1143	10	1214	+6%
C130	79450	33092	29278	3814	7718	10	8749	+13%
LeO H257	9568	5304	5616	459	717	7	1052	+47%
Average						11		

TABLE 2.5

LANDING VELOCITY FUNCTION DATA

Aircraft	AUM (kg)	V_{stall} (mph)	Mass of Float System (kg)	AUM x V_{stall} (x10^4)	AUM x V_{stall}^2 (x10^5)	AUM- x V_{stall}^2 (x10^4)
Twin Otter	5670	67	672	38.0	254.5	142.8
Caravan	3327	71	524	23.6	167.7	112.4
Beaver	2311	60	275	13.9	83.2	62.9
PA18	795	42	109	3.3	14.0	15.1
PA22	885	58	109	5.1	29.8	31.0
Arctic Tern	966	34	109	3.3	11.2	11.3
Cessna 150	749	30	100	2.2	6.7	7.4
Cessna 172	1008	32	109	3.2	10.3	10.3
Scout	976	51	109	5.0	25.4	25.6
Maule M5	1249	58	154	7.2	42.0	39.0
Maule M6	1249	56	154	7.0	39.2	36.4
Maule M7	1249	54	154	6.7	36.4	33.8
Cessna 180	1339	37	193	4.9	18.3	16.6
Cessna 185	1507	39	193	5.9	22.9	20.0
Cessna 206	1634	41	213	6.7	27.5	23.3
Helio 295	1544	35	213	5.4	18.9	16.4
PA32-300	1542	63	213	9.7	61.2	53.0
Zenair CH701	436	28	38	1.2	3.4	4.5
Rebel	658	28	77	1.8	5.2	5.9
Kitfox	636	44	45	2.8	12.3	14.3
Avid IV	522	36	43	1.9	6.8	8.4
Magnum	749	36	114	2.7	9.7	10.7

TABLE 2.6

SINGLE FLOAT MASS AGAINST DISPLACEMENT

Float	Float Displacement (kg)	Float Mass (kg)
Superfloat 500	227	19
Superfloat 800	363	20
Superfloat 1000	434	33
Superfloat 1200	545	34
Superfloat 1400	636	37
Superfloat 1600	726	52
Superfloat 1800	817	54
Superfloat 2000	908	57
Superfloat 2300	1044	59
Zenair 550	250	8
Zenair 750	341	13
Zenair 950	431	19
Zenair 1150	522	26
Zenair 1400	636	32
Zenair 1650	749	35
Zenair 1900	863	39
Full Lotus 1220	555	21
Full Lotus 1260	573	22
Full Lotus 1650	750	24
Full Lotus 2150	975	34
Full Lotus 2250	1021	39
Edo 1650	749	50
Edo 2000	908	55
Edo 2130	967	57
Edo 2440B	1135	77
Edo 2960	1357	96
Edo 3430	1557	106
Edo 4930	2238	137
Wipline 4000	1726	120
Wipline 6000	2571	272
Wipline 8000	3545	262
Wipline 13000	5831	336

TABLE 2.7

TOTAL SINGLE FLOAT SYSTEM MASS

AUM (kg)	1.8 x AUM	Float Mass (kg)	Tip Float Mass (kg)	Total Mass (kg)
200	360	22.3	2	24.3
400	720	44.6	3	47.6
600	1080	67.0	4	71.0
800	1440	89.3	5	94.3
1000	1800	111.6	6	117.6
1500	2700	167.4	9	176.4
2000	3600	223.2	12	235.2
2500	4500	279.0	15	294.0
3000	5400	334.8	17	351.8
3500	6300	390.6	18	408.6
4000	7200	446.4	19	465.4
4500	8100	502.2	20	572.2
5000	9000	558.0	22	580.0
6000	10800	669.6	25	694.6
7000	12600	781.2	28	809.2
8000	14400	892.8	30	922.8
9000	16200	1004.4	31	1035.4
10000	18000	1116.0	32	1148.0

TABLE 2.8

FLOAT MASS DATA FROM REFERENCES

AUM (kg)	Float Mass (kg)	Reference
463	62	Brimm: Seaplanes - Manufacture, Maintenance and Operation.
654	102	
801	115	
1001	134	
1194	154	
1498	187	
1725	218	
1998	240	
2406	261	
2815	282	
500	50	Nelson: Seaplane Design (Single Floats).
1000	100	
1500	150	
2000	200	
2500	250	
3000	300	
4000	400	
6000	600	
8000	800	
500	65	Nelson: Seaplane Design (Twin Floats)
1000	130	and
1500	195	Currey: Aircraft Landing Gear - Principles and Practices.
2000	260	
2500	325	
3000	390	
4000	520	
6000	780	
8000	1040	
500	44	Rosenthal: Weight of Seaplane Floats.
1000	84	
1500	122	
2000	159	
2500	195	
3000	231	
4000	302	
6000	441	
8000	575	
500	58	Langley: Seaplane Hull and Float Design.
1000	75	
1500	92	
2000	109	
2500	126	
3000	143	
4000	177	
6000	245	
8000	314	

TABLE 2.9a

FLOAT DIMENSION DATA - TWIN FLOAT FLOATPLANES

Type	Name	AUM (kg)	l (m)	b (m)	h (m)	l_{fb} (m)	l/b	l/h	l/l_{fb}
Civ Twin	Nomad	3855	8.5	-	1.0	4.6	-	8.1	1.8
	Sokol	2030	8.4	-	0.9	4.6	-	9.4	1.8
	C5	1855	6.5	0.7	0.7	3.6	9.3	9.2	1.8
	Scion	1452	7.1	1.0	0.7	4.1	7.1	9.6	1.7
	Cant Z511	33560	19.8	1.8	1.8	10.4	10.8	10.8	1.9
	Mercury	5670	10.2	1.2	1.0	5.1	8.7	10.4	2.0
	SM 87	16965	13.7	1.3	1.2	4.1	10.3	11.8	3.3
	Mussel	744	4.7	0.6	0.5	2.5	7.8	9.0	1.9
	Islander	2993	7.2	1.1	1.0	3.6	6.5	7.5	2.0
	Cant Z506	10500	12.1	1.7	1.0	7.0	7.1	12.3	1.7
	Average						8.4	9.8	2.0
Mil Twin	Arado 196	3365	8.8	1.1	1.0	4.8	8.0	9.3	1.8
	Stearman	1513	5.7	0.8	0.8	2.9	7.1	7.1	2.0
	Gurnard	2180	7.4	1.1	0.8	4.1	6.7	9.7	1.8
	Ca312	6188	9.1	1.1	1.1	4.4	8.3	8.7	2.1
	Bv139	19017	12.6	1.2	1.4	7.0	10.5	9.0	1.8
	Bv140	8490	10.3	1.3	1.2	5.6	7.9	8.4	1.8
	He115	10689	10.7	1.5	1.3	5.5	7.1	8.0	1.9
	N3PB	4172	8.5	1.0	1.1	4.4	8.5	8.1	1.9
	Fokker T8	6600	7.6	1.1	0.9	4.1	7.1	8.4	1.8
	Aichi E13A1	4000	7.9	1.2	1.0	4.3	6.6	7.6	1.8
	Aichi E16A1	4553	7.7	1.2	1.1	4.2	6.4	7.1	1.8
	Aichi M6A1	4445	8.1	1.0	1.1	4.5	8.1	7.2	1.8
	Yoko E14Y1	1600	5.4	0.8	0.7	3.1	6.8	7.6	1.8
	Kawa E7K2	3300	6.9	1.1	0.9	3.7	6.3	7.4	1.9
	Fleet Finch	885	5.0	0.6	0.6	2.7	7.9	7.9	1.8
	Fiat RS14	7264	8.8	1.3	0.8	4.4	7.0	11.7	2.0
	LeO H46	-	11.6	1.8	1.5	6.0	6.4	7.7	1.9
	He59	8907	10.9	1.2	1.4	5.6	8.9	7.8	2.0
	He60	3396	8.0	1.2	1.0	4.0	6.7	7.9	2.0
	He119	-	11.1	-	1.1	6.1	-	10.3	1.8
	Lat 298D	-	8.3	-	1.2	4.9	-	6.7	1.7
	Tupolev TB1	8000	10.7	-	-	-	-	-	-
	Bolingbroke	6719	9.7	1.5	1.3	5.1	6.5	7.5	1.9
	Bloch MB-480	10010	11.5	1.8	1.4	6.8	6.4	8.2	1.7
	Centre NC-470	6005	9.5	1.4	0.9	5.9	6.8	10.5	1.6
	Centre NC-410	11990	11.6	1.5	1.0	7.0	7.7	11.6	1.7
	LeO H257/8	10229	10.9	1.6	1.1	6.5	6.8	9.9	1.7
	Loire-Nieuport 10	13957	11.2	1.8	1.6	6.2	6.0	7.0	1.8
	SE400	5504	9.2	1.4	1.0	5.0	6.6	9.2	1.8
	Ca316	4808	9.2	1.3	0.9	5.0	7.1	10.2	1.8
	Cant Z515	2657	19.0	2.5	2.0	11.2	7.6	9.7	1.7
	Dewoitine HD730	1871	6.5	0.8	0.7	3.6	8.1	9.3	1.8
	Gourdou G120	1601	6.5	0.9	0.6	3.6	7.2	10.8	1.8
	Lat 29	4804	9.6	1.5	0.9	5.7	6.4	10.7	1.7
	C130	79450	20.9	2.8	1.8	11.7	7.5	11.6	1.8
	Average						7.3	8.8	1.8

TABLE 2.9b

FLOAT DIMENSION DATA - FLOATS

Type	Name	AUM (kg)	l (m)	b (m)	h (m)	l_{fb} (m)	l/b	l/h	l/l_{fb}
Float	Wipline 13000	6479	9.4	1.3	1.2	4.6	7.1	8.0	2.1
	Wipline 8000	3939	8.4	1.0	1.0	4.1	8.2	8.8	2.0
	Wipline 6000	2857	6.9	1.0	0.9	3.5	6.8	8.0	2.0
	Wipline 4000	1918	6.4	0.9	0.8	3.2	7.4	8.4	2.0
	Full Lotus 1220	615	3.8	0.7	0.3	2.1	5.4	12.7	1.8
	Full Lotus 1260	636	4.2	0.7	0.3	2.1	6.1	13.1	2.0
	Full Lotus 1650	832	4.6	0.7	0.3	2.1	6.5	14.4	2.2
	Full Lotus 2150	1085	5.1	0.8	0.4	2.5	6.1	13.1	2.2
	Full Lotus 2250	1135	5.4	0.9	0.4	2.5	6.3	15.0	2.4
	Edo 1650	832	4.3	-	0.5	2.1	-	8.1	2.0
	Edo 2000	1009	4.9	-	0.6	2.7	-	8.8	1.8
	Edo 2130	1074	5.1	-	0.5	2.9	-	9.4	1.8
	Edo 2440	1261	5.2	-	0.7	2.6	-	7.6	2.0
	Edo 2960	1507	6.4	-	0.7	3.0	-	9.3	2.1
	Edo 3430	1730	5.9	-	0.8	3.0	-	7.9	2.0
	Edo 4930	2487	6.8	-	0.8	3.5	-	8.5	1.9
	Edo 62-6560	3309	7.6	1.0	0.9	-	7.6	8.8	-
	Edo 61-5870	2961	7.0	1.0	0.9	-	7.0	7.8	-
	Edo 59-5250	2431	7.1	0.9	0.8	-	7.9	8.9	-
	Edo 58-4560	2109	6.5	0.9	0.8	-	7.2	8.1	-
	Edo 45-2660	1342	5.8	0.7	0.7	-	8.3	8.3	-
	Edo 44-2425	1223	5.2	0.7	0.7	-	7.4	7.4	-
	Edo 47-1965	991	5.0	0.7	0.6	-	7.1	8.3	-
	Edo 46-1620	817	4.4	0.7	0.6	-	6.3	7.3	-
	Edo 60-1320	660	4.4	0.5	0.5	-	8.8	8.8	-
	Edo 54-1140	575	4.1	0.5	0.5	-	8.2	8.2	-
	Edo D-1070	540	3.7	0.6	0.5	-	6.2	7.4	-
	Superfloat 500	252	3.7	-	-	-	-	-	-
	Superfloat 800	404	3.7	-	-	-	-	-	-
	Superfloat 1000	504	4.6	-	-	-	-	-	-
	Superfloat 1200	605	4.6	-	-	-	-	-	-
	Superfloat 1400	706	4.6	-	-	-	-	-	-
	Superfloat 1600	807	5.1	-	-	-	-	-	-
	Superfloat 1800	908	5.1	-	-	-	-	-	-
	Superfloat 2000	1009	5.1	-	-	-	-	-	-
	Superfloat 2300	1160	5.1	-	-	-	-	-	-
	Zenair 550	277	3.3	-	-	-	-	-	-
	Zenair 750	378	3.9	-	-	-	-	-	-
	Zenair 950	479	3.9	-	-	-	-	-	-
	Zenair 1150	580	4.0	-	-	-	-	-	-
	Zenair 1400	706	4.3	-	-	-	-	-	-
	Zenair 1650	832	4.6	-	-	-	-	-	-
	Zenair 1900	958	4.9	-	-	-	-	-	-
	Murphy	762	4.3	0.7	0.5	2.1	6.3	8.4	2.0
	Average						7.4	9.2	2.0

TABLE 2.9c

FLOAT DIMENSION DATA - SINGLE FLOAT FLOATPLANES

Type	Name	AUM (kg)	l (m)	b (m)	h (m)	l_{fb} (m)	l/b	l/h	l/l_{fb}
Mil Single	Arado 196	3365	9.2	1.1	1.0	5.1	8.3	9.7	1.8
	Gurnard	2180	8.3	1.1	1.1	4.1	7.7	7.7	2.0
	Kawa E15K	4900	9.4	1.5	1.1	5.2	6.3	8.3	1.8
	Kawa N1K	3712	8.0	1.3	0.9	4.2	6.0	9.0	1.9
	Mitsu F1M2	2550	7.2	1.4	0.9	4.0	5.3	7.8	1.8
	Naka E8N	1900	7.3	1.1	0.9	4.5	6.8	8.6	1.6
	Naka A6M2-N	2880	7.1	1.2	1.0	3.9	5.8	7.0	1.8
	Grumman Duck	3047	8.4	1.5	0.9	4.3	5.5	9.2	2.0
	Douglas XO2D	2317	7.5	1.2	1.0	4.4	6.3	7.7	1.7
	Kingfisher	2724	8.1	0.9	0.8	5.3	8.6	10.3	1.5
	Seamew	3178	7.9	1.0	0.9	4.3	8.3	9.0	1.8
	Seahawk	4086	9.0	1.3	1.3	4.8	6.8	7.2	1.9
	Edo XOSE-1	-	7.7	1.2	0.8	4.2	6.4	9.1	1.8
	Mussel	744	6.3	0.7	0.7	3.3	8.9	8.8	1.9
	Loire 210	2152	7.8	1.3	1.0	4.5	6.0	7.8	1.7
	Average						6.9	8.5	1.8

TABLE 2.10

FLOATPLANE SPRAY HEIGHT - EMPIRICAL METHOD

Type	Name	AUM (kg)	h (m)	h 45.0	span (m)
Single Engine Twin Float	Aichi E13A1	4000	1.2	1.7	14.5
	Aichi E16A1	4533	1.1	1.5	12.8
	Aichi M6A1	4445	1.1	1.6	12.3
	Yoko E14Y1	1600	0.8	1.2	11.0
	Kawa E7K2	3300	0.9	1.3	14.0
	Gurnard	2356	1.0	1.4	11.3
	Mussel	715	0.9	1.3	11.4
	S'man S76	1633	0.7	1.0	9.8
	Avid Flyer	522	0.6	0.8	9.1
	Finch	885	0.5	0.7	8.5
	N3PB	4172	0.8	1.2	14.9
	Beaver	2043	0.8	1.1	14.6
	C5	2020	0.7	1.0	13.7
	Arado 196	3723	1.3	1.8	15.1
	He60	3396	1.0	1.4	13.7
	Norseman	2747	0.6	0.8	15.7
	Caravan	3632	0.6	0.9	15.9
	Sokol	2030	0.8	1.1	13.7
Multi-engine Twin Float	Scion	2607	0.7	1.0	12.8
	Islander	2993	1.0	1.3	14.9
	Ca312	5593	1.1	1.5	16.2
	Bv139	19017	0.7	1.0	29.5
	Bv140	8507	1.2	1.7	22.0
	He115	9100	1.6	2.3	22.3
	Cant Z506	12210	1.5	2.1	26.5
	Fiat RS14	7264	1.0	1.4	19.6
	Fokker T8	5008	1.1	1.6	18.0
	Mercury	5670	1.9	2.6	22.3
	Cant Z511	33560	2.3	3.2	40.0
	SM87	16965	1.1	1.6	29.7
	Twin Otter	5670	0.4	0.6	19.8
	Victor	1960	0.6	0.8	12.0
	Nomad	3855	0.0	0.0	16.5
	He59	8907	1.4	2.0	23.6
Single Engine Single Float	Kawa E15K1	4900	0.9	1.3	14.0
	Kawa N1K	3712	1.1	1.6	12.0
	Naka E8N2	1900	0.8	1.1	11.0
	Mitsub F1M1	2550	1.0	1.4	11.0
	Naka A6M2	2880	1.1	1.6	12.0
	Kingfisher	2724	0.8	1.1	11.0
	Seahawk	4086	0.7	0.9	12.5
	Gurnard	2500	0.9	1.3	11.3
	Mussel	744	0.5	0.7	11.4
	Arado 196	3306	1.3	1.8	15.1
	XO2D-1	2317	0.8	1.2	11.0
	Duck	3047	0.6	0.9	11.9
	Seagull	3178	0.6	0.8	11.6

TABLE 2.11

LONGITUDINAL STATIC STABILITY

Type	Aircraft	h_{actual} (m)	BM (m)	GM (m)	h_{max} (m)	difference $h_{act} - h_{max}$
Twin Float	E13A1	2.2	18.42	12.35	6.1	-3.9
	E16A1	2.0	14.98	12.88	2.2	-0.2
	M6A1	2.3	14.89	12.80	2.1	0.2
	E14Y1	1.8	9.81	9.11	0.7	1.1
	Gurnard	2.4	25.46	10.36	13.2	-10.8
	Mussell	2.2	10.43	7.06	2.7	-0.5
	S76	1.8	12.19	9.17	2.1	-0.3
	N3PB	1.9	18.33	12.53	5.8	-3.9
	Beaver	1.9	30.28	9.88	7.6	-5.7
	C5	1.7	12.91	9.84	2.0	-0.3
	Arado196	2.2	27.74	12.06	13.0	-10.8
	Scion	2.0	30.70	10.71	6.4	-4.4
	Islander	1.5	17.08	11.22	5.9	-4.4
	Ca312	2.8	16.68	13.81	4.6	-1.8
	Bv139	2.7	15.72	20.78	-5.0	7.7
	Bv140	2.5	20.84	16.32	2.8	-0.3
	He115	2.5	21.41	17.14	4.3	-1.8
	Z511	4.7	51.85	25.09	26.8	-22.1
	Mercury	2.6	27.97	13.88	14.1	-11.5
	SM87	3.2	24.54	19.99	4.5	-1.3
	Z506	2.6	35.72	17.04	18.7	-16.1
	T8	2.2	12.01	14.60	-5.5	-3.3
	E7K2	2.0	13.64	11.59	2.0	0.0
	Finch	1.1	10.55	7.48	2.1	-2.0
	RS14	1.9	15.19	15.07	0.1	1.8
	He59	3.4	21.73	16.13	5.6	-2.2
	He60	2.5	22.53	11.70	1.4	1.1
Single Float	E15K1	2.3	15.83	13.00	2.3	0.0
	N1K	2.2	11.17	11.85	0.2	2.0
	A6M2	2.0	9.29	10.89	-0.8	2.8
	Kingfisher	1.8	10.93	10.69	1.5	0.3
	Seagull	1.9	9.66	11.25	3.0	-1.1
	Seahawk	2.1	14.44	12.24	2.7	-0.6
	Gurnard	2.3	17.97	10.39	5.3	-3.0
	Mussell	1.3	14.65	6.94	7.7	-6.4
	Arado196	2.4	15.85	11.86	3.8	-1.4
	F1M2	2.1	12.76	10.46	2.3	-0.2
	E8N2	1.8	14.02	9.48	4.5	-2.7
	Duck	1.5	18.17	11.10	7.1	-5.6
	XO2D-1	1.7	14.72	10.13	3.5	-1.8

For these calculations K = 1.75

TABLE 2.12

LATERAL STATIC STABILITY

Type	Name	s min (m)	s actual (m)	Error (m)
Single Engined	Aichi E13A1	2.9	3.4	0.5
	Aichi E16A1	3.2	3.2	0.0
	Aichi M6A1	3.4	3.3	-0.1
	Yoko E14Y1	2.4	2.4	0.0
	Gurnard	2.3	2.7	0.4
	Crusader	2.3	2.0	0.3
	Mussell	1.9	2.4	0.5
	Stearman S76	2.4	2.5	0.1
	Northrop N3PB	3.2	3.4	0.2
	Beaver	2.2	2.8	0.6
	C5	2.7	3.3	0.6
	Arado Ar 196	2.8	4.9	2.1
	Kawa E7K2	2.9	2.8	-0.1
	Finch	1.9	2.1	0.2
	He60	2.6	3.7	1.1
Multi-Engined	Scion	2.6	3.5	0.9
	Islander	2.6	3.6	1.0
	Caproni Ca312	3.7	4.9	1.2
	Ha 139	6.5	6.0	-0.5
	Ha 140	4.3	5.4	1.1
	He 115	4.3	4.7	0.4
	Cant Z511	6.4	8.3	1.9
	Mercury	3.3	5.0	1.7
	SM87	5.6	6.7	1.1
	Cant Z506	3.7	6.5	2.8
	Fokker T8	4.4	3.8	-0.6
	Fiat RS14	3.9	5.3	1.4
	He 59	4.4	5.8	1.4

TABLE 2.13a

FLOATPLANE STEP OFF-SET ANGLES

TWIN FLOATS

Aircraft	Angle (°)
Ar196	14
He115	18
Cant Z506	21
Seahawk	14
Cant Z511	10
SM 87	30
Fokker T8	11
Aichi E13A1	20
Aichi E16A1	20
Aichi M6A1	11
Nomad	19
Fiat RS14	10
Beaver	9
Yokosuka E14Y1	18
Kingfisher	11
Seagull	16
Scion Senior	15
Twin Otter **	10
MFI 11	4
P68	10
Islander	11

Aircraft	Angle (°)
C5	14
Bv139	15
Bv140	15
LeO H46	22
Avid Flyer	15
Norseman	14
Caravan	14
N-3PB	16
Bolingbroke	5
AVERAGE	14.4

SINGLE FLOATS

Aircraft	Angle (°)
Scion Senior	15
Kawanishi E15K1	20
Kawanishi N1K1	10
Nakajima A6M2-N	6
Edo XOSE-1	16
Loire 210	20
Average	14.5

TABLE 2.14a

FLOAT STRUT CONFIGURATION - STRUCTURES

See Figure 10 for relevant drawings.

Single Float (Single Engine)

Single Cantilever

a.	Front/rear spar frames (open or closed struts)	6
b.	Engine bulkhead/rear spar frame/rear bulkhead	1
c.	Front spar frame/rear bulkhead	1
d.	Engine bulkhead/rear spar frame	2

Twin Cantilever

e.	Engine bulkhead/rear spar frame (with or without longitudinal-lateral bracing)	5
	Total =	15

Twin Floats (Single Engine)

f.	Front/rear spars (fuselage frames)	7
g.	Front/rear spars (low wing)	6
h.	Engine bulkhead/rear spar frame	16
i.	Front spar frame/rear bulkhead	8
j.	Engine bulkhead/rear bulkhead	4
k.	Front spar frame/engine bulkhead	1
l.	Engine bulkhead/front spar frame/rear bulkhead	1
m.	Engine bulkhead/front spar frame/rear spar frame	2
	Total =	45

Twin Floats (Multi-engine)

n.	Front bulkhead/rear bulkhead	1
o.	Front bulkhead/rear spar frame	2
p.	Front spar frame/rear bulkhead (door frame)	1
q.	Front spar/rear spar (on wings)	8
r.	Front spar/rear spar (on wings)/fuselage frame (lateral stiffener)	16
s.	Front bulkhead/rear spar (on wings)	1
t.	Front bulkhead/front spar frame	1
	Total =	30

TABLE 2.14b

FLOAT STRUT CONFIGURATIONS

a. Seahawk SC-1
Kawanishi E15K1
Curtis Seagull SOC3
Loire 210
Douglas XO2D-1
Nakajima A6M2 "Rufe"

b. Vought OS2U Kingfisher

c. Kawanishi N1K1 "Rex"

d. Mitsubishi F1M2
Edo XOSE1

e. Nakajima E8N2
Gurnard (single float)
Arado Ar 196 (single float)
Beriev KOR-1
Mussell (single float)

f. Supermarine S5
Latecoere Lat298D
Stearman S76D1
Fleet Finch
Norseman
Huskey
C5

g. Northrop N3PB
Aichi E13A1 "Jake"
Aichi E16A1 "Paul"
Aichi M6A1
Supermarine Seafire
Dewoitine HD730

h. Heinkel He51B
Heinkel He114
Seafox
Kawanishi E7K2
Sea Thrush
Cessna 208 Caravan
Zenair CH701
Kitfox
Cessna Stationaire
Cessna 150
ROCS-Aero T401
Cessna 206
Cessna 172
Arado Ar 196 (twin)
Swordfish
Compmonster

i. Bellanca 7GBC Catabria
Cessna 180/185 Skywagon
Piper PA22
UTVA 60H
Taylorcraft Seabird
ROCS-Aero Gratch
Arctic Tern
Latecoere 29

j. Helio 296 Super Courier
Bristol Crusader
Maule M5/M6
PZL-105L

k. MFI 96

l. Pilatus Porter

m. DeHavilland Beaver
Mussell (twin float)
Heinkel He60

n. Short Scion

o. Partenavia P68 Victor
DeHavilland Twin Otter

p. Douglas DC3 Dakota

q. Hall XPTBH-2
Blohm & Voss Ha140
Blohm & Voss Ha139
Fleet Model 50
Bristol Bollingbroke
Centre NC410
Loire-Nieuport 10
Caproni Ca316

r. Caproni Ca312
Cant Z506
Heinkel He115
LeO H46
Fokker T8
Nomad Aztec
Cant Z511
Short Mercury
Heinkel He59
Bloch MB-480
Centre NC470
Gourdon G120
LeO H257/8
SE 400
Junkers Ju52
Cant Z515

s. Islander

t. GAF Nomad

TABLE 2.15

PURE FLOAT COSTS

Float Company	Float Type	Float Cost per pair ($)	Fittings Cost per pair ($)	Total Cost ($)	Displ (each) (kg)	Cost per Unit displ (per float)
Wipaire	4000	26650	11185	37835	1816	10.4
	6000	47900	13150	61050	2724	11.2
	8000	96900	20200	117100	3632	16.1
	13000	210000	40000	250000	5902	21.2
Zedair	550	2240	549	2789	250	5.6
	750	2540	622	662	340	4.7
	950	3690	904	4594	431	5.3
	1150	3990	978	4968	522	4.8
	1400	9490	2325	11815	636	9.3
	1650	9780	2396	12176	749	8.1
	1900	9980	2445	12425	863	7.2
Stoddard Hamilton	-	6995	1395	8390	545	7.7
Superfloat	500	2598	395	2990	227	6.5
	800	2695	395	3090	363	4.3
	1000	2895	395	3290	454	3.6
	1200	2995	395	3390	545	3.1
	1400	3195	395	3590	636	2.8
	1600	4095	495	4590	726	3.2
	1800	4195	495	4690	817	2.9
	2000	4495	495	4990	908	2.7
	2300	4695	595	5290	1044	2.5
Full Lotus	1220	2345	800	3145	554	2.8
	1260	2445	800	3245	572	2.8
	1650	4250	800	5050	749	3.4
	2150	5050	800	5850	976	3.0
	2250	5560	800	6360	1021	3.1
Edo	1650	14490	5500	19990	749	13.3
	2000	11790	8200	19990	908	11.0
	2130	12300	8200	20500	967	10.6
	2440B	11900	8600	20500	1108	9.3
	3430	18095	11900	29995	1557	9.6
	4930	38900	25600	64500	2238	14.4

Note: costs are US$ 1994.

TABLE 2.16

AMPHIBIOUS FLOAT COSTS

Float Company	Float Type	Float Cost per pair ($)	Fittings Cost per pair ($)	Total Cost per pair ($)	Displ (each) (kg)	Cost per unit displ (per float)
Wipaire	4000	56100	12965	69065	1816	38.0
	6000	99900	14800	114700	2724	42.1
	8000	146500	22100	168600	3632	46.4
	13000	395000	45000	440000	5902	74.5
Zedair	550	4400	620	5020	250	20.1
	750	4560	780	5340	340	15.7
	950	6100	1043	7143	431	16.6
	1150	6530	1117	7647	522	14.6
Superfloats	500	3895	395	4290	227	9.4
	800	3995	395	4390	363	6.0
	1000	4895	395	5290	454	5.8
	1200	4995	395	5390	545	4.9
	1400	5195	395	5590	636	4.4
	1600	6495	495	6690	726	4.8
	1800	6595	495	7090	817	4.3
	2000	6995	495	7490	908	4.1
	2300	7495	595	8090	1044	3.9
Stoddard Hamilton	-	9495	2295	11790	545	21.6
Full Lotus	1220	3615	800	4415	554	8.0
	1260	3715	800	4515	572	7.9
	1650	5520	800	6320	749	8.4
	2150	6320	800	7120	976	7.3
	2250	6830	800	7630	1021	7.5

Note: costs are US$ 1994

TABLE 2.17

FLOAT KIT COST RATIOS

Float company	Float Type	Assembled Price ($)	Kit Price ($)	Ratio
Zenair (pure)	550 750 950 1150 1400 1650 1900	2240 2540 3690 3990 9490 9780 9980	1240 1395 1970 2250 4910 4995 5130	0.55 0.55 0.53 0.56 0.52 0.51 0.51
Average				0.53
Zenair (amphib)	550-A 750-A 950-A 1150-A	4400 4560 6100 6530	2990 3200 4320 4630	0.68 0.70 0.71 0.71
Avid (amphib)	1100-A	8158	5826	0.71
Average				0.70

TABLE 2.18

EXTRACT OF FLOAT DRAG DATA FRON NACA REPORT 236

Float	Drag (lb)	V (ft/sec)	area (ft^2)	C_{D0}
1	0.0366	44.0	0.0751	0.211
2	0.0394	44.0	0.0554	0.308
3	0.0423	44.0	0.0751	0.244
4	0.0339	44.0	0.0729	0.201
5	0.0443	40.0	0.0456	0.510
6	0.556	98.6	0.2326	0.206
7	0.456	98.6	0.2160	0.182
8	0.33	98.6	0.1525	0.187
9	0.366	98.6	0.1940	0.163
10	0.552	97.5	0.2255	0.216
11	0.0588	40.0	0.3180	0.097
12	0.0441	40.0	0.1780	0.130
Average				0.221

TABLE 2.19

FLOATPLANE TO LANDPLANE DRAG RATIOS

Aircraft	AUM (kg)	S (m^2)	l (m)	b (m)	h (m)	Area (m^2)	Float C_{D0}	Land plane C_{D0}	Float plane C_{D0}	Drag ratio
Cessna 152	757	14.59	4.48	0.60	0.51	0.27	0.0041	0.0380	0.0419	0.91
Beech Skipper	760	14.60	4.49	0.60	0.51	0.27	0.0041	0.0490	0.0529	0.93
Cessna 172	1143	16.16	4.99	0.66	0.57	0.34	0.0046	0.0360	0.0404	0.89
Piper Warrier	1054	15.80	4.87	0.65	0.56	0.32	0.0045	0.0340	0.0383	0.89
Beech Sierra	1247	13.57	5.12	0.68	0.59	0.36	0.0058	0.0340	0.0396	0.86
Piper Arrow	1247	15.79	5.12	0.68	0.59	0.36	0.0050	0.0270	0.0318	0.85
Cessna 182	1338	16.16	5.24	0.70	0.60	0.37	0.0051	0.0310	0.0359	0.86
Piper Cub	794	16.58	4.53	0.68	0.58	0.39	0.0045	0.0373	0.0461	0.81
Piper Cherokee	1542	16.21	5.50	0.73	0.63	0.41	0.0056	0.0358	0.0412	0.87
Mooney 201 *	1243	15.51	5.12	0.68	0.58	0.36	0.0050	0.0170	0.0220	0.77
Beech Bonanza *	1542	16.80	5.50	0.73	0.63	0.41	0.0054	0.0190	0.0244	0.78

* retractable undercarriage

TABLE 2.20

FLOATPLANE PERFORMANCE COMPARISONS

a. Fixed Undercarriage Aircraft

Name	Speed (land) (km/hr)	Speed (float) (km/hr)	Max Speed Factor	ROC (land) (m/min)	ROC (float) (m/min)	ROC Factor	Range (land) (km)	Range (float) (km)	Range Factor
Scion	203	196	0.97	-	-	-	624	595	0.95
Scion Senior	226	216	0.96	-	-	-	675	645	0.96
Gurnard	268	258	0.96	-	-	-	-	-	-
Ju52	262	254	0.97	-	-	-	-	-	-
Cherokee 32	279	246	0.88	320	229	0.72	845	732	0.87
Piper Cub	208	185	0.89	293	253	0.86	735	663	0.90
Cessna 172	233	180	0.77	206	191	0.93	1367	885	0.65
Cessna 180	282	264	0.94	364	332	0.91	2035	1971	0.97
Cessna 185	295	277	0.94	320	311	0.97	1802	1673	0.93
Cessna 206	288	267	0.93	296	276	0.93	1697	1544	0.91
MFI-11	240	190	0.79	456	229	0.5	614	534	0.87
MFI-9	236	185	0.78	220	216	0.98	800	680	0.85
Procter	265	216	0.82	240	189	0.79	-	-	-
S-76	243	217	0.89	-	-	-	-	-	-
Finch	182	175	0.96	-	-	-	-	-	-
Norseman	272	246	0.90	254	218	0.86	960	880	0.92
Otter	257	245	0.95	260	229	0.88	1545	1385	0.90
Do27	255	237	0.93	-	-	-	792	700	0.88
Do28	280	258	0.92	408	365	0.89	1150	1070	0.93
Caravan	337	293	0.87	314	228	0.73	1760	1664	0.95
Twin Otter	306	293	0.96	488	427	0.88	-	-	-
Beaver	256	248	0.97	335	285	0.85	736	688	0.93
C5	240	220	0.92	240	210	0.88	-	-	-
Ar95	306	299	0.98	-	-	-	-	-	-
P28-160B	221	202	0.91	210	183	0.87	1175	1137	0.97
P28-160C	229	205	0.90	223	192	0.86	1183	1153	0.97
P28-180B	240	210	0.87	220	195	0.89	1119	1055	0.94
P28-180C	243	213	0.88	229	204	0.89	1167	1071	0.92
Tern	188	169	0.90	389	305	0.78	-	-	-
Average			0.91			0.85			0.91

b. Retractable Undercarrige Aircraft

Name	Speed (land) (km/hr)	Speed (float) (km/hr)	Max Speed Factor	ROC (land) (m/min)	ROC (float) (m/min)	ROC Factor	Range (land) (km)	Range (float) (km)	Range Factor
Bollingbroke	421	388	0.92	462	347	0.75	-	-	-
A6M2N	534	436	0.82	811	758	0.93	3105	1785	0.57
Wildcat	512	428	0.84	1113	750	0.67	1448	965	0.67
Ca312	415	400	0.96	483	333	0.69	1997	1498	0.75
Average			0.88			0.76			0.66

TABLE 2.21

WETTED AND CROSS-SECTIONAL AREAS

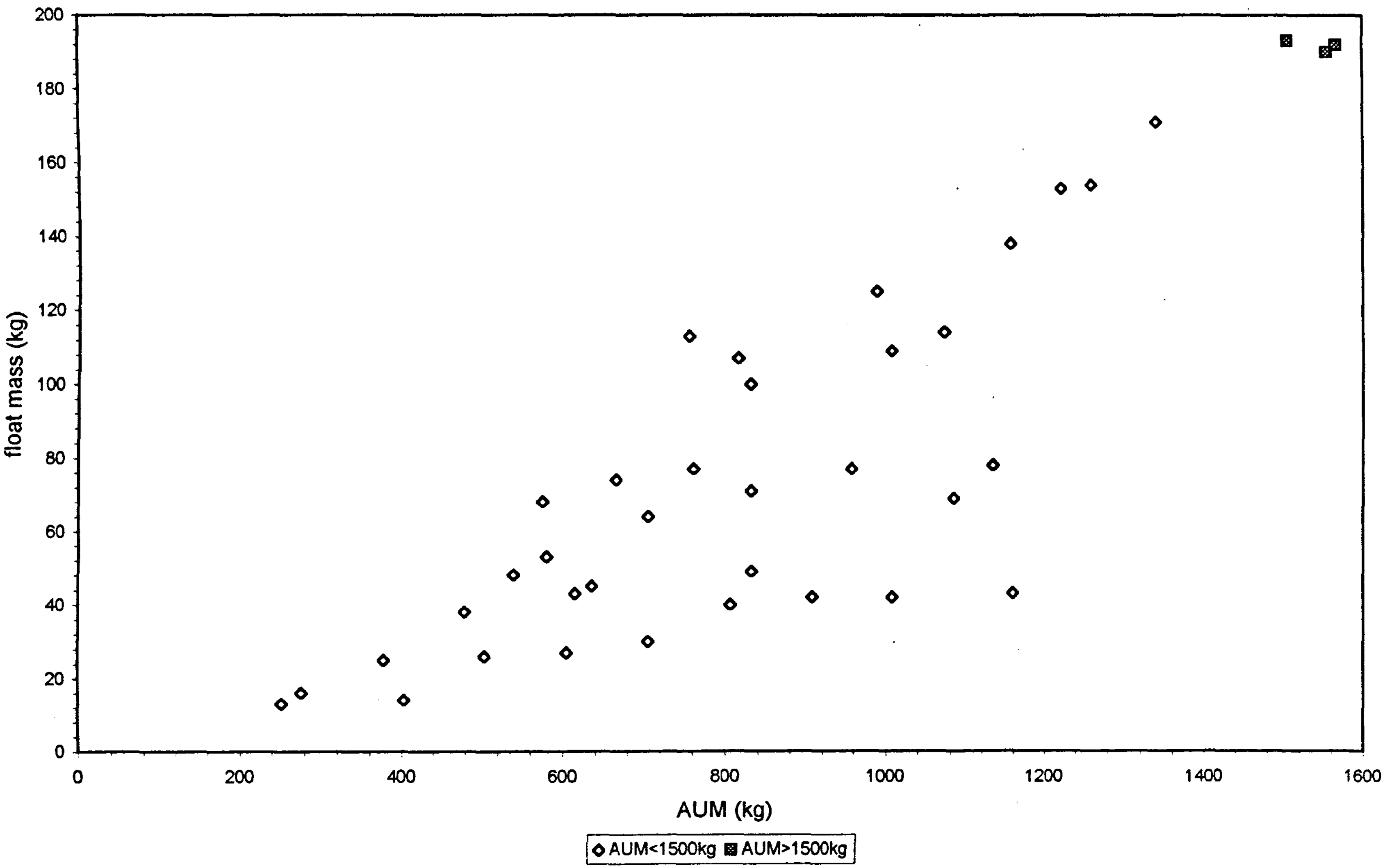
AUM (kg)	Single Float		Twin Float	
	Wetted	X-section	Wetted	X-section
2500	31.33	3.21	42.34	2.12
3000	33.27	3.41	44.17	2.21
3500	35.27	3.62	46.04	2.30
4000	37.33	3.83	47.95	2.40
4500	39.44	4.04	49.90	2.50
5000	41.62	4.27	51.89	2.59
5500	43.85	4.49	53.92	2.70
6000	46.14	4.73	55.99	2.80
6500	48.49	4.97	58.10	2.90
7000	50.90	5.22	60.24	3.01
7500	53.36	5.47	62.42	3.12
8000	55.88	5.73	64.65	3.23
8500	58.47	5.99	66.91	3.35
9000	61.11	6.26	69.21	3.46
9500	63.81	6.54	71.55	3.58
10000	66.56	6.82	73.93	3.70

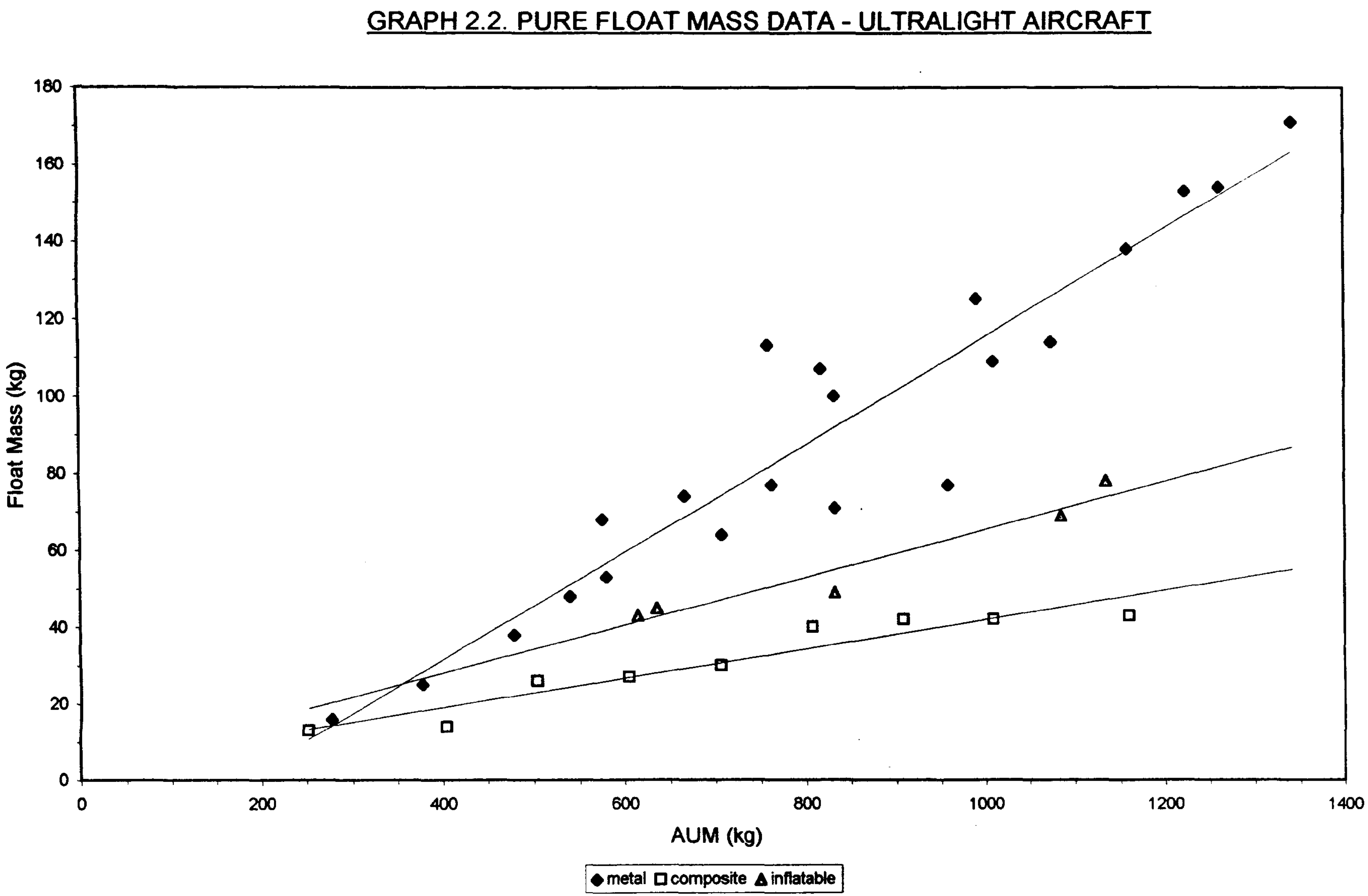
TABLE 2.22

WEATHERCOCK STABILITY

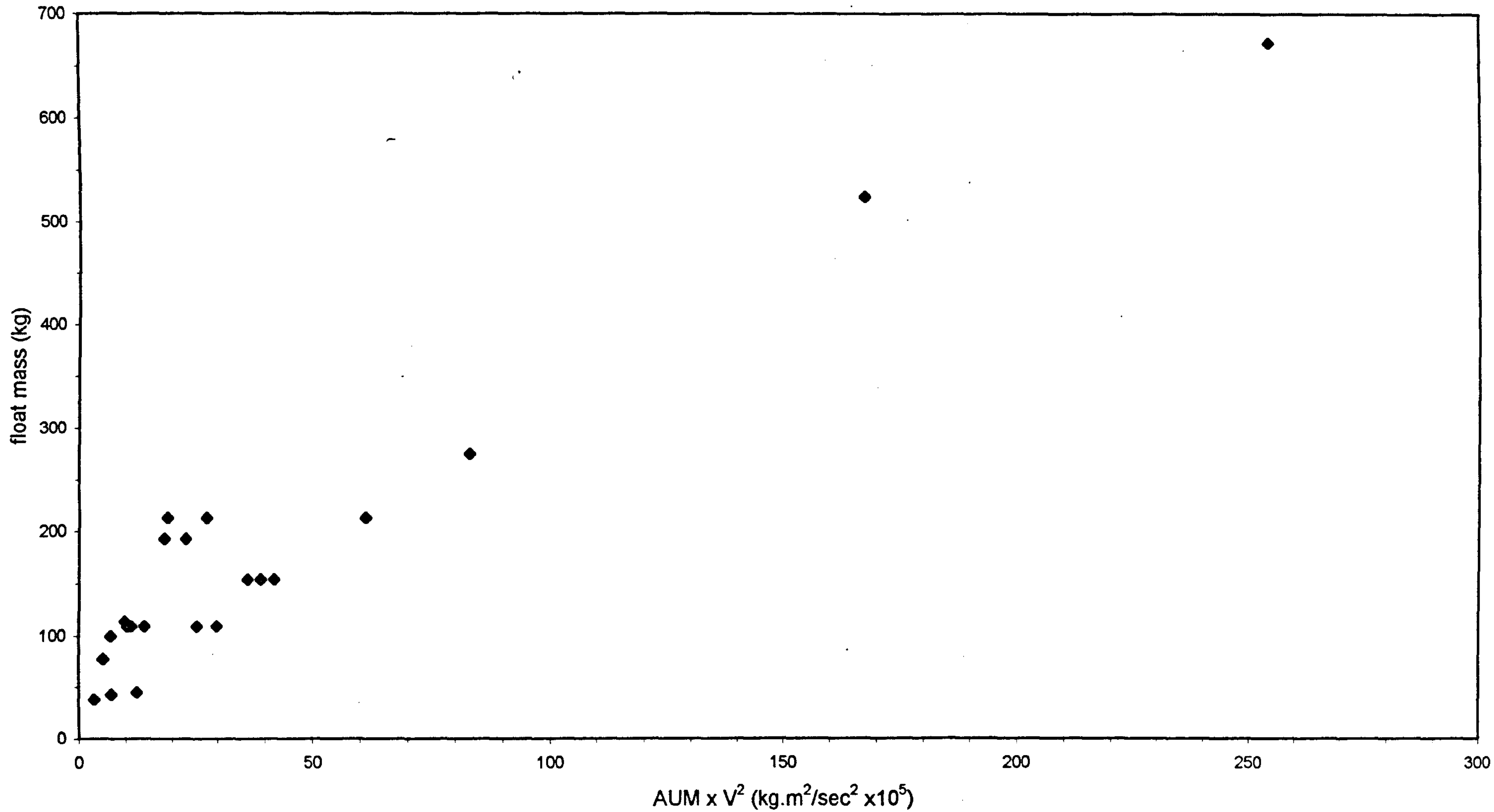
Aircraft	Ratio (without fin)	Ratio (with fin)	Aircraft	Ratio (without fin)	Ratio (with fin)
C5	1.04	0.91	Nomad	0.95	0.69
He119V3	1.26	1.02	Twin Otter	1.08	0.99
Beaver	0.89	0.81	Islander	0.93	-
Norseman	0.83	-	P68 Victor	0.95	0.87
ROKS T401	1.06	0.93	PZL105L	1.26	-
ROKS T101	0.79	-	Aero 270W	1.27	0.90
Cessna Caravan	0.92	0.77	Gavilan EL1	1.13	-

GRAPH 2.1. PURE FLOAT MASS DATA

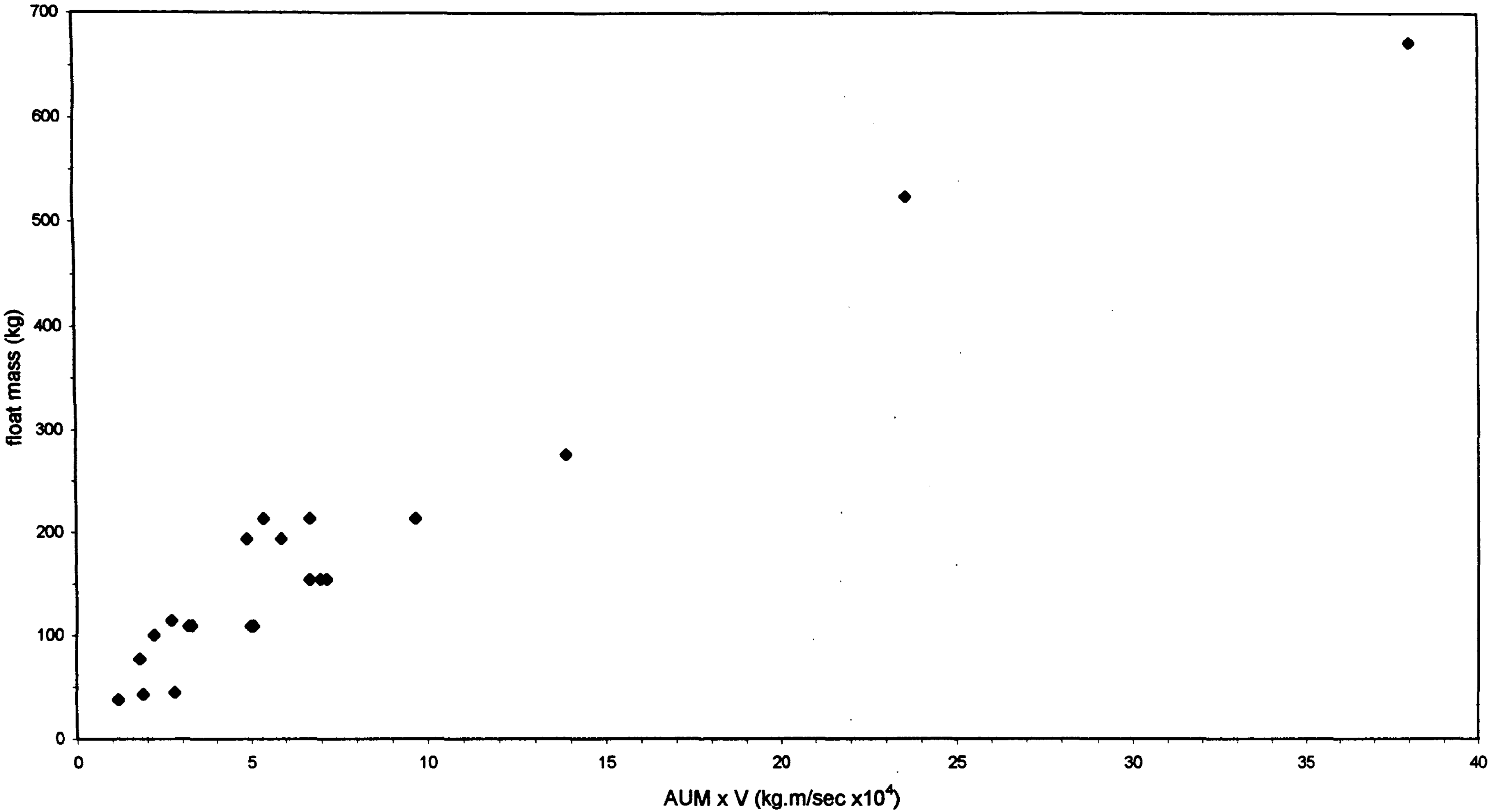



GRAPH 2.2. PURE FLOAT MASS DATA - ULTRALIGHT AIRCRAFT
Float Mass (kg)
0
20
40
60
80
100
120
140
160
180
0
200
400
600
800
1000
1200
1400
AUM (kg)
metal
composite
inflatable

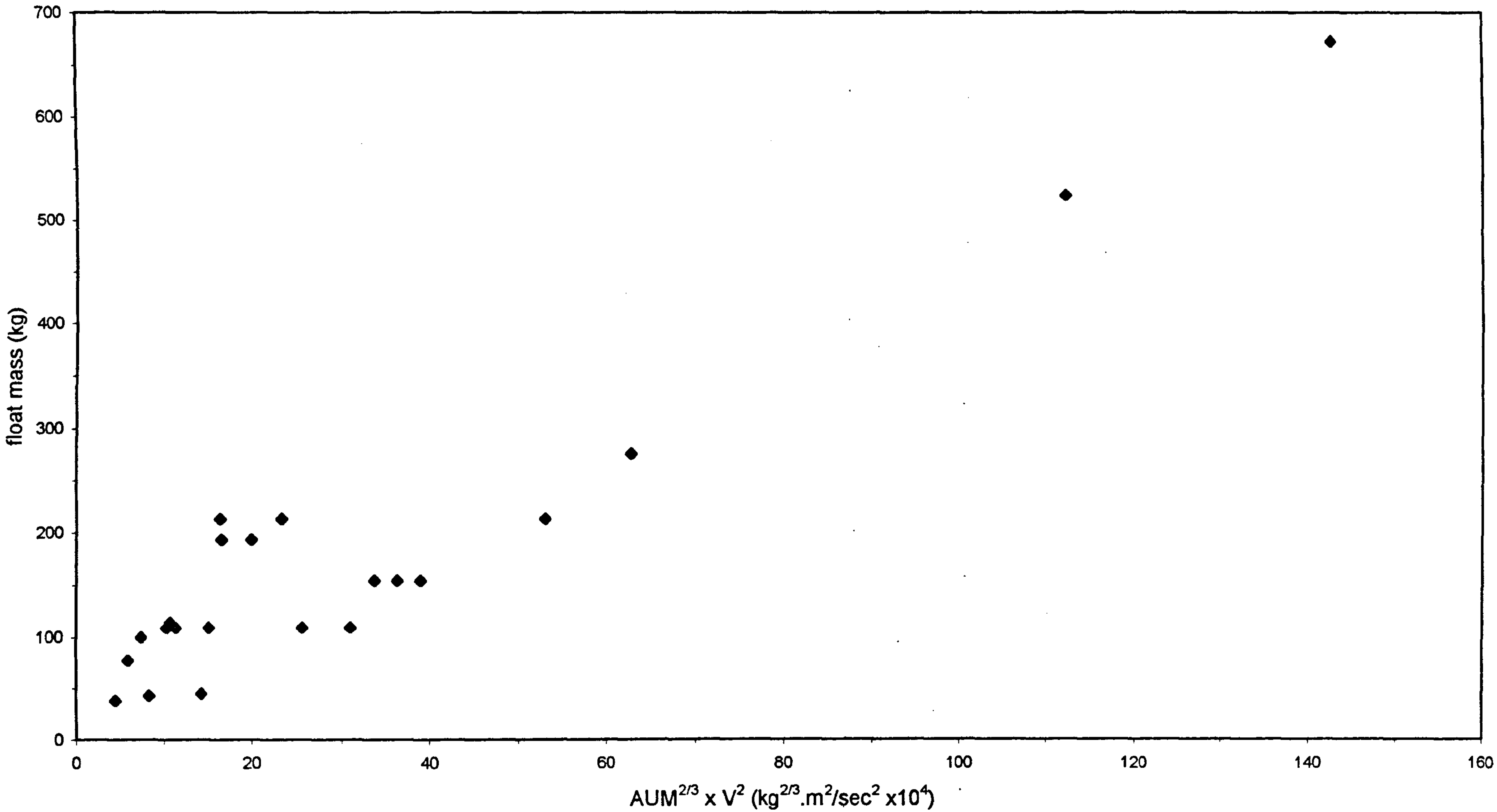
GRAPH 2.3a. LANDING VELOCITY FUNCTION - AUMxV^2



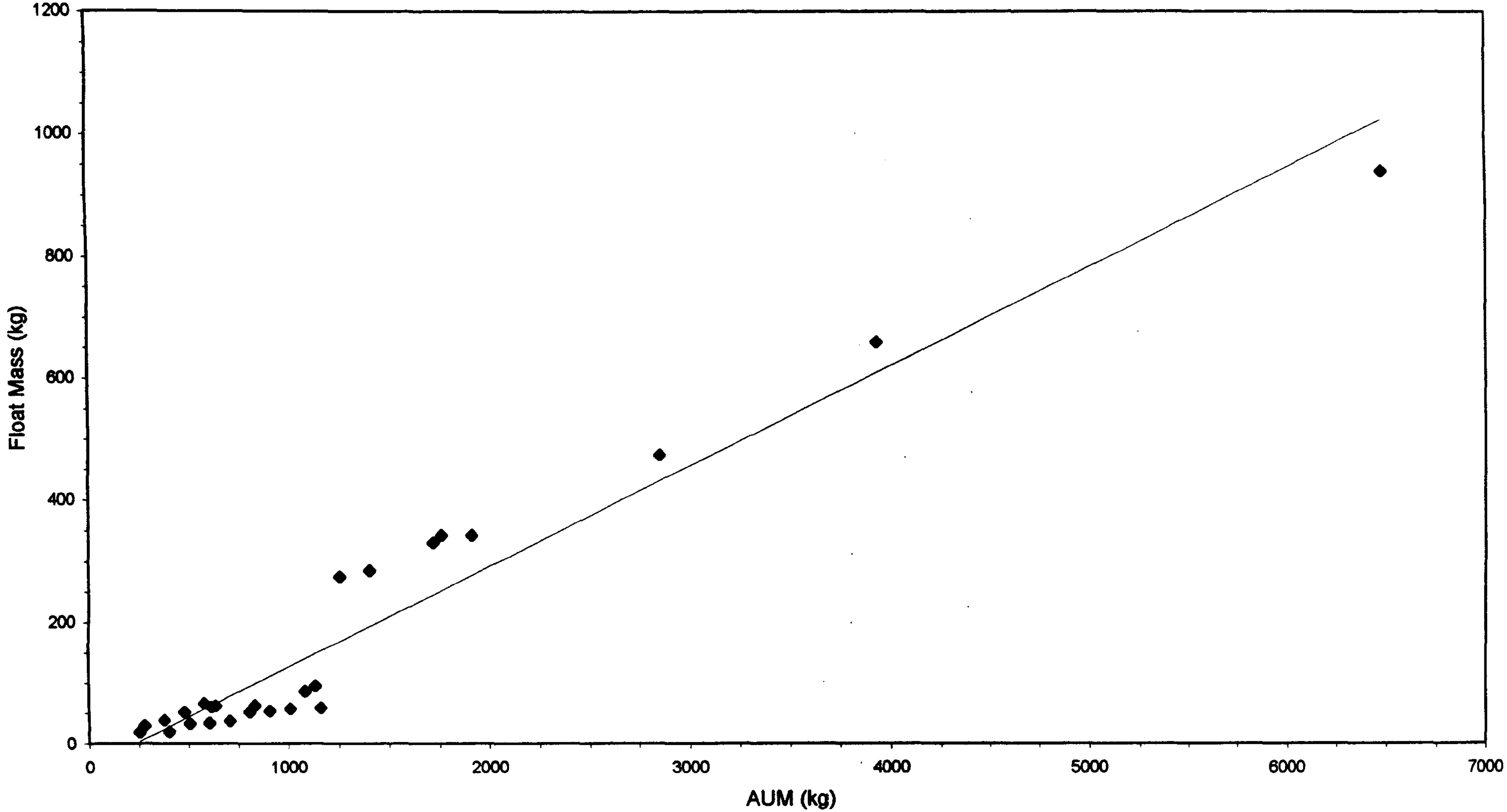
GRAPH 2.3b. LANDING VELOCITY FUNCTION - AUMxV



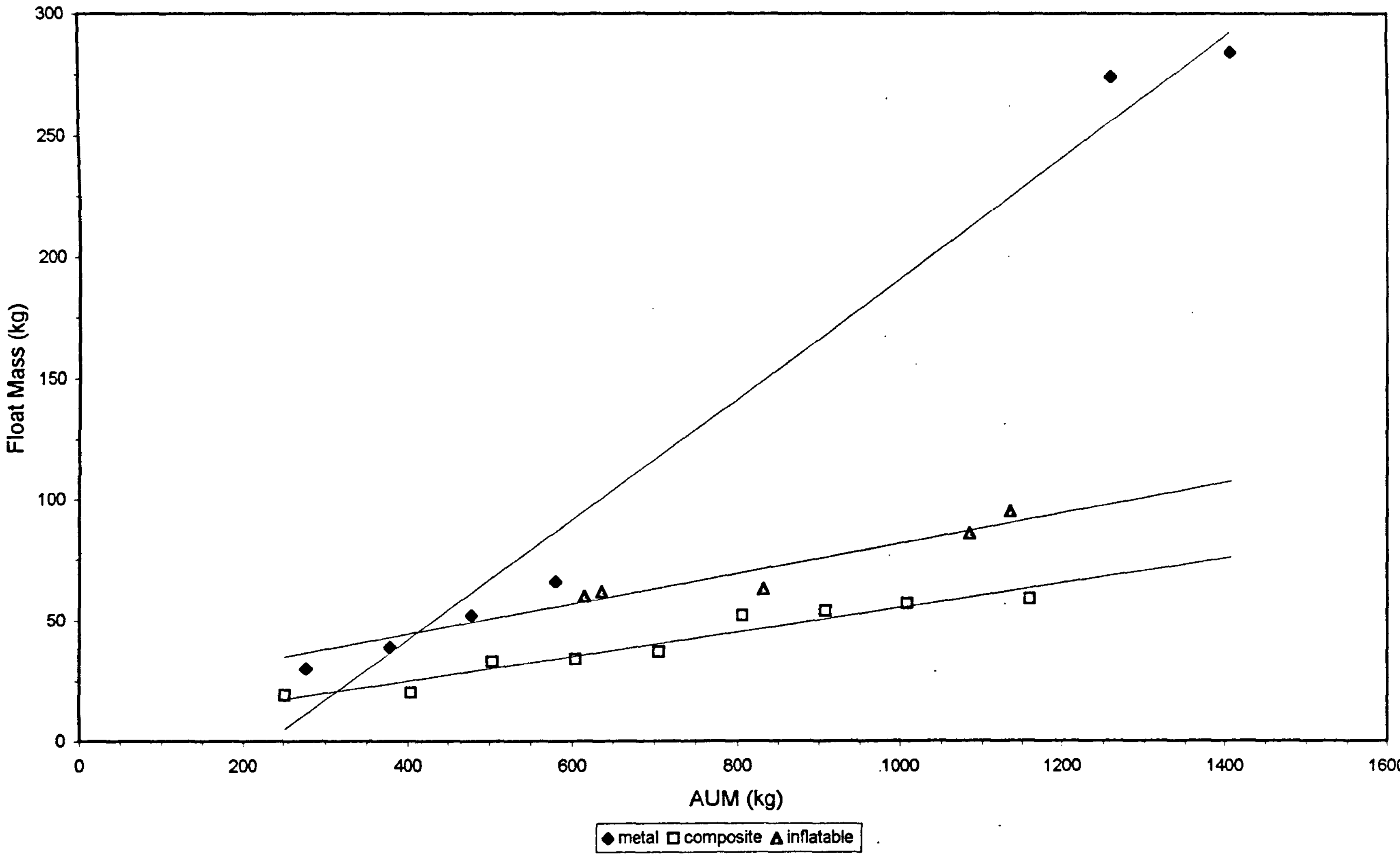
GRAPH 2.3c. LANDING VELOCITY FUNCTION - $AUM^{2/3}$ x V^2



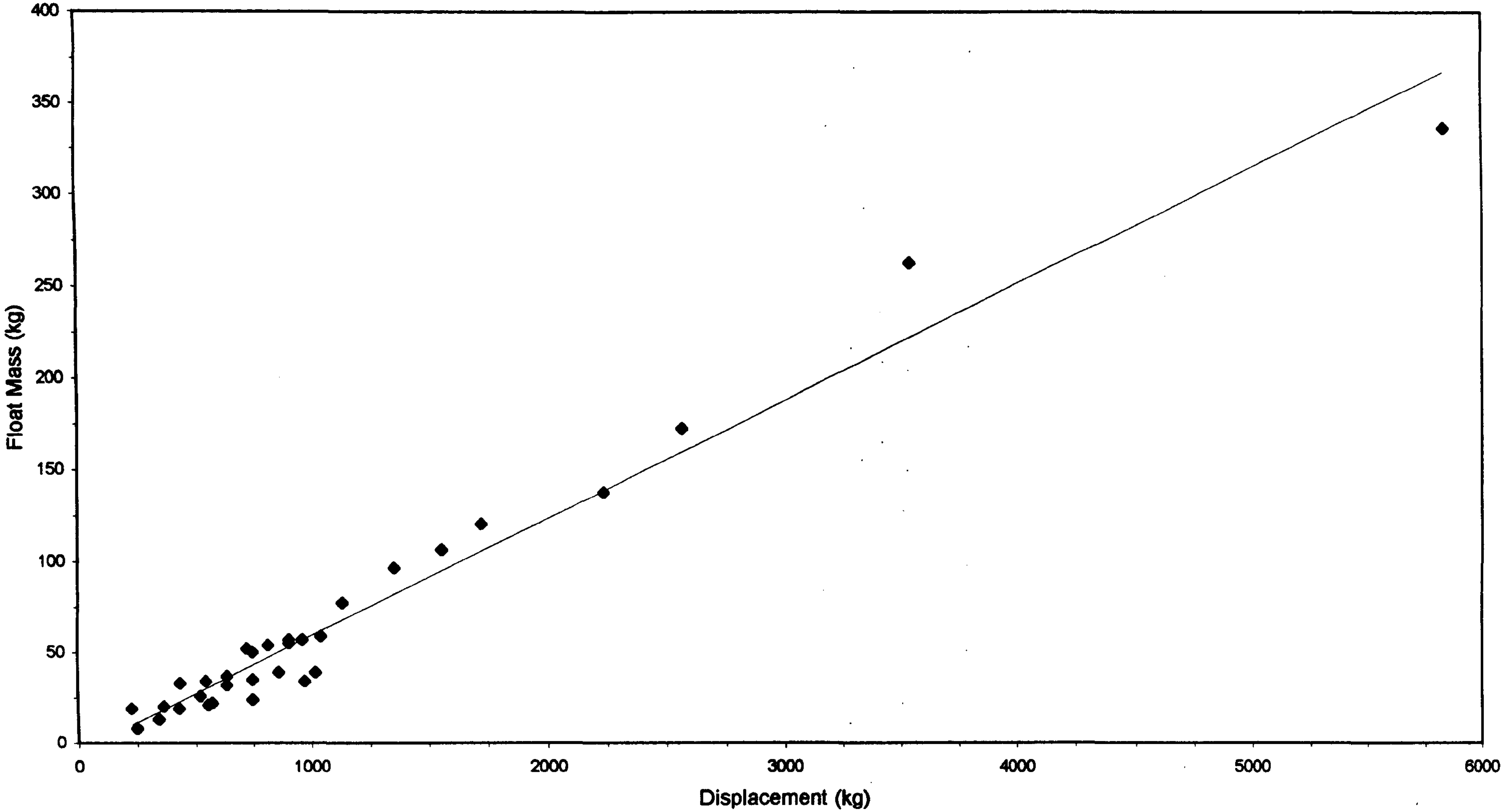
GRAPH 2.4. AMPHIBIOUS FLOAT MASS DATA



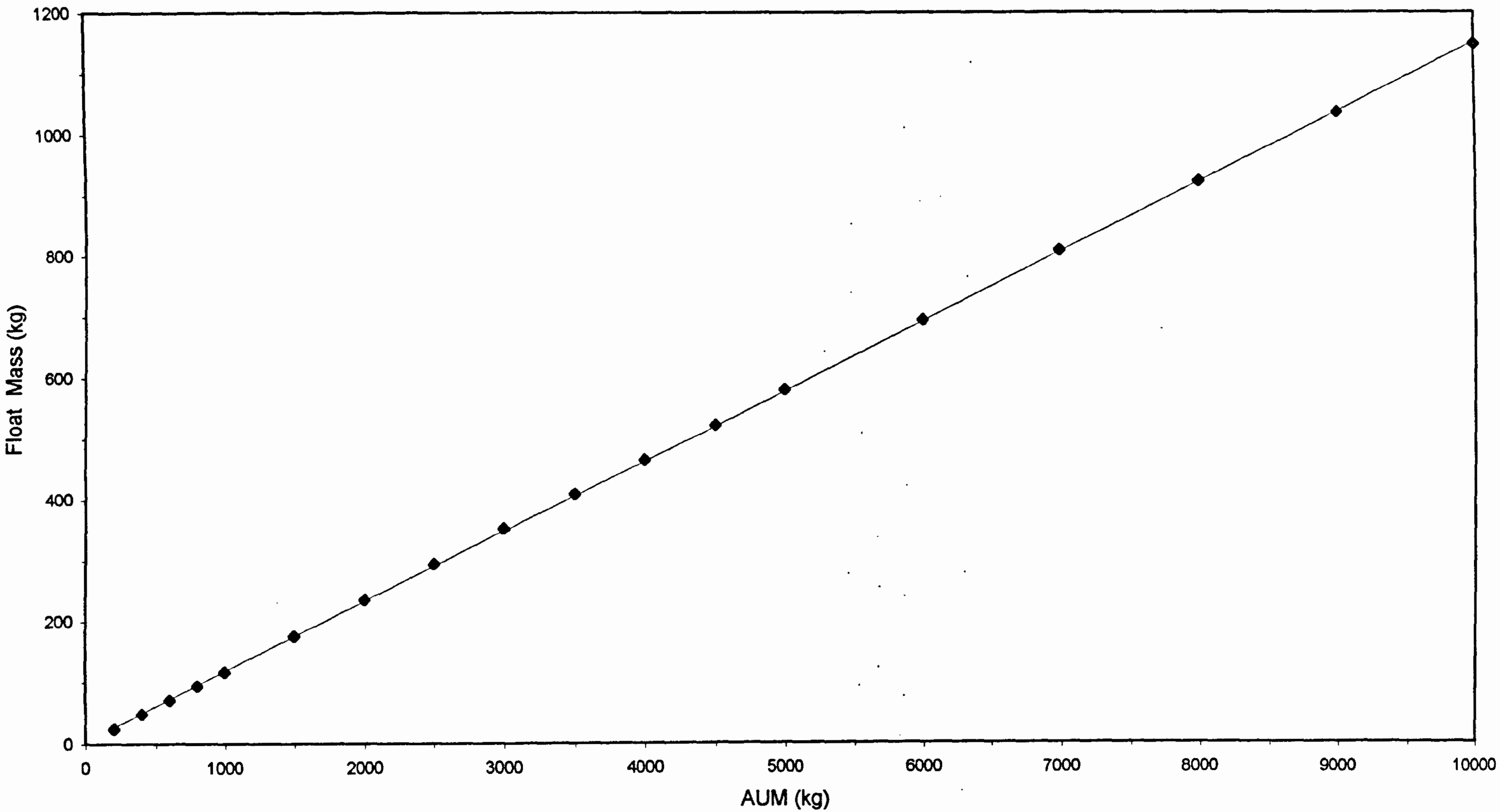
GRAPH 2.5. AMPHIBIOUS FLOAT MASS DATA - ULTRALIGHT AIRCRAFT



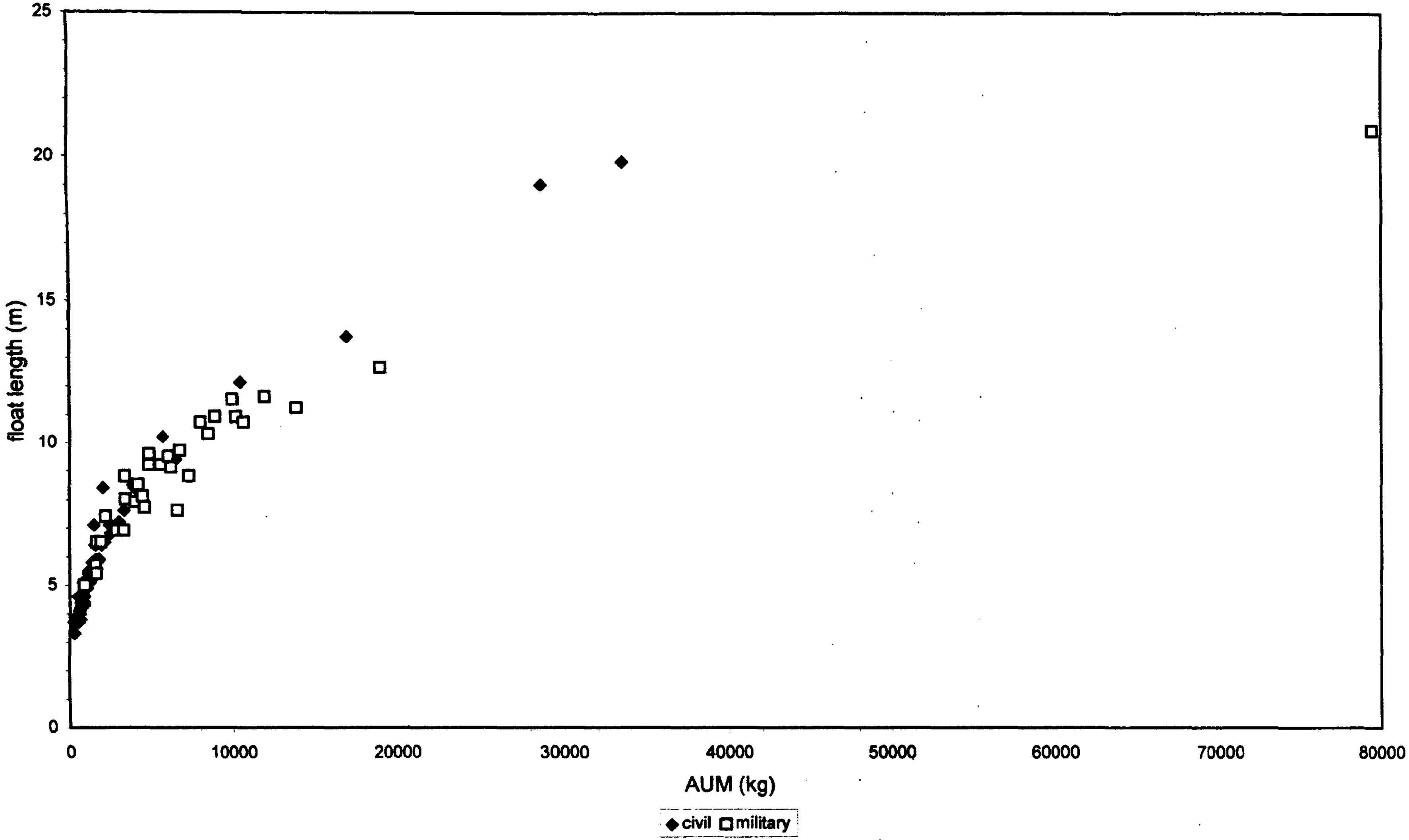
<u>GRAPH 2.6. SINGLE FLOAT MASS AGAINST DISPLACEMENT</u>



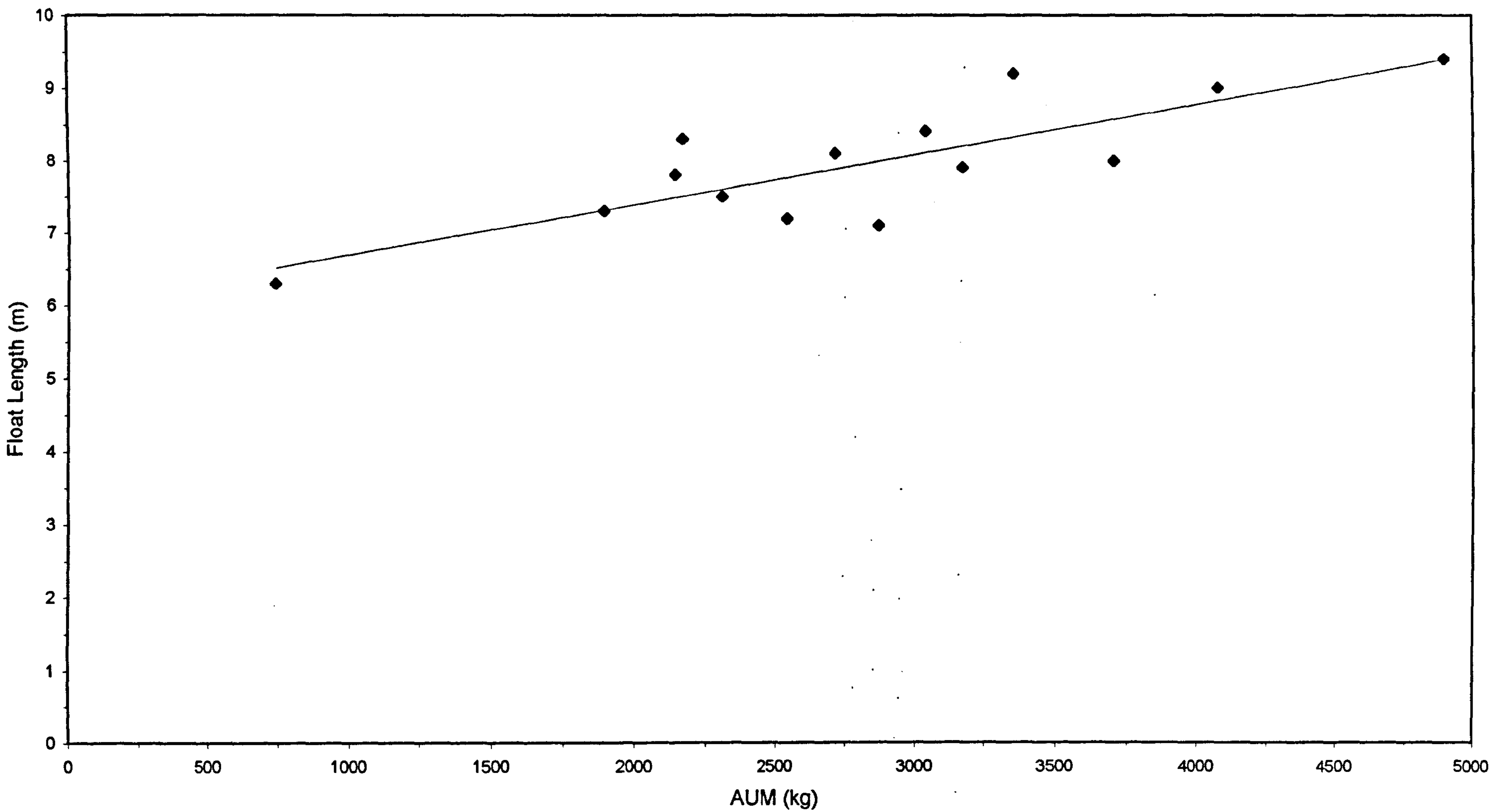
GRAPH 2.7. TOTAL SINGLE FLOAT SYSTEM MASS



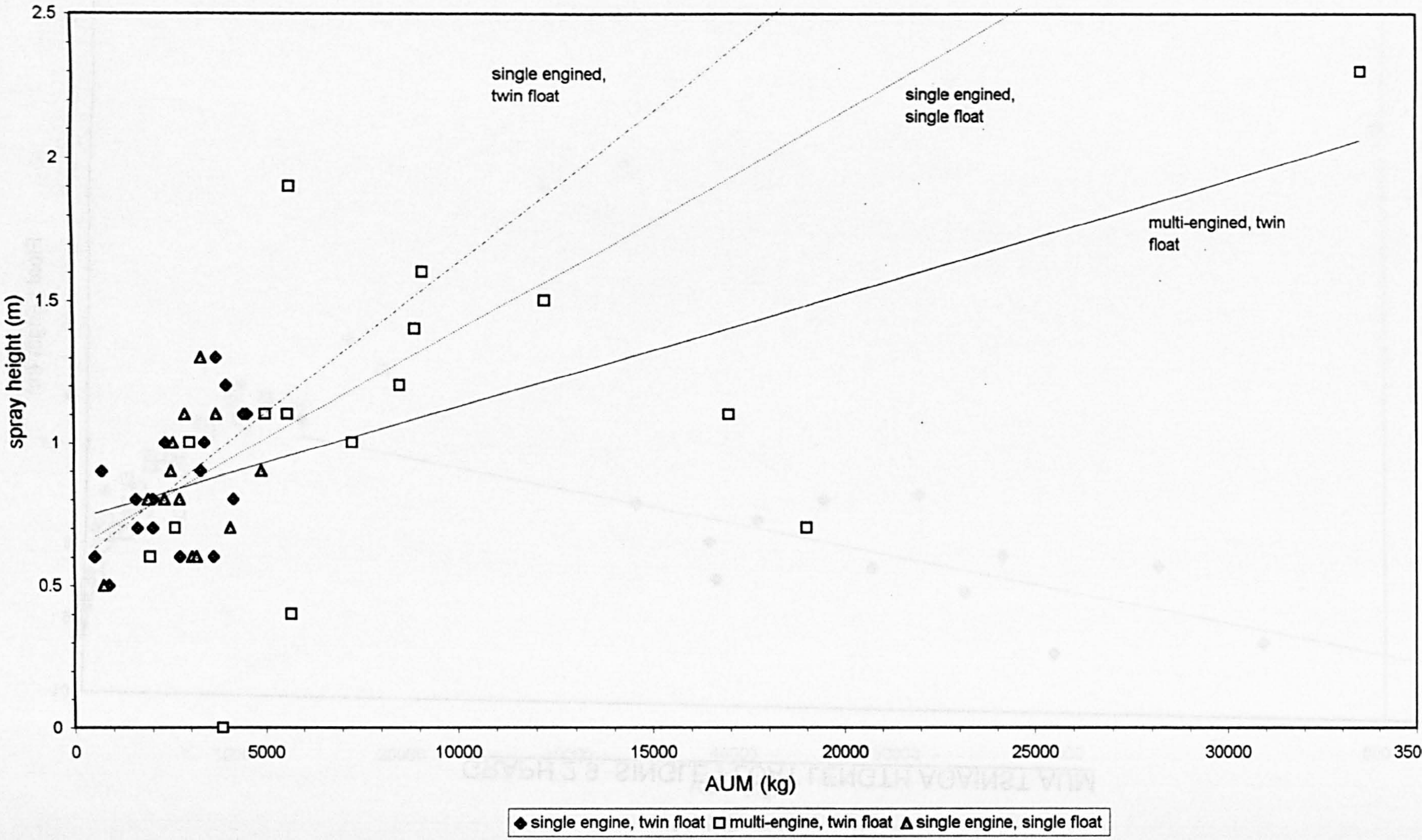
GRAPH 2.8. FLOAT LENGTH DATA



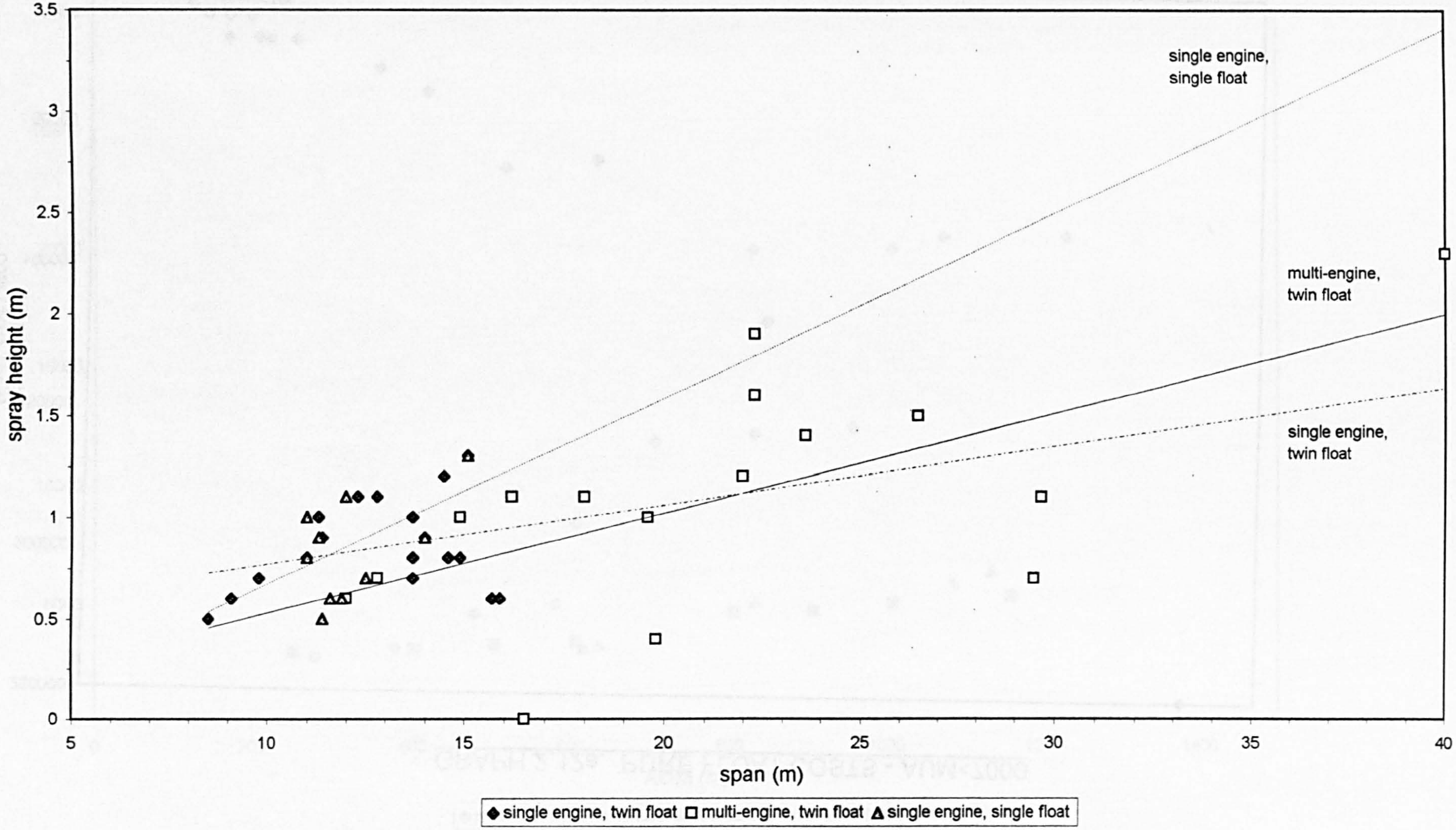
GRAPH 2.9. SINGLE FLOAT LENGTH AGAINST AUM



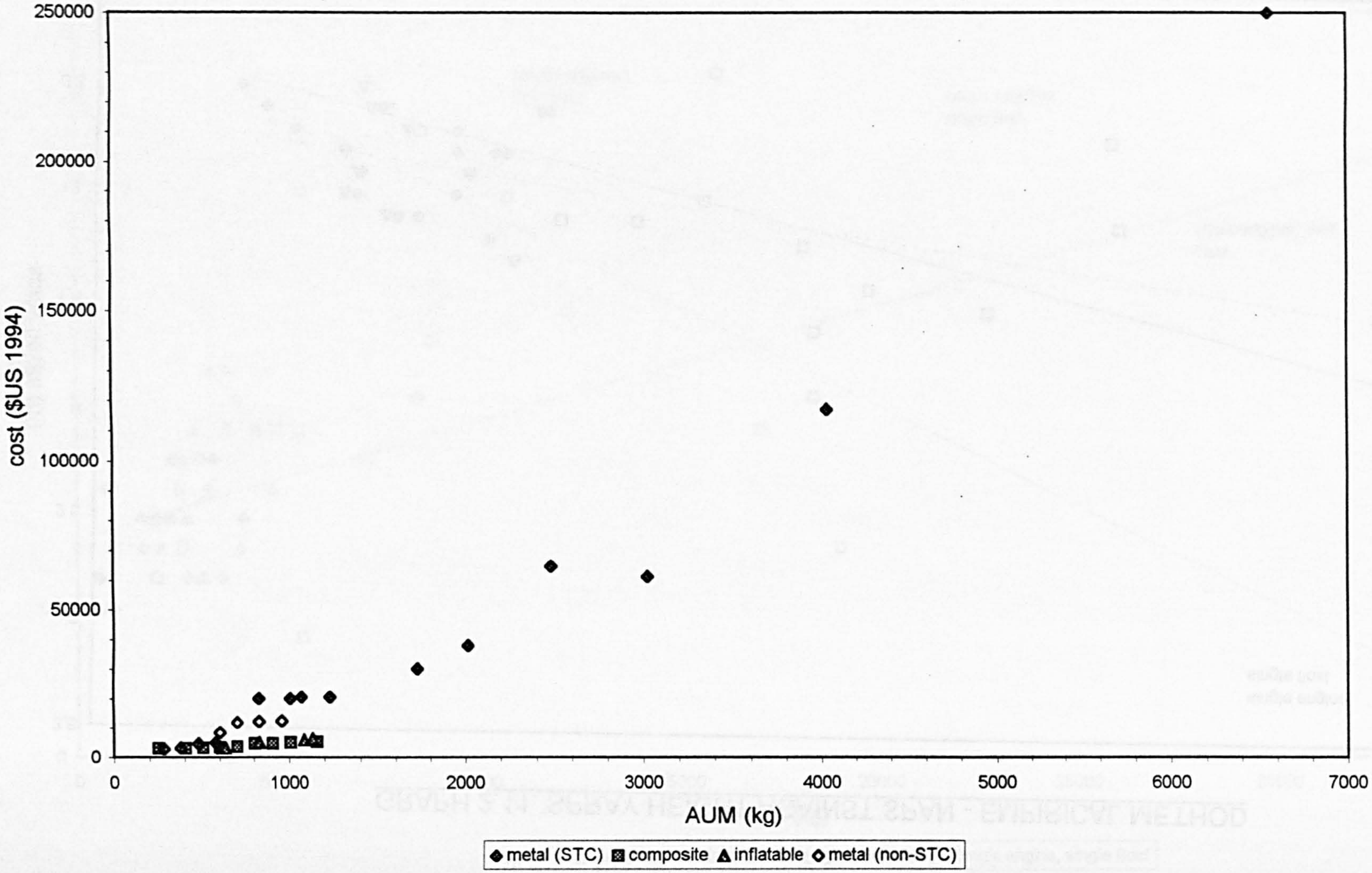
GRAPH 2.10. SPRAY HEIGHT AGAINST AUM - EMPIRICAL METHOD



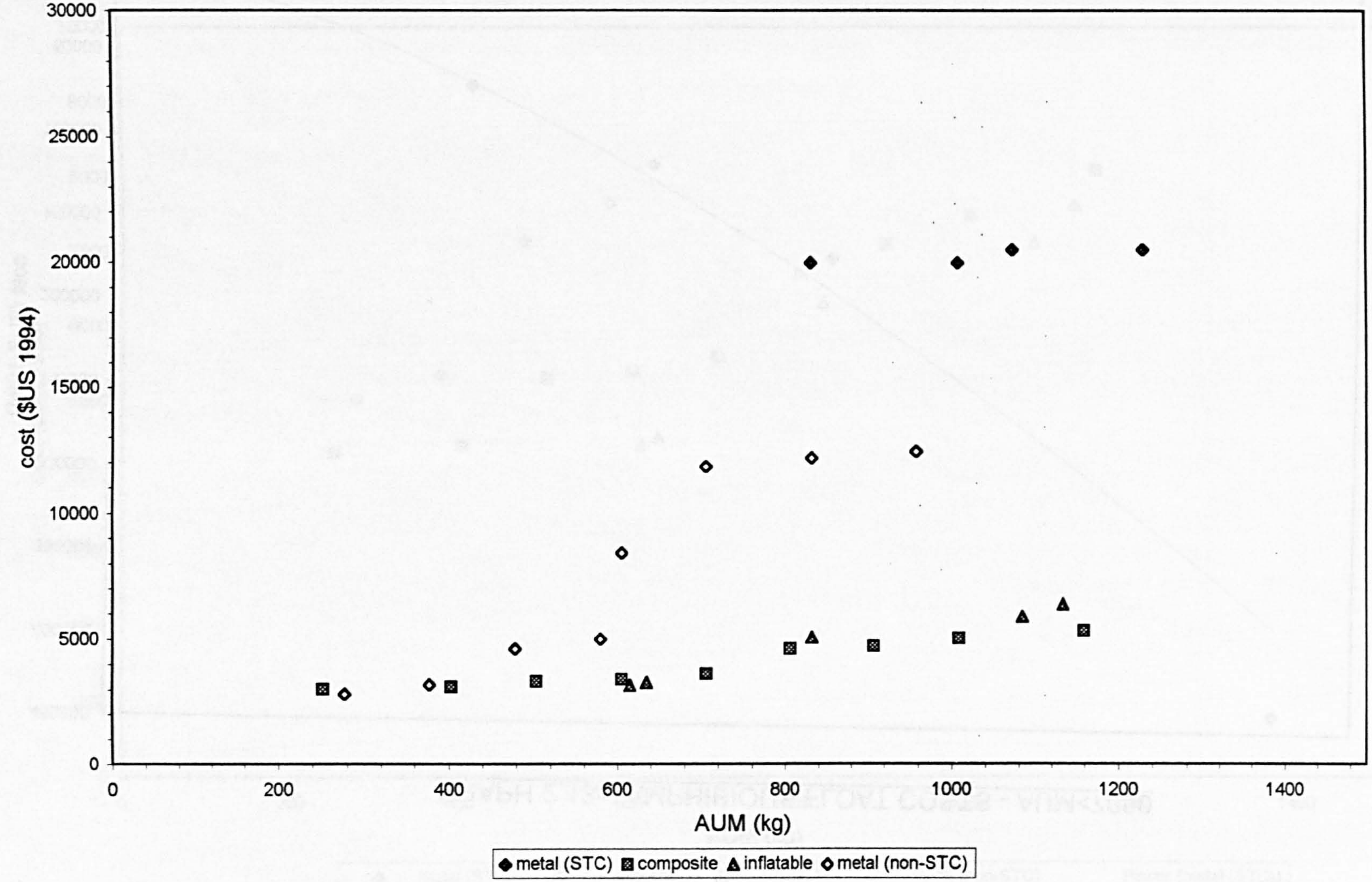
GRAPH 2.11. SPRAY HEIGHT AGAINST SPAN - EMPIRICAL METHOD

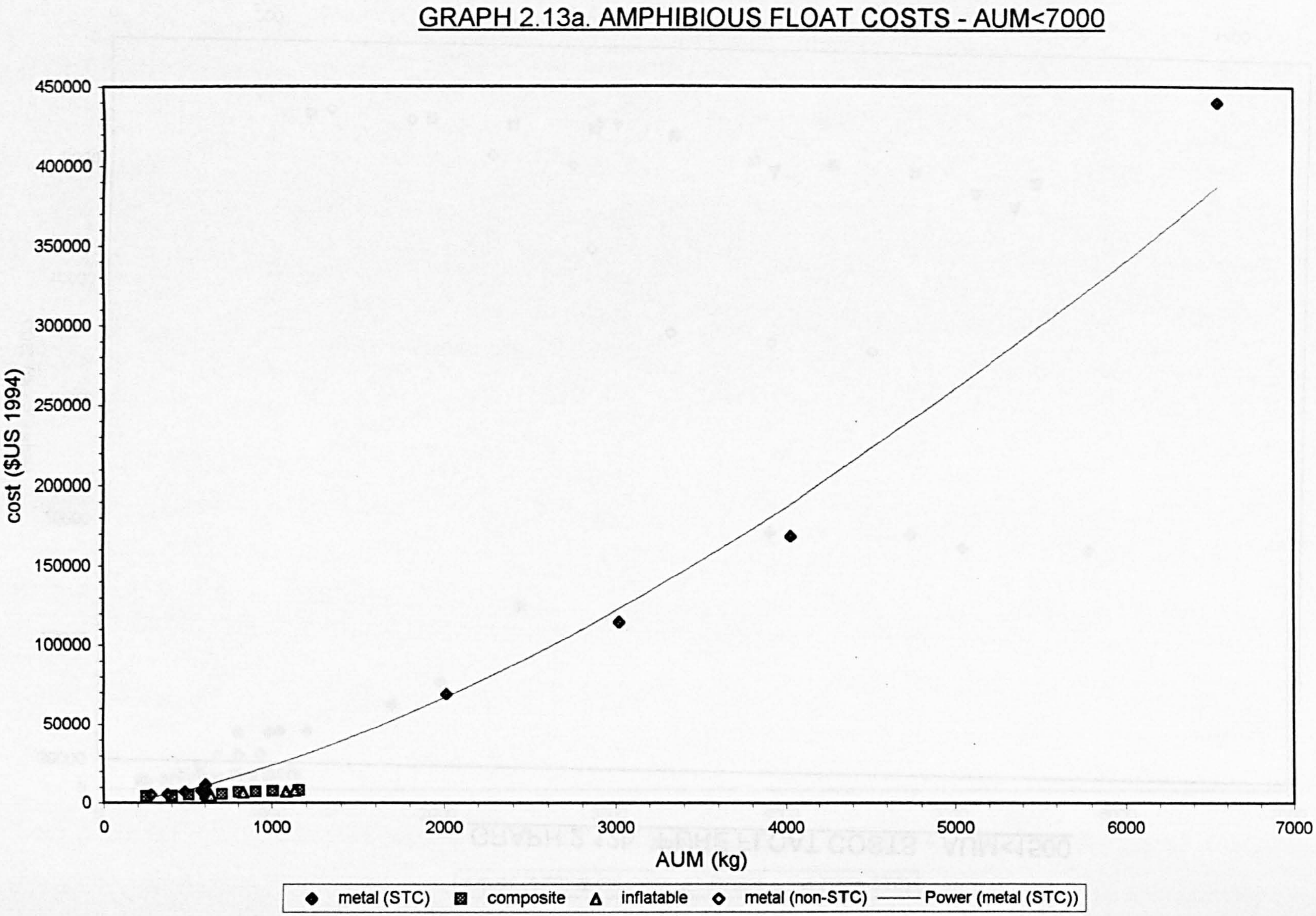


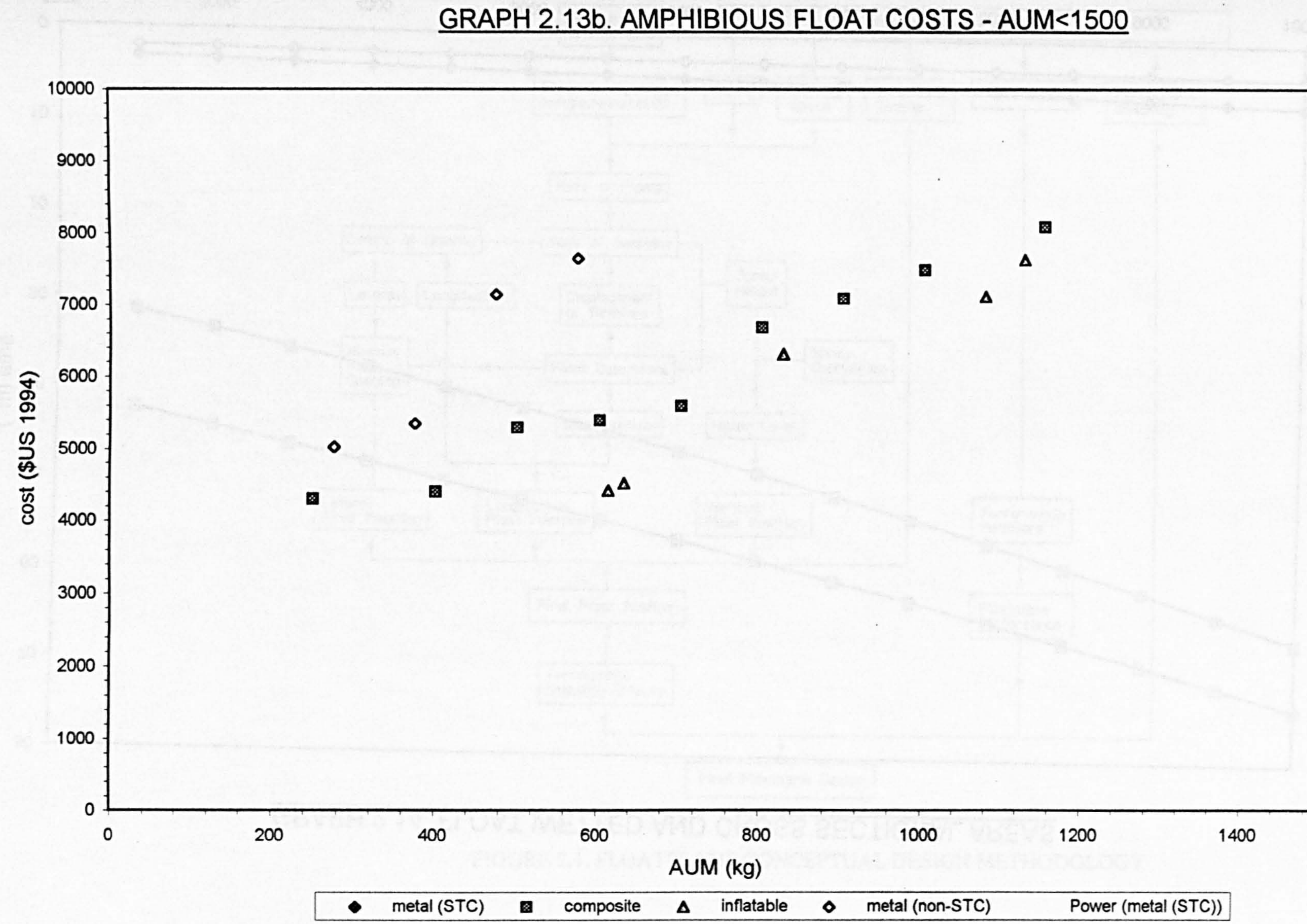
GRAPH 2.12a. PURE FLOAT COSTS - AUM<7000



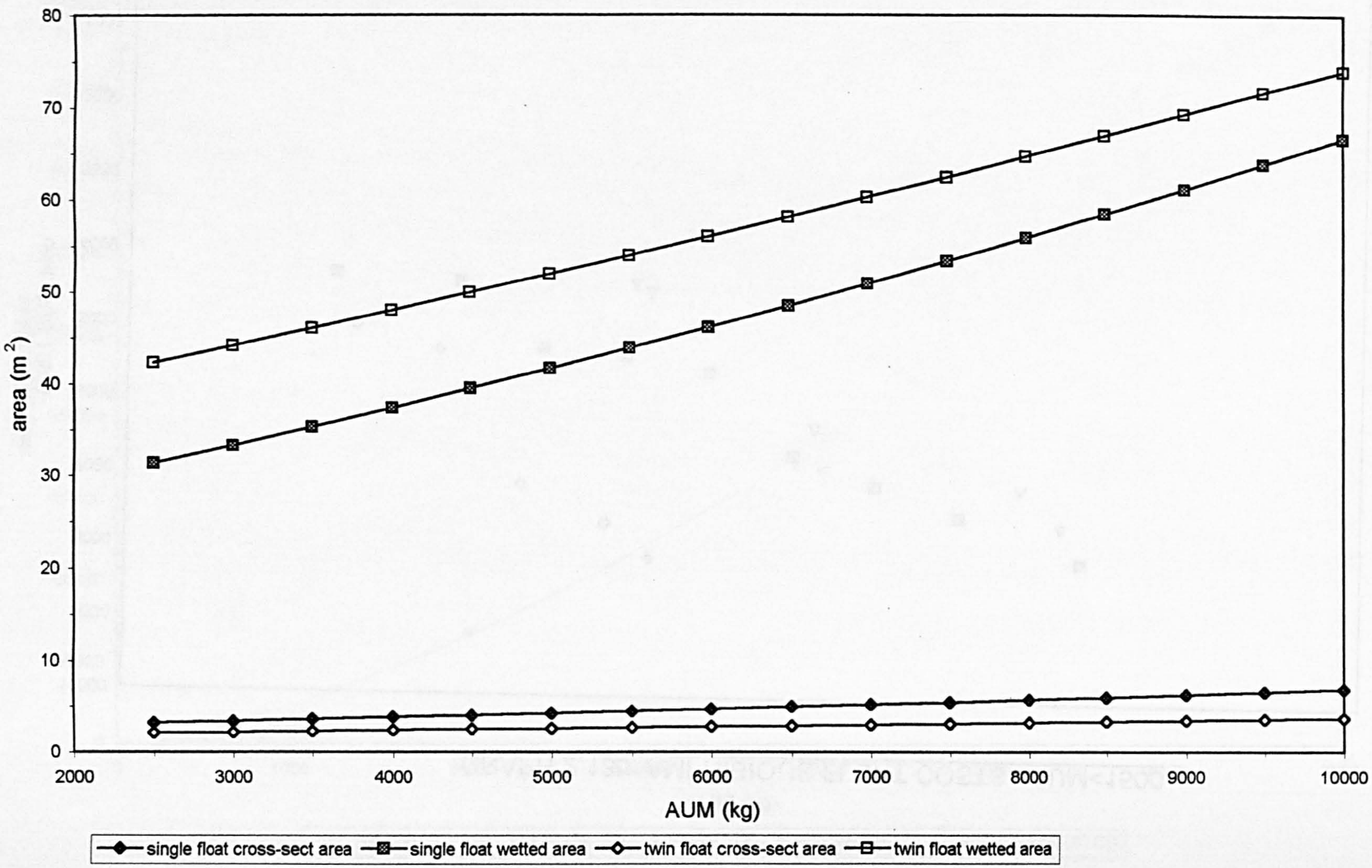
GRAPH 2.12b. PURE FLOAT COSTS - AUM<1500




GRAPH 2.13a. AMPHIBIOUS FLOAT COSTS - AUM<7000
cost ($US 1994)
AUM (kg)
0
50000
100000
150000
200000
250000
300000
350000
400000
450000
0
1000
2000
3000
4000
5000
6000
7000
metal (STC)
composite
inflatable
metal (non-STC)
Power (metal (STC))


GRAPH 2.13b. AMPHIBIOUS FLOAT COSTS - AUM<1500
cost ($US 1994)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
200
400
600
800
1000
1200
1400
AUM (kg)
metal (STC)
composite
inflatable
metal (non-STC)
Power (metal (STC))

GRAPH 2.14. FLOAT WETTED AND CROSS SECTIONAL AREAS



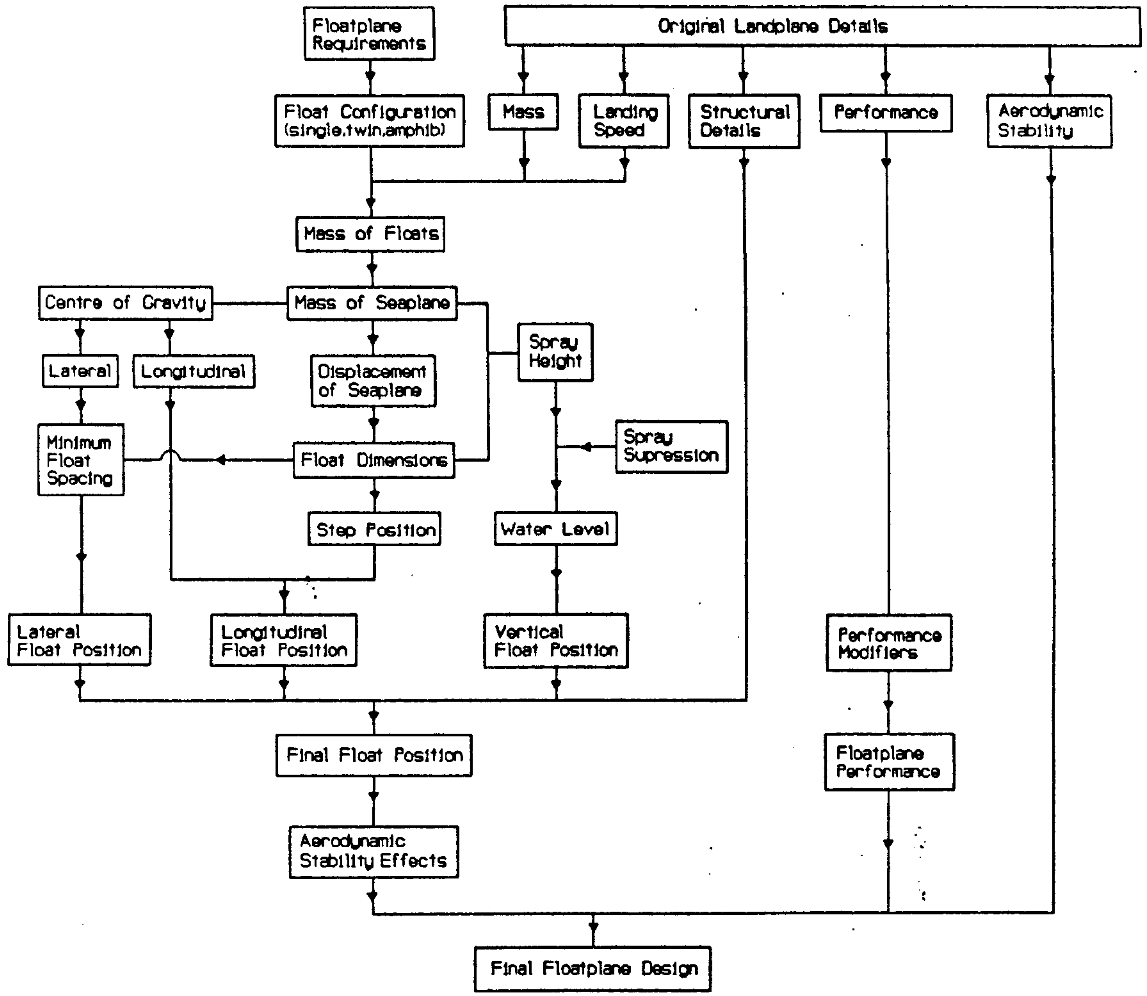


FIGURE 2.1. FLOATPLANE CONCEPTUAL DESIGN METHODOLOGY

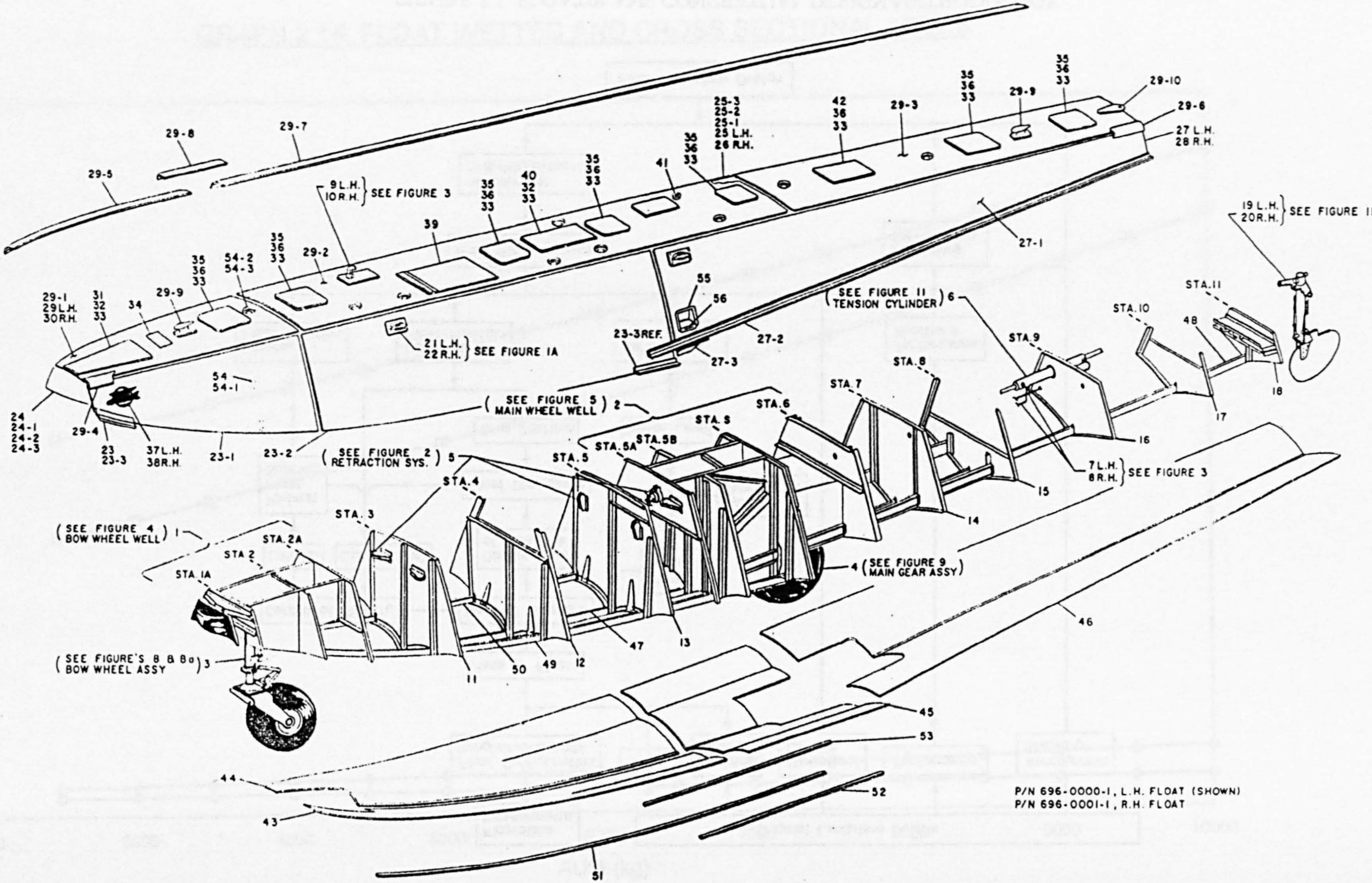


FIGURE 2.2. FLOAT CONSTRUCTION

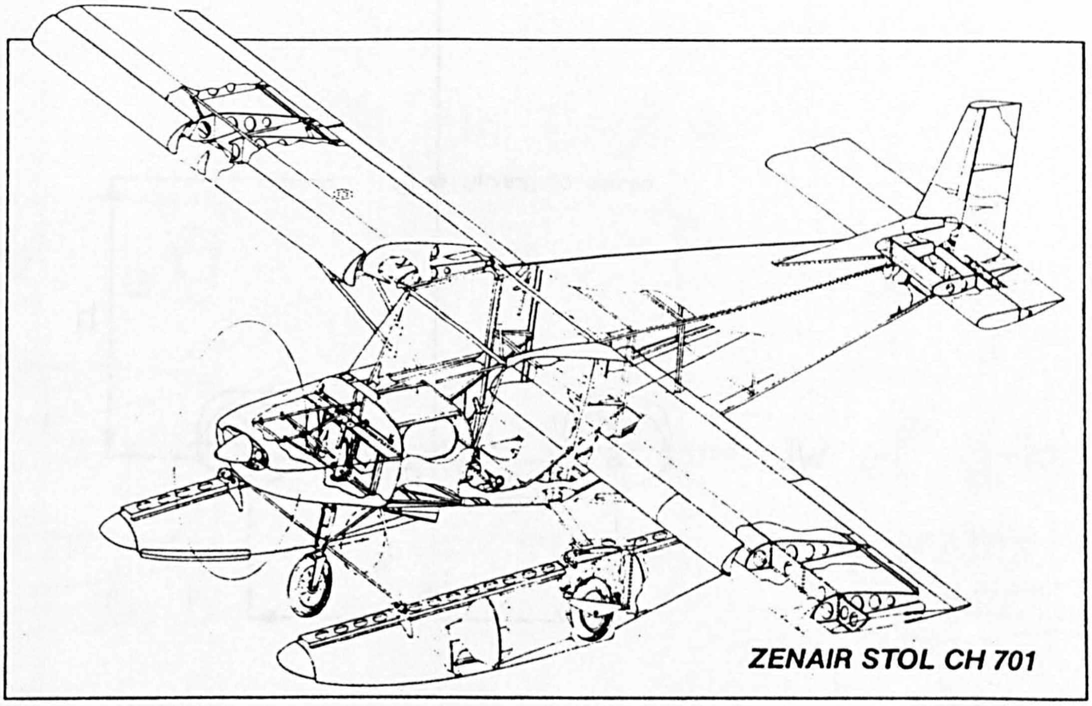


FIGURE 2.3. FLOAT WITH MULTIPLE ATTACHMENT POINTS

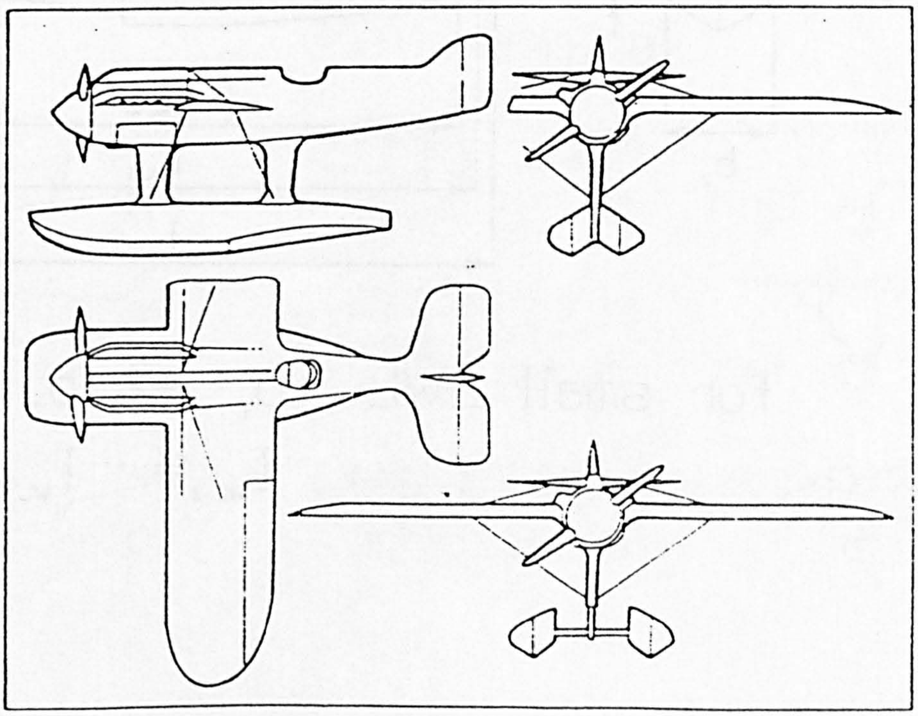
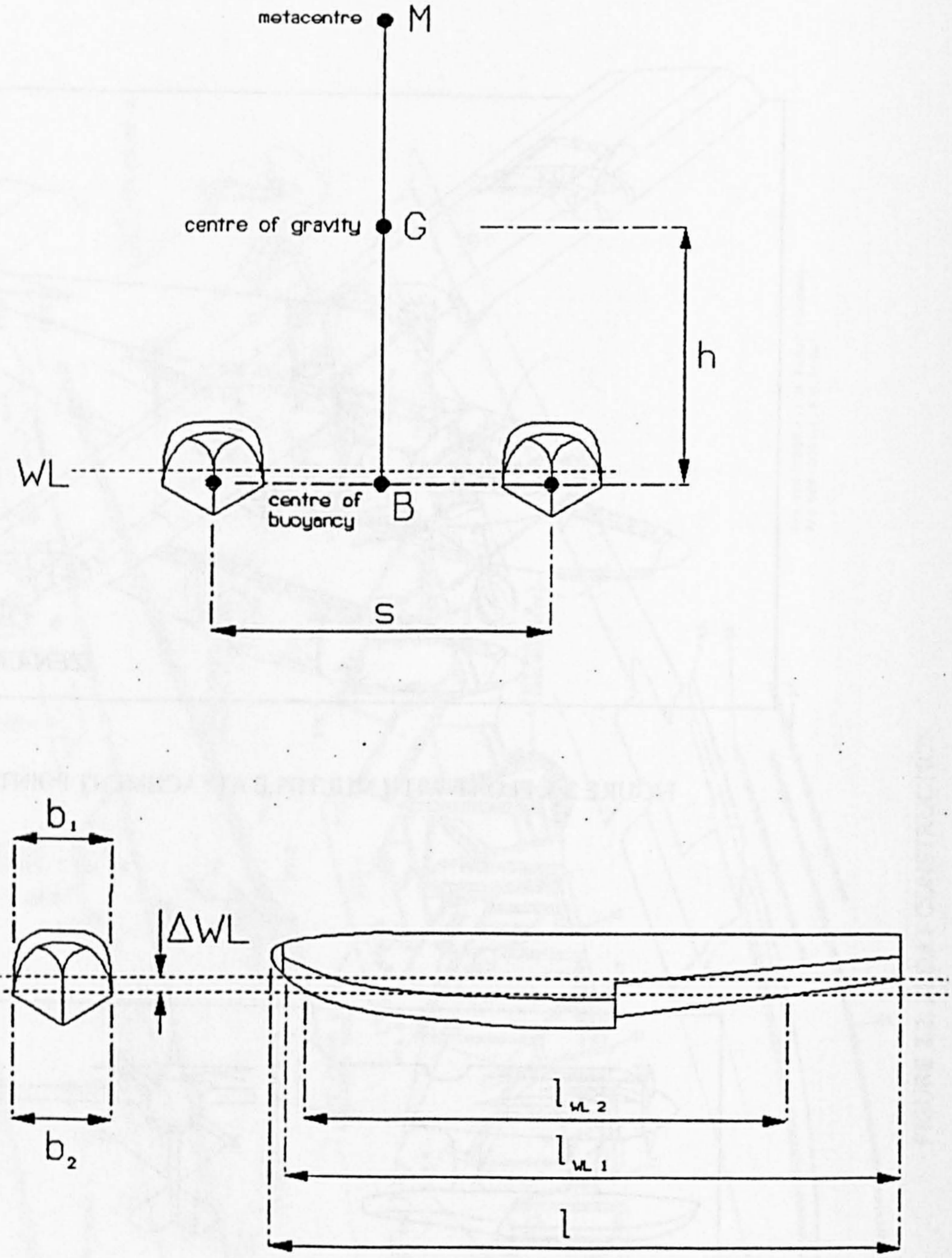


FIGURE 2.4. SAUNDERS UNCONVENTIONAL FLOATPLANE



for small ΔWL: $b_1 = b_2 = b$

$l_{WL\,1} \neq l_{WL\,2}$

FIGURE 2.5. STATIC STABILITY TERMS

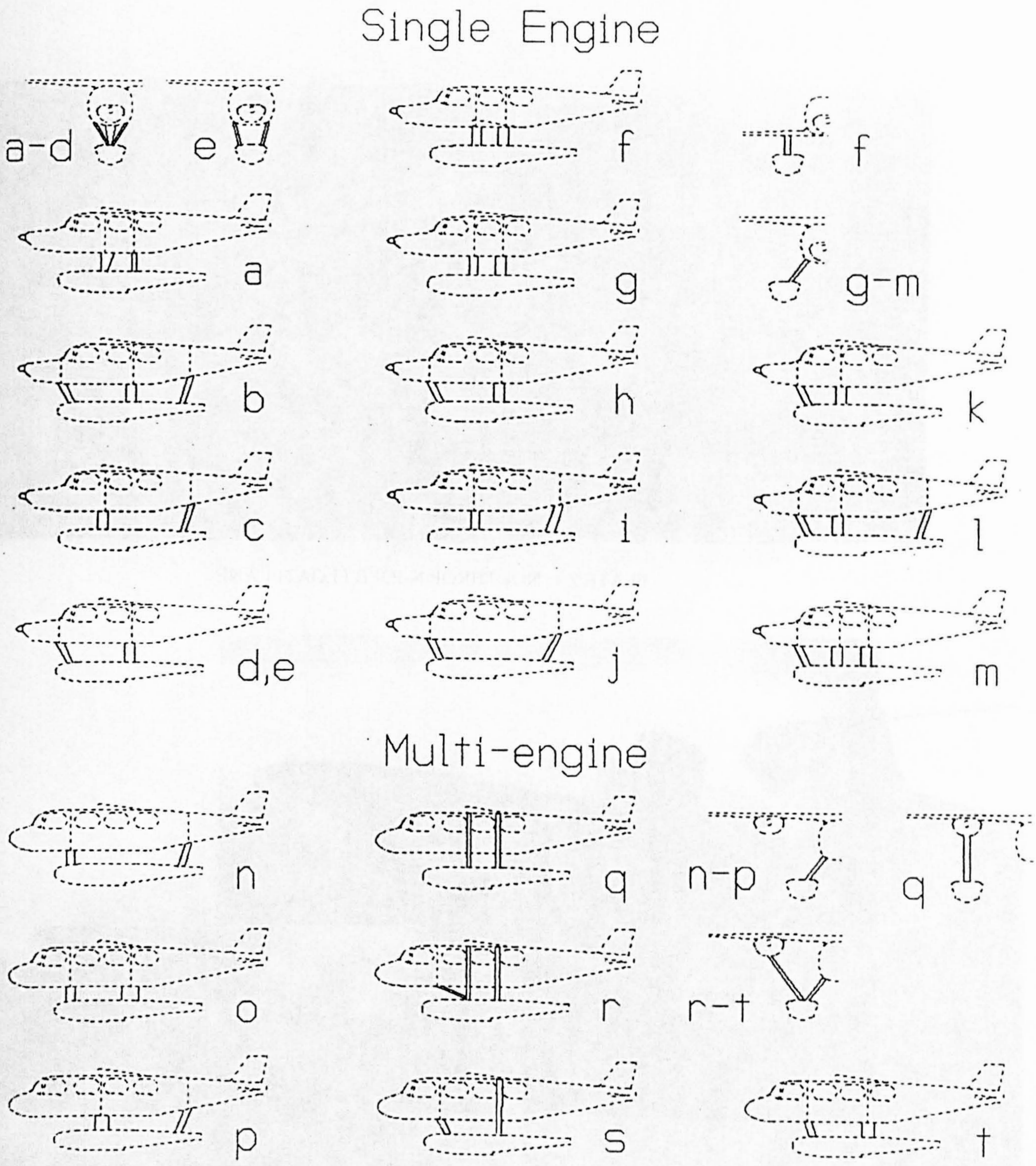


FIGURE 2.6. STRUT/FLOAT CONFIGURATIONS

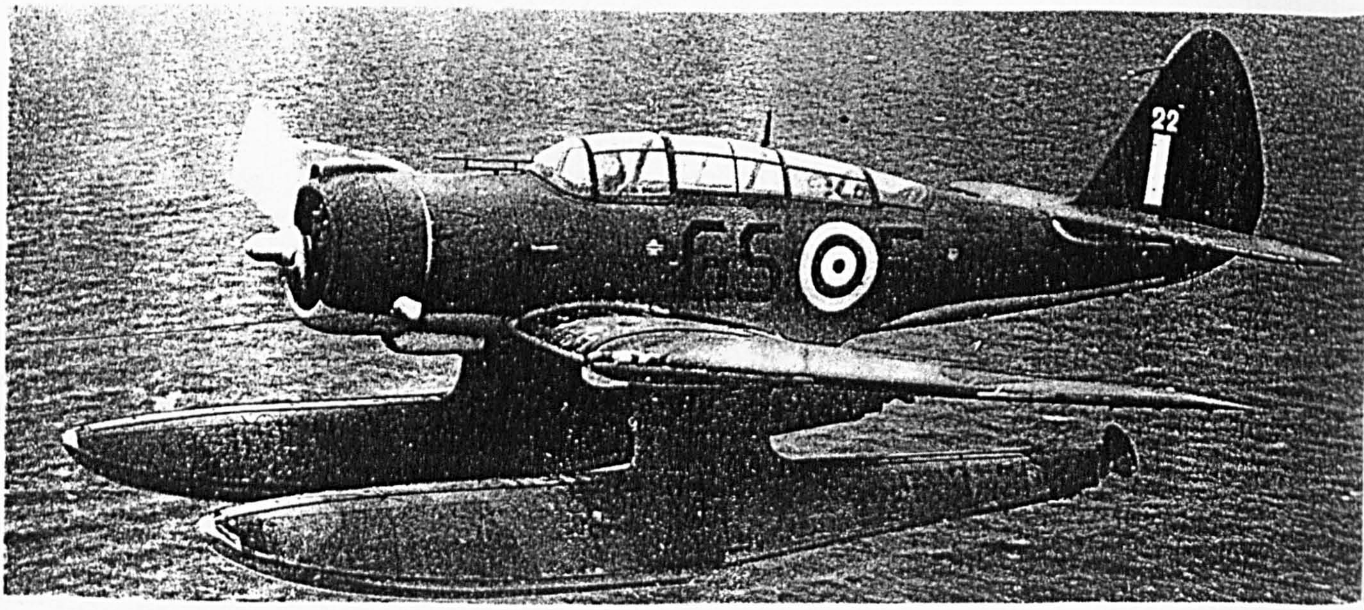


PLATE 2.1. NORTHROP N-P3PB FLOATPLANE

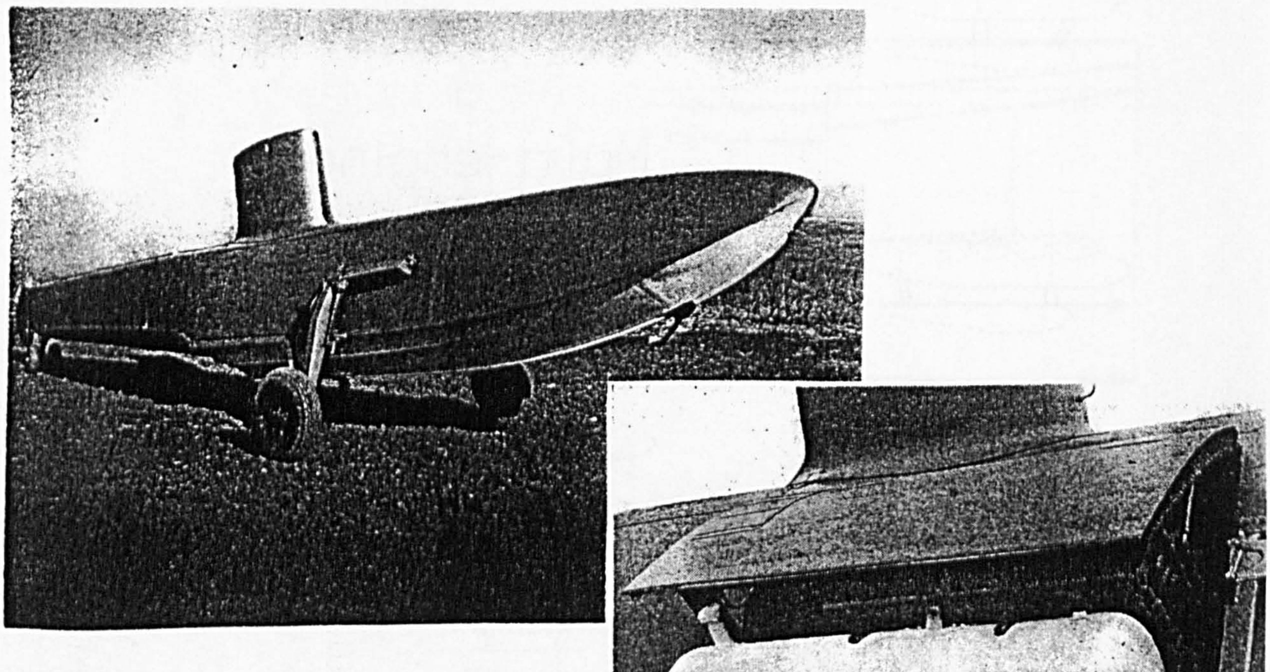


PLATE 2.2. SEAHAWK FLOAT INTERNAL WEAPON STOWAGE

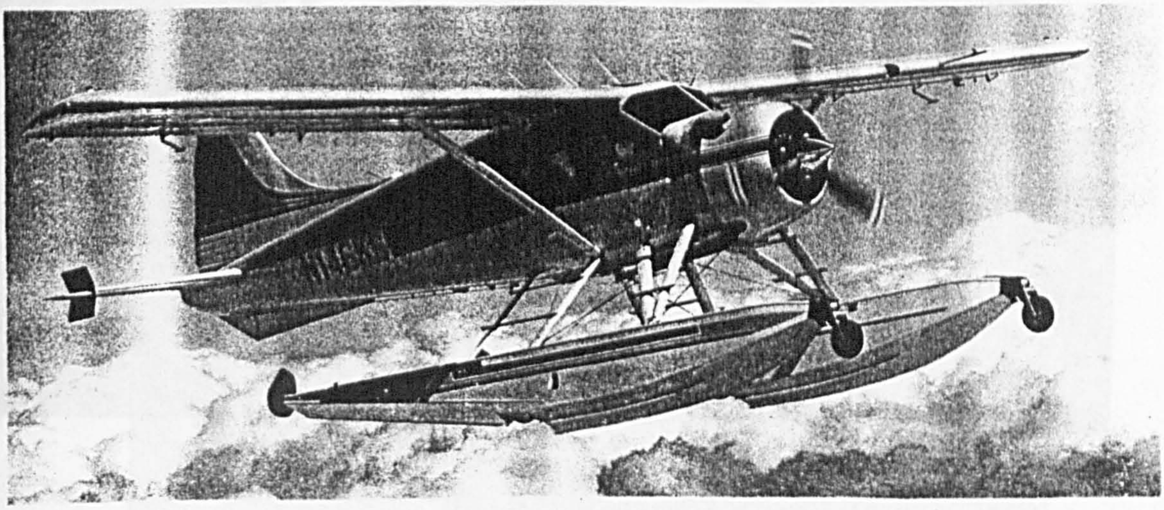


PLATE 2.3. AMPHIBIOUS FLOATPLANE UNDERCARRIAGE - BEAVER

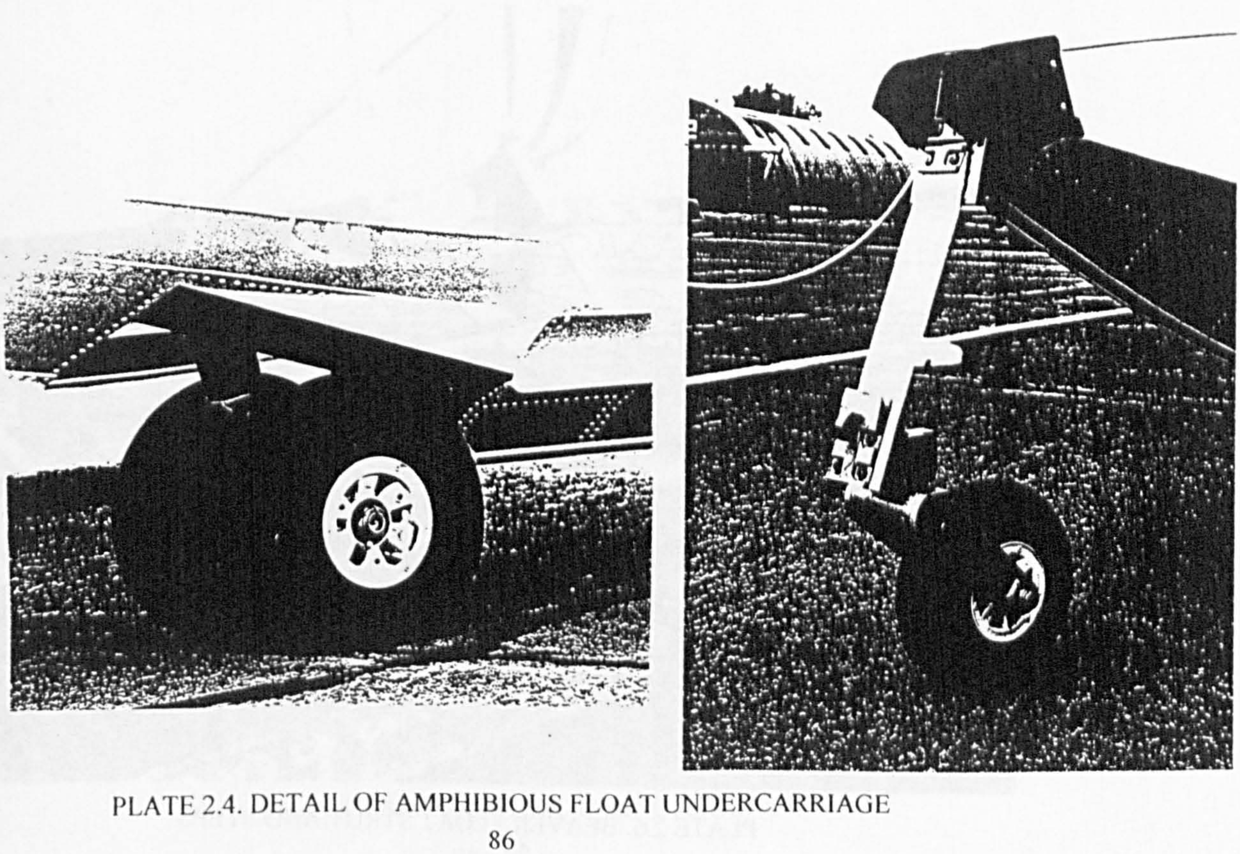


PLATE 2.4. DETAIL OF AMPHIBIOUS FLOAT UNDERCARRIAGE

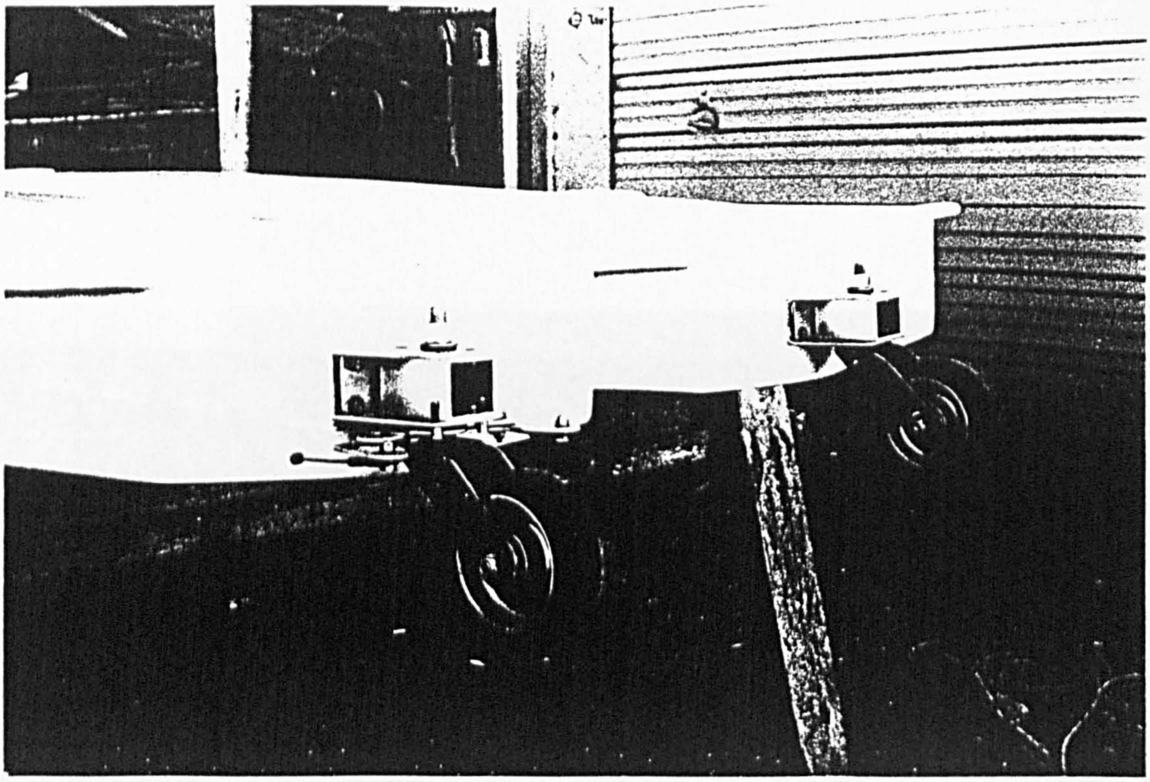


PLATE 2.5. AMPHIBIOUS FLOAT UNDERCARRIAGE - TAILWHEEL

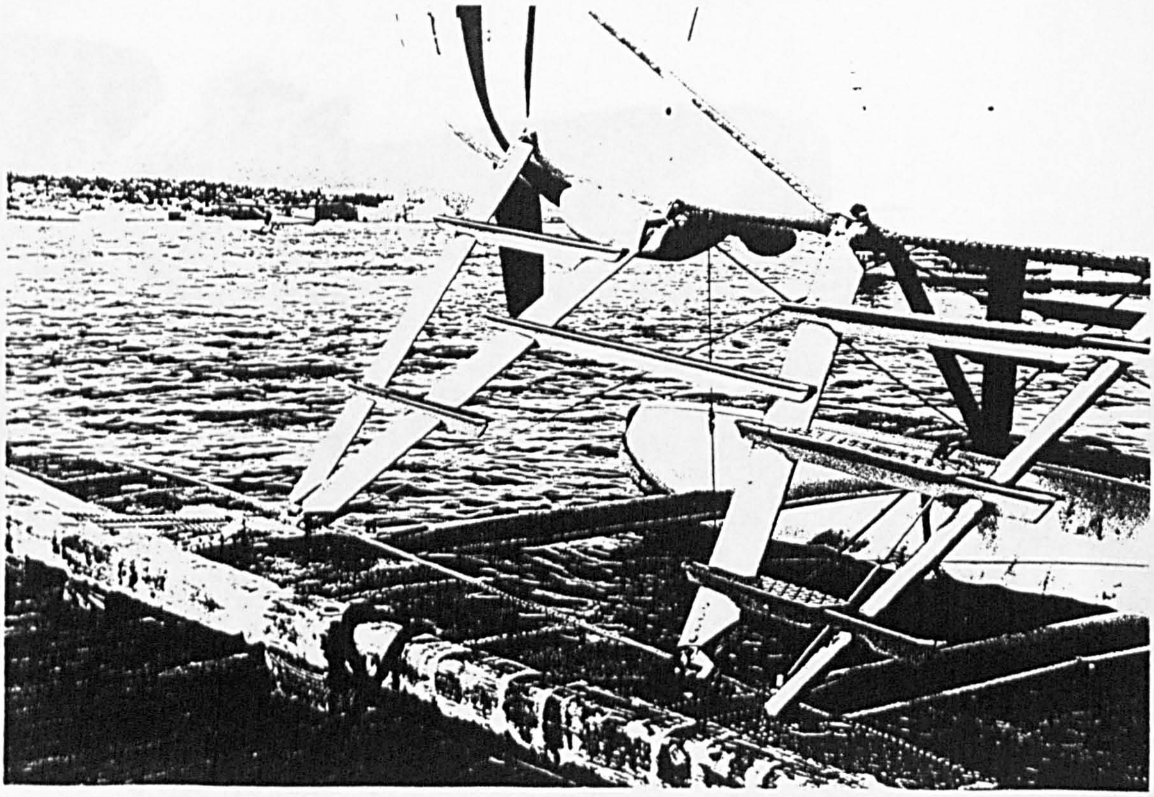


PLATE 2.6. BEAVER FLOAT STRUT AND STEPS

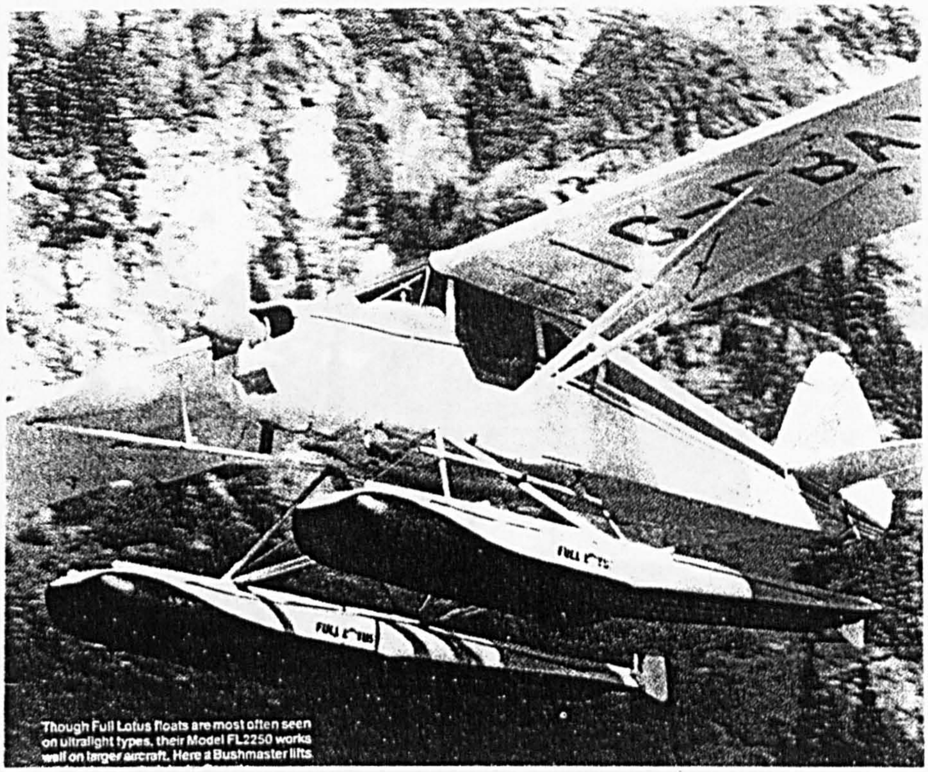


PLATE 2.7. FULL LOTUS INFLATABLE FLOATS ON A BUSHMASTER AIRCRAFT

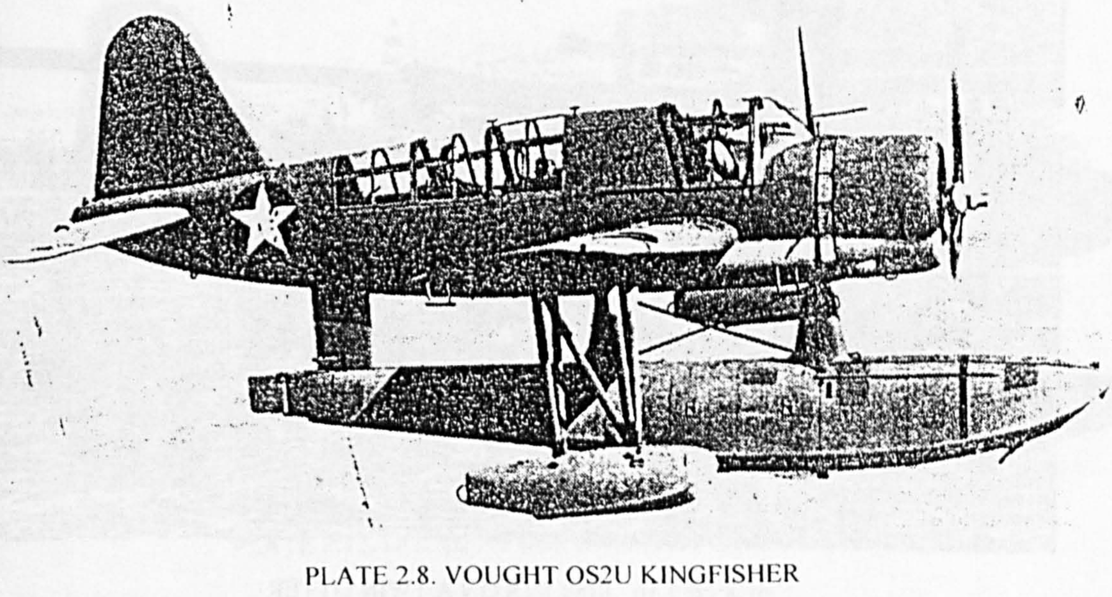


PLATE 2.8. VOUGHT OS2U KINGFISHER

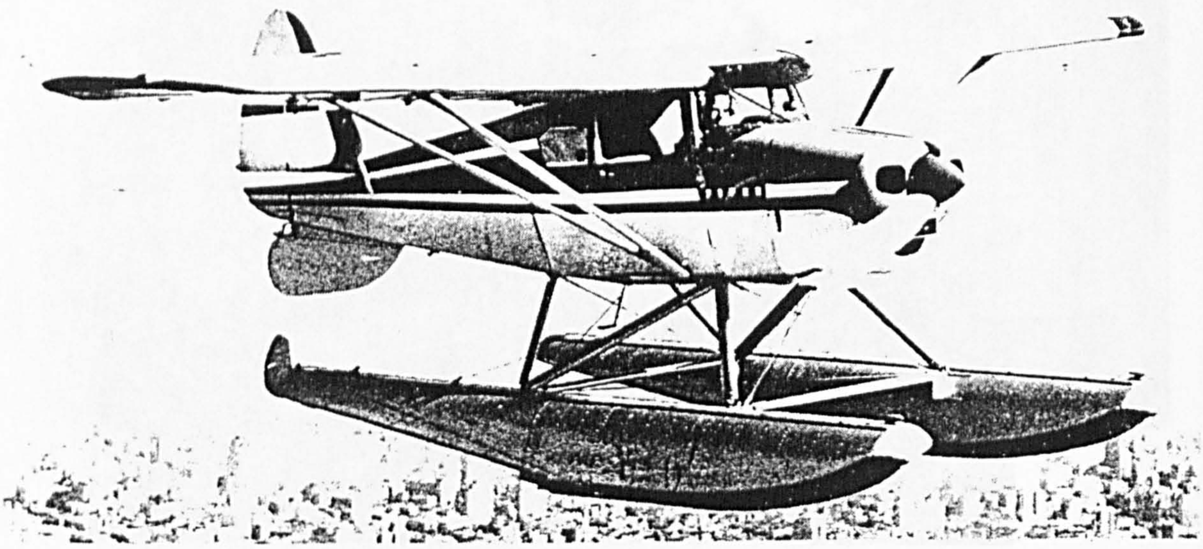


PLATE 2.9 VENTRAL FIN ON PIPER PA-22

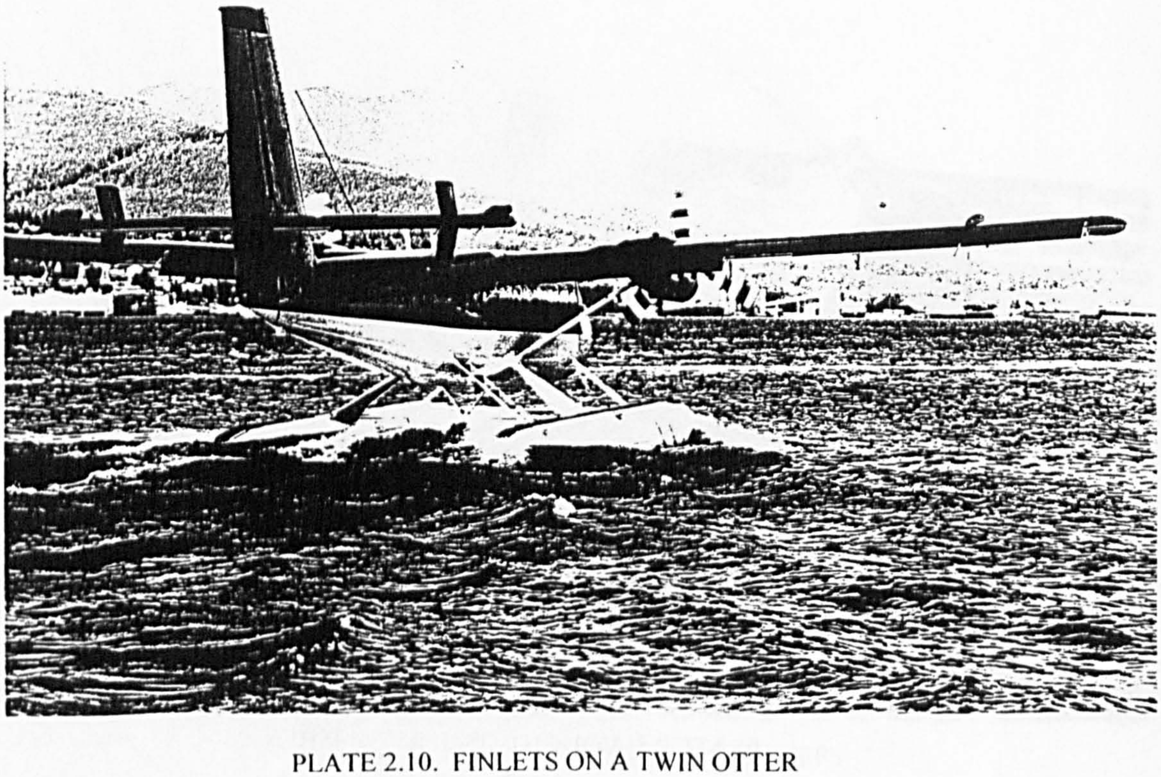


PLATE 2.10. FINLETS ON A TWIN OTTER

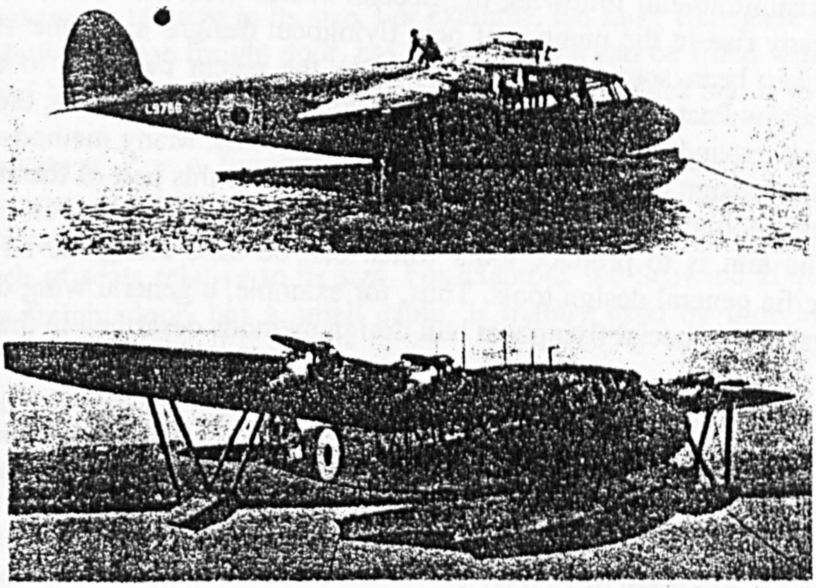


PLATE 2.11. SHORTS SCION SINGLE FLOAT FLOATPLANE

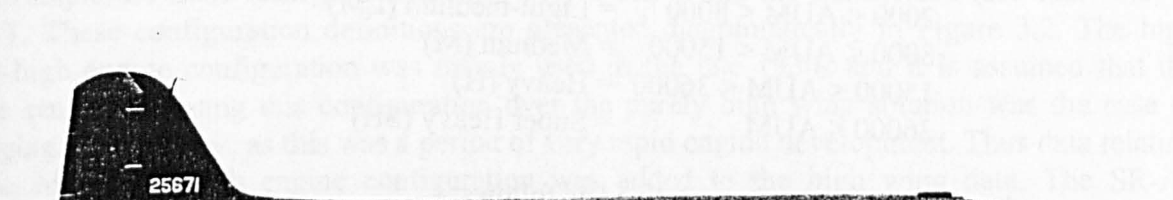


PLATE 2.12. DOUGLAS DC3 DAKOTA FLOATPLANE

3. FLYINGBOATS

3.1 INTRODUCTION.

As part of a prelude to the deeper investigation into flyingboat design the database (see Appendix 1) was consulted to confirm that there was an on-going requirement to design flyingboats (see Table 3.1 and Graph 3.1). The data clearly illustrates the rise of the type in the 30s and the precipitous fall following the Second World War. However, the data also shows a continuing steady rise in the number of new flyingboat designs since the 1980s. Although this pattern may have been somewhat exaggerated in the recent past due to the break-up of the monolithic Warsaw Pact aerospace industry into competing design teams, the data still illustrates an on-going and expanding need for flyingboat design tools. Many methods already exist to aid in the conceptual design of conventional aircraft. Therefore this part of the study investigates the additional methodologies required to enable a modern flyingboat conceptual design to be completed. The aim is to produce tools which can be used alongside any open literature or company-specific general design tools. Thus, for example, a general wing design technique can be used alongside the special flyingboat hull design methods described in the study.

3.1.1 Flyingboat Design Cycle. Like so many design activities, flyingboat conceptual design is a cycle. In the particular case of flyingboats the initial design cycle involves configuration, mass, static and dynamic stability buoyancy, spray height and performance. This cycle is represented diagramatically in Figure 3.1.

3.2 GENERAL CONFIGURATION.

3.2.1 Classifications. To aid in the generalisation of flyingboat data a number of AUM and role classifications were created.

a. AUM. AUM was classified as follows:

AUM < 1000 kg	= Ultra-light (UL)
1000 < AUM < 2000	= Light (L)
2000 < AUM < 8000	= Light-medium (LM)
8000 < AUM < 15000	= Medium (M)
15000 < AUM < 36000	= Heavy (H)
36000 < AUM	= Super Heavy (SH)

b. Role. Roles were defined as follows:

Transport of Mass = T(M) = a flyingboat designed to transport high mass/low volume payloads such as military non-cargo loads or fire extinguishing foams. For example, the Catalina (see Plate 3.1) was designed purely as a maritime patrol aircraft (MPA) and is therefore T(M).

Transport of Volume = T(V) = a flying boat designed to transport high volume/low mass payloads such as general cargo or passengers. For example, the C Class Empire flyingboat (see Plate 3.2) was designed purely to carry passengers and freight and is therefore T(V).

Transport of Volume/Mass developed from Transport of Mass/Volume = T(V)or(M)d T(M)or(V) = a flyingboat used for the transport of either mass or volume loads but developed directly from one designed for the other role. For example, the Sunderland (see Plate 3.3) was primarily a MPA and therefore a T(M) but was developed directly from the C Class Empire flyingboats which were T(V). The Sunderland is therefore T(M)dT(V).

Utility = U = a flyingboat designed equally for a variety of small-scale T(M) and T(V) roles primarily for commercial operations in rugged conditions. Characterised over similarly sized P or T(M) aircraft by the presence of a large freight door, and similarly sized T(V) aircraft by the possibility of carrying large numbers of passengers relative to its size. For example, the Lake Renegade (see Plate 3.4) has a relatively large freight door, has a cabin which can be filled with passenger seats, is used by mining and timber organisations in the outback and is therefore U.

Private = P = a flyingboat designed primarily for use by an individual for the pleasure or transport of that individual. Characterised over similarly sized U or T(V) aircraft by the lack of a large freight door and similarly sized T(M) aircraft by the lack of seats relative to its size. For example, the Seawind 2000 (see Plate 3.5) has no freight door, has a small cabin, is mainly used by individuals as opposed to companies and is therefore P.

3.2.2 Configuration Choice. To form the basis of conceptual design iterations it is essential that the designer has an early indication of the general configuration of the flyingboat. The most important factor which influences this configuration is the method of maximising the distance between the propulsion source (propeller or jet) and the water spray generated at take-off and landing. The database was studied and 6 basic flyingboat configurations were distilled from the details available.

High wing = HW	Parasol wing = PW	Gull wing = GW
High engine (on fuselage) = HE		High engine on fin = HE-F
High engine in cut-out = HE-CO		

All are possible with tractor (T), pusher (P) a combination (T+P) or jet (J) propulsion.

For example the Lake Renegade (see Plate 3.4) is HE-P and the Sunderland (see Plate 3.3) is HW-T. These configuration definitions are presented diagramatically in Figure 3.2. The high wing-high engine configuration was mainly used in the late 1930s and it is assumed that the prime reason for using this configuration over the purely high wing solution was the ease of changing engine types, as this was a period of very rapid engine development. Thus data relating to the high wing-high engine configuration was added to the high wing data. The SR-A1 flyingboat jet-powered fighter (see Plate 3.6) with its nose intake was a unique layout and was therefore not included in the configuration choice methodology; neither were scale research aircraft (see Section 3.17). Having decided on the configuration options the database was then studied to see if any patterns were present (see Tables 3.2 to 3.4). In the T(V) role 59% of aircraft had the HW-T configuration, the large fuselage required by the role fulfilling the useful synergy of mounting the wings and engines well above the spray. Although, at 25%, HW-T was still the most common configuration for the popular LM mass classification in the T(V) role, there was also a mixture of configurations with close statistics. Both PW-T and HE-CO-P were at 14% of the sample and there were examples of almost all configurations. This is because the fuselage design driver for this size of aircraft is the height of a man, which can be very close to the height which requires some configuration input other than cabin height to place the engines above the spray. The larger M, H, and SH mass classifications all positively favoured the HW-T configuration. In the T(M) role 40% of the aircraft had the HW-T configuration. In the SH mass category all T(M) aircraft were HW-T, but the H, M and LM categories followed similar patterns to the T(V) role classification. Again, the height of a man is likely to be the driver for this pattern as the main T(M) sub-role in the database was MPA which require comfortable working conditions for the crew. Moreover, firebombers, the other major T(M) sub-role, are often required to carry fire-fighting crews and may also be marketed as general purpose transport aircraft, thus adding the man-height input into the design. This input was clear in the conceptual design process of the CL215 firebomber $_{(51)}$. In the U role 57% of the sample were in the HE-P configuration. This is because the vast majority of this role of aircraft were in the L mass category, resulting in a fuselage size less than a standing man and therefore requiring a configuration input to raise the engine above the spray. The HE-P configuration not only fulfils this requirement but also places the propeller well away from the loading area of the aircraft, significantly increasing safety. For identical reasons the HE-P configuration is also the most popular (42%) for P aircraft, with the similarly safety-orientated HE-CO-P configuration also popular (27%). Overall the following guidance can be gained from this exercise. The configurations in bold type are the most popular of a similar statistical grouping.

T(V) + {SH or H or M} = HW }
T(V) + LM = {**HW** or PW or GW} }
T(M) + SH = HW }
T(M) + H = {**HW** or PW or GW} }Eqn 3.1
T(M) + M = {**HW** or PW} }
T(M) + LM = {**HW** or PW or HE-P} }
U + L = HE-P }
P + {L or UL} = **HE-P** or HE-CO-P }

3.3 LATERAL STABILITY METHOD CHOICE.

3.3.1 Database Study. The database was examined for patterns of lateral static stabilising method configuration, form and location (see Table 3.5).

a. Configuration. The vast majority of flyingboats used floats of some form to gain lateral stability; only 12% (16/132) used stubs and 3% (4/132) the wing volume. Of the flyingboats which used floats 25% (26/103) had some method of retracting the floats to reduce drag. A significant minority (38% of data sample) used some form of design synergy in mounting their floats. It is likely that more used synergy, but the method was not visible on the photographs or drawings in the database.

b. Float Form. Twelve float forms were identified from the database (see Figure 3.3). Of these the B1 and C1 type were, at 28% (27/97) and 33% (32/97) of the sample, clearly the most popular. There seemed to be no apparent reason why some floats were stepped and others were not, yet in every flyingboat design upgrade for which information was available, steps were added to floats $_{(52)}$.

c. Position of Stabilising Floats. The most popular position (33% of data sample, 31/93) for stabilising floats was at 70%-79% semi-span. With the exception of the actual wingtip 82% of the sample lay between 50 at 90% semi-span. Detailed sizing of floats is discussed in Section 3.12.

3.3.2 Advantages of Configurations.

a. Tip Floats. The main advantage of the tip float is its simplicity. Unlike stubs, tip floats do not take significant landing loads and can therefore be of relatively light construction. The main disadvantages of tip floats are their awkward position in relation to coming alongside jetties and the limit of their use for functions other than static stability; for example, only the Grumman Albatross uses tip float volume as fuel tanks (53).

b. Stubs. Sometime known as stummel, sponsons or seawings, stubs were most frequently used by Dornier (see Plate 3.7). Stubs can be used for the storage of fuel, payload or undercarriage mechanisms due to their location on the fuselage and their more robust structure. However, this robust structure is due to the fact that stubs can take a proportion of the water landing loads and are therefore significantly heavier than the equivalent tip float. Additional advantages of stubs include their ability to be used as a loading platform between the flyingboat and a jetty and their role as spray dams.

c. Wing Volume. The main advantage of using inner wing volume as the source of lateral on-water static stability is the obvious design synergy of the structure and the commensurate saving of mass. The inevitable low mounted wings of this configuration also allow the flyingboat to use the advantages of ground effect during take-off and landing. However, the proximity of the wing to the water makes the use of other high lift devices difficult and adds a requirement for a strong lower wing surface to take landing loads in a similar manner to stubs (see Plate 3.8).

d. The advantages and disadvantages of the 2 main lateral static stability choices, tip floats and stubs, are summarised in Table 3.6.

3.3.3 Retractable Tip Floats. The concept of retractable tip floats has been tried with a variety of success for many years. The basic reason behind the concept is to reduce drag in the flight regime by mechanically moving the float and its support structure as much as possible into the wing volume. The most common design involves the float support structure being hinged some distance inboard of the wing tip and the float retracting upwards to form the tip. Not only does this take the support structure out of the airflow, but the float itself can act as an end-plate to the wing. The PBY Catalina is probably the most numerous aircraft which uses this technique (see Plate 3.1). The Unikomtranso 11 uses the actual wingtips as floats which pivot down from a full chord hinge line. Attempts to bury more of a retractable float into the wing volume invariably means that the float is retracted inboard to utilise the thicker wing section. The SR-A1 flyingboat jet fighter (see Plate 3.6) mechanically retracted the float and support strut inboard and rotated the float through 180^{O} about its fore-aft axis to ensure that the aerodynamic upper surface rather than the stepped lower surface remained in the airflow. The paper designs of the Saro S38 and S39 featured floats which split longitudinally using the mechanical lever effect of its retracting support structure (21). This effectively reduced the beam if the float by half and enabled it to be fully retracted into the wing volume (see Figure 3.4). The Do26 retracted its column-type floats into the wing, the slab sides of the float forming a smooth lower wing surface (see Plate 3.9). The Bv222 used a similar technique but split the float and retracted half inboard and half outboard. French designs of the 1940s and 50s, such as the Latecoere 631 favoured retracting floats in a fore-aft sense into the rear of the outboard engine nacelle (see Plate 3.10). The disadvantage of this solution is the relatively small lateral moment arm of the float resulting in a larger displacement requirement and attendant volume and mass. A French design which was to be installed in the SE200 was a partially inflatable float which again served to reduce the volume of float to be retracted into the wing volume (54). A common disadvantage to all these designs is the additional mass of the retracing mechanism and any structural reinforcement needed around the wing structure cut-out. Also, the greater complexity adds to initial manufacturing and maintenance costs. Finally, any wing volume used to house a retractable float and/or support structure cannot be used to hold fuel. Thus any drag advantages of a retractable tip float should be balanced against these disadvantages. The methods of retracting floats are summarised in Figure 3.5.

3.3.4 Retractable Stubs. No retractable stub design has ever been attempted. Stubs are usually too heavily loaded to be easily retractable and bearing this in mind, a pure horizontal lateral inboard retraction is likely to be the only practical method of removing stubs from the airflow (see Figure 3.5). However, this solution uses potential payload volume in the fuselage and is therefore unlikely to be cost-effective.

3.3.5 Unconventional Solutions. An interesting example of design synergy can be seen in the Saro P106/2 design (see Figure 3.6) for a twin boom MPA flyingboat (21). This design used the lower fin surface below the twin booms to mount the floats. Although never taken beyond the drawing board this configuration may have had problems with the hull wake and spray striking the floats and causing unacceptable tail buffet. A further unconventional solution for lateral stability may be to use high pressure bleed air vented from the wing tip in a similar manner to the Harrier V/STOL aircraft. Although having the advantage of no drag producing structure, the control method would be complex and the hot air piping would create additional mass.

3.4 LATERAL STABILITY CHOICE SIZING.

3.4.1 Introduction. As a precursor to the detailed calculation of lateral stability it is desirable to have a relatively general method of estimating the size of the various methods of on-water lateral stability. The main methods covered here are tip floats and stubs. Tip floats will be examined first.

3.4.2 Tip Floats.

a. Introduction. The flyingboat database was examined and 64 aircraft extracted where sufficient information was available to derive tip float volume. As tip float form is so variable (see paragraph 3.3.1b) a generalised fuselage volume estimation methodology was used from Torenbeek (44). This method was considered valid as most float forms are roughly fuselage shaped; full depth vertical or column-like floats as used in the Lake amphibians (see Plate 3.4) and Do26 (see Plate 3.9) are discussed later. However, to check that the method was valid a validation exercise was carried out with the following results:

Mars tip float volume (55):	Actual = 1.6m^3	Estimate = 1.59m^3
SeaRanger tip float volume (56):	Actual = 1.6m^3	Estimate = 1.49m^3
Tradewind tip float volume (57):	Actual = 5.6m^3	Estimate = 6.25m^3*
		= 4.52m^3**
		Average = 5.4m^3

Note that the first Tradewind estimate (*) is based on the float height as the "fuselage" diameter whilst the second (**) is based on the float beam. In the other 2 cases the estimate is based on float beam. It was therefore decided to standardise on float beam as the diameter dimension.

b. Developing the Method. Torenbeek(44) specifies 2 ways of estimating volume depending on length to diameter ratio (λ).

for $\lambda \geq 4.5$ then volume = $(\pi/4)D^2 l_f (1-(2/\lambda))$ where D = diameter
for $\lambda < 4.5$ then volume = $(\pi/4)D^2 l_f [0.5 + 0.135(l_n/l_f)]$

Examination of float forms revealed an approximate pattern that $l_n = l_f/3$, thus simplifying the latter equation. These 2 methods were used to estimate tip float volume. The results are presented in Table 3.7. Having estimated the float volume the second major influence, float spanwise moment arm, was gained from the database (for discussion of float spanwise position see paragraph 3.3.1c).

c. Examination of Results. Thurston (58) recommends that, for flyingboats under 8000lb, AUM the product of fresh water tip float displacement (ie a function of volume) and moment arm is:

$$\Delta y = 0.7 \text{ to } 1.25 \text{ w} \quad \text{(Imperial units)}$$

This relationship was investigated for the larger AUM sample range but did not produce an acceptable statistical pattern. Several other relationships were investigated including wing area functions to add an aircraft size input and attempt to derive a non-dimensional coefficient; no acceptable relationships were found. However, examination of the full method of calculating on-water lateral stability (see Section 3.12) revealed the importance of the beam^3 function, and when this was divided into the volume x arm product to form a $(v.a)/b^3$ factor, an adequate statistical pattern was established, albeit not a non-dimensional one (see Table 3.7). Some data points diverged from the pattern and these were examined in detail. The Italian Macchi C94 and C100 both had obsolete planing bottom forms which resulted in a wider beam than equivalent aircraft, thus the beam^3 function tended to unduly reduce the factor. As this form of planing bottom is no longer used these aircraft were removed from the sample. Aircraft with full depth vertical floats tended to exhibit low factors. This was due to an assumption that the float beam represented the fuselage diameter dimension in the volume assumption. Closer examination of the relevant aircraft along with plots of acceptable heel angles revealed that a dimension of 2b for the smaller aircraft (UL, L, LM) and 1.5b for the larger ones (M, H, SH) was more representative of the waterline on the floats. When applied these amendments produced an acceptable statistical pattern (see Graph 3.2), thus allowing a stability factor to be established for each flyingboat class as follows:

$$\left.\begin{array}{ll} \text{SH:} & (v.a)/b^3 = 1.31 \\ \text{H:} & (v.a)/b^3 = 0.76 \\ \text{M:} & (v.a)/b^3 = 0.54 \\ \text{LM:} & (v.a)/b^3 = 0.39 \\ \text{L:} & (v.a)/b^3 = 0.23 \\ \text{UL:} & (v.a)/b^3 = 0.12 \end{array}\right\} \text{Eqn 3.2}$$

Examining the peaks and troughs of Graph 3.2 illustrates qualitative factors which need to be accounted for with particular design variables. For example, the Tradewind (see Plate 1.9) exhibits a very high factor due to a high vertical centre of gravity position caused by the large quantity of fuel held in wing tanks. Conversely, the Mars exhibits a low factor as its fuel is held in underfloor tanks, thus producing a low vertical centre of gravity position. At the other end of the size scale the Osprey also has a low factor, again probably due to a low vertical centre of gravity, but also because of the relatively benign operating conditions of a very small home-built flyingboat. The Catalina (see Plate 3.1) shows a low factor, probably due to its relatively large beam. Additionally, due to its wing tip retractable configuration, the Catalina's float size was probably defined by its retracted tip position and wing chord dimension. This is supported by the similar, low factor for the identically configured Coronado (see Plate 3.11). Thus the designer may add a multiplication factor between 2 and 0.5 to account for such qualitative design decisions. Design constraints on tip float volume and moment arm include wing structure design synergy for float position (eg using a flap or aileron wing rib). Equally, if a retractable float is to be stored semi-conformally in the wing it must be short enough to fit between the spars as is the case for the Douglas DF (see Plate 3.12). When the hull form and other design aspects are more clearly defined a full on-water static stability study can be completed to confirm the tip float restoring moments.

3.4.3 Stubs. A method was required to estimate the dimensions of the second most popular method of obtaining on-water static stability: stubs. The database was examined and 10 flyingboats were found for which sufficient information was included to calculate stub volume. To increase the sample size, details of 5 pre-1936 Dornier flyingboats were also included (59). In cases where the stub volume was not known it was estimated by assuming the geometry of Figure 3.9. In some cases, particularly the Freget, the actual stub geometry was considerably different from the assumption and more detailed assumptions were required to simplify the complex shape. In only 2 cases were the actual stub volumes and sufficient information needed to make an estimate known:

DoX	estimate = $48.32m^3$	actual = $43.5m^3$	error = 11%
Do24	estimate = $13.4m^3$	actual = $9.3m^3$	error = 44%

The magnitude of the errors is a good indication of how close the stub form was to the assumed form; the DoX stubs are very simple and close to the assumption whilst the Do24 stub form was more complex and further from the assumption (see Plate 3.7). These variables need to be taken into account when using this technique. The dimensions and estimated volume are summarised in Table 3.8. The volume was plotted against AUM (see Graph 3.3) which resulted in an acceptable relationship. It was suspected that, as was the case for tip floats, there would be configuration inputs into stub requirements and as with tip floats, the $beam^3$ function was investigated to include the hull's influence on static stability. However, no function provided an acceptable statistical pattern and when stub lateral centre of buoyancy was included little change resulted. Thus, a simple AUM relationship is proposed as follows. Note that the date of the data and the variable nature of the assumptions make this method only applicable with care.

$$\text{Stub volume} = 8.74\text{x}10^{-4} \text{ x AUM} \qquad \text{Eqn 3.3}$$

Also:

$b_{stub}/b = 0.95$ $\qquad$ $l_1/b_{stub} = 2.14$

$l_1/l_2 = 1.45$ $\qquad$ $t_{stub}/b_{stub} = 0.29$

As an extremely rough estimation method, note the pattern of Table 3.8 which approximates stub span as equal to the hull beam.

3.5 STEP CONFIGURATION AND SIZING

3.5.1 Introduction. At different times during take-off and landing a flyingboat hull must act as both a displacement and a planing craft. As a displacement craft the position of the centre of buoyancy must be close to the longitudinal centre of gravity to ensure stability, yet as a planing craft the centre of pressure of the planing surface must be close to the centre of gravity. In the latter case acceptable performance cannot be gained by a hull with one planing surface because the centre of pressure moves aft as the wetted area decreases with increased speed and the attendant drop in loading due to wing lift. A flyingboat hull must therefore have at least 2 planing surfaces, the separation occurring at a structural discontinuity known as the step. The step also restricts the planing wetted area to the minimum necessary to develop hydrodynamic lift with minimum hydrodynamic drag. The discontinuity at the step also serves to generate an area of low pressure which draws air onto the forward part of the afterbody decreasing hydrodynamic drag and therefore easing take-off. Although 2 or more steps were common in the early designs of flyingboats, greater understanding of hydrodynamics and advances in planing bottom form negated the need for all but one step on modern aircraft. Thus only single step design methodologies will be considered further. Step longitudinal position, depth, form and fairing are design variables and various forms of natural and artificial step ventilation have been attempted to increase both aerodynamic and on-water performance.

3.5.2 Initial Step Positioning. Various references quote a assortment of methods to initially position the step, usually relating step/keel centroid location to the aircraft AUM centre of gravity. Thurston $_{(58)}$ and Munro's $_{(31)}$ so-called "American Method" place the step 10° behind a vertical line dropped from the centre of gravity position. Munro's "British Method" places the step 2° behind the centre of gravity. Deihl $_{(60)}$ suggests 15-25° behind the centre of gravity and Benson and Bidwell $_{(61)}$ recommend 10-20°. The database was used to verify whether these methods were valid across all flyingboat types. The centre of gravity of the aircraft was first located on side elevation drawings from the database and then the position of the step relative to this point was noted. Also note that Stinton $_{(62)}$ recommends that increased afterbody ventilation is achieved by positioning the step slightly aft of the widest point of the planing bottom.

a. Centre of Gravity. A key requirement before checking step position was locating the flyingboat's centre of gravity position. Methods of calculating the longitudinal position are widely available, but rely on a relatively detailed knowledge of the location of certain major components. Errors in the longitudinal position of such components can greatly effect the centre of gravity position yet, with a few exceptions, details of their placement was unknown for database aircraft. It was therefore decided to significantly simplify the procedure by standardising on a longitudinal centre of gravity position at 25% root mean chord for all aircraft. No technique for calculating vertical centre of gravity position could be found in any reference and therefore a method was developed which included some, admittedly, very general assumptions (see Appendix 4). However, a relatively low level of accuracy was deemed acceptable, bearing in mind that the position found would be plotted on an invalidated drawing of the aircraft. Once located in the longitudinal and vertical sense, the centre of gravity position was marked onto side elevation drawings of 59 flyingboats from the database.

b. Results. Having established the centre of gravity position, a vertical line was dropped from this point perpendicular to the keel datum. A further line was then drawn from the step centroid through the centre of gravity position. The angle between these 2 lines was measured and the results are presented in Table 3.9. These showed considerable statistical scatter, but the average of 25° was considerably more than all methods contained in the references. A little more result consistency was obtained when the various flyingboats were grouped by manufacturer. Here, close groupings were immediately visible for Dornier and Grumman aircraft and similar chronological groups of Martin and Shorts aircraft. However, as a generalisation, the scatter was still to great to derive any confident methodology except to state that off-set angles are likely to be between 10-25°.

3.5.3 Theoretical Step Position. When planing, a flyingboat is reacting to a combination of five main moments in balance about a fulcrum at the centroid of the planing area immediately forward of the step (see Figure 3.10 and Plate 3.11). For straight, lateral steps the planing area can be assumed as an equilateral triangle having as its base the full beam along the step and the other 2 sides meeting at the keel at a longitudinal distance from the step of one beam $_{(33)}$. The fulcrum is therefore at a point approximately 1/3b forward of a lateral step. For steps which are pointed in planform, the fulcrum can be assumed to be at 2/3 of the length measured from the aftmost end of the step. The balance equation is therefore:

$$L\,l_{lift} + D\,h_{drag} = B\,l_{tail} + T\,h_{thrust} + w\,l_{weight}$$

As all the parameters are known, the horizontal tail lift due to elevator input can be calculated and compared with that gained using conventional aircraft detailed design methodologies, the purpose being to confirm that there is sufficient elevator authority to control the flyingboat on the step. The equation can be simplified by assuming that, for a conventional flyingboat configuration during planing, $L\,l_{lift} = w\,l_{weight}$. Similarly, examination of the database revealed that, with few exceptions, $h_{drag} = 0.5h_{thrust}$. Therefore the balance equation can be simplified to:

$$D\,h_{thrust} = B\,l_{tail} + T\,h_{thrust} \qquad \text{Eqn 3.4}$$

The h_{thrust} value will usually have been set by spray considerations. Drag and thrust will be known in the planing condition (ie just before take-off) and therefore the B L_{tail} product can be derived and compared with results from conventional detailed design methodologies.

3.5.4 Step Form. There are 4 main forms of step: lateral, tapered plan-form, elliptical plan-form and swallow-tailed (see Figure 3.11). The lateral form is the most simple from the construction standpoint and is therefore the cheapest to manufacture. The majority of flyingboats in the database for which step-form was visible (39/62, 63%) had lateral steps. The more complex plan-form steps were primarily designed to reduce aerodynamic drag (see Section 3.14) and were present on 37% (23/62) of the aircraft in the database. Note that of these aircraft 52% (12/23) could be regarded as high speed (max velocity > 250 kts), whilst only 10% (4/39) of the flyingboats with lateral steps could be so considered. All of the high speed project aircraft had tapered or elliptical plan-form steps. This illustrates the performance value gained by these more structurally complex and therefore expensive step forms. Hydrodynamically, the plan form of the step has little effect $_{(63)}$.

3.5.5 Step Depth. The depth of the step has a major input into a number of flyingboat performance functions including aerodynamic and hydrodynamic drag and dynamic stability. Reference 61 states that the aerodynamic drag of a step is approximately proportional to the rise area of the step. There are therefore sound performance reasons to minimise step depth. A deep step also causes excessive water resistance due to turbulence when the flyingboat is acting as a displacement craft yet results in low hydrodynamic drag and an extensive stability range when planing $_{(51,55,56)}$. Conversely, a shallow step, although creating less overall aerodynamic drag and hydrodynamic resistance when acting in the displacement regime, causes high water resistance when above the hump speed. A shallow step can cause dynamic instability during take-off and landing due to reduces trim limits (see Section 3.15) $_{(66)}$. The database could not be used to establish step depth relationships as large scaling errors were likely during measurement of such relatively small dimensions from side elevation drawings. A small number of step depths which were either directly quoted in references or were measured by the author from actual flyingboats was therefore used (see Table 3.10) alongside methods from references. There was a variety of guidance in references on the depth of steps as follows:

NACA ARR L4I12 $_{(66)}$:	8-12% beam
NACA TN 535 $_{(65)}$:	2.5-6% beam (but this for flyingboats with 2 steps)
Aircraft Design $_{(3)}$:	5% beam
Anatomy of the Aeroplane$_{(62)}$:	6-10% beam
Design for Flying $_{(58)}$:	4-8% beam for $l_{afterbody}/b = 2.5 - 4$ Eqn 3.5

Table 3.10 shows that the average of the database aircraft was 8.3% beam with a variation between 5 - 15.8%. As indicated in the latter reference the depth of a step should, intuitively, be

related to the dimensions of the afterbody due to its major influence on how water contacts that portion of the planing bottom. Thurston (58) gives a graph of step depth against afterbody length/beam ratio which seemed to warrant further investigation. The step depths available from aircraft in the database were plotted on this graph (see Graph 3.4) and all but the Martin Mars fell well within the safety band. It was therefore decided to use Thurston's method to estimate step depth having already established afterbody length and beam.

3.5.6 Step Fairing. Fairing a step is the gradual reduction of the step height over a certain length of the afterbody. A fairing can be in the form of a simple wedge or concave in shape (see Figure 3.11). The main reason for fairing a step is to reduce aerodynamic drag. The air drag of a transverse step can almost be eliminated by the use of a fairing having a length of 4-6 times the step depth (64, 67). However, a faired step has an adverse effect on hydrodynamic stability as the step's functions of forming a rear edge to the planing area and allowing air to ventilate onto the afterbody are compromised. These aspects are discussed in greater detail in Section 3.15.

3.5.7 Step Ventilation. Ventilation of steps or step fairings can be used to reduce planing drag and improve stability of flyingboats with shallow steps by artificially introducing more air onto the afterbody than could be generated by the discontinuity of the step alone. Reference 68 claims that ventilation has little effect on normally sized steps yet a number of conventional Grumman flyingboats have ventilated steps. It is assumed that this ventilation aimed to marginally decrease planing resistance and, as the vents are in the close-by wheel wells, the additional mass is likely to have been negligible. Ventilation can be either natural, using the negative pressure immediately aft of the step to draw air from elsewhere on the aircraft, or forced ventilation, which uses a power source such as an auxiliary power unit to provide compressed air (see Figure 3.12). Unsurprisingly, forced ventilation produces greater improvements than natural ventilation (69) but the method of generating the compressor air creates additional mass and uses volume which could earn revenue. In the case of trials undertaken on a Sunderland flyingboat in 1952 (70) the naturally ventilated area was 0.042 $(\text{beam})^2$ immediately behind the step with a further equal area 0.8 x beam aft. The vents were placed between the keel and 0.8 x half-beam and reduced resistance at high planing speeds by 30%. Reference 64 recommends that the vents are placed as close to the keel as possible. The disadvantage of vents is the additional mass and complexity of the installation, but they may be essential to gain acceptable hydrodynamic performance from low aerodynamic drag hulls.

3.6 PLANING BOTTOM DIMENSIONS.

3.6.1 Linear Dimensions. The flyingboat hull linear dimensions of length, beam and height are firstly determined by a combination of the fuselage dimensions required by the specified role. These are calculated in the same manner as for land-based aircraft. Specific to flyingboat hulls is the requirement to generate the buoyancy required to support the aircraft's AUM when static (see Section 3.9) and planing (see paragraph 3.6.3) and on-water static stability requirements (see Section 3.12). The overall length of the hull also has an input into tail surface sizing (see Section 3.7) and height is driven by spray considerations (see Section 3.10). Following initial fuselage sizing, this section can be used to generate the first iteration of planing bottom dimensions which can then be considered in more detail using other sections if required.

3.6.2 Overall Length-beam Ratio. The overall length to beam ratio has an impact on aerodynamic and hydrodynamic performance (although in the latter case, less so than forebody length to beam ratio) as well as a great influence on available fuselage volume. Fine hulls ($l/b>10$) are impractical for small flyingboats due to the narrow width of their disposable load volume, but are necessary to ensure low aerodynamic drag on large, high performance aircraft. Note, for example, the low ratio of the Dornier Seastar at 4.33 compared to the Beriev Mermaid at 13.41 although both are mid-1980s designs. Past research studies of advanced, large flyingboats also tended to regard a ratio of 15 as essential to gain the necessary performance (71), although these studies tended to be targeted at patrol aircraft where fuselage width was not an important design input. This effect is illustrated by comparing the ratio of the Saro Princess at 7.39 (see Plate 1.5) with that of the Martin Seamaster at 13.40 (see Plate 3.13). Hydrodynamic tests have shown that at the same AUM the length to beam ratio may be varied without appreciably altering the hydrodynamic performance with respect to water drag and spray characteristics provided that the product of the beam and square of the length is kept constant (72). An average length to beam ratio from the database would be meaningless as it would be date, role and AUM sensitive (see Table 3.11). More practical guidance is summarised as follows:

SH:	T(V) or T(M)dT(V)	$l/b \approx 8.4$	}
	T(M) or T(V)dT(M)	$l/b \approx 9.23$	}
H:	T(V) or T(M)dT(V)	$l/b \approx 5.7$	}
	T(M) or T(V)dT(M)	$l/b \approx 6.46$	}
M:	all	$l/b \approx 5.57$	}Eqn 3.6
LM:	T(V) or U	$l/b \approx 5.29$	}
	T(M)	$l/b \approx 5.96$	}
L:	U or P	$l/b \approx 5.9$	}
UL:	P	$l/b \approx 4.8$	]

3.6.3 Area. It is essential that the planing bottom generates sufficient hydrodynamic lift to ensure that the flyingboat planes successfully. The database was examined to determine if an empirical method could be derived to check this. Intuitively, planing bottom lift should be a function of forebody area, take-off speed squared, all-up mass and deadrise. As changes in deadrise angles across the database were relatively small (see Table 3.11) this factor was initially deemed negligible. Forebody area is defined as follows:

$$area_{fb} = (l_{fb} \times b) - (l_{bow} \times b)$$

where l_{bow} is assumed to equal b for all but very high speed flyingboats.

When forebody area was examined across the database as a function of AUM a relatively linear pattern emerged (see Table 3.12 and Graph 3.5). Other factors, including an attempt to define a planing bottom lift coefficient (K_{pb}) such as that below did not achieve any acceptable relationships.

$$C_L = K_{pb}\, AUM/(TO\ speed^2 \times area_{fb})$$

Thus the simplistic AUM to area relationship is postulated as follows:

for AUM > 8000kg (ie SH, H and M):	$area_{fb} = 10 + 5.8\times10^{-4}\, AUM$	}Eqn 3.7
for AUM < 8000kg (ie LM, L and UL):	$area_{fb} = 1.4 + 1.5\times10^{-3}\, AUM$	}

3.6.4 Forebody Length-beam Ratio. Conventional practice as described in many references states that a flyingboats's forebody length-beam ratio, the structural configuration factor which most effects planing, should be approximately 4. This is generally borne out by the results of Table 3.13 which shows the ratio oscillating between 2.2 and 6.8 with an average of 3.5. This relationship should be used to check the step position estimated in paragraph 3.5.2.

$$\{l_{fb}/b\} \approx 3.5 \qquad \text{Eqn 3.8}$$

3.6.5 Beam Loading. One of the design variables much discussed in past references was beam loading:

$$C_\Delta = (AUM \times b^3)/\rho_{H2O}$$

The historic rise in maximum acceptable beam loading is illustrated in Table 3.13. Note that the maximum established is not a required level, compare the Be200 at 2.57 to the Mermaid at 3.82, but a safe upper limit. Thus the current maximum beam loading is 4.36.

$$C_{\Delta\ max} = (AUM \times b^3)/\ \rho_{H2O} \leq 4.36 \qquad \text{Eqn 3.9}$$

← wrong!

3.6.6 Deadrise Angle. The deadrise angle is measured between the tangent to the planing bottom at the keel and the horizontal. The magnitude of the deadrise angle is a compromise between the superior planing qualities, ground clearance and fuselage volume utilisation of small angles (ideally a flat plate, $\beta = 0°$) and the water impact force vector reduction qualities of larger angles. The effect of the magnitude of the deadrise angle on planing bottom impact loads is examined in detail in Section 4.5. Reference 58 recommends that the deadrise angle at the step should not be less than 15° on small flyingboats and 25° for larger aircraft. Examination of the database generally supported this pattern with notable exceptions such as Dornier's consistently low angles (see Table 3.12).

SH: $\beta = 20°$ H: $\beta = 18°$ M, LM, L, UL: $\beta = 16°$ Eqn 3.10

Note that the small statistical sample of M mass classification flyingboats makes its average of 11° unlikely. This class has therefore been joined with the lower mass classifications as a conservative assumption. To decrease wave impact loading the deadrise can be increased at the bow.

3.6.7 Afterbody Angle. The afterbody angle fulfils the same general purpose as rear fuselage uplift on land-based aircraft, that is to give clearance to the rear of the aircraft on take-off and landing. The angle is therefore usually defined by the take-off angle of attack. Too small an angle results in the sternpost remaining in contact with the water causing hydrodynamic drag whilst too large an angle causes aerodynamic drag due to separation. References usually quote afterbody angles of around 8° and examining the database revealed an average afterbody angle of 7° with the sample extremes at 3° and 11° (see Table 3.12). Note that when measuring the angle from the database drawings of 2-stepped flyingboats the average of the 2 angles is recorded.

afterbody angle $\approx$ 7° to 8° Eqn 3.11

3.7 TAIL CONFIGURATION AND SIZING.

3.7.1 Introduction. Flyingboat tails have 3 addition design requirements to those of landplanes. Firstly, the horizontal surfaces must be sufficiently high to avoid the impact of spray. Secondly, as the water-borne flyingboat has no rigid runway to react conventional undercarriage nosewheel steering or differential braking loads, steering at low airspeeds must be completed using a combination of water and air rudders, the latter therefore having potentially greater importance than that of a landplane. Finally, the flyingboat take-off requirement of planing on the step may generate the need for extra elevator area to generate the required moment (see paragraph 3.5.3). To provide a comparison, a similar number of landplane tail details was extracted from Janes using approximately the same number of types of landplanes per 5 year date bracket as was gained for flyingboats from the database (see Table 3.14). As expected the results showed the flyingboat designers' preference for high (12% of sample) and mid (51% of sample) horizontal tailplanes over the equivalent landplanes (7% and 6% respectively). There were very few low tailplanes (14%) on flyingboats compared to landplanes (77%); those present were largely fitted to aircraft of the HW-T configuration with a resulting large water-to-tail distance. There were more twin and triple vertical tails on flyingboats. It is assumed that this method was used to ensure that the rudders were placed into the propeller slipstream to generate greater directional force at low taxiing speeds.

3.7.2 Fin (Vertical Tail) Volume Coefficient. The fin volume coefficient (FVC) is defined by Torenbeek $_{(44)}$ as:

$FVC = (s_v\ l_v)/(s\ b)$ where s = wing area, b = span and sub v = fin

This was examined for a variety of land-based aircraft and flyingboats. The data was split into 4 engine position related sets to account for one of the main factors affecting this variable (see Table 3.15). It was initially assumed that flyingboats, with their high forward fuselage sides, would have significantly greater fin volume coefficients than similarly configured landplanes. However, this was not the case in all but the light, single propeller aircraft. For multi-engined wing and fuselage-mounted engine, land-based aircraft the average coefficient was 5-8% above that of similar flyingboats. This was even the case when aircraft with similar engine-out power cases were examined such as the Sealand and the Islander and the BAe748 and the Marlin. Other factors such as low landing speeds and high T-tails did not influence the relationship. However, as the percentage difference is within the 10% error envelope expected of the dimensional estimation method it was decided that no difference between land-based aircraft and flyingboat fin volume coefficients be postulated for these classes of aircraft. The single propeller flyingboat class showed a 19% increase in fin volume coefficient over a similar group of land-based aircraft. This difference is outside the method error envelope and should therefore be considered as significant. Note that this effect includes the fact that all of the flyingboats have mid or high T tails and put the fin in the propeller slipstream, further increasing its effectiveness. It is therefore postulated that single engined propeller flyingboats have a 19% greater additional fin volume coefficient than the equivalent landplane.

$$(FVC)_{\text{single-engined light floatplane}} = 1.19\ (FVC)_{\text{single-engined light landplane}} \quad \text{Eqn 3.12}$$

3.7.3 Horizontal Tailplane Volume Coefficient. The horizontal tailplane volume coefficient (HVC) is defined in Torenbeek $_{(44)}$ as:

$HVC = (s_h\ l_h)/(s\ c)$ where s = area, c = chord and sub h = horizontal tail

The coefficient for flyingboats and landplanes was examined in the same way as for the FVC. Although not a key design feature, the data was expressed in the same engine-related groups as this also served as a size-related function (see Table 3.16). Only the single engined and twin engined flyingboats exhibit the greater HVC expected. Even in these 2 areas the statistical scatter is such that no particular confidence can be placed in the result. However, as the single engined result closely matches that of the TVC, this relationship can be conservatively used. In the other areas it is recommended that conservative methods using existing landplane horizontal tailplane volume coefficient estimation techniques are used. Fuselage length was used as an alternative matching criteria, but produced similar results.

3.8 MASS ESTIMATION.

3.8.1 Introduction. The aim of the following mass estimation techniques is to provide a valid approximation of the extra mass of a flyingboat over that of a conventional aircraft of the same size. Thus existing, well proven, mass estimation techniques for conventional aircraft can be used to gain the first estimate of the flyingboat mass as if it were a land-based aircraft and the additional masses relating to its function as a water-borne aircraft can then be added. Stinton (62) gives an overall approximation of the extra mass of the structure of a pure flyingboat as 5% over the equivalent landplane structural mass, rising to 10% for an amphibious flying boat. However, common sense suggests that there should be a scale factor between the extra mass required for a small flyingboat to that for a very large one. Thus, after the examination of a variety of information, but particularly the mass breakdown of the Canadair CL415 provided by Canadair, it was decided to divide the extra mass into 3 major independent areas and consider each in turn. The 3 independent areas of extra mass are the planing bottom, the chosen form of lateral stability and the extra equipment required to operate a flyingboat.

3.8.2 Planing Bottom. Burt (73) provides a graph from which planing bottom mass can be deduced from the AUM. The function or source data of the graph is not derived, explained nor supported except for reference to its source, Saunders Roe Ltd. It was therefore decided to develop a planing bottom mass estimation technique based on information obtained from existing flyingboats. First the mass of a conventional aircraft fuselage (M_f) having the same dimensions as the flyingboat was estimated using the method of Reference 74. The proportion of the area of the fuselage which equated to the area of the flyingboat's planing bottom (P) was calculated. The theoretical mass of the area of the conventional aircraft equivalent to the flyingboat's planing bottom ($M_{pbTheory}$) was calculated as:

$$M_{pbTheory} = P\,M_f$$

Next the mass of the planing bottom of actual flyingboats was calculated ($M_{pbActual}$). This information was either gained from visiting examples of the relevant aircraft and taking measurements of the structure (Sunderland and Catalina), using data from the aircraft's construction drawings or structural repair manual (CL415, Renegade, Mariner, Marlin and Mars) or other sources such as detailed drawings and descriptions from journals (Seabee, Do26, Bv222, Seagull, Piaggio, Shetland and Shin Meiwa US1). An example calculation is at Appendix 8. In some cases assumptions had to be made to fill gaps in the latter sources. If this was the case similar authoritative data was used from the aircraft closest in size. The Shin Meiwa US1 was the only case where an authoritative source actually stated the mass of the planing bottom. This data point was therefore used as a validation example rather than being included in the relationship data (see Table 3.17). As expected, the conventional fuselage estimation technique significantly underestimated the planing bottom mass. This over-estimate ranged from over 200% in the case of the lighter flyingboats to 15% for the larger types. It was concluded that AUM was a significant variable and both the error between the estimate of the actual masses and the actual mass itself were plotted as a percentage of AUM against AUM. The latter relationship produced the closest statistical patterns, and the resultant assumed lines (see Graph 3.6) are recommended as an estimation method as follows:

$$\left.\begin{aligned} &\text{pure flyingboats:} && M_{pb} = 38.9AUM^{-0.33} \quad (\%AUM) \\ &\text{amphibious flyingboats:} && M_{pb} = 17.8AUM^{-0.25} \quad (\%AUM) \end{aligned}\right\}\text{Eqn 3.13}$$

Note that the pure flyingboat data tends to be at the high AUM end of the data set and that for amphibious flyingboats is at the low end. This data spread must be taken into account when using this technique. The method was validated by applying the Shin Meiwa US1 details to the method which resulted in an estimated planing bottom mass of 1.26% AUM which is 496.4kg. The actual US1 planing bottom mass is 565.5kg, an acceptable error of 12%. Note that in all cases Burt's graphical method significantly over-estimated the planing bottom mass. The method of calculating the actual planing bottom mass data produced a breakdown of structural mass into skin, frame and stringer masses (see Table 3.18) and this data was examined for patterns. The only pattern readily visible was that lighter flyingboats tended to have a higher skin mass than was estimated. This is probably due to the need to countersink bottom fasteners resulting in a thicker skin than theoretically necessary with consequently less stiffening being required from stringers and frames.

3.8.3 Extra Equipment.

a. Introduction. Several contemporary and more historic references were used to identify the main items of extra equipment required by amphibious aircraft over more conventional aircraft $_{(75)}$. These are dinghies/life jackets, refuelling equipment, bilge pumps, drogues/sea anchors and normal anchors. Dinghies and lifejackets should be included in the equipment mass of any aircraft flying over water and are therefore not considered in detail. However, note that a 4-6 man life raft weighs approximately 5-10kg and a 9-13 man raft 8+kg depending on additional contents $_{(76,\ 77)}$. Similarly refuelling equipment should be included in the equipment mass for any utility aircraft likely to operate away from main bases. This is therefore not considered further. Bilge pumps are either hand pumps for light flyingboats or electric pumps for larger types; both are not considered to significantly add to the AUM. Drogues or sea anchors are usually in the form of open-mouthed canvas bags attached to the sides of amphibious aircraft by lines. Their purpose is to provide extra water drag either symmetrically, to allow the use of greater engine power when taxiing on water (for example to allow greater prop-wash to impinge upon the rudder), or asymmetrically to balance the use of asymmetric engine power on a multi-engined amphibious aircraft (for example in the case of an engine failure). Drogues have become less important emergency devices as reliable water rudders, water brakes and engines have been introduced and, even if fitted, their mass is considered to be insignificant.

b. Anchors. Anchors are required to withstand the force applied to the flyingboat or floatplane from both wind and current/tide. Thus the size and therefore mass of an anchor is related to both the air and water-related drag and to the situation the aircraft is expected to be anchored in. Developing concepts outlined in several references $_{(75,\ 78)}$, two mass prediction methods have been proposed. Firstly, a detailed method was developed taking into account aircraft drag coefficient, displacement, expected tidal flow and wind speed. The derivation is detailed in Appendix 9.

$$(\text{anchor mass})_{tide} = 1.05\times10^{-5}\ \text{AUM}\ V^3_{tide} \qquad \text{Eqn 3.14}$$

$$(\text{anchor mass})_{wind} = 0.024\ C_{DO}\ V^2_{wind}\ S \qquad \}\text{Eqn 3.15}$$
$$(\text{anchor mass})_{wind} = 7.4\times10^{-4}\ V^2_{wind} S \quad \text{if } C_{DO} \text{ unknown} \qquad \}$$

Actual estimated anchor mass is the greatest of tide and wind generated masses. The second, more simple method uses empirical data (see Table 3.19) to present a graph of aircraft AUM against anchor mass (see Graph 3.7). However, the scatter of the few data points makes the latter method relatively unreliable. Note that as a generalisation the length of the anchor line should be seven times the depth of the water $_{(79)}$; this will tend to define the additional mass due to the line as well as the stowage volume required.

3.8.3 Lateral Stability Method Mass.

a. Tip Floats. The mass of tip floats was initially estimated using a structural breakdown method similar to that used for the planing bottom. However, when validation examples were compared to the results, an unacceptably large scatter was evident. This was probably because small errors in assumptions and measurements had a proportionately larger effect on the relatively small floats compared to the large planing bottom. It was therefore decided to only use actual float masses (see Table 3.20). The masses are presented as a percentage of AUM in Graph 3.8, the resulting relationship being:

$$M_{tip\ float} = 2.4AUM^{-0.1} \quad (\%AUM) \qquad \text{Eqn 3.16}$$

Although producing the type of relationship expected, the small number of data points makes this method suspect and therefore it should only be used with care. Note that the Princess is the only data point which is a retractable float.

b. Additional Wing Mass. One of the disadvantages of tip floats is that some additional force is transferred to the wing as a point load at the float attachment mounting. It is assumed that this additional load requires additional mass over a wing without a float. Intuitively, the extra mass of wing structure should be a function of the extra bending moment the float's action adds. Thus, making the following assumptions (see Figure 3.11):

(1) Simplify the wing structure as a simple rectangular-section cantilever beam.
(2) Treat lift as point load at tip.
(3) Treat float load as point load at a distance x from root.

a method for calculating the mass of a flyingboat wing equipped with a stabilising float (M_{W2}) compared to a conventional aircraft wing (M_{W1}) was developed which led to the conclusion that the extra mass required was negligible. The derivation is detailed in Appendix 10.

$$M_{W2}/M_{W1} = 1 + (x/l)\{[(A + BV_F x)/A]-1\}$$

Where: $A = K_1 Mgl$ — K_1 = normal acceleration factor
$B = K_2\, \rho_{H2O}\, g$ — K_2 = rough weather factor

c. Stubs. The main perceived disadvantage of stubs as a method of providing lateral static stability is their additional mass. The only reference found where actual stub mass was available (as opposed to a generalised theoretical percentage) was a 1932 Dornier paper (59). This information is summarised in Table 3.21a and Graph 3.9. The extremely high percentage of AUM, combined with the date of the reference cast doubts on the validity of the data and therefore the related information on other Dornier structure was examined (see Table 3.21b,c). This examination revealed that component mass estimation using the methods from the Cranfield University College of Aeronautics notes (24) were, on average, 51% of the masses quoted in the 1932 Dornier reference. This factor was therefore applied to the Dornier stub masses to produce the results of Table 3.21d and Graph 3.9. The relationship developed is:

$$M_{stub} = 4AUM^{-0.1} \quad (\%AUM) \qquad \text{Eqn 3.17}$$

Note the relationship to the tip float mass estimation (Eqn 3.16). Stub volume is an additional design variable and therefore this information is presented in Graph 3.10, resulting in the following relationship:

$$(M_{stub})/(\text{unit volume}) = 73\,AUM^{-0.15} \qquad \text{Eqn 3.18}$$

A structural analysis of the Do24 stubs based on build drawings produced a validation point somewhat higher in mass than the relationship, although this aircraft was also designed in the late 1930s. This result, combined with the small number of data points available to gain the relationships, means that they should be used with care.

d. Retractable Floats. The similarity of concept and operation of retractable undercarriages and retractable tip floats was used to develop a method of estimating the mass of the latter's mechanism. Although the aerodynamics of a float are considerably different from those of a wheeled undercarriage this effect is assumed to be negligible when applied to the mass of the mechanism. Only one reference could be found which provided an estimate for a retractable undercarriage mechanism $_{(80)}$:

$$M_{uc\ mechanism} = 0.014\ AUM$$

From Cranfield University College of Aeronautics notes $_{(24)}$:

$$M_{uc} = 0.048\ AUM \qquad (AUM<5000kg)$$
$$M_{uc} = 0.038\ AUM \qquad (AUM>5000kg)$$

Therefore:

$$\left.\begin{array}{ll} M_{mechanism} = 0.29\ M_{retracted\ item} & (AUM<5000kg) \\ M_{mechanism} = 0.37\ M_{retracted\ item} & (AUM>5000kg) \end{array}\right\} \text{Eqn 3.19}$$

This factor can be applied to the tip float mass to account for a retraction mechanism, although, the lack of a validation example and the unknown assumption built into the references' equations means that this technique must be used with care.

3.9 DRAFT ESTIMATION.

3.9.1 Simplified Lower Hull Shape Method. Many of the buoyancy, spray and static on-water stability calculations require the waterline of the flyingboat to be established. Archimedes' Laws state that mass is a function of displaced volume and therefore the position of the waterline is a function of the AUM and the dimensions of those parts of the hull which are fully immersed. Once the dimensions of this part of the hull are finalised this calculation can be completed with some confidence, but until then an approximation technique is required. To develop this approximation technique a generalised hull was developed as a combination of basic 3-dimensional enclosures so that simple equations could be derived. These enclosures are the bow, upper and lower forebody (less bow) and afterbody (see Figure 3.12). A further simplification was possible by assuming that the portion of the lower hull having deadrise (ie below the chines) was always fully immersed. This assumption is supported by examination of photographs of flyingboats at rest on water (see Plate 3.7). Based on these assumptions the following estimation for flyingboat draft is postulated; the equation's full derivation is at Appendix 11.

$$\text{draft} = h_1 + \frac{\{ (M/\rho) - h_1 b [\, l_b/4 + l_{fb}^*/2 + l_{ab}/4 \,] + h_2 b [\, l_{ab}/4 \,] \}}{b [\, l_b/2 + l_{fb}^* + l_{ab}/2 \,]}$$

where: h_l = height of lower hull (m) M = AUM (kg)
b = beam (m) l = length (m) ρ = water density (kg/m^3)
sub b = bow sub fb* = partial forebody (ie forebody - bow)
sub ab = afterbody sub s = step

The equation can be simplified by further assuming that for low speed flyingboats: $l_b = b$.

The equation was used on 59 aircraft from the database for which good quality photographs showing the waterlines were available (see Table 3.22). In no cases was the mass of the individual aircraft in the photograph known, and it was therefore assumed that the aircraft were at or around AUM. The graph illustrates considerable differences between actual and estimated drafts due, not only to the simplifying assumptions of the estimating method, but also due to the waterline measurement from the photographs. No pattern could be discerned from the more extreme errors. It was therefore decided to add an empirical adjustment factor which minimised the total of all the errors across the data set. This value proved to be 1.2.

3.9.2 Centre of Buoyancy Simplification Method. An even more simplified model can be used to estimate draft as the basis of a simple centre of buoyancy calculation method. This method is based on the assumption that the prismatic portion of the hull can be simplified as a rectangular box of unknown height (see Figure 3.12). Unlike the more complex model this assumes that there is no immersion of the chine. The resulting equation is as follows; the equation is derived in Appendix 11.

$$\text{draft} = \text{AUM} / \{ \rho\, b\ [l_{fb}^{*} + \tfrac{1}{2}(l_b + l_{ab})] \}$$

The equation was used to estimate the draft of the same 59 flyingboats as described in paragraph 3.9.1. The results are presented in Table 3.23. In a similar way to the earlier method the error between the actual and estimated drafts was calculated and the sum of the errors across the data set minimised by the use of an empirical factor. In this case the factor was 1.55. As the displaced volume has been simplified as a rectangular box it follows that the vertical centre of buoyancy is at 50% of the draft. Thus a first estimate for centre of buoyancy can also be made. Note that no particular pattern of AUM or any other flyingboat design input could be found. The only point worthy of note was the consistent under-estimation of the Dornier Seastar. It is suspected that the displacement effects of the low stubs causes this effect and should be taken into account if this method is used.

3.9.3 Draft to Structure Relationship. To help in gauging the significance of draft on a conceptual fuselage/hull design the relationship between the actual measured draft and the h_l planing bottom dimension was examined (see Table 3.22). This illustrated an average ratio of draft/ h_l of 2.56. No pattern could be discerned across AUM and therefore this average is recommended for all flyingboats.

3.10 SPRAY.

3.10.1 Introduction. Spray height is a key flyingboat design parameter. Designs must seek to keep control surfaces and engines out of the vertical and horizontal spread of spray generated by the high speed movement of the flyingboat through the water (see Plates 3.7, 3.11 and 3.12). The key piece of spray information which most influences the conceptual design of a flyingboat is the vertical height of the spray above the water-level. There are several methods described in various references which give indications of satisfactory or unsatisfactory spray performance, but few which give an estimate of actual spray height. This is probably due to the many different detailed design aspects which can significantly influence spray height. However, the importance of this dimension is such that an attempt is made here to develop a technique.

3.10 2 Longitudinal Position. No attempt is made to estimate the longitudinal position of the maximum spray height due to a lack of suitable general data in a compatible format. Longitudinal spray position is included in model test result papers as a carpet plot of height at a variety of beam positions, l/b ratios and speeds (81). The aft movement of the maximum height point can be seen as speed increases and the spray-generating stagnation line moves aft along the forebody (see Plates 3.11 and 3.12). This effect is also visible in alternative methods of presenting spray information where the spray at a set height is seen to occur first at the propellers and then at the flaps as speed increases (82). Another type of presentation is the chine stations of the spray blister at various l/b ratios as it moves towards the step (83). Note that as l/b rises so the point where the blister leading edge starts moves forward. Similarly, Reference 81 shows that at a set C_Δ the maximum spray height moves aft as l/b increases. Also visible in this reference is the decrease in height of the rearmost position of the blister (ie after it has passed aft of the wings) for high l/b ratio hulls (the reference data is for l/b = 5.07, 6.19, 7.32 and 8.45). As no pattern can be drawn from these references a general conservative rule is postulated which places both the horizontal tailplane and the wing and engine above the maximum vertical spray height irrespective of its longitudinal position.

3.10.3 Spray Data. To form the basis of a method of estimating spray height some source data was first needed. The only reliable information based on actual aircraft (as opposed to models) was in Reference 84; this is reproduced in Table 3.24. When the spray heights from this reference were compared to the relevant 10 aircraft drawings a pattern emerged which indicated that for these particular flyingboats the maximum spray height coincided with the wing root lower surface. Interestingly, this was the case for all configurations represented by these data points including parasol wings (Catalina) and mid-wings (Bv222) as well as the more common high wing configuration. It was therefore initially decided that this level would represent a "success" criteria. Note that all the aircraft in the reference data sample were SH or H class, were propeller driven and had approximately the same propeller/wing/fuselage configuration.

3.10.4 Spray Performance Indicators from References. The following references provided general spray height calculation/validation methods.

a. Reference: Thurston. The most general spray height estimation method (which is suspected to be based on Reference 84) is in Design For Flying (58):

$K = \Delta / w b l_{fb}^2$ satisfactory if K = 0.0675
satisfactory (overload) if K = 0.0825

Using this method with the spray height success criterion of paragraph 3.10.3 resulted in 26% (17 from 64) of the flyingboats in the database having a satisfactory spray performance at normal load and 58% at overload. The reference states that, for aircraft under 5000lb (2270kg) AUM the beam across the spray dams (if present) may be used. This added 1 more aircraft to the satisfactory list. It is therefore clear that this method has its limitations and is not studied further. Note that if, as postulated, this method is based on Reference 84, the l/b ratios covered are 6 to 15 and l_{fb}/b ratios are 3.45 to 8.63.

b. Reference: Patterson. The graphical method described by Patterson (85) was used to estimate the spray height of the 10 aircraft with known spray heights. The results showed poor correlation for both the beam loading and forebody loading against forebody l/b ratio methods ($C_{\Delta 0}$ $[b/l_{fb}]^2$). It should be noted that Patterson was working on the Princess at the time of writing the paper and that the only good data point was that aircraft.

It may therefore be the case that the data used to produce his graph is based on the Princess configuration performance at various masses. Therefore, this method is not studied further.

c. Reference: Knowler. Knowler (86) presents the following equation:

$$z_2 = K_2 \, AUM / \rho_{H20}(l^{3/2} \, b^{1/3})$$

Using the data of Table 3.24, K_2 was calculated resulting in an average of 5.35 (see Table 3.24). This value was then used to calculate an estimate of z_2 for 58 flyingboats (see Table 3.25).

d. Reference: Smith. This reference (84) postulated a spray height coefficient of:

$$C_z = (C_{\Delta 0})^{2/3} / (l_{fb}/b)$$

where $C_z = z/b$ and $C_{\Delta 0} = AUM/b^3$

therefore:

$$z_1 = K_1 \, b \, (C_{\Delta 0})^{2/3} / (l_{fb}/b)$$

Using the spray heights from the 10 reference aircraft the value of K_1 was calculated in each case and an average of 2.1 calculated. This value was then used to estimate z_1 for 58 flyingboats from the database (see Table 3.25).

The methods of paragraphs c and d produce a spread of results with a % difference between them of -0.1% to 65%. Although the majority (45 from 58) were -10 to 20% in variance, the differences were such that it was felt that one particular model should be accepted above the other. The z_1 method gave a greater spray height in 79% (46/58) of the cases and therefore, to ensure a conservative result, this method is pursued further.

3.10.5 Developing "Success" Criteria. The z_1 height was plotted against drawings of 51 flyingboats (the 58 aircraft detailed in Table 3.25 less the 7 basic data points common to Tables 3.24 and 3.25). The result was that 63% (32/51) passed the "success" criterion of spray height occurring below or at the wing root lower surface (see Table 3.25). Analysing the 37% "failures" revealed that 3 were gull winged aircraft. It was noted that in all 3 cases the spray height coincided with the lower surface of the wing at the kink as opposed to the root. Remembering that the "success" criterion data set did not include gull-winged aircraft it seemed logical to include this aspect as part of the criterion. Five jet powered flyingboats (representing all the non-project jets in the list) were in the "failure" percentage, as were 8 ultra-light (UL) aircraft. As all the flyingboats used to develop the "success" criterion were large (SH or H), propeller aircraft it is not surprising that jets and ultra-lights required a different approach. The remaining 2 "failure" aircraft were the SE4000 and the Do 26. No reason for the SE4000 could be deduced, but it was noted that the Do26 had a complex mechanism to raise the rear propellers on take-off (see Plate 3.9). It this raised position is used as a pseudo-wing position the aircraft passes the "success" criterion.

3.10.6 Examination of "Failure" Cases.

a. UL Flyingboats. In an attempt to isolate a factor which influenced the spray height the landing speeds of the 8 "failure" cases which were in the UL mass category were examined. All were under 50kts. However, there were 5 aircraft with landing speeds under 50kts which had successful spray height results (Trimmer, Cloud, Seagull, Do18 and Ekholm) and, although only 2 of these were UL, it was concluded that this was not the influencing factor. Remembering that all the "success" criterion setting aircraft were multi-engined HW or PW, a configuration effect was examined next. This possibility was supported by the specific example of the Seabee which, as a HE-P did not have spray dams on the production model (although some owners have since added them), but when modified to a twin-engined HW-T configuration required dams. This addition tends to support the conclusion that the new engine/propeller position significantly affected the spray "success" criterion. On further examination it was noted that all 8 UL "failures" were HE-P or T configurations. In these cases the wing acts as a partial spray blocker for the engine/propeller and the engine/propeller height above the cabin is often decided more by the propeller diameter than any other consideration. When spray height was positioned on the drawings of the 8 aircraft it emerged that in 6 cases the line was at the furthest down extent of the propeller disc. in one case the spray height was 75% down the disc (Coot) and in the final case the spray was somewhat below the disc (Teal). It was therefore decided that the bottom of the propeller disc be nominated as the successful spray height line for the HE-P or T flyingboat configurations.

b. <u>Jet Flyingboats</u>. The "success" and "failure" jet flyingboats were examined $_{(87, 88, 89, 90, 91)}$. Of the 3 successful aircraft, 2 (Be8 and US Project 1) had their jets mounted high on their wings and thus mirrored the common propeller configurations. One (US Project 2) used a variable incidence wing to not only gain additional lift on take-off, but also to lift the intakes above the spray height. Turning to the "failure" cases, it could be argued that the wings of the Mermaid (see Plate 1.1 and 1.6) and the Be200 (see Plate 1.11) protect the intakes from the spray. Similarly, the forward position of the Be10 intakes could have kept them away from the highest point of the spray further aft. An extreme example of the latter effect is the nose intake of the SR-A1 jet fighter flyingboat (see Plate 3.6). However, these factors cannot be applied to the Duchess or the Seamaster (see Plate 3.13). In particular, the latter was a successful real aircraft (as opposed to a paper design) and thus some weight must be given to its data. It must therefore be assumed that a factor other than configuration reduced the spray height or moved it sufficiently aft to avoid ingestion into the jet intakes. Note that Reference 81 shows how the spray blister moves laterally away from the hull as C_v increases. Thus for jet flyingboats with high take-off speeds a jet intake close to the hull (as seen on the Be10, Be200, Mermaid and Seamaster) would not be as badly affected as a propeller engine on the wing at the same speed.

3.10.7 <u>Effect of Forebody Length/Beam Ratio</u>. Reference 81 states that increasing l_{fb}/b ratios reduce spray height. This would partially explain the failure of the jet flyingboats as they have high l_f/b ratios and would therefore have lower spray heights than the comparable type of aircraft used to establish the "success" criterion. The average l_{fb}/b ratio of the latter group of flyingboats is 3.48 compared to 6.00 for the "failure" jets. The proposal that the "failure" criterion is false for high l_f/b ratio hulls is supported by a study of the flyingboats with the top highest l_f/b ratios (see Table 3.26). All 5 "failure" jet flyingboats were in the top 10. Indeed, if the 2 US project aircraft (USP1 and USP2) are removed from the list the 5 jets are in the top 6 l_{fb}/b ratios. It is therefore likely that the spray success criterion is not applicable to high l_{fb}/b ratio hulls. Examination of Table 3.26 suggests that an upper cut-off value of 5.1 should be used.

3.10.8 <u>Summary of Spray Height Estimation Technique</u>. The following technique is applicable to flyingboats with l_{fb}/b ratios less than 5.1:

$$z = 2.1\ b\ (C_\Delta)^{2/3} / (l_{fb}/b) \qquad \text{Eqn 3.20}$$

for HE-P or HE-T configurations place bottom of propeller disc at this vertical point
for GW-T or GW-P configurations place lower surface of wing kink at this vertical point
for all other configurations place lower wing surface at this vertical point

3.11 SPRAY REDUCTION.

3.11.1 Introduction. It may often be the case that the measured or estimated spray height does not match that required by other aspects of the design. A process of spray height reduction will therefore be required. Without exception spray reduction methods involve a cost compromise either in terms of performance or manufacturing complexity.

3.11.2 Spray Reduction Methods from Database. The use of methods such as chine flare, forebody warp, tailored afterbody and spray fences, along with other miscellaneous solutions such as sponsons, low wings and longitudinal steps are summarised from the flyingboat database in Table 3.27. From examination of this table it is clear that the vast majority of flyingboats have some form of spray reduction method. The simple and cheap solution of spray dams is favoured for the UL class whilst the more expensive structural complexities of chine flare, tailored afterbody, Shin Meiwa tunnels, longitudinal steps etc have, in the past, only been cost-effective on the larger flyingboats. This does not mean that the cheap solution of spray dams is not used on the larger aircraft; the Beriev jet-powered Mermaid has extensive spray dams, although it is likely that these were added late in the hydrodynamic test programme as opposed to being designed in from the drawing board. Similarly, the construction of more flyingboats from composite materials has made the process of manufacturing the complex, double curvature shapes required of the advanced spray reduction methods practical for smaller aircraft.

3.11.3 Spray Reduction Methods from References. A number of references propose methods of spray reduction supported by varying amounts of test data. The effects of these specific tests were generalised by allocating the control result in the data set a value of 1 and expressing all other results as a factor of 1. Thus the effect of the spray reduction method can be simply expressed. Appendix 12 shows a simple method of costing the structural changes necessary for such spray reduction methods.

a. Length/Beam Ratio.

(i) Reference: NACA ARR4F15. (81)

l/b	C_z	Factored	Reduction
5.07	2.5	1	0
6.19	1.75	0.7	30%
7.32	1.5	0.6	40%
8.45	1	0.4	60%

Note that on the XP5Y the real spray is lower than theory which support the fact that high l/b ratios have a significant effect on spray height.

(ii) Reference: NACA TN 1726.(83)

l/b	Speed	Factored	Reduction
6	13	1	0
9	14	0.93	7%
12	14.5	0.9	10%
15	16	0.81	19%

Note that the speed taken is that at which the spray hits the propeller (28% of centre of gravity position, mass = 90lb)

(iii) Reference: JRAeS Aug 1950. (92)

l/b	z	Factored	Reduction
6	0.875	1	0
8	0.75	0.857	14%
10	0.6125	0.699	30%

The data refers spray height on models maintaining a constant beam.

(iv) Summary. Although referring to spray height, each reference data set varies design parameters which are not common to the other references and therefore the data cannot be easily linked. However, the conservative results of NACA TN 1726 are an acceptable guide to the effect of high l/b ratios when working outside the parameters of paragraph 3.10.9.

b. Chine Flare.

(i) Reference: NACA TN 725.(93) With 22.5° deadrise, qualitative data suggests that 5° flare at 0.083b was the best case.

(ii) Reference: NACA TN 522.(94) Flutes (small scale chine flare) give slightly better spray performance.

(iii) Summary. Lack of qualitative information forces an assumption based on the (poor) spray performance photographs of NACA TN725 to be approximately 10% reduction in spray. Details of reduction with various forms of flare are contained in this reference.

c. Forebody Warp.

(i) Reference: ARC CP203.(95)

Warp	C_z	Factored	Reduction
0	1.9	1	0
4	1.5	0.79	21%
8	1.25	0.66	34%

Forebody warp is the progressive increase in angle of deadrise from step to bow. It is measured in degrees of warp per beam length.

(ii) Reference: NACA TN183. (96) 25% increase in load for same spray height with forebody warp from 20° deadrise at step to 85° at bow (65° over forebody length).

(iii) Reference: ARC CP201. (97) Not that loss of forward displacement (80° gives 1.4° nose down trim) and C_x increase which puts spray onto tail surface.

(iv) Reference: NACA TN1780. (98) With forebody warp and extended afterbody, mass at which spray entered propeller rose from 75000 to 85000 (ie a 11.8% reduction). This had a greater effect in waves with some spray at 45lb and 60lb (25% reduction).

(v) Summary. An average of these figures gives a reduction of 27%. However, to be conservative, assume the lowest figure (21%).

d. Tailored Afterbody.

(i) Reference: ARC CP351. (99) At step l/b = 11. Average is 10.5% but take conservative spray reduction of 7%.

e. Use of Deadrise.

(i) Reference: NACA TN2297. (100)

Deadrise	Load at set spray level
20°	75lb
40°	70lb

Negligible effect therefore not investigated further in terms of spray performance as deadrise has greater impact on other areas of design interest.

f. Other Methods.

(i) Anything which increases attitude (ie a shorter afterbody or larger afterbody angle) moves the spray origin aft for a given speed and therefore reduces the chance of the spray blister hitting the propellers (101). The inverse also holds true (102, 103).

3.11.4 Approximate Construction Cost Factors. As an aid to estimating the cost trade-offs between complex spray reduction-related structural shapes a cost appraisal task was set on the RAF's jobbing factory at RAF St Athan. The task required a cost increase factor to be applied to a variety of increasingly complex fore and afterbody shapes based on an initial, simple shape with a unit cost. The results are in Appendix 12.

3.12 ON-WATER STATIC STABILITY.

3.12.1 Introduction. Hydrostatic calculation of on-water static stability requires a number of key dimensions, specifically the length and beam of the hull, the waterline position, and the length of the forebody. Examination of photographs in the database allowed a number of assumptions to be made. First, the length of the waterline approximated to the length of the planing bottom from the nose to the stern or, in multi-step designs, the second step. If this end position was not obvious a line was drawn just below the tip float keel on a side elevation drawing and this was assumed to be the waterline at AUM. This method produced acceptable results without using the doubtful draft estimation methods previously described.

3.12.2 Quantifying Lateral Stability. There are several ways to size the method of lateral stability chosen for the flyingboat. Thurston (104) suggests a simple relationship for tip floats for aircraft having an AUM of less than 8000lb as:

$$\Delta y = K\,(AUM)$$

where K varies between 0.75 and 1.25 depending on the amount of reserve stability and growth required, y is the lateral distance from the centre line and Δ is the freshwater displacement of the float. Note units are Imperial. More thorough (although old) British (27) and US (105) methods defining minimum values are as follows:

UK: $\Delta y \geq Km\,(GM + \sqrt[3]{W})\sin\theta$ Eqn 3.21

US: $\Delta y \geq m[(GM \sin\theta) + (0.1b/(m/S)) + 0.06\sqrt[3]{W}]$ Eqn 3.22

where: GM = hull metacentric height,
θ = angle of keel to totally submerge the float (if less than 7° use 7°)
b = span S = wing area.

K is a factor varying as follows:

AUM = 0-2000 lb:	K = 0.75
AUM = 2000-5000 lb:	varies linearly
AUM = 5000 lb +:	K = 1

Note, again, that units are Imperial. These 2 methods, along with any which are relevant to the use of stubs or inner wing volume, first require the hull-only metacentric height to be calculated.

3.12.3 Hull Metacentric Height. The static stability of a hull in water depends on what is known as the metacentric height (GM in Figure 2.5). The magnitude of this height has a large impact on the design of any stabilising method. Calculating the lateral metacentric height depends on the earlier calculation of draft and hence the centre of buoyancy. The GM value is also related to the vertical position of the centre of gravity (KG) and the establishment of a generalised flyingboat planing bottom form. Additionally, the height of the centre of buoyancy (KB) needs to be calculated along with the height of the metacentre above the centre of buoyancy (BM). The centre of buoyancy is assumed to be 2/3 of the draft (105). The value of BM is calculated as follows:

a. Hull BM.

$$BM = I/V$$

$$I = (2/3)(1/3)(l/N)(\Sigma M y^3)$$

where: $V = AUM/\rho_{H20}$ (use fresh water ρ)
I = moment of inertia of the waterplane
V = displaced volume M = Simpsons multiplier
l = waterline length N = number of ordinates
y = lateral half-ordinate taken from the centreline

To calculate I the principles of Simpsons multipliers are used to split the flyingboat waterline into a number of beamwise equal length ordinates (see Figure 3.13). The Simpsons Multiplier Method is explained in detail in Reference 27. Each ordinate slice's area is then calculated. The greater the number of ordinates the better the accuracy, so this is an ideal method to apply to spreadsheets. An example calculation and spreadsheet for the Martin Mariner is at Appendix 13. The bow, forebody and afterbody of the generalised flyingboat bottom (see Figure 3.12) have different equations to calculate y. Firstly it was assumed that, for the majority of cases (and in a similar manner to Section 3.9), the waterline at maximum draft would be above the mid-body chine. This enables the half ordinate equations to be simplified to 2-dimensional problems by removing the depth term. Thus:

$y_{bow} = (x\ b)/(2\ l_{bow})$ but assuming $b = l_{bow}$ then $y_{bow} = x / 2$

$y_{forebody}{}^{*} = b / 2$

$y_{afterbody} = [\ b\ (l_{afterbody} - x + l_{bow} + l_{forebody}{}^{*})\ ] / (2\ l_{afterbody})$

In an initial attempt to allow the spreadsheet to be used quickly for a large number of flyingboat examples the point at which the bow section assumptions cease and the mid-section starts, along with the similar mid to afterbody interface, needed to be defined. Examining the ratios of beam (assumed to equal bow length) to total length (see paragraph 3.6.2) produced an average ratio of 0.16 which set the break point at Ordinate 8 for a 50 ordinate set. However, the large length to beam ratio flyingboats such as the Beriev Mermaid produced ratios as low as 0.08. Moreover, shorter, wider hulled flyingboats such as the Dornier designs, produced ratios over 0.2. Forebody length to total length was examined (see paragraph 3.6.2) to determine the position of the mid-section to afterbody interface. The average was 0.56 (Ordinate 28), although upper and lower options of 0.6 (Ordinate 30) and 0.52 (Ordinate 26) were used for aircraft having forebody to total length ratios significantly greater or lesser than that figure. However, when these approximations were plotted any deviation from the actual section produced significant changes in the key stability dimensions and it was therefore decided that each flyingboat would have to be set up individually. Having calculated I, the BM value can be calculated knowing AUM. Fresh water ρ was assumed to produce a conservative result. For flyingboats with stubs or using undercarriage fairings to gain lateral stability, the centre portion of the forebody will include the larger y ordinate to reflect the wider water plane at those points (1). Having calculated hull BM any changes due to fuel held in the fuselage needs to be estimated.

b. Fuselage Fuel BM. The delta BM of any fuel held in the fuselage is:

$\Delta BM_{fuel} = (\rho_{fuel}\ I)/V$

where: $I = (n/12)(lb^3)$

n = 1 for full beam tanks n = 2 for half beam tanks
l = length of tank b = beam of tank

ρ_{fuel} = fuel density　　　　V = displaced volume

The value of y against lengthwise ordinate can be plotted to visualise the form of the waterline. Note that Δ BM_{fuel} is expressed as a reduction in hull BM.

c. Vertical Centre of Gravity Position. The vertical centre of gravity position is estimated in accordance with the method of Appendix 4.

d. Hull GM. Hull GM is calculated as:

GM = centre of gravity - (centre of buoyancy +BM)

e. Tip Float Righting Moment Arm. Use either the US or UK method to calculate Δy_{float}, remembering that the units are Imperial. The calculated value of Δy_{float} can then be compared to the initial design produced from Section 3.4.

f. Additional Check. As a further check the righting factor as defined in Reference 91 can be calculated as follows:

$RF = (\Delta y_{float})/(AUM\ GM\ \sin\theta)$

RF should be greater than 1 for safety. Any additional moments generated by extreme scenarios such as a full, single wing fuel tank and a mechanic on the same wing. This extra moment can be added to the righting factor as follows:

$RF = (\Delta y_{float})/[(AUM\ GM\ \sin\theta) + \text{extra moment})$　　Eqn 3.23

Some float configurations such as full length vertical floats require additional assumptions (see Section 3.4). A worked example is at Appendix 13.

3.13 HYDRODYNAMIC DRAG.

3.13.1 Introduction. The hydrodynamic drag of a flyingboat is a key factor influencing take-off and landing performance. Hydrodynamic drag consists of the sum of a variety of factors depending on water speed as the flyingboat moves from the slow speed, displacement regime to high speed planing

a. Frictional Drag. Frictional or surface drag is a function of immersed area, the type of hull surface and a power of speed in the order of 2 (27).

Friction drag = $f S V^n$

f = coefficient of friction of the surface
S = wetted area
V = speed
n = 2 (for short, rough surface) to 1.84 (for long smooth surface) but usually assumed to be 2

Both the speed and the wetted area change during take-off.

b. Wave-making Drag. Wave-making drag is a function of displacement and is approximately proportional to speed to the power 6 (85). Its variation during take-off is complex due to the way the hull responds in attitude with the formation of a bow wave. As speed increases the hull tends to rise nose-up as it mounts its bow wave which in turn increases wing angle of attack, creating lift and reducing displacement. However, the details of hull design which determine the extent of this effect are largely driven by longitudinal stability and spray reduction requirements $_{(106)}$.

c. Planing Drag. Planing drag replaces wave-making drag at high speeds and is the horizontal component of the hydrodynamic force on the planing surface. It is therefore proportional to the square of the speed. As speed increases the lift due to the wing increased reducing the magnitude of the planing force and thus that of the drag-producing component. From Reference 92:

Planing drag = $\Delta \tan \tau$

Δ = load on water τ = mean inclination wetted area of planing bottom

A typical make up of hydrodynamic drag is presented in Figure 3.14. Variation with speed is complex and does not lend itself to the same simple form of representation available for air drag $_{(106)}$. It is therefore difficult to develop a method of predicting hydrodynamic drag at the conceptual design stage and scale models (see Section 3.17) and graphical integration methods using lift, thrust and hydro and aerodynamic drag assumptions are usually used to estimate the forces. Once forces from scale models are available detailed methods such as those described in Reference 107 may be used. However, Reference 106 provides a very rough guide that the maximum drag occurs at 0.4 take-off speed and the hydrodynamic part of this has a magnitude of 0.15 take-off mass. Future potential values of 0.12 may be possible. References $_{(106,\ 92)}$ also suggests that whilst changes in hull design parameters such as deadrise, afterbody to forebody length and forebody length to beam ratios may reduce this drag, the result is a more hydrodynamically unstable flyingboat. It is also quite easy for the resistance components to increase. For example, the skin friction component can be changed quite considerably by the impact of spray on the afterbody. Accepting the difficulties in estimating hydrodynamic drag, and therefore take-off distance, at the conceptual stage, a number of empirical methods using the database were investigated.

3.13.2. Power Loading Method. Assuming maximum hydrodynamic drag is approximately equal to 0.15 take-off mass it is likely that a relationship exists between the power necessary to accelerate through the drag and the mass of the flyingboat. The power loading of 67 aircraft from the database was examined (see Table 3.28) and the average power loading of mass classification groups extracted:

UL = 5.86 kg/bhp	L = 5.81 kg/bhp	LM = 4.55 kg/bhp	Eqn 3.24
M = 6.68 kg/bhp	H = 5.35 kg/bhp	SH = 6.12 kg/bhp	

There was no relationship between the averages of the mass classifications, and therefore a total relationship was not possible. The data spread within and across the classifications was sufficiently close that confidence could be placed in these figures.

Applying the same method to jet aircraft produced the following small number of results which may be used with care:

Be200	244.5 kg/KN (2.4 lb/lb)	USP1	181.3 kg/KN (1.78 lb/lb)
Be42	365.3 kg/KN (3.58 lb/lb)	USP2	186.4 kg/KN (1.83 lb/lb)
R-1	315.8 kg/KN (3.1 lb/lb)		

power loading (kg/KN) < 365 Eqn 3.25

However, this method is clearly very crude and therefore a more exact method was sought.

3.13.3 Take-off Distance. The database was examined for take-off and landing distances. The results are summarised in Table 3.29. A number of variables were plotted against take-off distance, but only wing loading produced acceptable results (see Graph 3.11) resulting in a relationship as follows:

$$d_{TO} = 4.7L - 15 \qquad \text{Eqn 3.26}$$

where d_{TO} = take-off distance (m) L = wing loading (kg/m^2)

Note that several data points on Graph 3.11 represent the same aircraft at different masses. In particular, the data points for the Catalina and Mariner show the sharp increase in take-off distance as the loaded mass increases past the design point. Note that the overload conditions of these aircraft are not included in the calculation of Eqn 3.26. Also not included is the Shin Meiwa PS1/US1 aircraft as its data includes the fact that this particular aircraft uses sophisticated blown control surfaces and flaps. However, the data's position on Graph 3.11 illustrates the potential advantages of such a system. The greatest limitation with this relationship is the top level of wing loading defined by the data sample. Excluding the Shin Meiwa design, the highest wing loading is the 1940's Solent aircraft at 258kg/m^2. This is therefore defined as the upper limit of the relationship at Eqn 3.26.

3.13.4 Wing Loading Effect. It is important to be able to calculate take-off distances for flyingboats with wing loading greater than the 258kg/m^2 limit set above. Even relatively conventional post-war flyingboats such as the Tradewind had wing loadings greater than 280kg/m^2. In the past the wing loading of flyingboats has been influenced by the need for a relatively short take-off run to quickly remove the aircraft from the risk of wave and floating object damage. This has resulted in cruise performance being significantly less than the equivalent landplane where high wing loading can be off-set by longer runways. Therefore, if high performance transport or maritime patrol aircraft conceptual design decisions are to be made, a method of estimating take-off distances for large jet aircraft is required. Reference 107 gives an equation for take-off distance as:

$$d_{TO} = (0.755/\rho C_{LUS}\, g)(Mg/S)(Mg/T_O)^2 \qquad \text{Eqn 3.27}$$

where d_{TO} = take-off distance (m) ρ = air density (kg/m^3)
C_{LUS} = unstick lift coefficient g = gravity acceleration (m/sec^2)
M = mass (kg) S = wing area (m^2)
T_O = static thrust (N)

Full derivation is in the reference. Using the only jet flyingboat for which the take-off distance is known (Be42) gives a estimated take-off distance of 1510m compared to an actual distance of 1200m. Built into the derivation of the above equation is a key empirical non-dimensional factor, K_2 which is defined as:

$$K_2 = D_H/Mg$$

where D_H = the maximum value of the total aero and hydrodynamic drag at hump speed

As a generalisation, this maximum total drag at the hump speed can be said to be the sum of the hydrodynamic (approximately 15% take-off weight) and aerodynamic (approximately 10% take-off weight) drags. This gives a K_2 factor of 0.25. However, Reference 107 states that a well-designed flyingboat can have a K_2 factor of 0.18. Examining references resulted in the following table which supports this contention.

reference	D_H (lb)	C_R	W (lb)	C_Δ	Ratio
ARC R&M 1411	5900	-	30000	-	0.20
	5500	-	28300	-	0.19
	5200	-	26500	-	0.20
	4200	-	24000	-	0.18
	3500	-	21500	-	0.16
NASA TM X249 (89)	65000	-	250000	-	0.26
	57000	-	225000	-	0.25
	45000	-	175000	-	0.26
NACA TN3119	-	7.4	-	0.0317	0.23
NACA TN513	6000	-	34000	-	0.18
NACA TN668	45000	-	250000	-	0.18
NACA Report 766	-	0.177	-	0.8	0.22
	-	0.12	-	0.6	0.20
	-	0.08	-	0.4	0.20
NACA TN1057	-	0.575	-	1.2	0.48
	-	0.370	-	1.0	0.37
	-	0.25	-	0.8	0.31
	-	0.15	-	0.6	0.25
NACA ARR L4I12 (66)	23000	-	120000	-	0.19
	52400	-	300000	-	0.17
	79000	-	480000	-	0.16

Note all units are Imperial and that, depending on the reference, the load and resistance coefficients can be defined differently. Details of the above reports are in the bibliography.

$C_R = R/\rho b^3$ or $R/\rho l b^2$

where: R = resistance force ρ = water density l = length b = beam

The breakdown of K_2 into air (zero lift and lift induced) and hydrodynamic (skin friction and wave) drag was attempted. At the conceptual stage sufficient information is available to gain the aerodynamic and, with the exception of a relevant friction coefficient, skin friction components. However, no method of gaining the critical wave drag figure could be deduced or derived from references.

3.13.5 Take-off Time. Allied to many references' calculation of hydrodynamic drag and therefore take-off distance are methods of estimating take-off time. Again, all require information not present at the conceptual design stage. A highly simplified (but well supported by data) method from Reference 108 is:

$$t_{TO} = d_{TO}/0.6V_{TO} \qquad \text{Eqn 3.28}$$

where t_{TO} = take-off time (sec) V_{TO} = take-off velocity (m/sec)

3.13.6 Landing. Landing times and distances can be accurately estimated using the results from model tests (109), but, again, this information is not available at the conceptual design phase. The information from the database was therefore examined in an attempt to gain a simple relationship. Table 3.29 illustrates that the ratio of take-off to landing distance lies between 2.74 and 0.94 with 78% (21/27) being between 2 and 1. The average, 1.52, is therefore a likely first order approximation of this ratio.

$$d_{land} = 1.52\ d_{TO} \qquad \text{Eqn 3.29}$$

3.14 AERODYNAMIC DRAG.

3.14.1 Introduction. The zero lift drag coefficient of an aircraft is a variable which feeds into many important design relationships and therefore a method of estimating a flyingboat's drag at an early stage in the design process was required. Although there are many initial drag estimating methods available in the open literature the method of Reference 110 was used as it contained an "area factor" and a "type factor", both of which could be readily developed to quantify the difference between flyingboats and conventional aircraft.

3.14.2 Estimation Method. From Reference 110:

$$C_{D0} = R\ F\ T\ C_f$$

where: R = ratio of overall wetted area to wing reference area - typical values are as follows:

sailplanes: 3 single engined propeller: 3.75
twin prop, high wing loading: 4.8 twin prop, low wing loading: 5.0
bomber, jet: 4.25 jet trainer: 4.5
jet fighter (clean): 4-5 jet fighter (stores): 6.0
jet and turboprop airliner, executive jet, freighter: 5.5

F = size factor - a measure of the degree of which the inevitable gaps, leaks and excrescences increase drag = $1 + 0.1(20/S)^{1/4}$

$$C_f = [0.0048 - 0.0006 \log_{10}(10.7\ S)](1 - 0.2M_n)(1 - c_l)$$

where: S = wing reference area
c_l = fraction of chord with laminar flow (usually assume = 0)
M_n = operating Mach number (usually assume = 0 for incompressible flow)

Substituting and simplifying for low speed aircraft gives:

$$C_{D0} = 0.005\ S^{-0.1}\ R\ T \qquad \text{Eqn 3.30}$$

or:

$$T = C_{D0} / 0.005\ S^{-0.1}\ R$$

Thus if a variety of flyingboat C_{D0} values could be found, a value of the type factor for flyingboats could be identified.

3.14.3 Flyingboat C_{D0} Values. From references (111, 112) the following C_{D0} figures were found:

Sunderland: 0.0307	Lerwick: 0.0328	Catalina: 0.0318
Coronado: 0.0312	Mariner: 0.0332	Shetland: 0.025
Solent: 0.033	Sealand: 0.037	Princess: 0.0188

Further C_{D0} values for RAE project aircraft were available (113). As 9 real aircraft data points is not regarded as sufficient to develop a confident methodology an alternative method of identifying a greater number of flyingboat C_{D0} values was investigated. The method of Reference 114 was used to estimate the drag of a larger number of flyingboats. This reference contains a BASIC programme into which size, mass, configuration and performance data can be input and the C_{D0} values output. The programme is limited to light aircraft and the top end of the methodology is aimed at light twin-engined commuter aircraft. This extreme was explored using the Sealand as an example for which the actual C_{D0} was known. The results were encouraging in that the actual C_{D0} was 0.037 and the estimate was 0.0387, an acceptable error of 4.6%. The programme was then tested for aircraft with a higher AUM, specifically the Lerwick. This produced an estimated C_{D0} of 0.0368 compared to an actual C_{D0} of 0.0328, a barely acceptable error of 12%. It was therefore decided to limit the programme's use to UL - M mass classifications.

3.14.4 Results. Details of 37 flyingboats from the database for which all the relevant information was available were input into the BASIC programme. Other C_{D0} values are either actuals from paragraph 3.14.3 or relate to RAE project aircraft. R and T values were calculated and are presented in Tables 3.30 and 3.31.

a. R Factor. The values of R for the flyingboats varied with mass classification. Unsurprisingly the average values for the UL and L classifications, at 4.40 and 4.52, were approximately 20% higher than the equivalent conventional aircraft, at 3.75. This was almost certainly accounted for by the addition of stabilising float area for all flyingboats and engine nacelle areas for the high, podded engine, HE-P and T configurations so popular for this size of flyingboat. Similarly, the value for the LM classification was, at 5.25, 5% higher than the equivalent low wing-loading, small twin propeller landplanes. Note the difference in ratio is less due to the proportionately smaller effect of the addition of the float area. Fuselage sizes are still largely driven by standing height rather than spray considerations and therefore have little impact on wetted area. M, H and SH flyingboat mass classifications all showed markedly lower area factors, at 4.45, 4.91 and 4.5 (the average of the real and RAE project aircraft), than the expected landplane type: turboprop airliners or freighters at 5.5. This was a surprising result as at these mass classifications the high, slab-sided flyingboat hull should produce a larger wetted area than the equivalent landplane. R was plotted against AUM but no relationship was present. Similarly, no relationship could be deduced by comparing R with configuration. The empirical factors for use in Eqn 3.28 are therefore presented with no further comment. Note, however, that the factors relating to the 3 heavier classifications should be used with care (a more conservative drag estimate can be gained by using the 5.5 factor recommended in the reference):

Class:	UL	L	LM	M	H	SH	
R Factor:	4.4	4.5	5.2	4.5	4.9	4.5	Eqn 3.30

b. T Factor. The T factors were all predictably higher than their equivalent landplane. There was no obvious pattern present relating either to AUM or, more surprisingly configuration. The empirical factors are therefore presented with no further comment. Note again the presence of a large proportion of project aircraft data in the SH classification.

Class:	UL	L	LM	M	H	SH	
T Factor:	3.0	2.3	2.1	2.6	2.4	1.6	Eqn 3.31

3.14.5 Methods from References.

a. NACA TN 1307.(115) This reference summarises a number of wind tunnel tests in a hull model having a length to beam ratio of 9, approximately equivalent to a XPBB-1 hull.

for conventional hull:	$C_D = 0.0074$
for rounded bow chines (for 7% of hull length):	$C_D = 0.0070$ 5% reduction
for step fairing (step depth x9):	$C_D = 0.0066$ 11% reduction
for full fairing:	$C_D = 0.0065$ 12% reduction
for full fairing and rounded bow chines:	$C_D = 0.0064$ 14% reduction
for complete fairing:	$C_D = 0.0055$ 26% reduction
for streamline fuselage:	$C_D = 0.0040$

b. NACA RM L8H11.(116) This reference explores the drag of these configurations. The hull form is again similar to that of the XPBB-1 and the value of l^2b was preserved for all models to ensure a similar hydrodynamic performance.

$l/b = 6$	9	12	15	20	30
$C_{D0} = 0.0072$	0.0062	0.0056	0.0053	0.0050	0.0049

The bottoming out of C_{D0} is due to the fact that for low l/b ratio hulls most of the drag is due to pressure drag whilst for the high l/b ratio hulls most is skin friction. Thus at approximately $l/b = 15$ the minimum of both occurs.

c. RAe TN(Aero)1724.(113) This reference quotes estimated C_{D0} values for a number of theoretical flyingboats designed for high sub-sonic speeds as follows:

Turbo-prop	240,000lb	$C_{D0} = 0.0202$
Turbo-prop	540,000lb	$C_{D0} = 0.0177$
Jet	240,000lb	$C_{D0} = 0.0221$
Prop	240,000lb	$C_{D0} = 0.0180$
Prop	540,000lb	$C_{D0} = 0.0160$

Assumptions included a step faired in both plan and elevation and retractable floats.

3.15 ON-WATER DYNAMIC STABILITY.

3.15.1 Introduction. The most common form of on-water dynamic instability is porpoising (117). Porpoising is so called because the flyingboat or floatplane heaves in pitch prior to take-off or after landing in a manner similar to a dolphin or porpoise. Porpoising is caused when the angle between the hull or float and the water surface exceeds the upper or lower limit of what is known as the trim angle (see Figure 3.17 taken from Reference 90). If the angle is held too low a small crest of water is built up in front of the bow. As the aircraft's speed increases towards take-off the bow is abruptly forced over this crest. This may cause premature take-off due to the increased angle of attack followed rapidly by a stall back onto the water.

However, if the aircraft does not take-off the crest passes down the hull or float and past the centre of gravity. The aircraft then pivots on the crest and noses down sharply causing a further crest to form and the process to repeat itself. The end result is that the aircraft literally shakes itself to pieces. Porpoising is avoided by designing the flyingboat or float with sufficiently wide trim limits, but care has also to be taken in establishing the limits at all mass and centre of gravity positions. For example, increased mass increases the draft and raises the lower trim limit and a forward centre of gravity position increases the chance of high angle porpoising during landings $_{(79)}$. Gaining the information to develop a trim diagram such as Figure 3.15 relies upon model testing, but an understanding of dynamic instability is needed at the conceptual design stage.

a. Low Angle Porpoising. Low angle porpoising is mainly a function of forebody design, although afterbody damping suppresses the lower limit in the hump region. The upper limit conforms very closely to those combinations of trim and speed which bring the afterbody into contact with the forebody wake $_{(85)}$.

b. High Angle Porpoising. The porpoising which occurs when the upper limit is penetrated does not become rapidly worse with the degree of penetration, but the trims are so high that the aircraft may be thrown clear from the water and stall on again. When this happens intermittently the effect is known as skipping.

3.15.2 Methods from References. Historically, as l/b ratios commonly rose into double figures (see Table 3.13) the trim range narrowed, resulting in flyingboats with long, thin planing bottoms moving away from having a forebody flat (a region of constant deadrise 1.5x beam from the step) and into the use of a uniform rate of change of deadrise known as forebody warp. Increasing the linear rate of warp progressively lowers the lower trim limit. Reference 85 gives the following equation:

rate of warp (°/beam) = 1.5 l_{fb}/b

This reference also suggests that to further improve the dynamic stability of high l/b ratio hulls an afterbody to forebody ratio of 1.25-1.35 is required. However, examination of the database did not reveal such a pattern. A large sternpost angle (also known as afterbody keel angle) can raise the lower trim limits but can also raise the upper limit, although for a given depth of step and length of afterbody landings are more stable with a low sternpost angle $_{(64)}$. The database was examined and 67 sternpost angles extracted where accurate measurement was possible (see Table 3.32). Although the average angle of 7° is statistically valid no other pattern emerged. For example, twin step German designs such as the Do18 (2°) and Do24 (2°) had low angles yet similar Grumman designs such as the G21A (9°) and Widgeon (10°) did not.

3.16 UNDERCARRIAGE CONFIGURATIONS.

3.16.1 Introduction. There are a number of undercarriage options available to flyingboat designers, the most popular being tricycle and tail wheel. More unusual possibilities are centre-line and outrigger units and exotic solutions such as that seen on the Gevers Genesis (see Figure 3.16).

3.16.2 Tricycle Undercarriage Configuration. The advantages of a tricycle undercarriage configuration include good visibility over the flyingboat's nose when taxiing. As flyingboats tend to have wider and/or longer nose sections than equivalent aircraft this is an important advantage. A nose undercarriage makes good use of forward fuselage volume/structure and gives some design flexibility in forward centre of gravity amendment. Mainwheels are placed aft of the centre of gravity, easing potential placement in stubs, attachment to a fuselage frame at or around the main step or in wing structure volume aft of the main spar. Disadvantages of the tricycle undercarriage configuration include the relative fragility of the nose wheel when taxiing from water onto unknown beaches. A nose wheel also causes problems when approaching a seaplane ramp in a cross wind/current as, on contact with the ground, the aircraft pivots on the protruding wheel to lie across the ramp (see Figure 3.17). Similarly, when taxiing from a ramp into the water the bow may become sufficiently buoyant to pivot the aircraft in the pitch sense about the mainwheels causing the sternpost to impact the ramp. When beaching, application of power lifts a tail wheel out of sand or shingle but tends to bury a nose wheel. A tricycle undercarriage retraction and braking mechanism is inevitably more complex than the equivalent tailwheel system and therefore more costly to build and maintain. The latter effect can be minimised by providing good access. Similarly, as the nose undercarriage should be designed to accept loads of up to approximately 25% of the AUM, it must be attached to relatively robust structure in the aircraft's nose, often requiring a special frame or reinforcement of an existing fuselage frame. The long contact point to centre of gravity moment arm of a nose wheel increases the likelihood of catastrophic damage following inadvertent gear-down water landing. One of the main advantages of a tricycle undercarriage on single-engined GA aircraft is that the nosewheel protects the propeller from violent nose-down moments. The high or rear propeller position on similarly-sized flyingboats negates this advantage.

3.16.3 Tailwheel Undercarriage Configuration. A tailwheel undercarriage has the converse advantages and disadvantages than a nosewheel system. Tailwheel steering can be integrated into a water/aerodynamic rudder system (see Figure 3.18), and, if retractable, uses relatively redundant rear fuselage volume. Additionally, when brakes are applied, the down load on the undercarriage legs increases thus improving braking performance. Similarly, during a 3-point landing, the aircraft is in a stalled attitude resulting in high drag and therefore reduced landing distance, especially on grass strips where braking can be ineffective. However, the main disadvantages of the tail wheel undercarriage are that sharp braking can tip the aircraft onto its nose, take-off drag is high until the tail is raised and, in a 2-point landing, a tail down moment is created which causes increased α, lift and therefore an uncomfortable bounce. Also, as any braking forces act ahead of the centre of gravity the effect can be destabilising in the yaw sense and can cause a ground loop. An often quoted disadvantage of tailwheel undercarriages is that the resultant inclined cabin is uncomfortable for passengers and makes freight loading difficult. However this effect is only very severe for low wing aircraft with wing-mounted propeller engines where the propeller clearance required results in long main undercarriage leg length (for example the DC3). In the case of the majority of larger flyingboats the high wing configuration is used, thus reducing the need for the undercarriage legs to provide the clearance required. The fuselage inclination is therefore considerably less. Tailwheel undercarriages involve the mainwheels being placed forward of the centre of gravity, which can sometimes be difficult to achieve on smaller aircraft where the available volume in the fuselage is required for crew or payload and the majority of the available wing volume is behind the centre of gravity. This is particularly visible inside the Grumman amphibians where the fuselage-mounted main undercarriage housings (for both the tricycle and tailwheel configured aircraft) significantly reduce the width of the cabin at those points.

3.16.4 Centreline Undercarriage Configuration. Centre line/outrigger undercarriage systems have many of the advantages and disadvantages of the tricycle layout, with the exception that there is a lesser moment arm to cause catastrophic damage following inadvertent gear-down water landing. Also this system has the additional disadvantage of fragile outriggers and the aircraft's landing attitude must be carefully maintained to avoid overstressing either of the bogies (see Figure 3.18).

3.16.5 Design Synergy. Some design synergy is possible in the conceptual design of a flyingboat's undercarriage (see Figure 3.18). Main wheel units and their fairings can be positioned on the fuselage to give additional on-water lateral stability. In addition, a retractable nosewheel can be designed to protrude forward of the nose to act as a bumper.

3.16.6 Database Work. Examining the database (see table below) revealed that, as expected, SH flyingboats were generally not fitted with undercarriages, thus saving the (0.038xAUM) undercarriage mass [(74)]. The only SH aircraft having undercarriages were the modern military maritime patrol aircraft such as the Be42 (see Plate 1.6) and SH5 where the reduction in payload is assumed to be an acceptable offset for greater basing flexibility; in both cases the undercarriage has a tricycle configuration. Although the majority of H and M class flyingboats have no undercarriages, this data is unduly influenced by the large number of 1940's military maritime patrol aircraft in the data set. More modern aircraft usually use a tricycle configuration, probably to maximise passenger comfort. In the case of the Shin Meiwa PS/US1 and the Martin Mariner, where both amphibian and pure flyingboat versions were produced, both aircraft use tricycle configurations. This is probable to ensure that the take-off and landing attitudes were similar between versions to avoid the need for different crew training or significant modifications to the control surfaces. In the LM class, all the aircraft with no undercarriage were 1940's Russian military maritime patrol aircraft. The more modern flyingboats favoured tailwheels with only moderately inclined cabins. L and UL flyingboats show similar preferences for tricycle configurations, presumably to allow easy wing mounting of the main undercarriages.

	SH		H		M		LM		L		UL	
	N°	%	N°	%	N°	%	N°	%	N°	%	N°	%
Tricycle	2	10	6	17	0	0	5	26	13	72	10	59
Tailwheel	0	0	3	9	1	14	9	48	4	22	7	41
None	17	90	26	74	6	86	5	26	1	6	0	0
Total	19	100	35	100	7	100	19	100	18	100	17	100

3.17 DYNAMICALLY SIMILAR MODELS.

3.17.1 Introduction. The use of highly accurate models in the design and development of amphibious aircraft began in earnest in 1938 when the concept of dynamically-similar models was pioneered by Consolidated Aircraft in the USA. This concept mirrored the use of aerodynamic models for conventional aircraft and enabled designers to rapidly and cheaply complete complex hydrodynamic research to optimise flyingboat configurations. The technique was used extensively during WWII; for example the operational gross weight of the Coronado aircraft was safely increased from 40,000 lb to 86,000 lb solely due to the application of an intensive dynamic model research programme [(92)]. This type of programme was considerably quicker and cheaper than the equivalent full scale testing and was used to establish patterns of resistance, spray and dynamic instability at a variety of loads, speeds and trim angles. Pure towing tank models often did not show dynamic instability problems which then occurred on the full scale aircraft. Expensive modifications were then required to rectify the problems. However, dynamically-similar models in terms of centre of gravity, power and inertia with relevant representations of control surfaces and flaps did exhibit the same instabilities, thus saving considerable sums of development money despite the models being some 50% more expensive than their tank test equivalents [(118)].

3.17.2 Theoretical Principle. The principle of dynamically-similar models assumes that the Froude number (V^2/gl) and trim angle remain constant (flyingboat beam is normally taken as the linear dimension). Other non-dimensional factors such as Reynolds number ($\rho Vl/\mu$) become important as the flyingboat moves from displacement to planing motion. Thus dynamically-similar modelling relies on a series of compromises based on judgement to ensure the closest similarity between the model and the full scale aircraft, as the conditions where Froude number and Reynolds number agree will only ever exist at full-scale. Fortunately, the majority of design-critical items, such as stability and spray height occur at low speeds in the range of transition from displacement to planing and therefore closely relate to Froude number. In its early years, dynamically-similar modelling was mainly restricted to towed tank tests of models as reducing hydrodynamic resistance was the main design aim due to low installed engine power. However, with increased knowledge of hull form and the development of high power piston and turbine engines the study of resistance became subordinate to dynamic stability, spray and seaworthiness. Yet to obtain accurate dynamic similarity for these areas required a model which was not only geometrically to scale but which was also scaled with respect to mass, inertias, power, accelerations and aerodynamic force and moments was required. The relationships with scale are not developed here, but are quoted in Table 3.33 directly from Reference 92.

3.17.3 Models. These relationships have not only been developed theoretically but have been validated on numerous model-to-full scale aircraft programmes. As aircraft sizes grew in the 1950s the development of dynamically-similar models moved from the towing tank to radio-controlled flying models which, bearing in mind the requirement to study the flyingboat in areas where Reynolds number and Froude number become closely related, were developed into a relatively large, manned aircraft. Examples of the use of dynamically-similar models include relatively small scale models in the huge number of tank tests undertaken by NACA and the Stevens Institute in the USA and the MAEE in the UK along with those completed by the various flyingboat manufacturers (see Plate 3.14) $_{(118)}$. The next level of models are the radio-controlled flying models varying from 1/5 scale models used in the current programmes for the Beriev Be103 and the Ross flyingboat conversion of the BN Islander $_{(119)}$ through 1/8 scale models of the twin engined XP4Y-1 and the 1/10 scale models of the Tradewind (see Plate 3.15). The latter models were a key aspect of the design of this aircraft from its inception. The prototype Tradewind operated at full AUM on its 7th flight and overload on its 8th flight, a feat only possible due to the confidence in the extensive dynamically-similar model programme $_{(120)}$. Large scale, manned models of flyingboats include the examples below. Note that no major successful flyingboat design in the West has proceeded without some form of dynamically similar model. Miniaturised electronics have made manned scale models obsolete; there is now sufficient volume in radio controlled 1:5-1:10 scale models to hold the same instrumentation which previously needed a 1:3 sized manned aircraft. However, a manned, scale demonstrator may be more attractive as a promotional sales tool and certification confidence booster, as well as an instrumented test model. Equally, the development of modern computational fluid dynamics techniques to flyingboat hydrodynamic applications may ultimately reduce the need for models, although some will certainly be required for method validation use.

Model	Actual Aircraft	Scale	Nationality
FGP 227	Bv 238	1:3.75	German
Saro A37	Shetland (and others)	1:2	UK
Potez-CAMS 160	Potez-CAMS 161	1:3	France
Shin Meiwa UF-XS	Shin Meiwa PS1	Approx 1:2	Japan
SE 1210	SE 1200	1:3	France
Modified J4F-2	Marlin (and others)	Approx 1:2	USA
Martin 162-A	Mariner	1:4	USA
Spectra 2 seat	Spectra 4 seat	1:1.5	USA

3.18 UNCONVENTIONAL CONFIGURATIONS.

3.18.1 Introduction. The design challenge of matching an amphibious aircraft's air and waterborne characteristics has produced some configurations significantly different from conventional flyingboats. These include retractable planing bottoms, segmented hulls and flying wings in an attempt to equal the aerodynamic performance of equivalent landplanes and twin hulls to develop synergy between useful hull volume and on-water static stability.

3.18.2 Retractable Planing Bottoms. One unconventional method of keeping the wing and engine installation out of the spray blister and obtaining large angles of attack at take-off, yet a more level attitude and streamlined form at cruise, is to have a retractable planing bottom. On the water the aircraft's mass is displaced by a single large float supported from the conventional fuselage by a series of hinged struts. In this position the flyingboats wings are set at the best take-off angle of attack. After take-off the large float is retracted until it forms the underside of the fuselage, thus allowing the aircraft to establish an efficient cruise angle of attack and reducing the drag by minimising surface and cross-sectional area. This concept was developed successfully by the Blackburn company in 1940 with their 35000lb B-20 design (121, 122) (see Plate 3.16). In addition to providing floatation, the large float contained fuel tanks and marine equipment. The wing tip floats were also retractable. The float retraction mechanism reduced the height of the flyingboat from 25ft 2ins to 11ft 8ins. The hydrodynamic and functional aspects of the retractable planing bottom were trialed successfully, but the prototype crashed due to aileron control problems before the concept could be developed further.

3.18.3 Twin Hulls. Some design synergy can be obtained by combining the volume and mass carrying capabilities of the hull with the lateral stability aspects of the stabilising floats to create a twin-hulled flyingboat. This type of design was used successfully in Italy in the 1920s and 30s by Savoia Marchetti with the S55/66 series of flyingboats (123) (see Plate 3.17). Both types of aircraft carried the passengers in the hulls and the crew in a central pod blended into the wing root. Larger designs were the ANT-22 (91) and projected 6-engined Boeing Model 320 (124) both designed in the 1930s as "flying cruisers" with very heavy armament. This type of performance was only possible in those times by, in essence, hanging two relatively conventional flyingboat hulls beneath a large wing. The robust nature of the twin hull concept, without any fragile tip floats, allowed the ANT-22 to operate in 1.5m waves and a 12m/sec wind. Udin (125) and Lange (126) predict that the structural mass of the twin-hulled concept will usually be lower than that of a similarly sized single hull, largely due to lower wing root bending moments and knock-on effects. However, profile drag may be considerably larger.

3.18.4 Flying Wing. Roxbee (127) proposes a number of configurations which gain the theoretical advantages of large flying wings whilst retaining the abilities of a flying boat to operate from water. The designs are based on a 70 ton AUM and include a retractable trailing edge to form a lateral step and wing tips which displace downwards to act as tip floats. In some designs longitudinal stability is gained by the booms on which the vertical and horizontal tails are mounted, whilst on the tail-less designs the tip floats fulfil this purpose, being well aft of the centre of gravity on the swept wings. The main design problem noted was propeller-to-water clearance. Pylon-mounted engines fixed to the top of the wing surface are proposed as a conventional solution, but retractable engines or propeller systems which are faired into the leading edges at cruise, but extend upwards for take-off and landing are recommended as the best solution. A similar, if less complex solution is used on the aft propellers of the Do26 (see Plate 3.9).

3.18.5 Segmented Hulls. In an attempt to reduce the drag caused by the high degree of rear fuselage upsweep usually found on conventional flyingboats. Daniels (128) suggests a segmented hull where the forward and rear portions of the fuselage could be moved vertically in relation to the centre section. For take-off and landing the forward fuselage would lower, revealing a deep lateral step and the rear fuselage would raise giving adequate afterbody clearance. For flight the forward and rear fuselage sections would move in line with the centre section, thus creating a low drag streamlined form without steps or upsweep. The structural and systems complexity of this concept, with their attendant mass, initial cost and cost of ownership issues, ensured that it never got off the drawing board.

3.18.6 Flyingboat Modifications of Landplanes. A number of largely unsuccessful attempts have been made to convert existing landplane designs into flyingboats. In some cases the design has been significantly different, as in the NI18 Delfin, a flyingboat version of the NI 17 (see Figure 3.19), but in most cases the modification has involved joining a hydrodynamically-shaped slipper to the bottom of the existing fuselage and adding tip floats to the wings. This type of modification is only practical for high winged aircraft and even in this case the engines may have to be moved from an underslung to an overwing position to keep the propeller disk out of the spray envelope. This modification can be seen on the Delfin and the modified Islander. The latter is a design originally proposed by Thurston (see Figure 3.20) but has been recently redeveloped by the Ross Aircraft Company $_{(119)}$. Note also the problem of adding a retractable undercarriage to what was a fixed undercarriage aircraft. Lockheed also developed a flyingboat variant of the C130 Hercules by adding a fuselage slipper but, although finding the concept technically feasible, discovered that a practical slipper blanked off the rear ramp and therefore much of the flexibility of this large aircraft. Overall, the concept of modifying an existing landplane to a flyingboat configuration is unlikely to be practical as the financial aspects of proposed weight and performance savings over a similar floatplane modification are likely to be balanced by the more complex and expensive certification issues. However, the use of composite materials, with their additional weight savings and ability to form complex shapes may cause a rethink of this assumption.

3.19 PURCHASE COST.

3.19.1 Introduction. The cost of various flyingboats was extracted from the database and various specialist references $_{(129,\ 130)}$. These were compared with equivalent land-based aircraft details gained from the same or related references $_{(131)}$. To maintain maximum relevance and accuracy the most recent reference was used where possible. All pre-1995/6 cost information was converted to 1995 $US using the method of Reference 132; this graphical method covers the period 1965-89 and therefore interpolation was required for aircraft outside this range. A lower date limit of 1952 was set to attempt to ensue that the interpolation errors did not become too great (see Table 3.34). It is accepted that initial purchase cost is related to the empty mass $_{(44)}$ and therefore the data was plotted against this variable (see Graphs 3.12a-b). In addition to a large degree of statistical scatter, it also became evident that even with then-year to 1995 factors of up to 6.4, the older flyingboats were showing a significantly lower cost-to-mass ratio than could reasonably be expected. An alternative technique was therefore required, although the following data comparisons of similar aircraft are worthy of note as the only accurate and relative comparisons available:

Be200: $22,000,000	BAe146-200: $17,978,000	ratio = 1.22
AAA: $18,000,000	EMB145: $13,000,000	ratio = 1.38
Seastar: $4,000,000	Kingair: $1,696,000	ratio = 2.36
Renegade: $220,000	Mooney M20: $211,140	ratio = 1.04
Pony: $58,000	Explorer: $60,000	ratio = 0.97

3.19.2 Flyingboat to Landplane Cost Relationship. The second technique involved calculating a cost relationship factor between landplanes and flyingboats in the same AUM and year band. However, in all cases except the L mass classification there was insufficient cost data to establish a meaningful pattern. For example, landplane comparisons with a 1966-priced CL215 produced the data in Table 3.35. A possible factor to account for this discrepancy is the actual use of, and therefore market for and revenue generating ability of, the comparison aircraft. As most of the larger flyingboats fulfil either fire bombing or military roles it is likely that their role accounts for their price discrepancy. For lighter aircraft this difference in roles tends to reduce in relevance. For L class flyingboats a meaningful pattern emerged as detailed in Table 3.36. To account for the additional cost of a retractable undercarriage an empirical factor was derived as described in Appendix 14. The date factor was gained from Roskam $_{(132)}$ again. The result was an AUM-related, flyingboat average additional cost difference of +31.9% of the equivalent landplane. Note that in this particular case all the aircraft had 6 seats. However, the small statistical sample and a scatter of additional cost percentages of +9.6% to +65.5% cannot produce a confident result and so a further method of cost estimation was examined.

3.19.3 Cost to Empty Mass Relationship. It was assumed that cost was directly proportionate to empty mass. The latter variable was plotted against 2 useful economic specification points, paying seats and payload, for 43 flyingboats and 53 equivalent landplanes. To ensure as accurate as possible relationship only those flyingboats which could be purchased new or second-hand today were considered for the seat number analysis - older flyingboats were included in the payload analysis to ensure sufficient datapoints. This distinction was thought to be valid as the concepts of past and present passenger aircraft are significantly different yet cargo carrying techniques are not. Details for landplanes were taken from 1995 and 1987 issues of Janes All the World's Aircraft. The results are summarised in Table 3.37 and Graphs 3.13 and 3.14. The graphs show a degree of statistical scatter, but illustrate a level of qualitative relationships. In particular, beyond 5 seats, flyingboats show almost twice the empty mass (and therefore assumed purchase cost) than the equivalent landplane. At or below 5 seats any difference disappears in the statistical scatter; an illustration of the overriding effect of other design factors at that size. This pattern is repeated, if less severely, when payload is considered. Again, the effect disappears at the small aircraft (payload<1000kg) end of the market. No confident relationships can therefore be presented for flyingboat cost. However, the general contention that above light aircraft size, flyingboats are most suitable for specialist, as opposed to mainstream, roles is supported.

TABLE 3.1

FLYINGBOAT CHRONOLOGY

Date	T(V)	T(M)	U	P	Total	Date	T(V)	T(M)	U	P	Total
1935-40	13	28	1	0	42	1966-70	0	2	1	5	8
1941-45	9	3	1	0	13	1971-75	0	1	1	3	5
1946-50	8	7	5	1	21	1976-80	1	0	0	2	3
1951-55	1	2	1	0	4	1981-85	1	1	2	7	11
1956-60	1	3	0	1	4	1986-90	1	1	1	2	5
1961-65	1	0	0	0	1	1991-95	5	2	3	4	14
						1996-00	4	0	2	1	7 (17)

Notes:

a. Includes paper designs if included in Janes All The Worlds Aircraft.

b. Table produced in 1997 therefore 1996-2000 estimate produced by extrapolated first 2 years rate across all 5 years.

TABLE 3.2

FLYINGBOAT CONFIGURATION TO ROLE DATA

	T(M)	T(V)	U	P	Total
HW-T	21(4)	20(16)	2	0	43(20)
HW-P	1	0(1)	0	0	1(1)
HW-T+P	0	1	0	0	1
HW-J	2(2)	0(2)	0	0	2(4)
PW-T	9(2)	4	1	2	16(2)
PW-P	2	0(1)	0	0	2(1)
PW-T+P	2	2	0	0	4
PW-J	0	0	0	0	0
GW-T	8(1)	0	0	0	8(1)
GW-P	0	1	0	0	1
GW-T+P	1	0	0	0	1
GW-J	1	0	0	0	1
HE-T	1	0	1	1	3
HE-P	3	0	8	11	22
HE-T+P	1	0	0	0	1
HE-J	1	1	0	0	2
HE-Fin-T	0	1	0	2	3
HE-Fin-P	0	1	0	0	1
HE-Fin-T+P	0	0	0	0	0
HE-CO-T	0	0	0(1)	3	3(1)
HE-CO-P	1	2(1)	2	7	12(1)
HE-CO-T+P	0	0	0	0	0
Total	53(9)	34(21)	14(1)	26	127(31)

Numbers in paranthasis are project aircraft.
Roles derived from other roles (ie T(M)dT(V)) are recorded under their original roles.
Scale aircraft are not included.

TABLE 3.3

FLYINGBOAT CONFIGURATION TO MASS CLASSIFICATION DATA

	UL	L	LM	M	H	SH	Total
HW-T	1	1(1)	8(1)	7(1)	15(3)	13(14)	45(20)
HW-P	0	0	0(1)	1	0	0	1(1)
HW-T+P	0	0	0	0	0	1	1
HW-J	0	0	0	0	0	2(4)	2(4)
PW-T	2	0	4	3	7(2)	0	16(2)
PW-P	0	0	1(1)	1	0	0	2(1)
PW-T+P	0	0	1	1	2	0	4
PW-J	0	0	0	0	0	0	0
GW-T	0	0	1	1	6(1)	0	8(1)
GW-P	0	0	1	0	0	0	1
GW-T+P	0	0	0	0	1	0	1
GW-J	0	0	0	0	1	0	1
HE-T	0	2	1	0	0	0	3
HE-P	8	10	4	0	0	0	22
HE-T+P	0	0	1	0	0	0	1
HE-J	0	0	0	0	0	2	2
HE-Fin-T	0	2	1	0	0	0	3
HE-Fin-P	0	0	1	0	0	0	1
HE-Fin-T+P	0	0	0	0	0	0	0
HE-CO-T	2(1)	1	0	0	0	0	3(1)
HE-CO-P	5	5	2(1)	0	0	0	12(1)
HE-CO-T+P	0	0	0	0	0	0	0
Total	18(1)	21(1)	26(4)	14(1)	32(6)	18(18)	129(31)

Numbers in parenthesis are project aircraft.
Nose-intake jet aircraft are not included.

TABLE 3.4

FLYINGBOAT ROLE TO MASS CLASSIFICATION DATA

	UL	L	LM	M	H	SH	Total
T(M)	0	0	10	10	24(5)	10(4)	54(9)
T(V)	0	1(1)	13(4)	4(2)	8	8(14)	34(21)
U	1(1)	11	2(1)	0	0	0	14(2)
P	17	9	0	0	0	0	26
Total	18(1)	21(1)	25(5)	14(2)	32(5)	18(18)	128(32)

Numbers in paranthasis are project aircraft and scale aircraft are not included.
Roles derived from other roles (ie T(M)dT(V)) are recorded under their original roles.

TABLE 3.5

LATERAL STABILITY METHODS DATA

a. Lateral Stability Method.

Method	Float	Stub	Wing root	Other (incl tip)	Total
N°	107	16	4	5	132
%	81%	12%	3%	4%	100%

b. Float Type.

Float Type	A1	B1	B2	B3	B4	C1	C2	C3	D1	D2	D3	E1	Total
N°	5	27	2	5	3	32	5	4	2	9	1	2	97
%	5%	28%	2%	5%	3%	33%	5%	4%	2%	9%	2%	1%	100%

c. Float Position.

Position (% semi-span)	100	99-90	89-80	79-70	69-60	59-50	49-40	39-30	Total
N°	9	4	11	31	22	8	5	3	93
%	10%	4%	12%	33%	24%	9%	5%	3%	100%

TABLE 3.6

COMPARISON OF TIP FLOATS AND STUBS

Tip Floats	Stubs
Easier to damage in heavy seas, particularly with side wind (A). Worse for high wings due to long struts (C). Only Albatross uses float volume for fuel. Greater possible lateral static stability (C). Easy to modify at design or prototype stage with little effect on the rest of the design (C).	Higher air drag (not including effect of needing smaller wing due to lift gererated by stub (A,C). Higher water drag (4% decrease in TO mass) (A). This is limited to low speed end of TO rum (C) and is due to unfavourable interference between stub and hull wave systems. Heavier due to requirement to take some elements of landing load (A). Estimate 2.5-3% heavier (this includes decrease in wing mass due to lift generated by stub) (C). Good potential useable volume close to longitudinal c of g. Ideal for disposable loads (eg fuel or water+foam). Good potential useable volume (eg fuel) low on aircraft to reduce lateral stability requirements. Good at spray suppression (C, D). Embarkation and mooring easier as no tip float to consider hitting dock (B, D).
Same: TO time, longitudinal static stability, dynamic stability	

References:

A. Garner, HM. Seaplane Research. JRAeS pp830. 1933.
B. Dornier, C. Notes on a Family of Flyingboats. JRAeS pp981. 1928.
C. Coombes. Notes on Stubs for Seaplanes. ARC R&M1755. 1935.
D. Dornier Seastar Promotional Leaflet.

TABLE 3.7a

TIP FLOAT DATA (SH AND H CLASSES)

Aircraft	Class	arm (m)	volume (m^3)	(vol x arm)/b^3
SH-5	SH	14.78	2.62	1.21
Bv238		22.51	1.78	1.02
Shetland		16.11	3.80	1.03
Bv222		16.44	2.55	1.76
Huges H3		31.98	9.20	1.18
ShinMeiwa		13.26	2.45	1.91
Seamaster		14.24	1.69	1.58
Princess		29.90	3.73	0.99
SeaRanger		15.41	1.49	0.73
Mars		21.95	1.59	0.51
Mermaid		20.69	2.03	1.91
Be10		14.21	2.33	0.62
Tradewind		16.20	4.52	2.58
LeO H47	H	7.44	2.06	0.83
Be200		12.65	1.29	1.18
Be12		13.41	1.40	0.78
Marlin		14.84	1.31	0.84
R-1		8.50	0.50	0.49
ANT 44D		10.37	2.36	0.90
Catelina		13.29	0.46	0.22
Corregidor		11.98	0.85	0.50
Be6		11.49	2.05	1.08
Macchi C100		8.49	0.30	0.10
Mavis		10.63	2.17	0.78
Emily		14.76	1.32	0.68
Do26		7.91	0.76	0.38
Noroit		10.50	1.08	0.45
CL215		13.24	1.09	0.85
Mariner		12.54	2.03	1.05
Lerwick		8.19	1.01	0.46
G Class		14.14	3.76	1.24
C Class		9.68	2.06	0.74
Sunderland		10.78	2.39	0.96

TABLE 3.7b

TIP FLOAT DATA (M, LM, L AND UL CLASSES)

Aircraft	Class	arm (m)	volume (m^3)	(vol x arm)/b^3
Macchi C94	M	7.94	0.35	0.21
LeO 24		7.72	1.45	0.54
Bv138		9.66	1.24	0.75
MDR-5		9.00	0.75	0.60
MDR-6B		6.24	0.73	0.43
DF151		9.45	1.27	0.53
Yamal		8.91	0.40	0.36
NI17	LM	7.52	0.41	0.40
MDR-6		5.38	0.49	0.39
Seagull		6.12	0.74	0.54
Sealand		5.93	0.28	0.43
SCAN 20		4.70	0.30	0.42
Goose		5.10	0.21	0.31
Widgeon		4.25	0.12	0.31
P136		5.37	0.12	0.27
MBR-7		4.50	0.44	0.52
Be4		3.90	0.26	0.31
Be8		6.90	0.26	0.35
TA-1		6.01	0.35	0.40
H9A1		6.23	0.84	0.39
Flamingo	L	4.43	0.17	0.19
Renegade		3.62	0.15	0.28
Riviera		4.19	0.09	0.27
Trigull		5.13	0.09	0.26
Goodyear		4.37	0.05	0.13
Adventurer	UL	4.22	0.05	0.09
Osprey		3.10	0.02	0.03
Kingfisher		4.58	0.04	0.14
Trimmer		3.76	0.05	0.10
TE-1		3.20	0.02	0.10
Seabird		5.55	0.03	0.20
Teal		3.30	0.06	0.15

TABLE 3.8

STUB DATA

Aircraft	Class	AUM (kg)	Beam (m)	Stub dimensions (m)				Volume (m^3)	
				t	l_1	l_2	b_{stub}	actual	estimate
DoX	SH	51500	4.2	1.09	9.05	7.13	2.74	43.5	48.32
Clipper	SH	37450	3.78	0.70	6.44	4.48	3.78	-	28.89
Lat300	H	23000	3.26	0.60	4.84	3.63	4.82	-	24.49
Super Wal	H	14100	3.15	?	?	?	?	9.5	?
Type 130	H	23133	3.4	0.63	5.67	4.03	3.4	-	20.77
A33	H	18841	2.6	0.65	5.85	2.21	3.58	-	18.73
Do24	H	13500	2.87	0.68	4.8	3.60	2.37	9.3	13.40
Wal	M	6030	2.1	?	?	?	?	5.8	?
Do18	M	10000	2.53	0.68	4.22	3.13	1.77	-	8.8
DoE	LM	2860	1.4	?	?	?	?	2.7	?
Seastar	LM	4200	1.95	0.46	4.02	2.88	1.27	-	4.01
Fregat	LM	2080	1.16	0.68	3.42	3.42	0.84	-	1.94
Finmark	LM	5504	2.02	0.38	3.00	2.25	1.88	-	3.69
Tibian	L	1910	1.55	0.18	1.65	1.1	1.65	-	0.83
Libelle	UL	670	0.7	?	?	?	?	0.42	?

TABLE 3.8 (cont)

STUB DATA

Aircraft	Beam (m)	Stub dimensions (m)				b_{stub}/ beam	l_1/ b_{stub}	l_1/l_2	t/ b_{stub}
		t	l_1	l_2	b_{stub}				
DoX	4.2	1.09	9.05	7.13	2.74	0.65	3.30	1.27	0.40
Clipper	3.78	0.70	6.44	4.48	3.78	1.00	1.70	1.44	0.19
Lat300	3.26	0.60	4.84	3.63	4.82	1.48	1.60	1.33	0.17
Super Wal	3.15	?	?	?	?	-	-	-	-
Type 130	3.4	0.63	5.67	4.03	3.4	1.00	1.67	1.41	0.18
A33	2.6	0.65	5.85	2.21	3.58	1.38	1.63	2.65	0.18
Do24	2.87	0.68	4.8	3.60	2.37	0.83	2.02	1.33	0.29
Wal	2.1	?	?	?	?	-	-	-	-
Do18	2.53	0.68	4.22	3.13	1.77	0.70	2.38	1.35	0.38
DoE	1.4	?	?	?	?	-	-	-	-
Seastar	1.95	0.46	4.02	2.88	1.27	0.65	3.17	1.40	0.36
Fregat	1.16	0.68	3.42	3.42	0.84	0.72	4.07	1.00	0.81
Finmark	2.02	0.38	3.00	2.25	1.88	0.93	1.68	1.30	0.20
Tibian	1.55	0.18	1.65	1.1	1.65	1.06	1.00	1.50	0.11
Libelle	0.7	?	?	?	?	-	-	-	-
AVERAGE	-	-	-	-	-	0.95	2.14	1.45	0.29

TABLE 3.9

STEP OFF-SET ANGLE

Aircraft	Offset (°)	Aircraft	Offset (°)	Aircraft	Offset (°)
Princess	25	Model 130	35	Flamingo	13
SE1200	31	Mariner	21	Widgeon	15
Bv238	17	VS-44	33	Equator	25
Tradewind	9	C-Class	32	Tribian	11
Lac 631	34	Mavis	38	Trigull	27
Mars	20	Do26	41	Riviera	19
SE200	39	CL215	20	Renegade	15
Shetland	37	LeO H-47	37	Goodyear	21
DoX	45	Do24	45	Seawind 2000	14
Bv222	30	Catalina	26	Trimmer	25
Ranger	22	LeO H-246	30	Coot	9
SH-5	22	Albatross	14	Teal	7
ShinMeiwa	25	Bv138	27	Osprey	25
Clipper	30	Do18	46	SMG III	30
Seaford	30	Seagull	6	Seabird	21
G Class	20	Finmark	25	P136	20
Marlin	18	Delfin	26	Eckholm	13
Emily	20	Seastar	35	AVERAGE	25
Mail	31	Sealand	9		
Coronado	30	G21A	12		
Sunderland	37	SE4000	30		

TABLE 3.10

STEP DEPTH

Aircraft	Depth (% beam)	$l_{afterbody}$ (m)	b (m)	$l_{afterbody}$ / b
Be42	6.5	9.1	2.8	3.3
Be10	11	7.6	2.9	2.6
Be12	11	9.5	2.9	3.3
Princess	8.1	17.1	4.8	3.5
Shetland	9	13.5	3.9	3.5
XPBB-1	8.8	9.1	3.2	2.9
CL215	10	10.7	2.6	4.2
Albatross	8.3	7.6	2.4	3.1
Coronado	5.1	7.1	3.2	2.22
Widgeon	5.3	2.9	1.2	2.4
VS44A	5	7.6	3.1	2.5
Tradewind	15.8	12.2	3.3	3.7
Mars	5	12.8	4.1	3.1
Sunderland V	7.6	9.9	3.0	3.3

TABLE 3.11

LENGTH TO BEAM RATIOS - SH AND H MASS CLASSES

Aircraft	Class	Role	l/b	Aircraft	Class	Role	l/b
Princess	SH	T(V) or T(M)dT(V)	7.39	G Class	H	T(V) or T(M)dT(V)	6.66
SE1200			8.08	Coronado			5.00
Bv238			9.84	Sunderland			6.45
Lac 631			10.60	Model 156			5.04
Mars			6.70	C Class			5.95
SE200			6.25	Model 31			5.55
Bv222			9.33	LeO H-47			5.49
Clipper			5.47	AVERAGE			5.70
Be200			11.98	Marlin		T(M) or T(V)dT(M)	8.51
AVERAGE			8.4	Emily			6.67
Mermaid		T(M) or T(V)dT(M)	13.41	Mail			7.20
Tradewind			9.21	Mariner			6.28
Shetland			6.92	Mavis			6.34
Ranger			6.25	Do26			6.62
SH-5			9.13	CL215			7.54
Shin-Meiwa			10.46	Do24			4.66
AVERAGE			9.23	Catelina			4.29
				AVERAGE			6.46

TABLE 3.11b

LENGTH TO BEAM RATIOS - M, LM, L AND UL MASS CLASSES

Aircraft	Class	Role	l/b
Albatross	M	T(M) or T(V)dT(M)	6.26
Bv138			6.27
Do18			4.80
MDR5			5.12
MDR6B5			5.39
AVERAGE			5.57
Trigull	L	U or P	5.36
Rivierra			5.71
Renegade			5.62
Goodyear			7.69
Seawind			4.83
Teal			6.18
AVERAGE			5.9

Aircraft	Class	Role	l/b
Finmark	LM	T(V) or U	4.93
Seastar			4.33
Sealand			6.54
G21A			5.47
P136			5.16
SCAN 20			5.71
Widgeon			5.64
Flamingo			6.24
Equator			3.64
AVERAGE			5.29
MDR6		T(M)	6.34
MDR7			5.65
Be4			5.29
Be8			6.37
AVERAGE			5.96
Trimmer	UL	P	4.11
Coot			4.35
Osprey			4.04
GlassGoose			3.41
Kingfisher			5.46
SMG III			6.00
Seabird			6.00
Eckholm			5.01
AVERAGE			4.80

TABLE 3.12

PLANING BOTTOM AREA FACTORS

Aircraft	AUM (kg)	Planing area (m^2)	TO speed (m/sec)	Coeff	Deadrise (°)	Afterbody (°)
Princess	143000	78	105	0.17	25	8
SE1200	140000	114	97	0.13	23	5
Bv238	100088	54	58	0.55	16	6
Mermaid	86000	38	209	0.05	23	8
Tradewind	77640	55	87	0.19	14	6
Lac 631	75000	68	58	0.33	24	8
Mars	74910	52	50	0.57	18	6
SE200	72000	61	55	0.39	23	6
Shetland	59000	45	55	0.44	25	9
Bv222	46031	38	54	0.41	15	6
SeaRanger	45912	29	46	0.76	15	5
SH-5	45000	42	81	0.16	15	5
ShinMeiwa	39400	31	77	0.21	24	8
Clipper	37455	44	48	0.37	16	4
Be200	36000	33	123	0.07	24	7
					Av = 20	
G Class	33800	33	51	0.39	29	8
Marlin	33166	26	44	0.67	17	8
Emily	32500	27	53	0.42	15	10
Be12	31000	28	58	0.33	17	6
Coronado	30872	23	41	0.79	20	8
Sunderland	29482	24	52	0.46	25	6
Model 156	28602	34	45	0.41	15	8
Mariner	26330	24	43	0.59	15	8
C Class	24200	26	48	0.40	26	8
Mavis	23000	26	47	0.40	14	7
Model 31	22700	18	39	0.79	25	6
Do26	20000	22	56	0.29	11	8
CL215	19278	18	68	0.23	17	7
LeO H-47	17900	20	52	0.33	19	9
Do24	16215	22	53	0.26	7	8
Catalina	15042	19	33	0.72	14	7
					Av = 18	
Albatross	12270	16	44	0.42	14	6
Bv138	11900	17	42	0.38	11	8
Do18	10805	16	41	0.39	8	3
					Av = 11	
Finmark	5804	8	49	0.30	22	8
Seastar	4200	8	67	0.11	7	7
Sealand	4130	7	53	0.20	25	5
G21A	3629	6	55	0.20	18	9
P136	2722	4	48	0.28	7	8
SCAN 20	2500	7	36	0.29	16	6
Widgeon	2053	4	44	0.28	19	9
					Av = 16	
Equator	2000	5	73	0.07	12	10
Trigull	1791	4	45	0.25	14	10
Riviera	1485	3	48	0.24	13	5
Renegade	1383	4	44	0.18	13	11
Goodyear	1305	4	35	0.29	16	5
Seawind	1270	4	52	0.11	8	4
					Av = 13	
Trimmer	998	3	33	0.32	18	8
Coot	884	2	38	0.32	14	7
Osprey	707	2	38	0.23	16	8
SMG III	575	3	18	0.64	14	10
Seabird	450	2	26	0.30	17	10
Eckholm	315	1	22	0.52	16	11
					Av = 16	

TABLE 3.13

BEAM LOADING AND LENGTH TO BEAM RATIOS

Aircraft	Date	AUM(kg)	L (m)	L_f (m)	b (m)	L/b	L_f/b	C_Δ
Catalina	1935	15042	13.00	7.74	3.03	4.29	2.55	0.53
Do18	1935	10805	12.00	7.80	2.50	4.80	3.12	0.67
C Class	1935	24200	17.86	10.20	3.00	5.95	3.40	0.87
Mavis	1936	23000	19.60	10.00	3.09	6.34	3.24	0.76
Do24	1937	16215	13.66	9.00	2.93	4.66	3.07	0.63
Bv138	1937	11900	15.79	8.10	2.52	6.26	3.21	0.73
Coronado	1937	30872	16.00	8.86	3.20	5.00	2.77	0.92
LeO H-47	1937	17900	14.50	8.80	2.64	5.49	3.33	0.95
Sunderland	1937	29482	19.35	9.44	3.00	6.45	3.15	1.07
Do26	1937	20000	16.56	10.00	2.50	6.62	4.00	1.25
Model 156	1938	28602	17.14	11.59	3.40	5.04	3.41	0.71
G Class	1939	33800	23.32	11.24	3.50	6.66	3.21	0.77
Mariner	1939	26330	18.20	9.83	2.90	6.28	3.39	1.05
Model 31	1939	22700	15.22	8.12	2.74	5.55	2.96	1.08
Emily	1940	32500	20.40	10.40	3.06	6.67	3.40	1.11
Bv222	1940	46031	26.88	14.80	2.88	9.33	5.14	1.88
Mars	1941	74910	27.82	15.19	4.11	6.77	3.70	1.05
G21A	1941	3629	8.31	4.51	1.52	5.47	2.97	1.01
Widgeon	1941	2053	6.71	3.83	1.19	5.64	3.22	1.19
Bv238	1943	100088	33.46	17.46	3.40	9.84	5.14	2.48
Shetland	1944	59000	27.00	13.50	3.90	6.92	3.46	0.97
SE200	1946	72000	26.17	16.70	4.19	6.24	3.99	0.95
SR A1	1947	6804	12.62	6.23	2.28	5.53	2.73	0.56
SCAN 20	1947	2500	8.56	5.20	1.50	6.71	3.47	0.72
Albatross	1947	12270	15.20	7.60	2.43	6.25	3.13	0.83
Seagull	1948	6585	12.54	5.61	2.03	6.18	2.76	0.77
Sealand	1948	4130	10.20	5.40	1.56	6.54	3.46	1.06
SE1200	1949	78480	45.50	23.00	5.63	6.08	4.09	0.43
Noroit	1949	20430	15.54	10.30	2.94	5.28	3.50	0.78
Ekholm	1949	315	4.42	2.00	0.89	4.97	2.25	0.44
Finmark	1949	5804	9.32	5.20	1.89	4.93	2.75	0.84
P136	1949	2722	6.91	3.80	1.34	5.16	2.84	1.10
Be6	1949	23400	19.40	10.10	2.79	6.65	3.62	1.05
Goodyear	1950	1305	8.92	3.92	1.16	7.69	3.38	0.82
Marlin	1950	3166	24.24	10.58	2.85	8.51	3.71	1.40
Princess	1952	143000	35.62	18.55	4.82	7.39	3.85	1.25
Seamaster	1955	68100	33.23	15.87	2.48	13.40	6.40	4.36
Riviera	1956	1485	6.21	3.10	1.10	5.65	2.82	1.09
Be12	1961	31000	20.82	11.10	2.89	7.20	3.84	1.25
CL215	1967	19278	19.37	8.40	2.57	7.54	3.27	1.11
ShinMeiwa	1968	39400	26.88	13.40	2.57	10.46	5.21	2.26
Teal	1968	771	6.80	3.00	1.10	6.18	2.73	0.57
Equator	1970	2000	5.74	3.90	1.65	3.48	2.36	0.43
Renegade	1970	1383	7.55	3.90	1.25	6.04	3.12	0.69
Osprey	1973	707	4.60	2.52	1.14	4.03	2.21	0.47
SH-5	1976	45000	28.95	14.90	3.17	9.13	4.70	1.38
Mermaid	1985	86000	37.54	14.90	2.80	13.41	5.32	3.82
Coot	1985	884	4.31	2.42	1.03	4.18	2.35	0.79
Seastar	1986	4200	8.23	5.30	1.90	4.33	2.79	0.60
Seabird	1993	450	5.40	2.50	0.90	6.00	2.78	0.60
Be200	1994	36000	28.64	15.10	2.39	11.98	6.32	2.57
Flamingo	1994	2050	9.98	4.70	1.57	6.36	2.99	0.52

TABLE 3.14

COMPARISON OF LANDPLANE AND FLYINGBOAT TAIL CONFIGURATION

Tail type	Land-based aircraft		Flyingboats	
	Number	Percentage	Number	Percentage
High	14	7%	15	12%
Mid	11	6%	66	51%
Low	155	77%	18	14%
Twin	14	7%	22	17%
Triple	1	0.5%	4	3%
Boom	5	2.5%	4	3%
TOTAL	200	100%	129	100%

TABLE 3.15

VERTICAL TAIL VOLUME COEFFICIENTS

a. Four (or more) Engines.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
C130	0.0575	Clipper	0.0661
Electra	0.0707	Coronado	0.0524
Britania	0.0774	Mars	0.0544
Constallation	0.0718	ShinMeiwa	0.0858
I176	0.0750	UFXS	0.0840
C141	0.0654	SH5	0.0473
KC135	0.0628	Princess	0.0510
B17	0.0453	Shetland	0.0420
Heron	0.0467	Spruce Goose	0.0460
B707/320	0.0626	Tradewind	0.0760
Average	0.0635	Average	0.0605
			-5%

b. Two Engines.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
BAe146	0.0703	Searanger	0.0443
Skyvan	0.0787	Goose	0.0419
Dutchess 76	0.0458	Albatross	0.0554
LET 410	0.0614	Type 31	0.0981
Cheyenne	0.0300	Marlin	0.0695
G222	0.0615	Mariner	0.0454
Atlantique	0.0517	Be12	0.0680
Bandeirante	0.0617	Be6	0.0451
Islander	0.0658	CL215	0.0536
Transall	0.0793	Sealand	0.0441
Average	0.0606	Average	0.0558
			-8%

c. Fuselage-mounted Multi-engined.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
HS125	0.0548	Avalon	0.0762
Caravelle	0.0379	Catalina*	0.0319
BAe111	0.0482	Seamaster	0.0655
B727	0.0905	Be103	0.0726
DC9	0.0810	Be42	0.0540
F28	0.0910	Be200	0.0481
Yak 40	0.0442	Yamal	0.0642
Citation	0.0806	Seastar	0.0679
Falcon	0.0720		
VC10	0.0453		
Average	0.0646	Average	0.0601
			-7%

* not fuselage mounted engines, but engines very close into centre line due to PW-T configuration.

d. Single Propellor Engined.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
Zenair	0.0247	Osprey	0.0401
Cessna 150	0.0359	Seafire	0.0783
Caravan	0.0587	Spectrum	0.0563
Sokol	0.0675	Renegade	0.0475
Cessna 182	0.0473	Flamingo	0.0735
Agriwagon	0.0313	Mini-Catalina	0.0351
Maule M6	0.0468	GlassGoose	0.0674
PXL 35	0.0533	Coot	0.0346
Rebel	0.0252	Kingfisher	0.0247
Chipmunk	0.0321	Trigull	0.0441
Average	0.0423	Average	0.0502
			-19%

TABLE 3.16

HORIZONTAL TAIL VOLUME COEFFICIENTS

a. Four (or more) Engines.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
C130	0.71	Clipper	0.64
Electra	0.87	Coronado	0.56
Britania	0.95	Mars	0.87
Constallation	1.20	ShinMeiwa	1.03
Il76	0.76	UFXS	1.07
C141	0.78	SH5	0.91
KC135	0.86	Princess	0.58
B17	0.62	Shetland	0.56
Heron	0.57	Spruce Goose	0.66
B707/320	0.90	Tradewind	1.15
Average	0.79	Average	0.80
			+1%

b. Two Engines.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
BAe146	1.01	Searanger	0.97
Skyvan	0.69	Goose	0.76
Dutchess 76	0.75	Albatross	0.78
LET 410	0.97	Type 31	1.01
Cheyenne	0.97	Marlin	0.74
G222	0.84	Mariner	0.87
Atlantique	1.24	Be12	0.79
Bandeirante	1.07	Be6	0.62
Islander	0.67	CL215	0.85
Transall	1.66	Sealand	0.95
Average	0.97	Average	0.83
			-14%

c. <u>Fuselage-mounted Multi-engined</u>.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
HS125	0.63	Avalon	0.62
Caravelle	0.54	Catalina*	0.65
BAe111	0.89	Seamaster	0.63
B727	1.15	Be103	0.39
DC9	1.40	Be42	0.90
F28	1.03	Be200	1.17
Yak 40	0.60	Yamal	0.81
Citation	0.52	Seastar	0.98
Falcon	0.62		
VC10	0.82		
Average	0.82	Average	0.77
			-6%

*** not fuselage mounted engines, but engines very close into centre line due to PW-T configuration.**

d. <u>Single Propellor Engined</u>.

Land-based Aircraft	Coefficient	Flyingboat	Coefficient
Zenair	0.54	Osprey	0.38
Cessna 150	0.37	Seafire	0.80
Caravan	0.39	Spectrum	0.88
Sokol	0.55	Renegade	0.78
Cessna 182	1.01	Flamingo	0.80
Agriwagon	0.58	Mini-Catalina	0.47
Maule M6	0.83	GlassGoose	1.73
PZL105	0.57	Coot	0.32
Rebel	0.52	Kingfisher	0.47
Chipmunk	1.06	Trigull	1.03
Average	0.64	Average	0.77
			+20%

TABLE 3.17

PLANING BOTTOM MASS ESTIMATION

Aircraft	AUM (kg)	M (theory)	M (Burt)	M (actual)	Actual/ theory	Diff (%AUM)	M (%AUM)	Config
Renegade	1383	16	-	33	2.06	+1.22%	2.4%	Amph
Mars	74910	476.4	726.4	628.1	1.32	+0.20%	0.8%	Pure
Sunderland	29482	212	386	291	1.37	+0.27%	1.0%	Pure
CL415	19278	145	405	306.2	2.11	+0.85%	1.5%	Amph
Seabee	1361	13.6	-	50.4	3.71	+1.76%	3.7%	Amph
Catelina	15042	128.9	435	287.6	2.23	+1.05%	1.9%	Amph
Albatross	12270	154.9	-	187	1.21	+0.20%	1.5%	Amph
Do26	20000	219.6	-	321	1.46	+0.50%	1.6%	Pure
Bv222	45640	488.9	1135	641.1	1.31	+0.30%	1.4%	Pure
Seagull	6568	70.2	-	123.4	1.76	+0.81%	1.9%	Amph
Piaggio	2450	25.8	-	69.1	2.68	+1.80%	2.8%	Amph
Shetland	59000	593.4	1226	682.2	1.15	+0.15%	1.2%	Pure
Sealand	4130	45.2	-	69.7	1.54	+0.60%	1.7%	Amph
ShinMeiwa	39400	368.2	1130	565.5	1.54	+0.50%	1.4%	Amph

TABLE 3.18

PLANING BOTTOM STRUCTURAL MASS BREAKDOWN

Aircraft	skin mass (kg)		frame mass (kg)		stringer mass (kg)		proportions (%)	
	theory	actual	theory	actual	theory	actual	theory	actual
Renegade	10.98	18.35	9.87	5.00	3.11	6.51	45/41/14	61/17/22
Sunderland	101.30	114.10	53.50	110.80	63.00	66.20	47/24/29	39/38/23
CL415	78.00	149.60	31.40	30.75	35.60	98.00	54/22/24	54/11/35
Seabee	9.10	36.00	1.50	2.70	3.10	7.10	66/11/23	79/06/15
Catalina	74.40	136.60	20.00	31.30	34.60	84.30	58/15/27	54/12/34
Albatross	75.50	96.10	30.40	46.50	34.90	44.40	54/21/25	51/25/24
Do26	113.80	144.20	48.60	73.80	57.20	40.30	52/22/26	56/28/15
Mars	208.50	313.00	112.30	117.20	155.60	140.80	44/23/33	56/20/24
Bv222	220.50	293.60	114.30	210.10	154.20	137.30	45/23/32	46/33/21
Seagull	42.70	55.40	14.70	21.50	12.80	46.50	61/21/18	45/17/38
Piaggio 136	15.75	22.40	5.10	23.80	5.00	22.80	61/20/19	32/34/34
Shetland	254.90	315.80	138.50	183.60	198.00	182.80	43/23/34	46/27/27
Sealand	25.20	27.10	9.20	10.50	10.80	25.70	56/20/24	43/16/41

TABLE 3.19

ANCHOR MASS

Aircraft	AUM (kg)	Anchor Mass (kg)	% AUM	Reference
unstated	908	4.54	0.500%	Water Flying Annual 1974.
unstated	2270	9.08	0.400%	
unstated	4540	13.62	0.300%	
unstated	1498	3.18	0.212%	Reference 68.
unstated	6356	31.78	0.500%	
unstated	9080	34.05	0.375%	
CL415	19890	9.08	0.046%	CL415 Data.
Mars	65830	45.40	0.069%	Martin Mars Data.
Princess	149820	45.40	0.030%	The Princess. Flight 26 Sep1952.
Seagull	6585	14.10	0.214%	Seagull Data.
ShinMeiwa	39400	51.70	0.131%	ShinMeiwa Data.
Petral	450	1.5	0.333%	Petral Data

TABLE 3.20

STABILISING FLOAT MASS ESTIMATION

Aircraft	AUM (kg)	Float Mass (kg)	Strut Mass (kg)	Total Mass (kg)	%AUM
ShinMeiwa	39400	165.7	72.7	238.4	0.60
CL415	19278	190	-	309.6	0.98
Solent	35400	-	-	306.5	0.87
Princess	149820	-	-	1112.3	0.74
Sunderland	29482	-	-	227	0.77
Kingfisher	680	-	-	8.2	1.21

TABLE 3.21

DORNIER STRUCTURAL COMPONENT MASSES

a. Dornier Stub Masses.

Aircraft	stub mass (kg)	AUM (kg)	% AUM	volume (m^3)	mass/unit volume (kg/m^3)
Libelle	25.80	670	3.8	0.42	61.40
DoE	112.50	2860	3.9	2.70	41.70
Wal	180.40	6030	3.0	5.80	31.10
Super Wal	381.60	14100	2.7	9.50	40.10
DoX	1323.00	51500	2.6	43.50	30.50

b. Dornier Wing Mass.

Aircraft	AUM (kg)	real mass (kg)	estimated mass (kg)	% (est/real)
Libelle	670	108.20	38.50	36
DoE	2860	535.10	190.20	36
Wal	6030	767.50	432.00	56
Super Wal	14100	1898.90	1099.70	58
DoX	51500	7475.80	4572.00	61

c. Dornier Fuselage Mass.

Aircraft	AUM (kg)	real mass (kg)	estimated mass (kg)	% (est/real)
Libelle	670	80.90	31.10	38
DoE	2860	303.30	172.50	57
Wal	6030	826.20	416.00	50
Super Wal	14100	1585.70	1133.50	71
DoX	51500	5912.30	2768.90	47

d. Factored Stub Mass.

Aircraft	AUM (kg)	real mass (kg)	factored mass (kg)	% AUM
Libelle	670	25.80	13.20	1.9
DoE	2860	112.50	57.40	2.0
Wal	6030	180.40	92.00	1.5
Super Wal	14100	381.60	195.60	1.4
DoX	51500	1323.00	674.70	1.3

TABLE 3.22

DRAFT CALCULATION (METHOD 1)

Aircraft	h_{est} (m)	h_{act} (m)	% error	mod h_{est} (m)	mod % error	h_l	h_{act} / h_l
Princess	1.79	2.41	25.6	2.15	10.7	1.11	2.17
SE1200	1.42	1.88	24.1	1.71	8.9	1.17	1.16
Bv238	1.48	1.46	-1.6	1.77	-21.9	0.49	3.00
Mermaid	1.53	1.45	-5.5	1.84	-26.6	0.58	2.50
Tradewind	1.27	1.66	23.1	1.53	7.7	0.41	4.00
Lac 631	1.15	1.37	16.0	1.38	-0.7	0.91	1.50
Mars	1.32	1.68	21.4	1.59	5.7	0.66	2.56
SE200	1.32	1.40	5.1	1.59	-13.8	0.87	1.60
Dutchess	1.44	1.88	23.06	1.73	7.67	0.75	2.5
Shetland	1.26	1.80	30.2	1.51	16.2	0.90	2.0
DoX	0.98	1.04	5.76	1.18	-13.08	0.55	1.89
Bv222	1.03	1.34	23.7	1.23	8.4	0.38	3.50
SeaRanger	1.29	1.28	-1.0	1.55	-21.2	0.43	3.00
SH-5	0.93	1.21	23.6	1.11	8.4	0.42	2.89
ShinMeiwa	1.13	1.57	28.1	1.36	13.8	0.57	2.75
Clipper	0.93	1.12	16.7	1.12	0.0	0.56	2.00
Be200	1.01	1.41	28.6	1.21	14.3	0.54	2.63
G Class	1.15	1.57	26.7	1.38	12.1	0.98	1.60
Marlin	1.01	1.22	17.1	1.21	0.5	0.45	2.33
Emily	0.98	1.13	13.7	1.17	-3.5	0.41	2.77
Be12	0.99	1.33	25.2	1.19	10.2	0.44	3.00
Coronado	1.20	1.92	37.7	1.44	25.3	0.60	3.21
Sunderland	1.14	1.06	-7.1	1.37	-28.6	0.71	1.50
Model 156	0.90	1.01	11.0	1.08	-6.7	0.45	2.22
Mariner	0.93	1.27	27.2	1.11	12.7	0.40	3.19
C Class	1.02	1.16	11.8	1.23	-5.8	0.72	1.61
Mavis	0.76	1.13	33.1	0.91	19.7	0.38	3.00
Model 31	1.13	1.12	-1.1	1.36	-21.3	0.63	1.78
Do26	0.73	0.94	16.6	0.94	0.0	0.23	4.01
CL215	0.84	1.10	23.9	1.00	8.7	0.40	2.75
LeO H-47	0.88	1.17	24.3	1.06	9.2	0.45	2.58
Do24	0.66	0.61	-8.3	0.79	-29.9	0.18	3.33
Catalina	0.76	1.07	28.6	0.92	14.3	0.39	2.74
Albatross	0.66	1.16	43.2	0.79	31.9	0.30	3.85
Bv138	0.58	0.84	31.0	0.70	17.2	0.25	3.33
Do18	0.58	0.52	-10.7	0.70	-32.9	0.17	3.10
Finmark	0.68	0.50	-34.5	0.81	-61.4	0.38	1.33
Delfin	0.67	0.90	25.66	0.80	10.79	0.56	1.60
Seastar	0.44	0.29	-54.0	0.53	-84.8	0.12	2.50
Sealand	0.58	0.72	19.6	0.69	3.6	0.36	2.00
Cloud	0.49	0.46	-6.50	0.59	-27.80	0.29	1.60

TABLE 3.22 (cont)

DRAFT CALCULATION (METHOD 1)

Aircraft	h_{est} (m)	h_{act} (m)	% error	mod h_{est} (m)	mod % error	h_l	h_{act} / hl
G21A	0.56	0.65	14.1	0.67	-3.1	0.25	2.60
SE4000	0.47	0.45	-4.44	0.57	-25.33	0.18	2.50
P136	0.47	0.48	1.4	0.57	-18.3	0.09	5.56
SCAN 20	0.38	0.48	20.9	0.46	5.1	0.21	2.24
Widgeon	0.48	0.47	-1.7	0.57	-22.1	0.20	2.29
Flamingo	0.35	0.56	37.82	0.42	25.38	0.26	2.13
Equator	0.38	0.49	21.1	0.46	5.3	0.17	2.8
Trigull	0.41	0.30	-36.1	0.50	-63.4	0.15	2.0
Riviera	0.39	0.35	-13.3	0.47	-35.9	0.12	2.78
Renegade	0.33	0.34	3.7	0.39	-15.6	0.15	2.27
Goodyear	0.33	0.49	32.0	0.40	18.5	0.17	2.89
Seawind	0.27	0.37	26.8	0.33	12.2	0.09	4.70
Trimmer	0.35	0.34	-2.4	0.42	-22.8	0.20	1.00
Coot	0.36	0.36	0.9	0.43	-18.9	0.13	2.86
Ospray	0.31	0.24	-27.9	0.37	-53.5	0.16	1.50
SMG III	0.19	0.37	47.5	0.23	37.1	0.15	2.43
Seabird	0.21	0.33	35.8	0.25	22.9	0.14	2.44
Eckholm	0.20	0.31	35.2	0.24	22.2	0.13	2.00
							Av = 2.56

TABLE 3.23

DRAFT CALCULATION (METHOD 2)

Aircraft	h_{est} (m)	h_{act} (m)	% error	modified h_{est} (m)	modified % error
Princess	1.17	2.14	51.35	1.82	24.59
SE1200	0.77	1.88	58.86	1.20	36.24
Bv238	1.46	16.93	16.93	1.87	-29.77
Mermaid	1.21	1.45	16.74	1.87	-29.06
Tradewind	1.01	1.66	38.89	1.57	5.27
Lac631	0.61	1.37	55.06	0.95	30.35
Mars	0.94	1.68	44.26	1.45	13.61
SE200	0.87	1.40	37.91	1.34	3.75
Dutchess	1.00	1.88	46.61	1.55	17.25
Shetland	0.81	1.80	55.19	1.25	30.55
DoX	0.68	1.04	35.09	1.05	-0.60
Bv222	0.80	1.34	40.20	1.25	7.30
SeaRanger	1.05	1.28	18.19	1.62	-26.81
SH-5	0.68	1.21	43.91	1.06	13.07
ShinMeiwa	0.79	1.57	49.57	1.23	21.83
Clipper	0.62	1.12	44.21	0.97	13.53
Be200	0.71	1.41	49.59	1.10	21.86
G Class	0.61	1.57	61.45	0.94	40.24
Marlin	0.71	1.22	41.83	1.10	9.84
Emily	0.75	1.13	33.95	1.16	-2.38
Be12	0.72	1.33	45.75	1.12	15.91
Coronado	0.87	1.92	54.74	1.35	29.84
Sunderland	0.74	1.06	29.99	1.15	-8.52
Model 156	0.65	1.01	35.71	1.00	0.35
Mariner	0.70	1.27	44.67	1.09	14.23
C Class	0.63	1.16	45.85	0.97	16.07
Mavis	0.55	1.13	51.52	0.85	24.85
Model 31	0.78	1.12	30.05	1.22	-8.43
Do26	0.65	0.94	30.80	1.01	-7.27
CL215	0.58	1.10	47.20	0.90	18.16
LeO H-47	0.64	1.17	45.09	0.99	14.89
Do24	0.55	0.61	10.28	0.85	-39.07
Catelina	0.55	1.07	48.88	0.85	20.77
Albatross	0.48	1.16	58.13	0.75	35.10
Bv138	0.43	0.84	48.67	0.67	20.44
Do18	0.49	0.52	6.97	0.76	-44.19
Finmark	0.47	0.50	5.87	0.74	-45.90
Delfin	0.35	0.90	61.30	0.54	40.01
Seastar	0.37	0.29	-29.00	0.57	-99.95
Sealand	0.37	0.72	48.90	0.57	20.79
Cloud	0.33	0.46	28.43	0.51	-10.93

TABLE 3.23 (cont)

DRAFT CALCULATION (METHOD 2)

Aircraft	h_{est} (m)	h_{act} (m)	% error	modified h_{est} (m)	modified % error
G21A	0.41	0.65	36.85	0.64	2.12
SE4000	0.37	0.45	17.35	0.58	-28.11
P136	0.42	0.48	11.87	0.66	-36.60
SCAN20	0.27	0.48	44.74	0.41	14.34
Widgeon	0.36	0.47	22.99	0.56	-19.37
Flamingo	0.19	0.56	65.95	0.30	47.22
Equator	0.29	0.49	41.23	0.44	8.90
Trigull	0.32	0.30	-6.83	0.50	-65.59
FN333	0.32	0.35	7.11	0.50	-43.97
Renegade	0.23	0.34	32.95	0.35	-3.93
Goodyear	0.19	0.49	61.43	0.29	40.21
Seawind	0.21	0.37	42.89	0.33	11.49
Trimmer	0.24	0.34	30.40	0.37	-7.88
Coot	0.29	0.36	20.49	0.44	-23.24
Osprey	0.21	0.24	14.54	0.32	-32.46
SMGIII	0.10	0.37	73.34	0.15	58.68
Seabird	0.13	0.33	59.78	0.21	37.65
Eckholm	0.13	0.31	59.45	0.20	37.15

TABLE 3.24

MEASURED FLYINGBOAT SPRAY HEIGHT

Aircraft	Spray height (m)	K_1	K_2
Shetland	3.05	1.875	4.67
Lerwick	2.28	2.395	6.96
Princess	4.43	1.870	5.55
Catalina	2.79	2.578	7.12
Sunderland	2.75	1.958	5.32
Bv222	2.43	1.550	5.24
Coronado	3.30	2.155	5.17
Mariner	2.31	1.952	4.71
Mars	2.54	2.622	4.00
	AVERAGE	2.100	5.35

TABLE 3.25

FLYINGBOAT SPRAY HEIGHTS

Aircraft	z_1	z_2	diff (%)	success
Coot	0.98	1.10	-12	X UL
Osprey	0.80	0.79	+1	X UL
Teal	0.81	0.74	+9	X UL
Lake	0.93	0.79	+14	X UL
Goodyear	0.94	0.81	+14	X UL
Clipper	2.57	1.96	+24	✓
SeaRanger	3.68	3.77	-2	✓
Trimmer	0.95	0.97	-1	✓
Tradewind	3.45	2.62	+24	✓
Goose	1.55	1.60	-3	✓
Albatross	2.11	1.96	+7	✓
Widgeon	1.29	1.31	-2	X
Catalina	2.22	2.09	+6	0
Model 31	2.93	3.09	-6	✓
Coronado	3.22	3.42	-6	0
Model 156	2.51	2.05	+18	✓
Marlin	3.12	2.98	+4	✓
Mariner	2.79	2.62	+6	0
SE1200	2.63	1.57	+41	✓
SE4000	1.41	1.39	+2	X
SE200	3.39	2.69	+21	✓
Noroit	2.28	1.88	+17	✓
SCAN 20	1.11	0.90	+19	X UL
LeO H-47	2.40	2.20	+8	✓
Princess	4.77	4.26	+11	0
Seagull	1.82	1.82	0	✓
Sealand	1.49	1.38	+8	✓
Shetland	3.51	3.14	+10	0
C Class	2.55	2.24	+12	✓
G Class	2.83	2.50	+12	✓
Sunderland	3.06	3.06	0	0
Equator	1.12	1.06	+6	✓
DoX	2.85	2.08	+27	✓
Bv138	1.96	1.70	+13	✓
Seastar	1.43	1.30	+9	✓
Bv222	3.09	2.49	+20	0
Bv238	4.40	3.88	+12	✓
Do26	2.42	2.09	+14	X
Do18	1.89	1.64	+13	✓
Do24	2.14	1.83	+14	✓
P136	1.50	1.66	-11	X gull
Rivierra	1.18	1.28	-8	✓
Be12	2.88	2.57	+11	✓
Flamingo	1.02	0.84	+18	X UL
Be6	2.57	2.28	+11	X gull
Finmark	1.80	1.86	-3	X gull
Seabird	0.68	0.63	+8	X UL
SH-5	2.94	2.29	+22	✓
Ekholm	0.27	0.09	+65	✓
Mavis	2.47	2.16	+13	✓

Aircraft	z_1	z_2	diff (%)	success
Seamaster	4.03	3.57	+11	X jet
Dutchess	3.69	2.97	+20	X jet
Mermaid	4.72	4.66	+1	X jet
Be200	2.76	2.07	+25	X jet
USP1	3.90	3.46	+11	✓
USP2	3.50	2.74	+22	✓
Be10	3.08	2.08	+32	X jet
Be8	1.84	1.13	+39	✓

TABLE 3.26

FOREBODY LENGTH TO BEAM RATIOS

Aircraft	Propulsion	l_{fb}/b	spray success
USP1	Jet	11.3	✓
USP2	Jet	9.4	✓
Dutchess	Jet	6.7	x
Seamaster	Jet	6.4	x
Be200	Jet	6.3	x
Tradewind	Prop	5.6	✓
Mermaid	Jet	5.3	x
Be10	Jet	5.2	x
Bv238	Prop	5.1	✓
Bv222	Prop	5.1	✓
SH-5	Prop	4.7	✓
SE1200	Prop	4.1	✓
SE200	Prop	4.0	✓
Be8	Jet	3.9	✓
Do26	Prop	4.0	✓
SE4000	Prop	3.9	✓
Princess	Prop	3.8	x
Be12	Prop	3.8	✓
Marlin	Prop	3.7	✓
Shetland	Prop	3.5	✓
			✓

TABLE 3.27

USE OF SPRAY REDUCTION METHODS

	UL	L	LM	M	H	SH	Total
Chine flare	1	0	6	8	22	16	53
Forebody warp	1	0	0	0	1	4	6
Tailored afterbody	1	1	4	1	4	9	20
Dams	11	5	2	0	4	2	24
Sponsons	2	1	3	2	3	2	13
Low wings	6	2	0	0	0	0	8
Steps	0	0	1	2	1	2	6
ShinMeiwa	0	0	0	0	0	2	2
None	4	6	2	0	0	0	12
Total	26	15	18	13	35	37	144

TABLE 3.28

POWER LOADING

mass class	aircraft	power loading (kg/bhp)	mass class	Aircraft	power loading (kg/bhp)
UL	Airshark	6.35	LM	Genesis	4.19
	Mini-catalina	8.38		Widgeon	5.13
	Adventurer	4.50		Avalon	3.51
	Glass Goose	4.54		Brigantine	4.08
	Osprey I	4.53		Seastar	3.54
	Osprey II	4.71		Sealand	5.99
	Trimmer	5.87		G21A	4.00
	Petral	5.63		P136	5.70
	Corvette	5.12		Finmark	4.80
	Uni11	6.76		AVERAGE	4.55
	Prize	6.80	M	Lerwick	4.70
	Coot	4.90		Bv138	6.60
	Dipper	6.00		Do18	7.90
	Kingfisher	6.80		DF	6.50
	CJ-59	6.9		Albatross	7.70
	Seabird	6.00		AVERAGE	6.68
	AVERAGE	5.86	H	Solent	5.28
L	Renegade	5.12		Catalina	6.43
	LA4-200	6.10		Mariner	5.88
	LA4-180	6.05		CL415	4.20
	Seawind 2000	5.80		C Class	5.00
	Seawind 3000	5.14		G Class	6.00
	Avocet	4.99		Sunderland	6.10
	Seafire	5.80		Mavis	4.00
	Teal	5.79		Emily	4.00
	Seabee	6.33		Marlin	3.75
	BAX4	6.56		Do26	6.00
	Aqua W6	6.54		Do24	5.90
	Trigull	5.27		Coronado	6.40
	Be103	4.94		Br761	5.90
	Flamingo	5.77		AVERAGE	5.35
	Goodyear	6.85	SH	SH5	3.31
	Riviera	5.94		Shin Meiwa	3.22
	AVERAGE	5.81		Shetland	5.90
				Mars	6.24
				Bv222	7.70
				Bv238	8.30
				Clipper	6.24
				Spruce Goose	7.60
				Lat631	6.58
				AVERAGE	6.12

TABLE 3.29

TAKE-OFF AND LANDING DISTANCES

Aircraft	Wing loading (kg/m²)	Power loading (kg/hp)	Take-off (m)			Landing (m)			TO Landing ratio
			land	Water	ratio	land	water	ratio	
Renegade	87.53	5.12	268	381	1.4	145	183	1.3	2.08
LA4-200	77.22	6.10	183	335	1.8	145	183	1.3	1.83
LA4-180	68.92	6.05	198	343	1.7	145	183	1.3	1.87
Mini-catelina	39.07	8.38	91	230	2.5	152	84	0.6	2.74
Genisis	95.14	4.19	183	305	1.7	71	152	2.1	2.01
Widgeon	90.36	5.13	?	273	?	?	?	?	?
Adventurer	89.97	4.50	183	244	1.3	213	213	1.0	1.15
Avocet	?	4.99	?	244	?	?	213	?	1.15
Airshark	95.92	6.35	266	610	2.3	?	?	?	?
GlassGoose	35.07	4.54	274	366	1.3	213	?	?	?
Osprey II	58.53	4.71	122	161	1.3	?	?	?	?
Osprey I	45.28	4.53	?	61	?	?	?	?	?
Seafire	85.35	5.80	198	259	1.3	?	?	?	?
Seamaster	125.35	4.33	427	564	1.3	366	427	1.2	1.32
Teal	63.44	5.79	305	366	1.2	213	275	1.3	1.33
Seabee	74.78	6.33	244	305	1.3	122	213	1.7	1.43
BAX-4	?	6.56	290	288	1.0	228	153	0.7	1.88
Aqua W6 *	82.16	6.54	?	366	?	?	?	?	?
Aqua W6 *	41.06	3.27	?	183	?	?	?	?	?
Trimmer	66.14	5.87	162	194	1.2	?	?	?	?
Avalon	107.26	3.51	244	366	1.5	198	213	1.1	1.72

* same aircraft at different masses

TABLE 3.29(cont)

TAKE-OFF AND LANDING DISTANCES

Aircraft	Wing loading (kg/m^2)	Power loading (kg/hp)	Take-off (m)			Landing (m)			TO Landing ratio
			land	water	ratio	land	water	ratio	
Catalina *	97.63	5.30	?	622	?	?	?	?	?
Catalina *	108.10	5.86	?	744	?	?	?	?	?
Catalina *	118.56	6.43	?	1410	?	?	658	?	2.14
Mariner *	209.14	8.05	-	1637	-	-	?	-	?
Mariner *	173.41	6.68	-	1042	-	-	920	-	1.13
Mariner *	152.61	5.88	-	680	-	-	655	-	1.04
ShinMeiwa	331.37	3.22	?	250	?	?	180	?	1.39
CL415	196.66	4.20	844	814	1.0	674	664	1.0	1.23
Seawind2000	97.64	5.80	267	525	2.0	?	?	?	?
Seawind3000	103.77	5.14	260	400	1.5	?	?	?	?
Trigull	78.62	5.27	275	408	1.5	265	238	0.9	1.71
Pedral	26.01	5.63	70	150	2.1	?	?	?	?
Freighty	?	?	530	655	1.2	620	700	1.1	0.94
Pony	45.45	9.38	120	300	2.5	80	120	1.5	2.50
Be103	73.03	4.94	215	390	1.8	190	350	1.8	1.11
Flamingo	99.13	5.77	205	300	1.5	225	270	1.2	1.11
Corvette	?	5.12	320	410	1.3	270	340	1.3	1.21
Brigantine	120.65	4.08	310	400	1.3	280	350	1.3	1.14
Uni 11	?	6.76	?	60	?	?	60	?	1.00
SGUA	?	4.62	150	300	2.0	?	?	?	?
Prize	?	6.80	159	214	1.3	170	150	0.9	1.43
Seastar	150.33	3.54	427	543	1.3	366	366	1.0	1.48
Sealand	125.91	5.99	?	763	?	?	?	?	?
Solent	258.51	5.28	-	1280	-	-	-	-	?
			AVERAGE		1.6	AVERAGE		1.2	1.52

TABLE 3.30

DRAG ESTIMATION

Aircraft	Class	C_{D0}	T
SooperCoot	UL	0.0505	3.54
Osprey		0.0410	2.59
Teal		0.0513	3.10
TE1		0.0704	3.14
Trimmer		0.0453	2.45
Kingfisher		0.0333	2.18
AVERAGE			2.95
Trigull	L	0.0295	1.96
Renegade		0.0428	2.46
Seafire		0.0301	1.75
Adventurer		0.0693	4.34
Be103		0.0255	1.45
Flamingo		0.0497	2.49
Spectra		0.0233	1.32
Riviera		0.02295	1.91
R50		0.0385	2.54
Goodyear		0.0369	2.39
AVERAGE			2.25
Seastar	LM	0.0416	1.96
Goose		0.0283	1.61
P136		0.0332	1.64
Widgeon		0.0425	2.29
Sealand		0.0370	1.89
MBR-6		0.0413	2.60
TA-1		0.0390	2.45
SCAN 20		0.0392	2.38
Delfin		0.0360	1.91
Finmark		0.0378	1.98
AVERAGE			2.07

Aircraft	Class	C_{D0}	T
Albatross	M	0.0229	1.57
C94		0.0371	2.70
H9A1		0.0426	2.75
H5Y		0.0395	2.87
MBR-5		0.0466	3.46
DF		0.0348	2.44
AVERAGE			2.63
CL215	H	0.0568	3.71
Sunderland		0.0318	1.93
Mariner		0.0322	2.09
Coronado		0.0312	2.21
Catalina		0.0318	2.72
Lerwick		0.0328	1.79
AVERAGE			2.41
Shetland	SH	0.0250	1.65
Princess		0.0188	1.51
AVERAGE			1.58

Aircraft	Class	C_{D0}	T
RAE 1	SH	0.0204	1.44
RAE 2		0.0188	1.40
RAE 3		0.0174	1.44
RAE 4		0.0165	1.43
RAE 5		0.0199	1.65
RAE 6		0.0183	1.72
RAE 7		0.0171	1.72
RAE 8		0.0165	1.71
AVERAGE			1.56

TABLE 3.31
DRAG DATA AND R FACTORS

Aircraft	A_{wing} (m^2)	A_{fus} (m^2)	A_{fin}(m^2)	A_{tail} (m^2)	A_{float} (m^2)	$A_{nacelle}$ (m^2)	A_{total} (m^2)	R Ratio
SooperCoot	33.44	10.64	3.86	3.04	9.02	3.30	63.30	3.79
Osprey	24.16	14.65	2.00	4.78	0.38	3.12	49.09	4.06
Teal	29.18	20.60	3.08	5.20	2.00	3.12	63.18	4.33
TE1	11.20	11.62	1.64	2.34	1.32	1.74	29.86	5.33
Trimmer	30.18	28.43	3.38	4.74	1.25	5.09	73.07	4.84
Uni 11	24.20	18.03	2.24	5.16	0.00	3.40	53.03	4.38
Kingfisher	34.40	22.48	2.34	5.82	1.25	3.49	69.78	4.06
						UL AVERAGE		4.40
Trigull	45.70	30.57	7.64	10.38	0.00	0.00	94.29	4.13
Renegade	31.60	24.39	4.08	4.46	3.20	4.80	72.53	4.59
Seafire	34.00	22.39	6.26	6.80	3.20	4.80	77.45	4.56
Adventurer	33.30	23.28	3.26	5.08	3.29	2.26	70.47	4.23
Be103	50.20	45.03	8.80	7.36	0.00	10.87	122.26	4.87
Flamingo	41.36	43.89	8.46	8.28	4.20	5.40	111.59	5.40
Spectra	37.20	30.44	5.58	11.70	0.00	3.29	88.21	4.74
Riviera	30.28	12.28	4.60	5.02	5.94	3.18	61.30	4.05
R50	57.60	44.58	6.86	9.66	0.00	3.35	122.05	4.24
Goodyear	38.80	29.24	3.38	4.74	3.19	6.67	86.02	4.43
						L AVERAGE		4.52
Seastar	57.00	59.71	6.30	12.64	22.77	10.64	169.06	5.93
Goose	69.60	64.65	7.70	15.00	8.50	9.42	174.87	5.02
P136	46.00	46.92	4.64	11.32	3.45	14.80	127.11	5.53
Widgeon	45.52	41.23	4.76	8.66	10.90	4.50	115.57	5.08
Sealand	66.70	73.33	8.38	12.66	5.62	18.70	185.39	5.56
MBR-6	118.80	95.80	5.78	22.58	15.12	25.60	283.68	4.78
TA-1	86.00	64.23	7.14	16.74	0.00	25.60	199.71	4.64
SCAN 20	64.00	46.42	6.86	12.50	11.54	7.54	148.86	4.65
Finmark	91.00	80.79	7.26	18.00	30.60	26.40	254.05	5.58
Delfin	96.40	107.49	14.50	22.00	12.70	20.52	273.61	5.68
						LM AVERAGE		5.25

TABLE 3.31 (cont)

DRAG DATA AND R FACTORS

Aircraft	A_{wing} (m^2)	$A_{fuselage}$ (m^2)	A_{fin}(m^2)	A_{tail} (m^2)	A_{float} (m^2)	$A_{nacelle}$ (m^2)	A_{total} (m^2)	Ratio
C94	152.00	88.31	16.32	15.12	12.48	38.02	322.25	4.24
H9A1	126.60	92.97	15.88	21.06	22.90	17.76	297.17	4.69
H5Y	215.40	156.66	15.84	33.26	34.24	17.76	473.16	4.39
MBR-5	157.00	90.10	14.50	23.84	14.56	27.54	327.54	4.17
DF	240.62	215.45	14.88	41.60	0.00	46.90	553.48	4.60
Albatross	192.30	148.51	25.40	38.80	15.12	21.50	441.63	4.59
						M	AVERAGE	4.45
CL215	200.66	150.31	29.06	56.56	10.10	40.19	486.88	4.85
Sunderland	276.40	314.23	36.20	38.08	28.28	52.80	745.99	5.40
Mariner	261.40	230.24	36.60	46.40	18.00	63.60	656.24	5.02
Coronado	330.80	290.73	40.48	61.00	0.00	48.80	779.73	4.71
Catalina	260.00	134.28	21.60	45.00	8.90	25.40	495.18	3.81
Lerwick	157.00	186.21	16.48	26.40	17.80	40.90	444.79	5.67
SH						H	AVERAGE	4.91
Shetland	447.80	493.16	45.00	76.20	37.90	67.87	1168.00	5.22
Princess	875.20	815.29	105.80	205.00	0.00	0.00	2001.00	4.57
						SH	AVERAGE	4.89

Note that the float area column also includes the wetted area of stubs and booms. Zero in this column indicates retractable tip floats. Zero in the nacelle wetted area column indicated highly faired engine installations.

TABLE 3.31 (cont)

DRAG DATA AND VR FACTOR - RAE PROJECT AIRCRAFT

Aircraft	A_{wing} (m^2)	$A_{fuselage}$ (m^2)	A_{fin}(m^2)	A_{tail} (m^2)	A_{float} (m^2)	$A_{nacelle}$ (m^2)	A_{total} (m^2)	R Ratio
RAE 1	566.82	594.27	54.20	81.30	0.00	118.18	1415	4.99
RAE 2	793.54	782.74	59.10	124.10	0.00	177.28	1937	4.88
RAE 3	1173.06	1068.91	110.90	155.30	0.00	177.28	2685	4.58
RAE 4	1557.52	1349.91	127.50	230.40	0.00	236.37	3502	4.50
RAE 5	807.70	594.27	55.50	105.00	0.00	210.71	1773	4.39
RAE 6	1256.86	838.40	86.30	157.40	0.00	210.71	2550	4.06
RAE 7	1774.38	1051.18	125.70	235.7	0.00	280.94	3471	3.91
RAE 8	2316.56	1366.56	158.10	323.5	0.00	351.18	4516	3.90
						SH(RAE) AVERAGE		4.40

TABLE 3.32

AFTERBODY KEEL ANGLES

Aircraft	Afterbody angle	Aircraft	Afterbody angle	Aircraft	Afterbody angle
SR-A1	9	Adventurer	7	Trigull	10
Seagull	8	Avocet	7	CL415	7
Sealand	6	USP1	7	C94	5
Lerwick	10	USP2	6	C100	5
Shetland	8	Coot	10	Riviera	6
C Class	10	Osprey	7	P136	9
G Class	8	Seafire	9	Lat 631	5
Sunderland	7	Teal	10	SE200	7
Mavis	6	Kingfisher	10	Noroit	4
SMG III	10	Seabee	7	H-47	9
Emily	5	Renegade	10	H-24-6	7
Shin Meiwa	8	Goodyear	6	Finmark	9
Tradewind	6	Clipper	5	SH-5	6
Mars	6	SeaRanger	5	Ekholm	12
Marlin	8	Trimmer	7	Be10	6
Seamaster	7	VS44 (XPBS1)	9	Be103	5
Mariner	8	G21A	9	Be12	7
Bv138	9	Albatross	5	Be42	6
Bv222	8	Widgeon	10	Flamingo	8
Bv238	6	Catalina	8	Yamal	7
Do26	5	Model 31	6	Be200	7
Do18	2	Coronado	6	AVERAGE	7
Do24	2	Martin 130	10		

TABLE 3.33

SCALE FACTORS

Unit	General conversion
Linear dimensions	X^{-1}
Area	X^{-2}
Volume, mass, force	X^{-3}
Moment	X^{-4}
Moment of inertia	X^{-5}
Linear velocity	$X^{-1/2}$
Linear acceleration	constant
Angular velocity	$X^{1/2}$
Angular acceleration	X
Time	$X^{-1/2}$
Rpm	$X^{1/2}$
Work	X^{-4}
Power	$X^{-7/2}$
Wing loading	X^{-1}
Power loading	$X^{1/2}$

TABLE 3.34a

AIRCRAFT PURCHASE COSTS - LANDPLANES

Aircraft	Empty mass (kg)	Cost (then year US$K)	Year	CEF	Cost (1995 US$K)
Jabiru	235	52	1995	1.00	52
Arctic Tern	487	69.9	1995	1.00	69.9
Privateer	521	72.3	1995	1.00	72.3
Explorer	522	60	1995	1.00	60
Huskey	540	86.5	1995	1.00	86.5
Kestrel	624	89	1995	1.00	89
Warrier	676	128.5	1995	1.00	128.5
Mooney M20	783	211.14	1995	1.00	211.14
Cirrus	789	130	1995	1.00	130
Commander	927	298.5	1995	1.00	298.5
PA32R-301	1072	314.2	1995	1.00	314.2
Angel	1760	585	1995	1.00	585
SOCATA	1826	1476	1995	1.00	1476
Islander	1866	470	1995	1.00	470
Caravan	2015	1005	1995	1.00	1005
PC12	2386	1950	1995	1.00	1950
Kingair	3028	1696	1995	1.00	1696
Do228-200	3547	2500	1995	1.00	2500
S Kingair	3675	2995	1995	1.00	2995
Metro III	3963	3700	1995	1.00	3700
Beech 1900	4815	4775	1995	1.00	4775
CASA212-300	4850	3500	1995	1.00	3500
DASH 8	10251	10000	1995	1.00	10000
ATR42-100	10285	11400	1995	1.00	11400
EMB145	11585	13000	1995	1.00	13000
IPTN N250-100	15700	14000	1995	1.00	14000
ATR82	18406	18000	1995	1.00	18000
Gulfstream	19278	23500	1995	1.00	23500
BAe146-200	22861	17800	1993	1.01	17978

TABLE 3.34b

AIRCRAFT PURCHASE COSTS - FLYINGBOATS

Aircraft	Empty mass (kg)	Cost (then year US$K)	Year	CEF	Cost (1995 US$K)
Corvette	360	30	1995	1.00	30
Pony	545	58	1995	1.00	58
Teal	608	17.95	1970	3.20	57.44
Lake LA4-200	705	52.5	1995	1.00	52.5
Lake LA4	714	25	1995	1.00	25
Lake LA4-EP	753	113	1995	1.00	113
Sportsman	769	15	1995	1.00	15
Renegade	839	236.5	1995	1.00	236.5
TurboRenegade	875	220	1995	1.00	220
Seafire	885	235	1995	1.00	235
Riviera	1045	17.5	1967	4.00	70
Be103	1210	300	1995	1.00	300
Widgeon	1470	105	1984	1.18	123.9
Avalon 680	1587	650	1983	1.23	799.5
Royal Gull (P136)	2126	90	1956	5.3	477
Seastar	2400	4000	1995	1.00	4000
Goose	2461	200	1984	1.18	236
TurboGoose	3039	415	1967	4.00	1660
Sealand	3181	15	1952	6.4	96
Albatross	10659	3300	1981	1.33	4389
CL215	10878	5150	1995	1.00	5150
AAA	12200	18000	1995	1.00	18000
CL415	12333	23400	1995	1.00	23400
Be200	23740	22000	1995	1.00	22000

TABLE 3.35

COST COMPARISON WITH CL215

Aircraft	Date	AUM (kg)	Seats (max)	Cost ($US)
Convair 600	1966	20975	52	780,000
F27	1970	20430	45	905,000
Gulfstream I	1966	15935	26	1,119,000
Herald	1966	19522	62	323,000
HS748	1971	20201	61	1,320,000
An24	1966	21020	53	607,000
CL215	1966	19749	21	675,000

TABLE 3.36

L CLASS FLYINGBOAT COST COMPARISONS

Aircraft	Lake Renegade	Beechcraft Bonanza	Mooney M20F	Piper Cherokee	Cessna 185	Beechcraft Sierra
AUM (kg). Factor.	1385 1	1498 0.92	1244 1.11	1161 1.19	1521 0.91	1251 1.11
Date. Factor.	1986 1	1986 1	1986 1	1986 1	1986 1	1983 1.10
Retractable Undercarriage. Factor.	Yes 1	No 1.3	No 1.3	No 1.3	No 1.3	No 1.3
Cost ($US). Factor.	250,000 1	190,000 1.2	150,000 1.44	139,000 1.55	128,000 1.18	103,000 1.59
Comparative Cost	250,000	228,000	216,000	215,000	151,000	164,000
% difference	-	+9.6%	+15.7%	+16.3%	+65.5%	+52.4%

TABLE 3.37a

SEAT NUMBER AND PAYLOAD COMPARISON - FLYINGBOATS

Aircraft	Empty Mass (kg)	Seats	Payload (kg)
Be200	23740	68	12260
AAA	12200	37	8000
CL415	12333	32	7398
Albatross	10389	14	5819
Seastar	2400	12	1850
Mallard	4177	10	1611
Equator	1070	8	830
Seamaster *	2204	8	1697
Goose	2467	7	1169
Widgeon	1470	5	583
P136	2126	5	877
Renegade	839	5	544
Airshark	590	3	589
Seafire	885	3	566
Seabee	884	3	477
Flamingo	1470	3	580
Seawind	1070	3	472
GlassGoose	476	1	341
Osprey	440	1	268
Kingfisher	495	1	231
Seabird	200	1	250
Be103	1475	5	375
Adventurer	863	1	544
Avocet	913	3	585
Searay	318	1	250
Petral	230	1	220
MiniCatalina	295	1	250
Be42	44500	105	41500
Pony	444	1	236

Aircraft	Empty Mass (kg)	Payload (kg)
ShinMeiwa	25515	19522
Catelina	9493	6588
Be12	21000	10000
Explorer	1950	1452
SH5	25000	11000
Hughes H3	119938	73020
Princess	86260	56740
Shetland	34438	21582
G Class	17100	19700
Lat631	32361	39053
SE200	32746	27000
Mars	36461	36448
Bv238	52829	40256
Bv222	30028	20216

* Thurston not Martin

TABLE 3.37b

SEAT NUMBER AND PAYLOAD COMPARISON - LANDPLANES

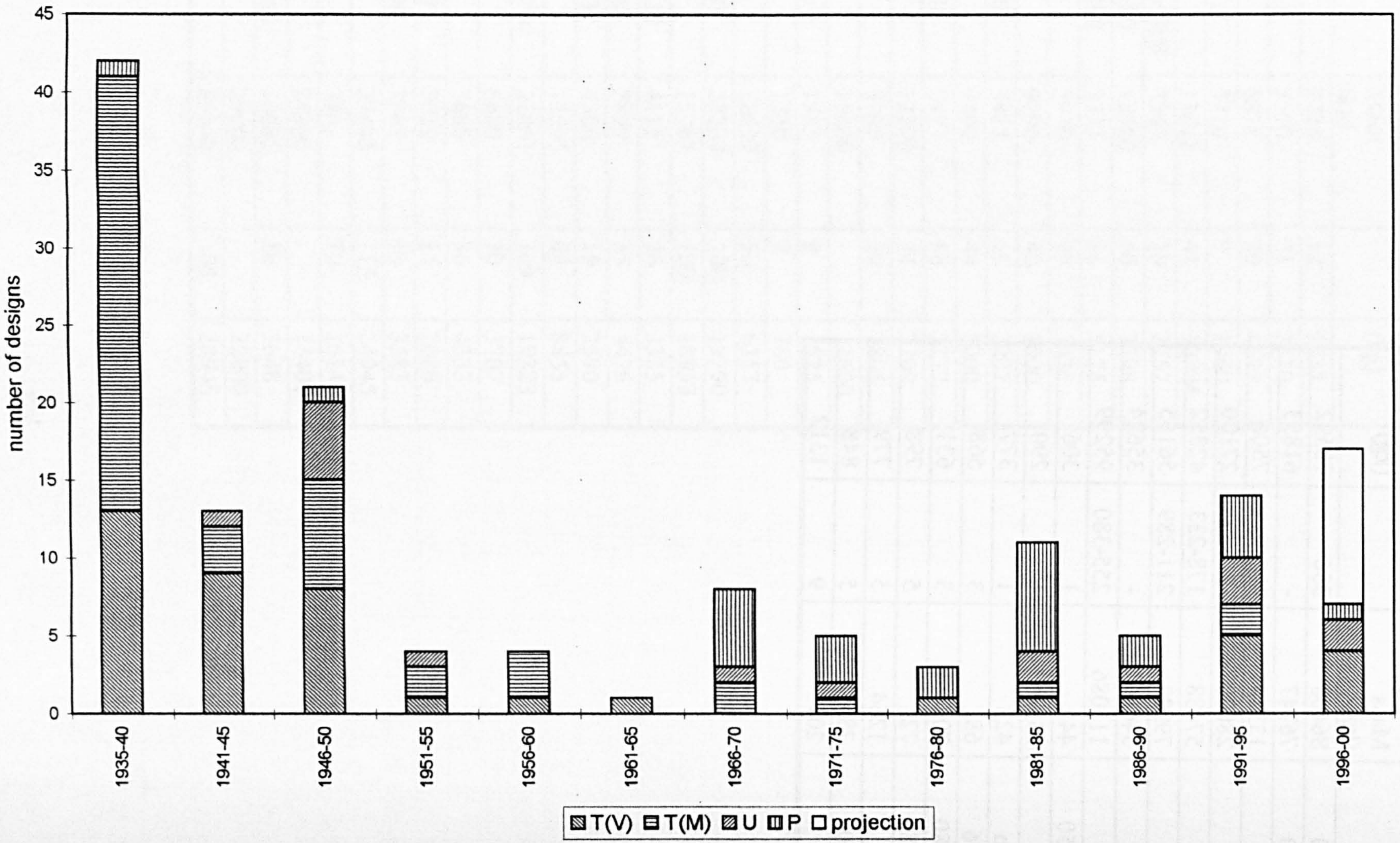
Aircraft	Empty Mass (kg)	Seats	Payload (kg)
Nomad	2228	12	1832
EMB-110	3590	21	2310
EMB-120	6878	30	4622
EMB-121	3710	9	1960
Buffulo	11412	41	10904
Twin Otter-300	3363	20	2257
DASH 7-100	12560	50	7398
DASH 8-100	9793	36	5175
LET 410	3970	19	2430
LET 610	9000	40	5000
Do228-100	3413	15	2287
CN235	9400	44	5000
ATR42-200	9973	50	5777
ATR72	12200	74	7790
IAI 201	3999	20	2805
G222	15400	-	12600
SM SF600	1875	9	1525
PA 68	1230	7	760
Fokker 50	12633	50	6357
Fokker 100	23800	100	19290
BAC 111	25267	109	18933
CASAA 212	4115	26	3335
Saab SF340	7899	35	4476
Jetstream 31	4360	19	2590
ATP	13595	64	8855
BAe 146-200	22861	109	19323
Short 330	6680	30	3707
Short 360	7666	36	4333
Beech C99	3039	15	2086
Beech 1900	3947	19	3583
737-200	27445	115	24945
Metro III	3963	20	2614
Kawa C1	24300	-	14400
Gulfstream I	10682	38	5648
Transall	29000	-	22000
DC9-30	25940	105	28945

TABLE 3.37b (cont)

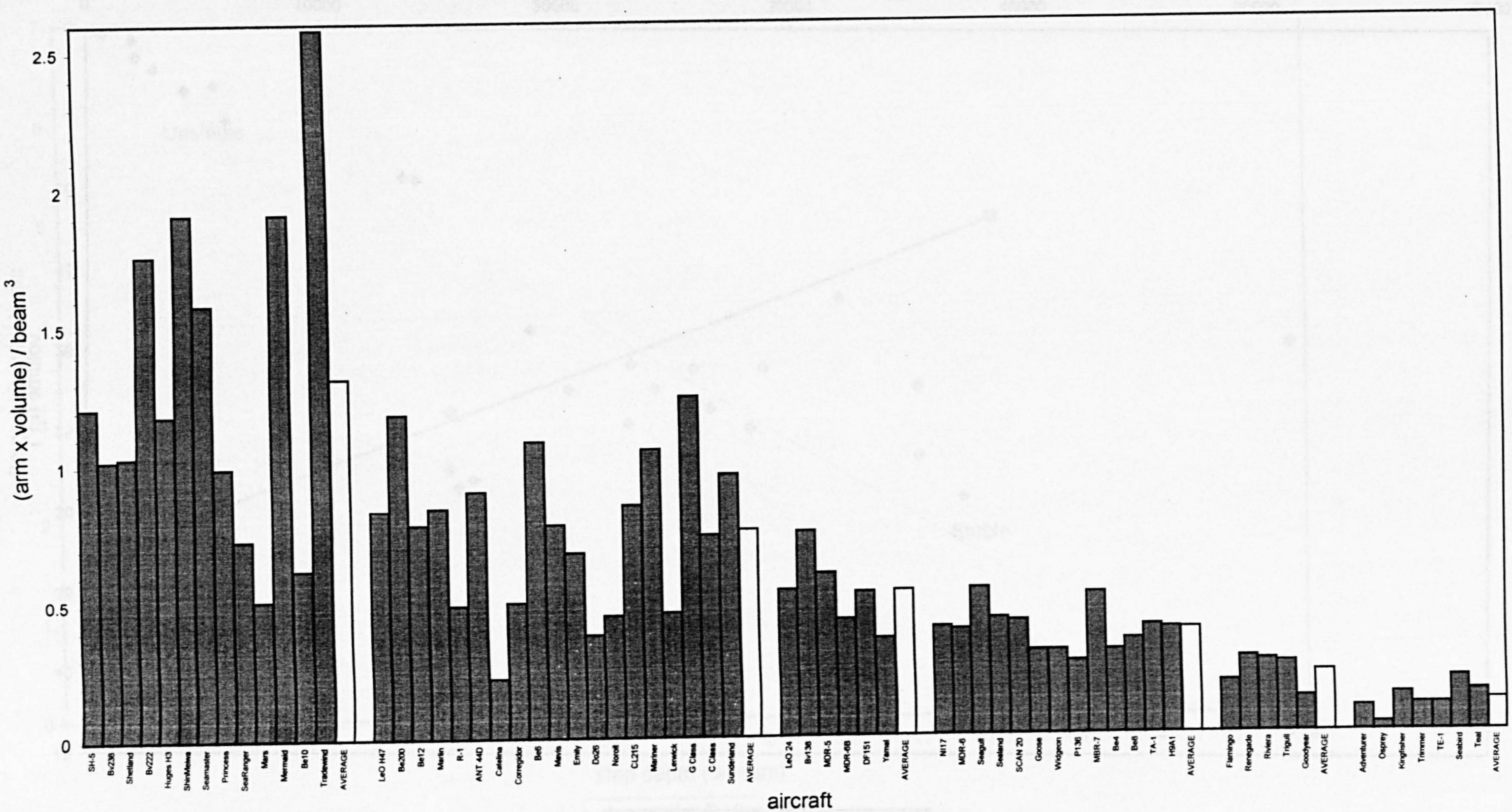
SEAT NUMBER AND PAYLOAD COMPARISON - LANDPLANES

Aircraft	Empty Mass (kg)	Seats	Payload (kg)
A300-600	86408	336	78592
A310-200	76747	-	61853
F28	13314	-	7506
An12	28000	-	27100
757-200	57438	178-233	42352
767-200	79923	211-289	56155
C130H	34686	-	35624
DC10-10	111086	255-380	95299
Cessna 150	442	1	306
Avid IV	232	1	290
Piper Cub	422	1	377
Maule M6	681	3	568
Cessna 180	707	3	631
Cessna 185	721	5	798
Beaver	1264	5	779
Cessna 206	785	5	848
Caravan	2015	9	1312

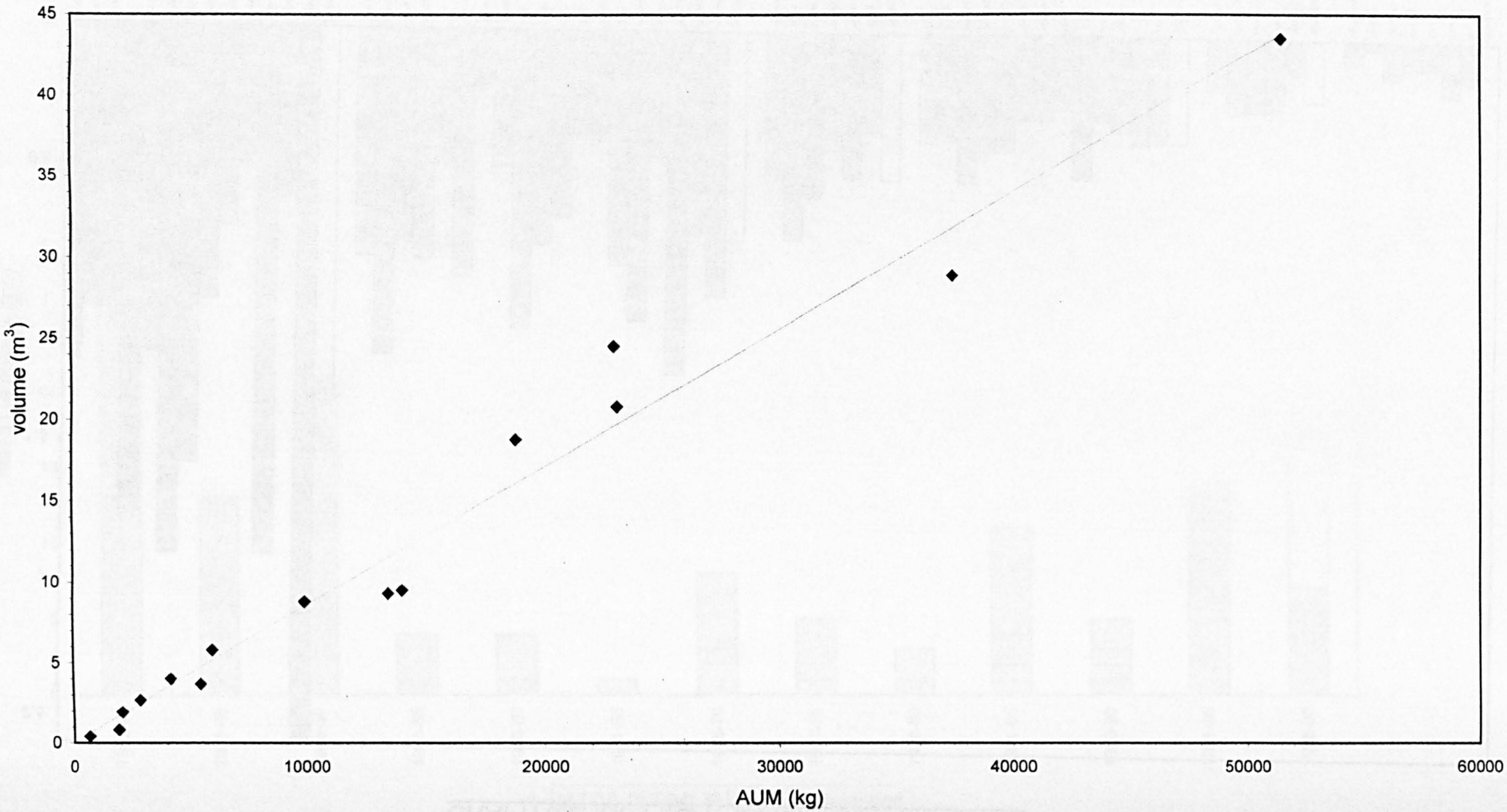
GRAPH 3.1. FLYINGBOAT CHRONOLOGY



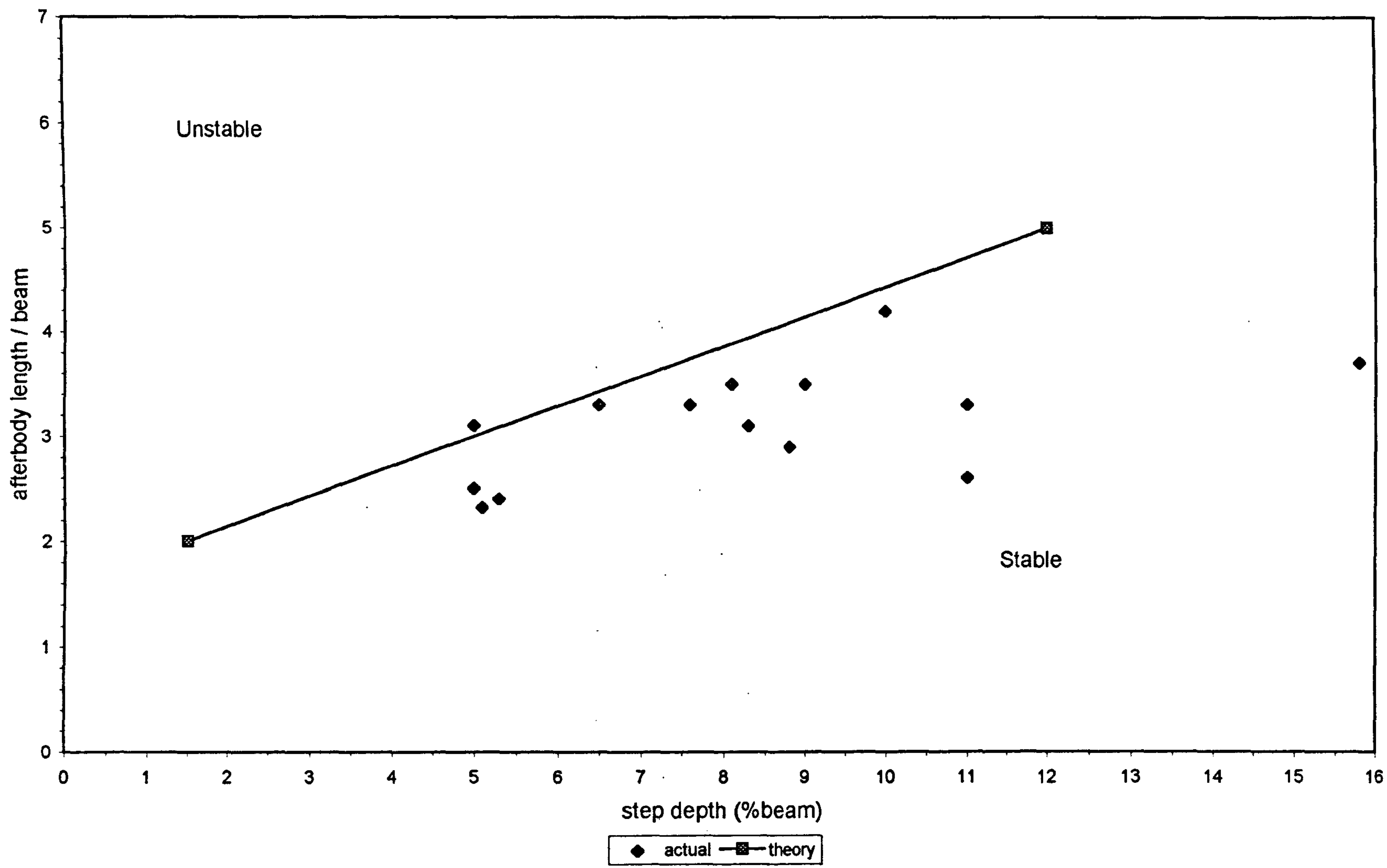
GRAPH 3.2. TIP FLOAT ESTIMATION FUNCTION



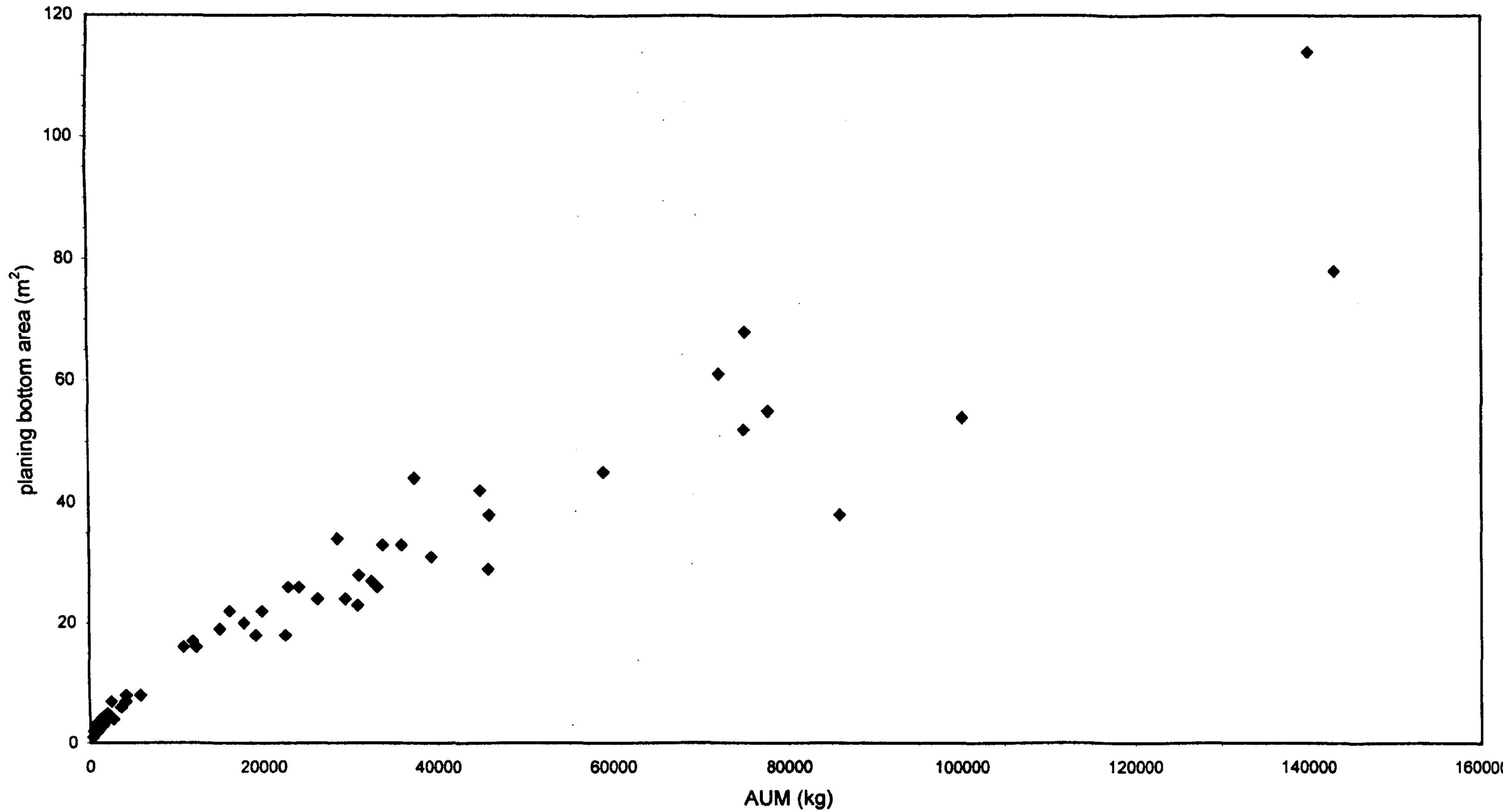
GRAPH 3.3. STUB VOLUME



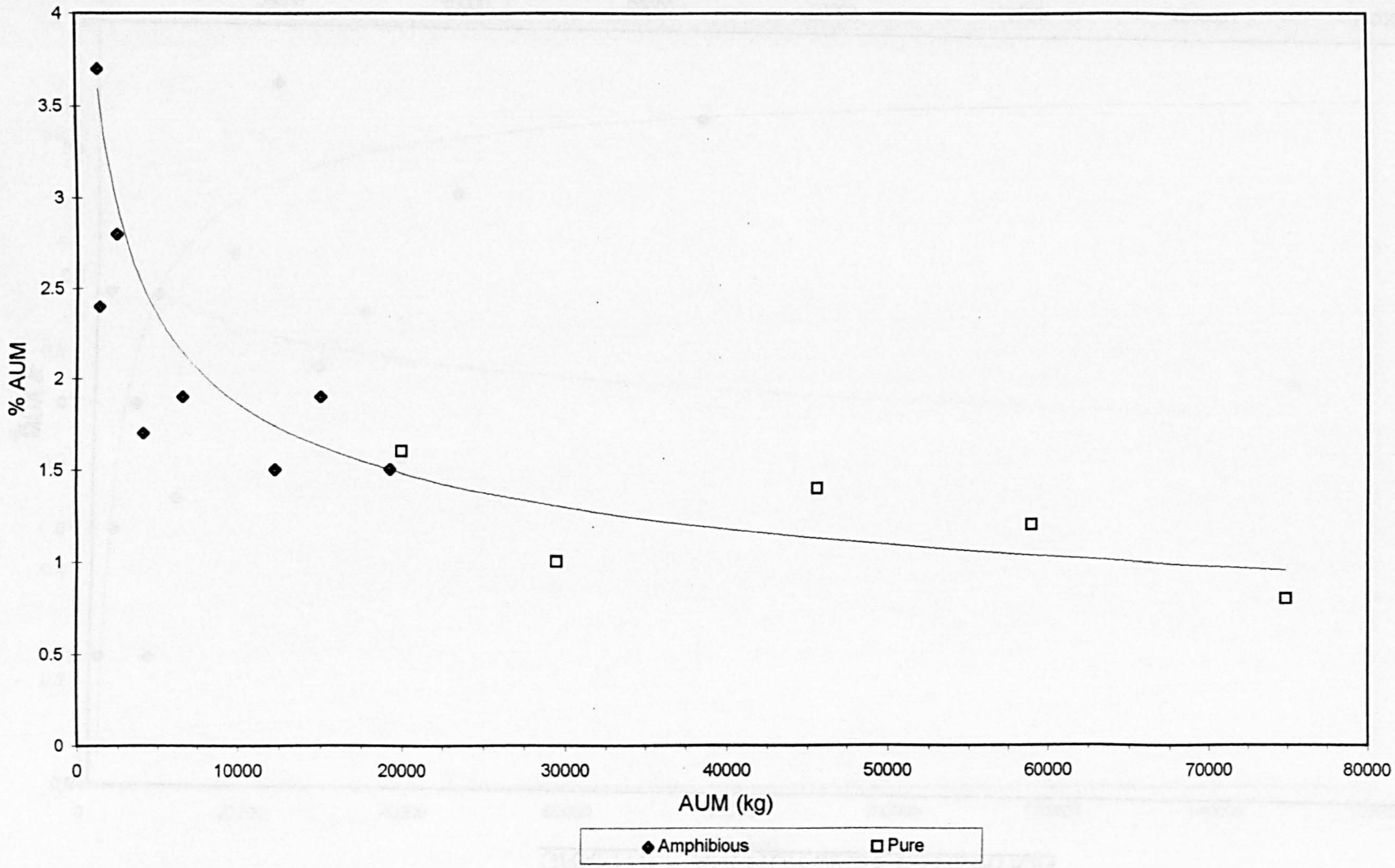
GRAPH 18. STEP DEPTH



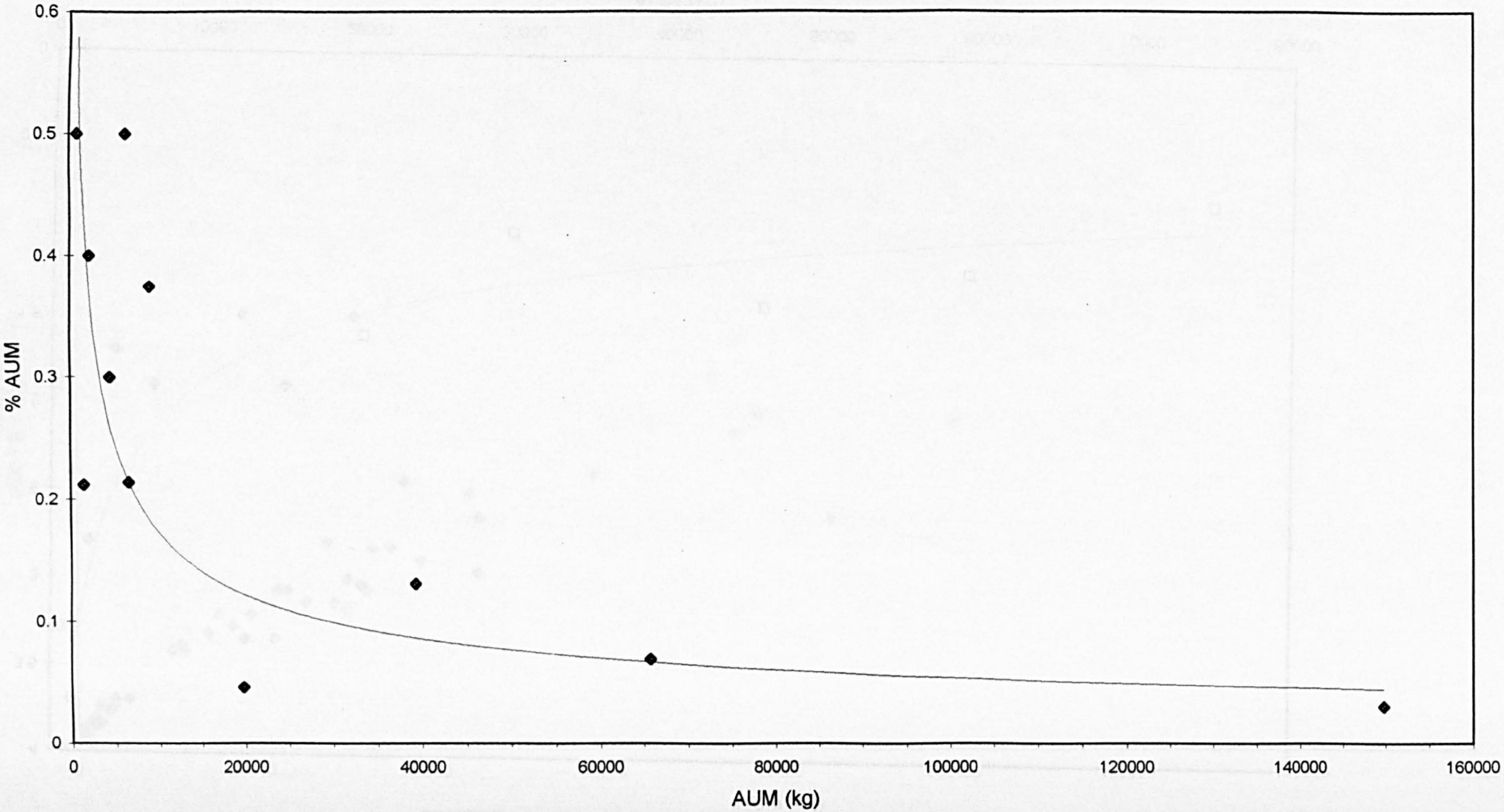
GRAPH 3.5. PLANING BOTTOM LIFT



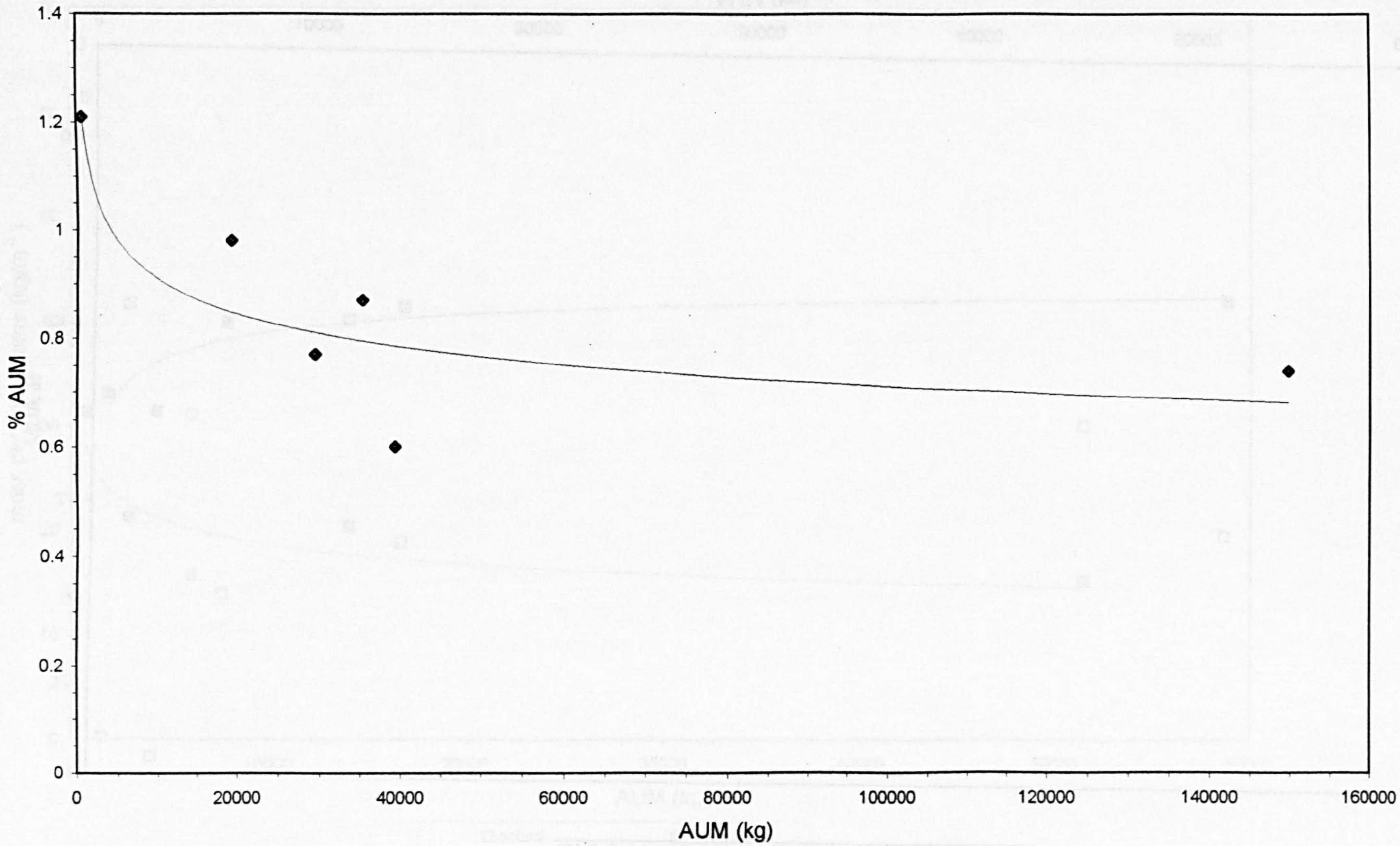
GRAPH 3.6. PLANING BOTTOM MASS ESTIMATION



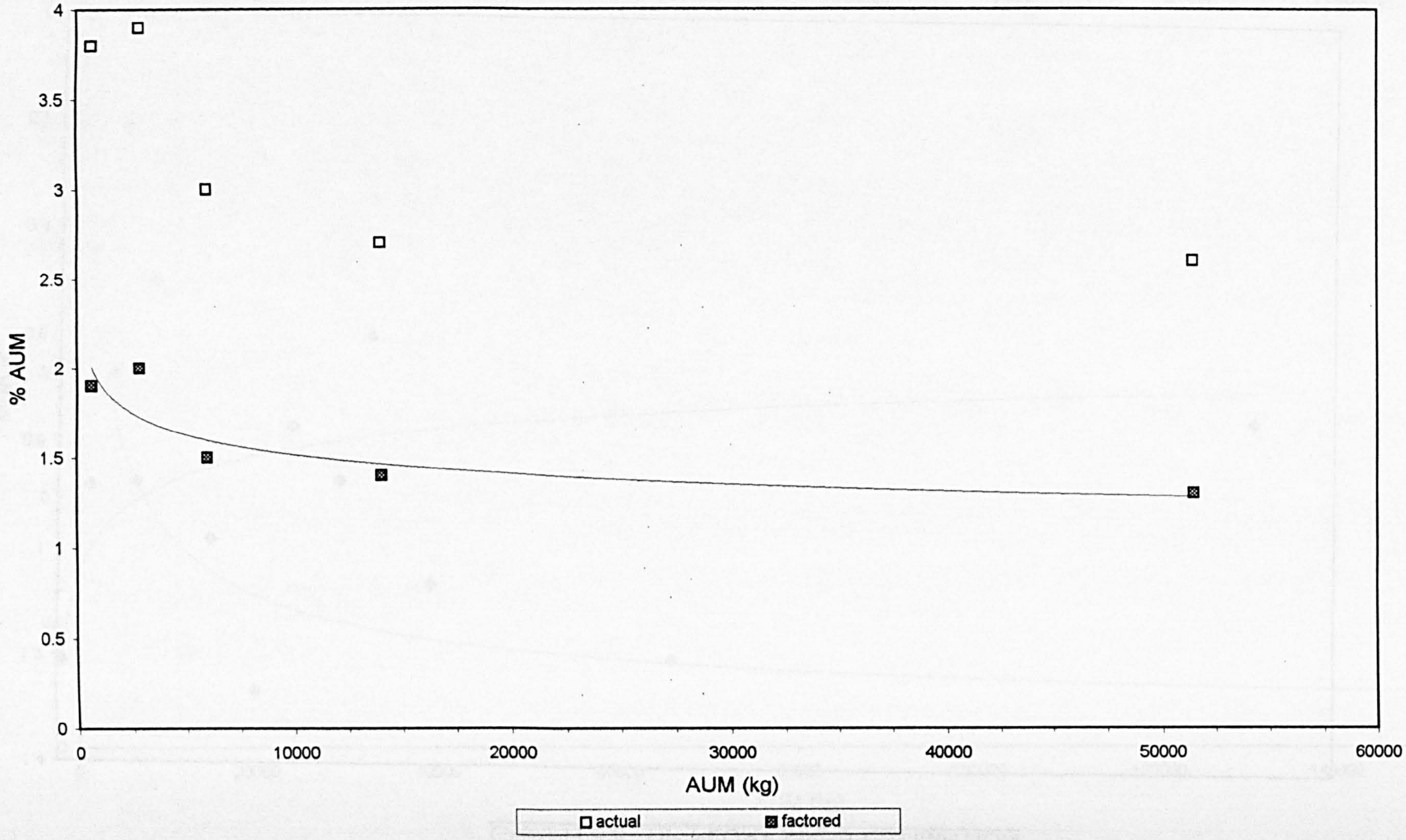
GRAPH 3.7. ANCHOR MASS ESTIMATION



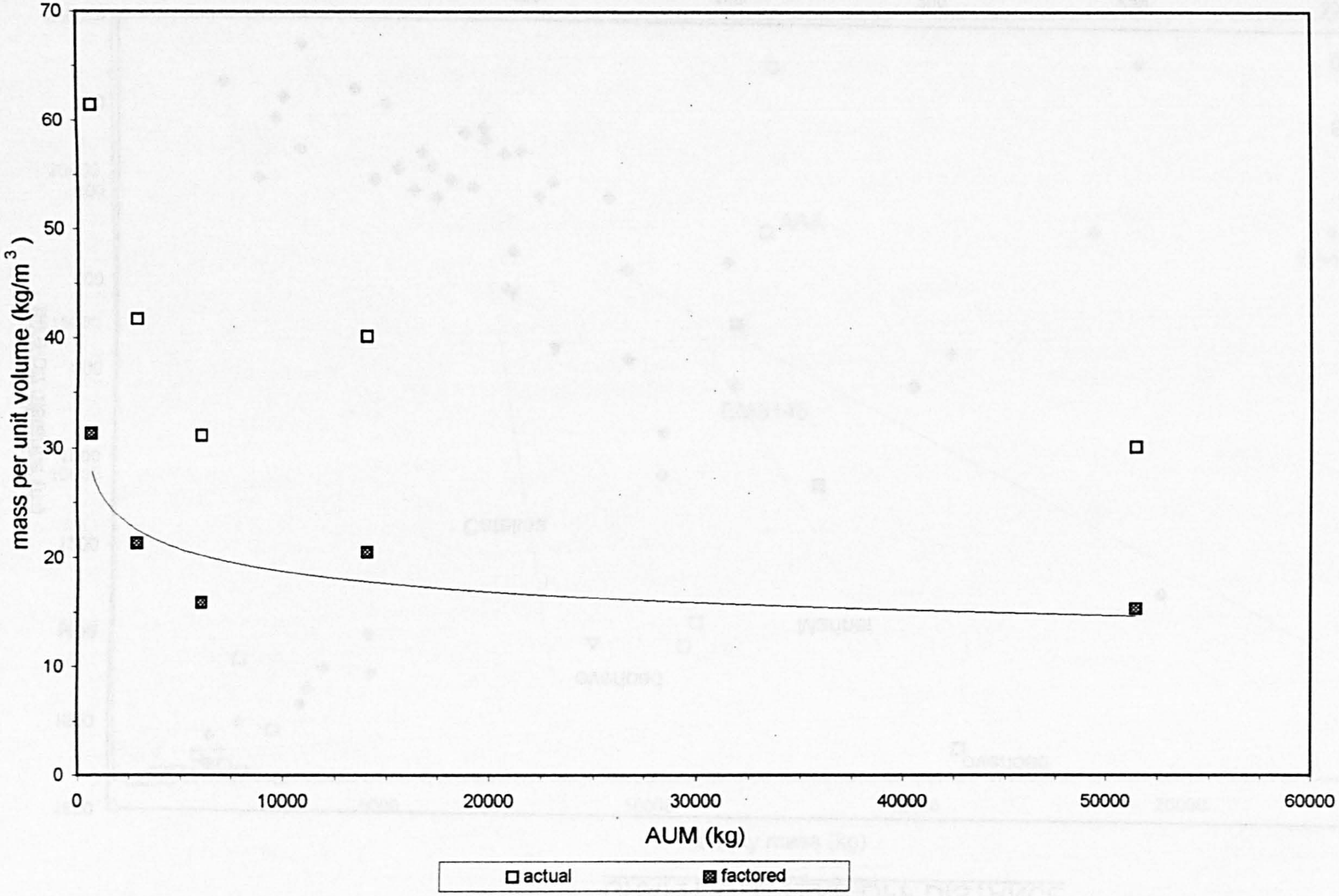
GRAPH 3.8. TIP FLOAT MASS ESTIMATION



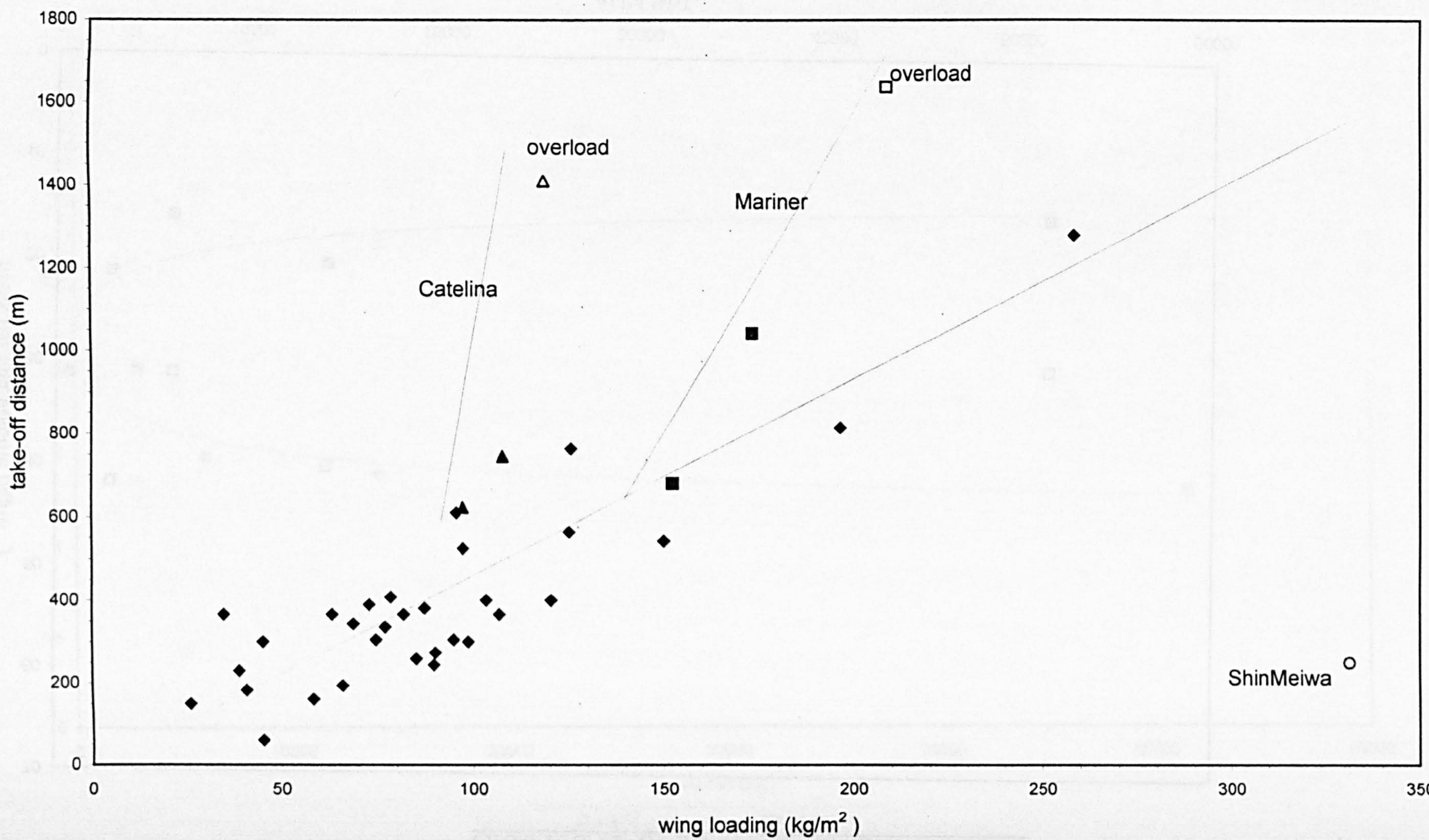
GRAPH 3.9 . STUB MASS ESTIMATION



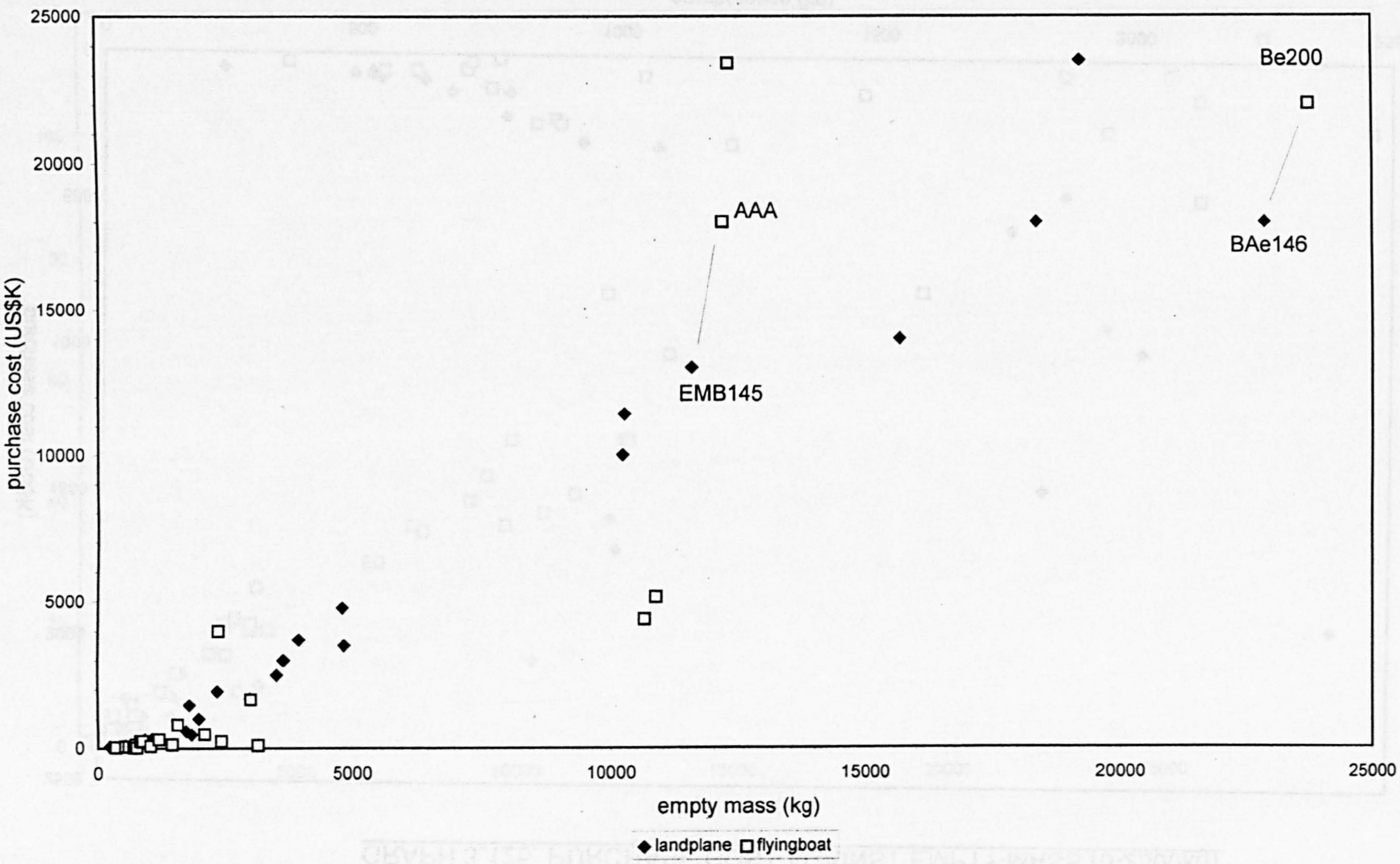
<u>GRAPH 3.10. STUB MASS PER UNIT VOLUME</u>



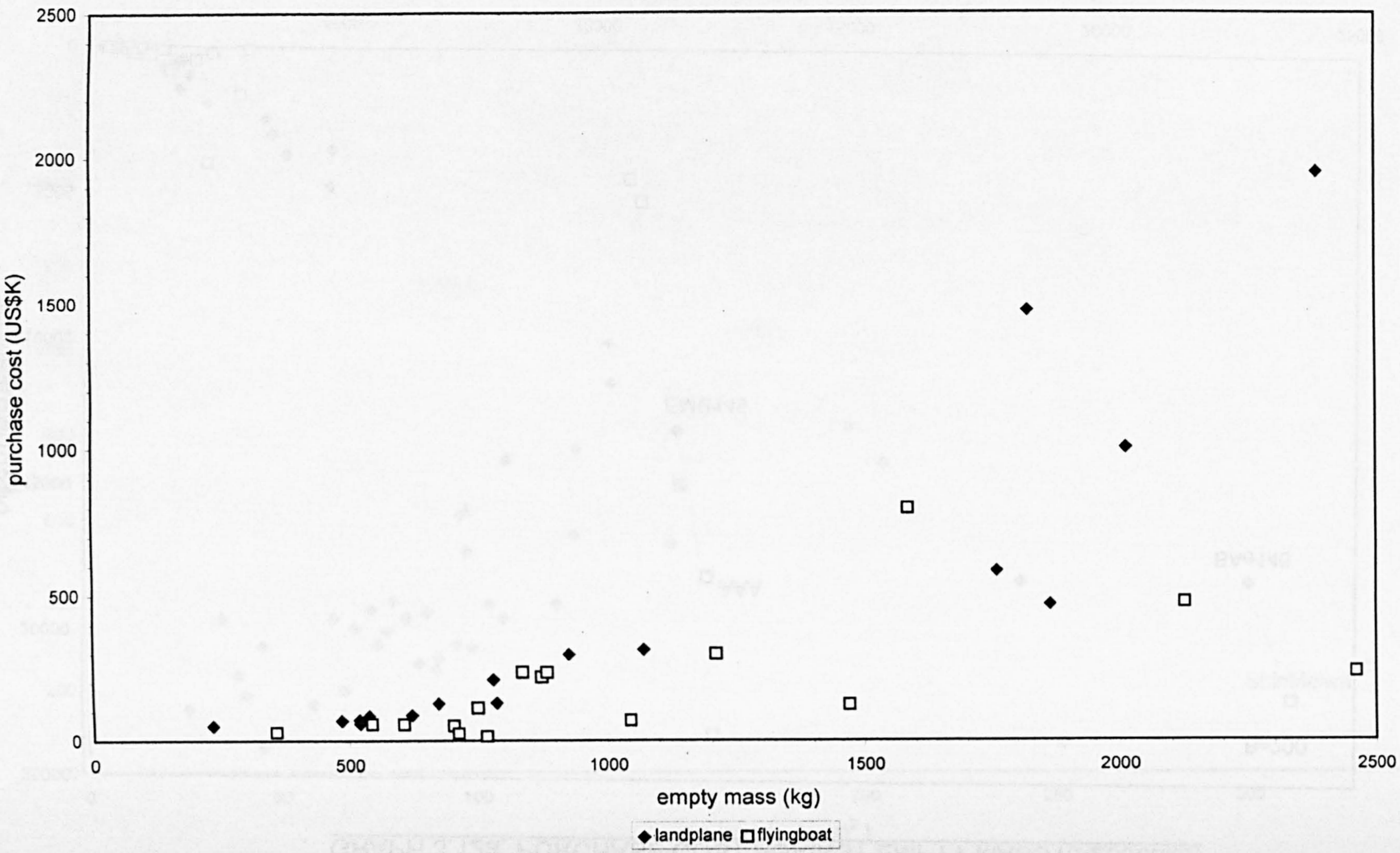
GRAPH 3.11. TAKE-OFF DISTANCE



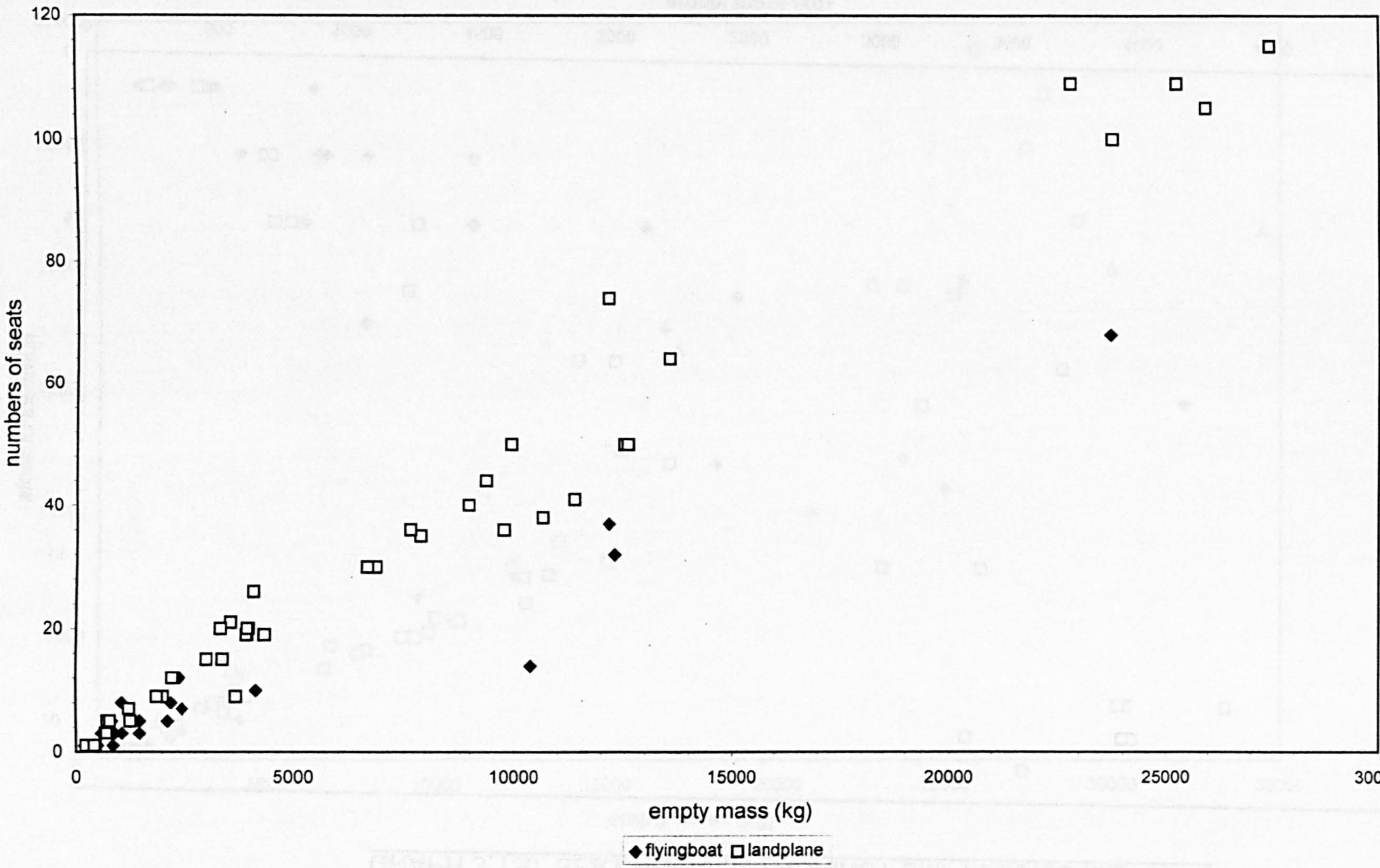
GRAPH 3.12a. PURCHASE COST AGAINST EMPTY MASS (0-25000kg)



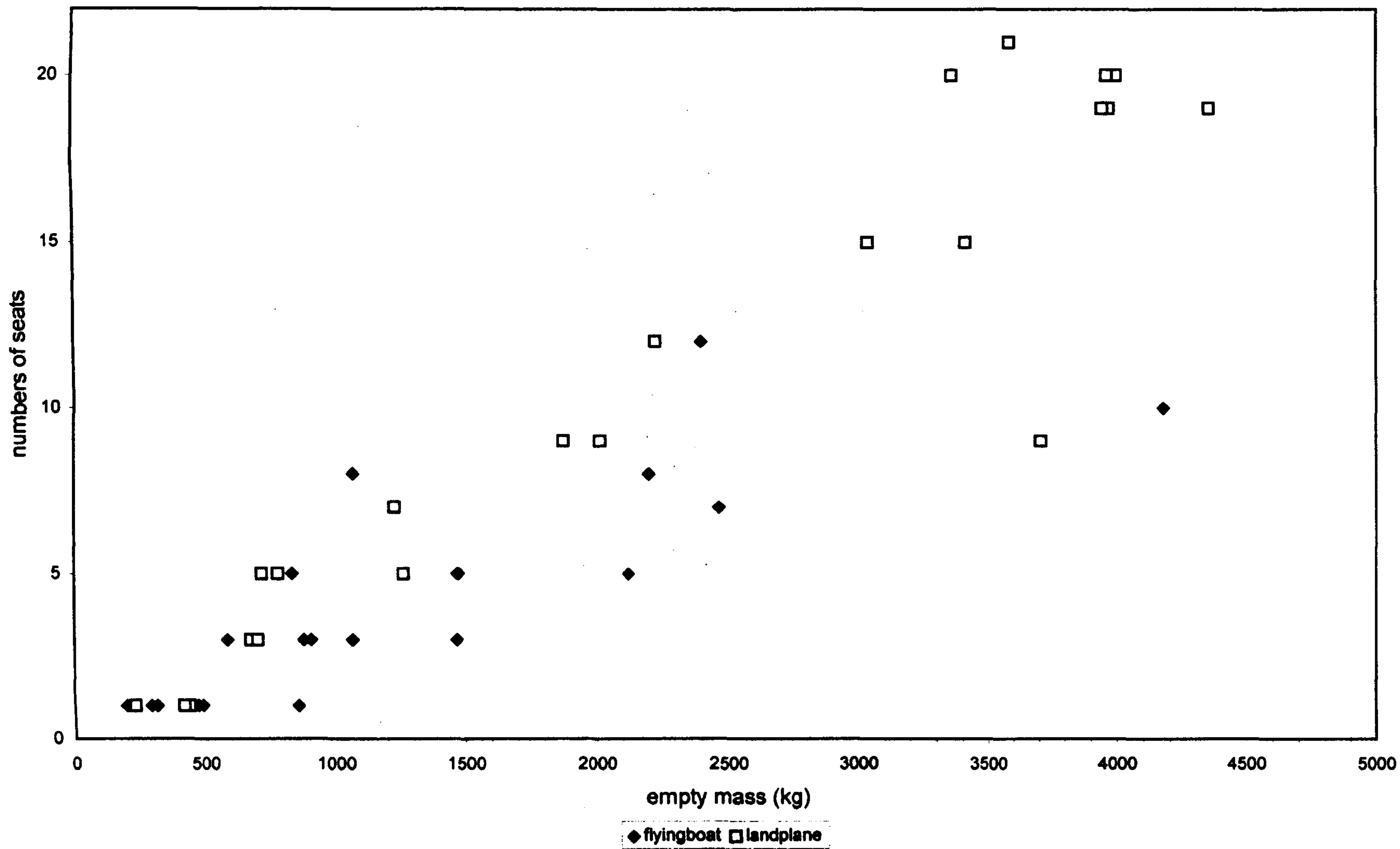
GRAPH 3.12b. PURCHASE COST AGAINST EMPTY MASS (0-2500kg)



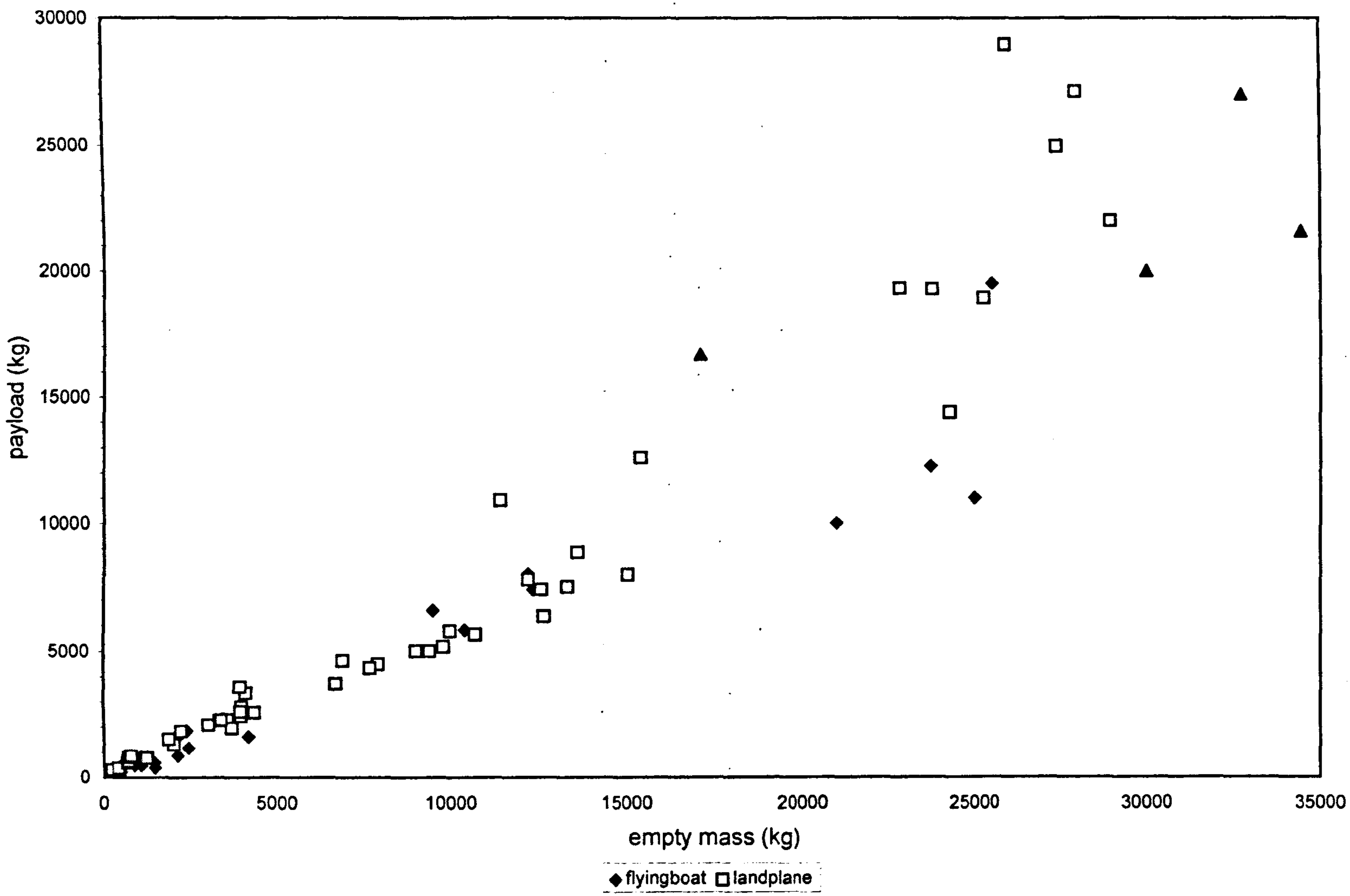
GRAPH 3.13a. SEAT NUMBERS AGAINST EMPTY MASS (M_e <30000)



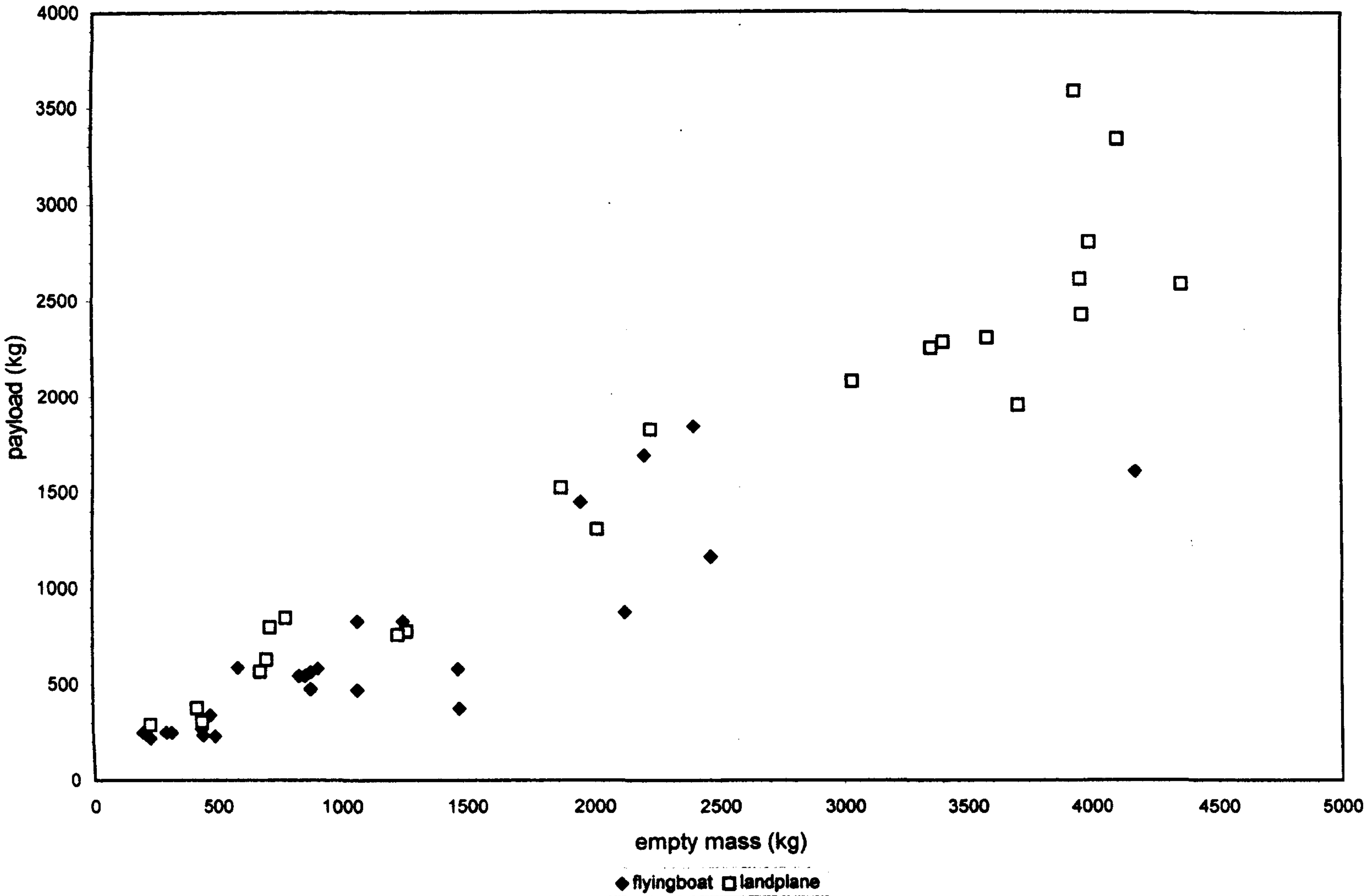
GRAPH 3.13b. SEAT NUMBERS AGAINST EMPTY MASS (M_e <5000)



GRAPH 3.14a. PAYLOAD AGAINST EMPTY MASS (M_e < 35000)



GRAPH 3.14b. PAYLOAD AGAINST EMPTY MASS (M_e < 5000)



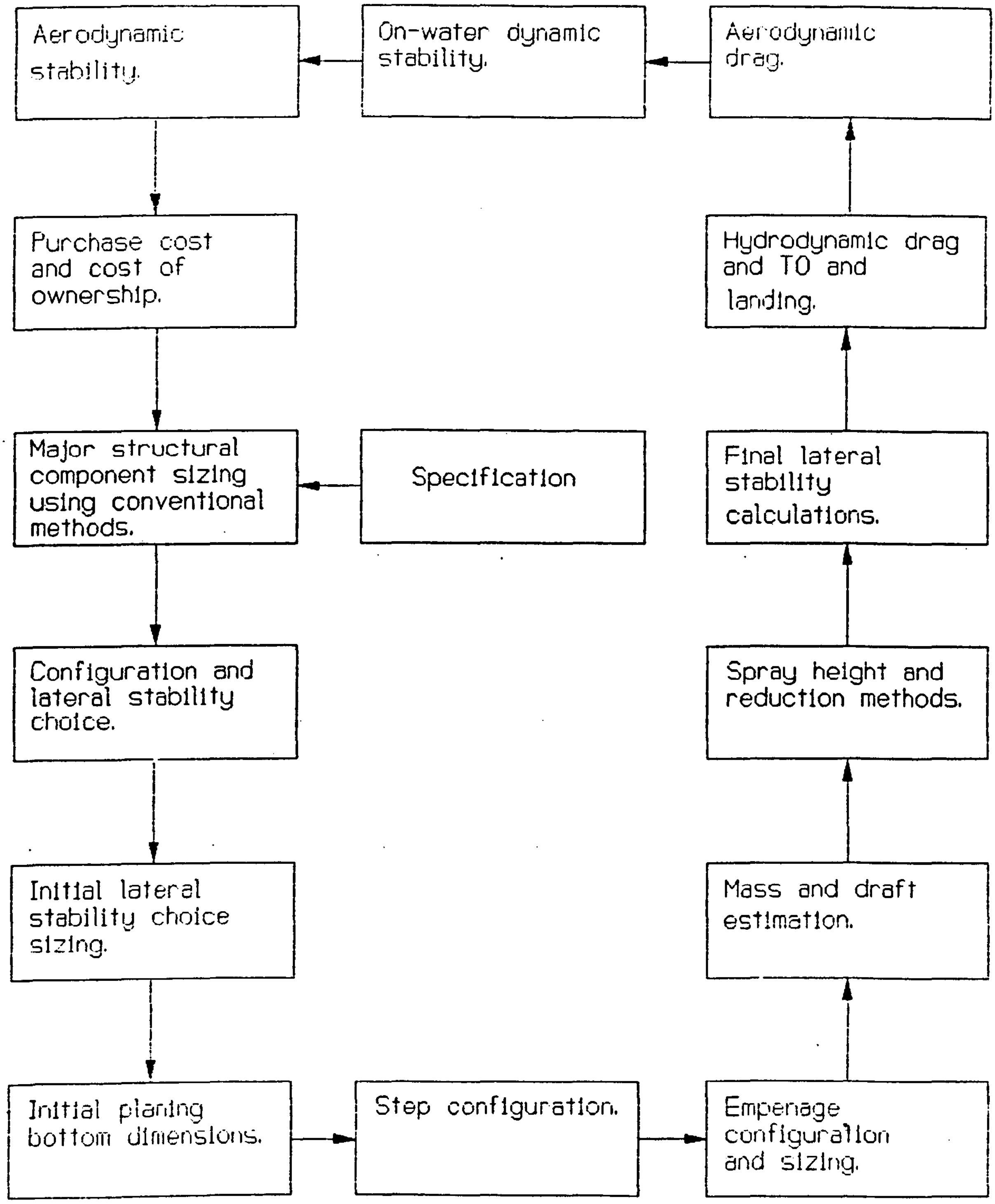


FIGURE 3.1. FLYINGBOAT CONCEPTUAL DESIGN CYCLE

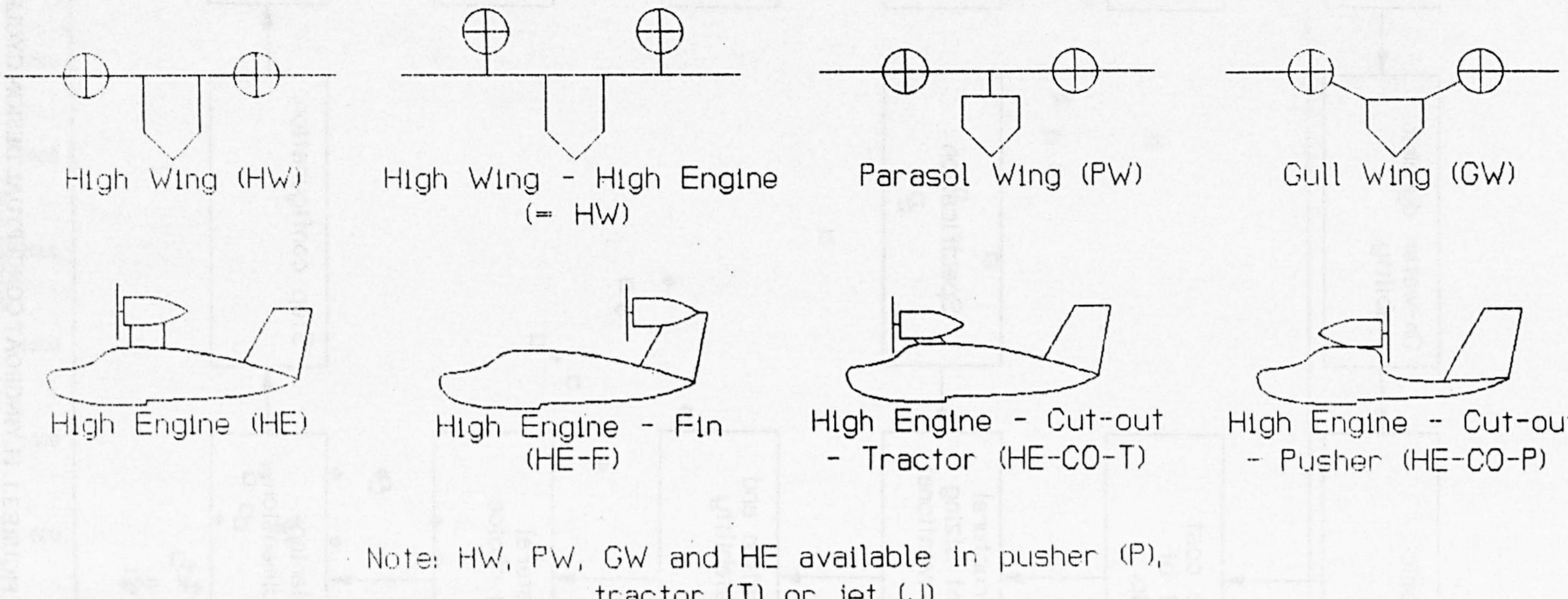


FIGURE 3.2. FLYINGBOAT CONFIGURATIONS

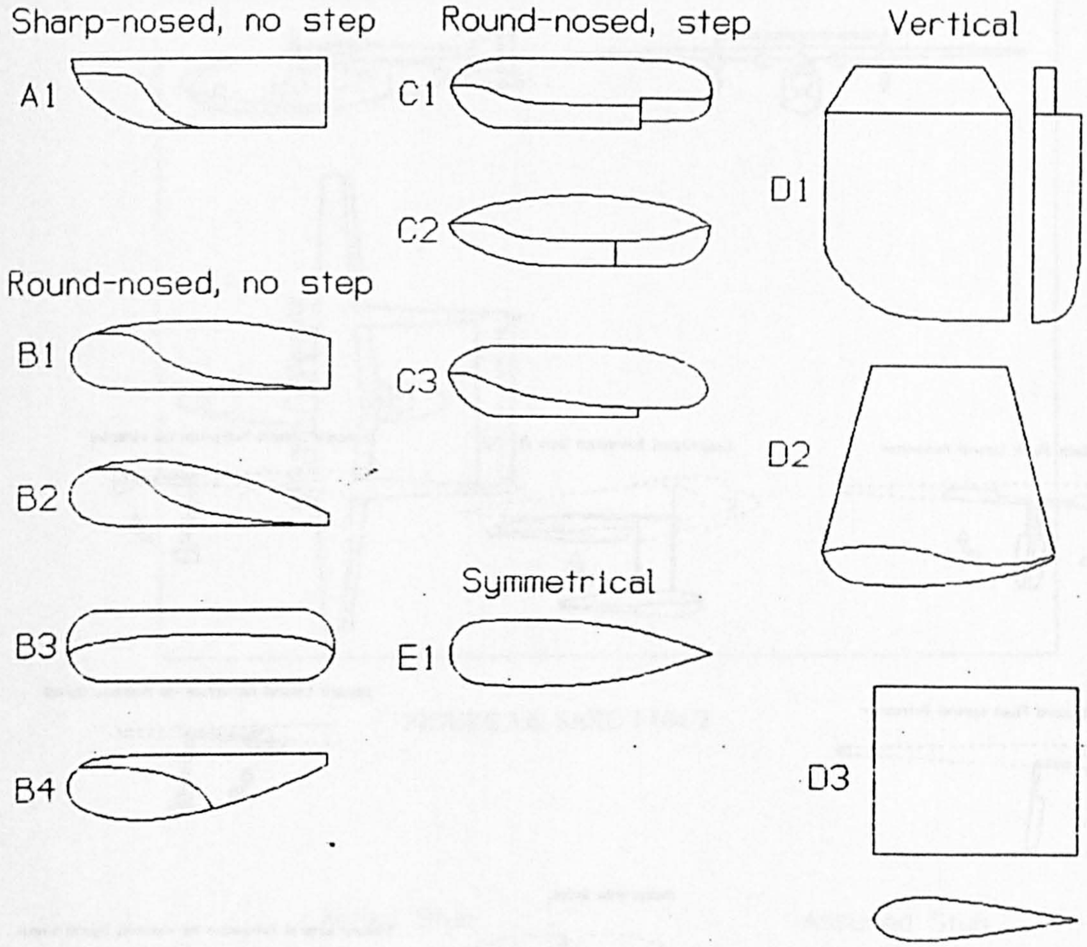


FIGURE 3.3. TIP FLOAT FORMS

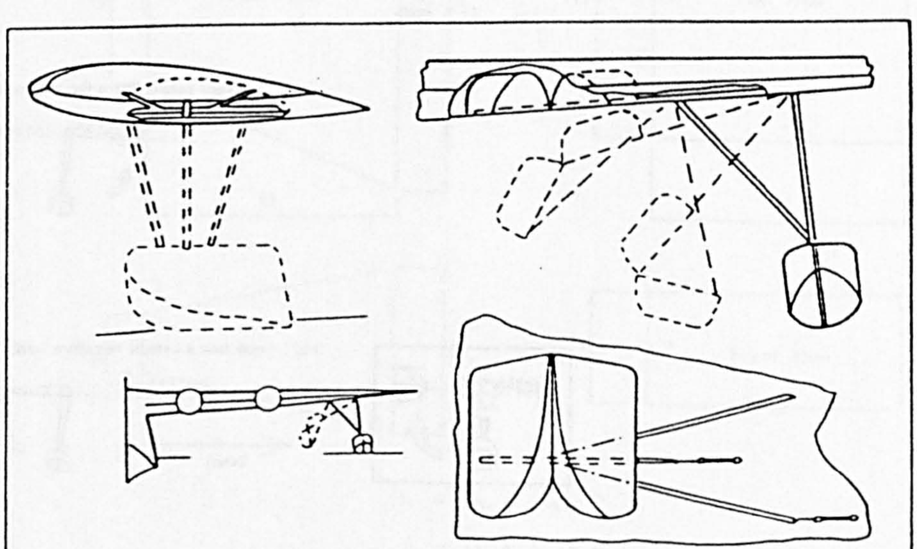


FIGURE 3.4. SARO S38/39 FLOAT DESIGNS

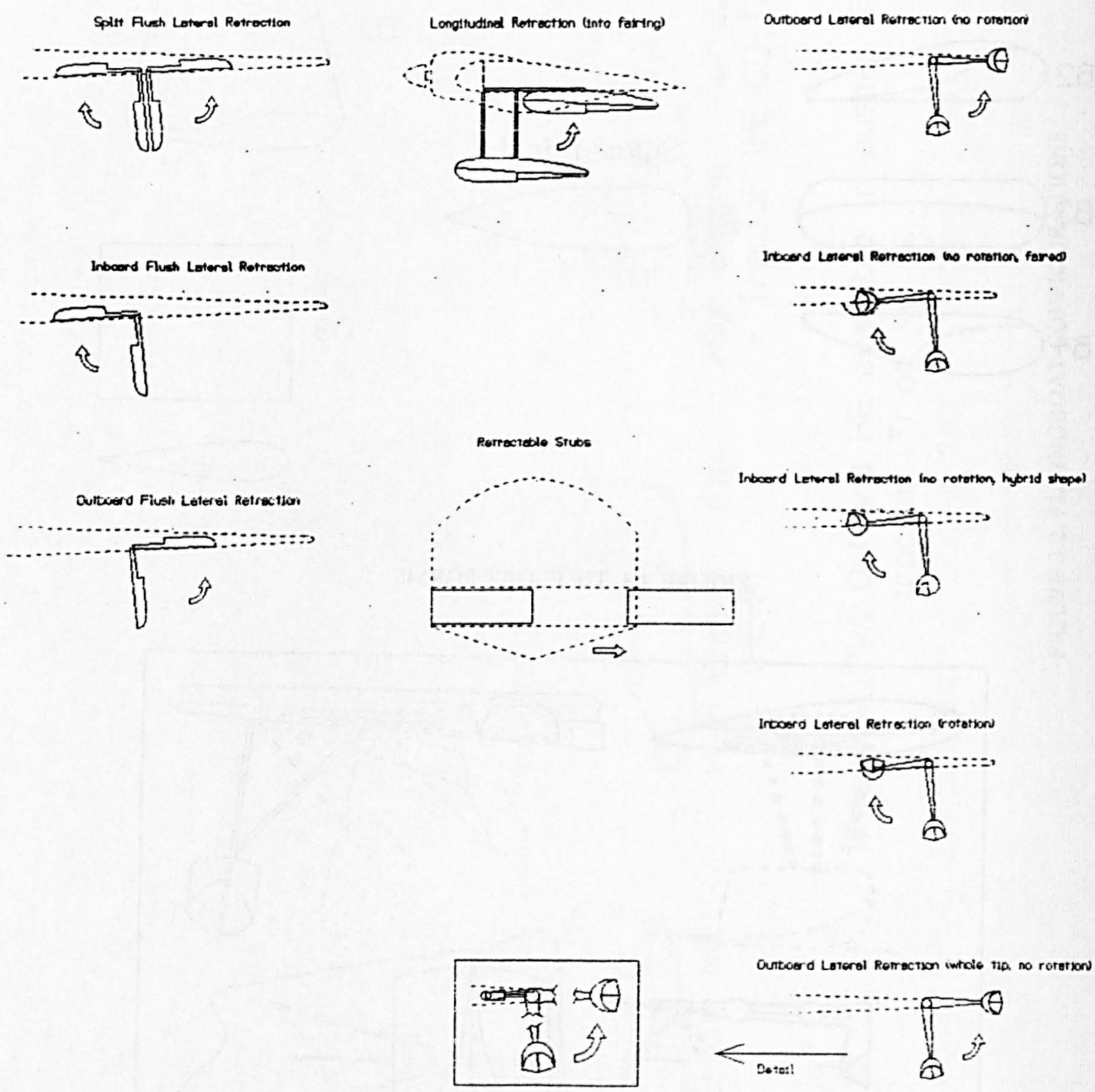


FIGURE 3.5. RETRACTABLE FLOATS

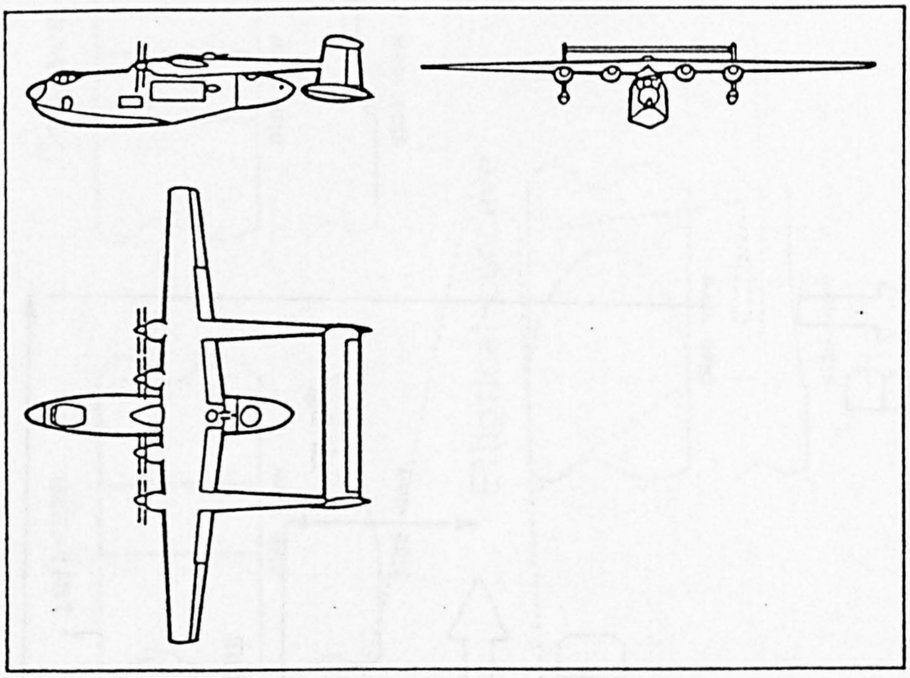
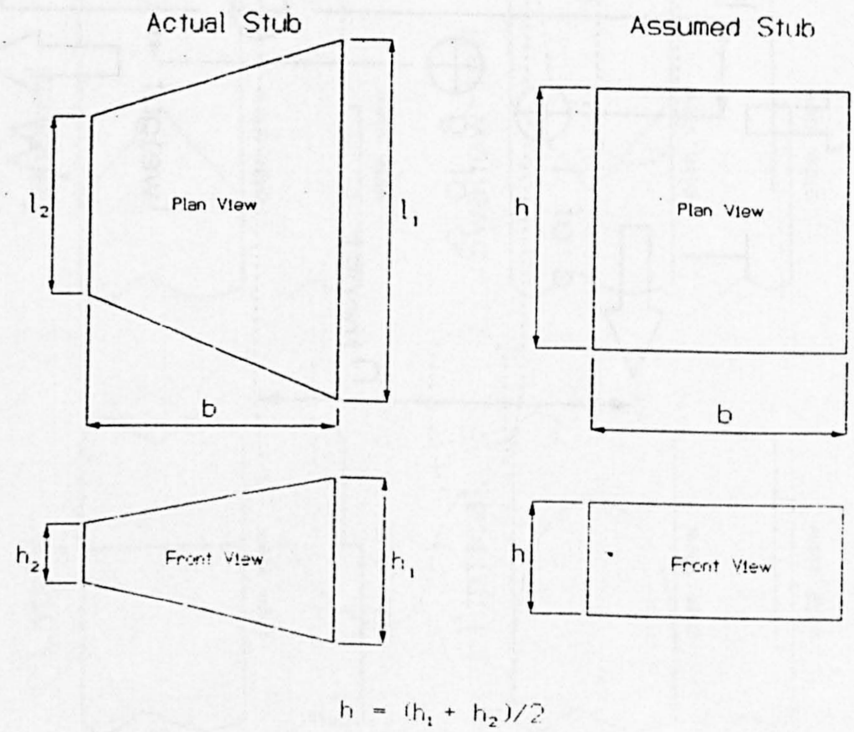


FIGURE 3.6. SARO P104/2



$$h = (h_1 + h_2)/2$$

$$l = (l_1 + l_2)/2$$

FIGURE 3.7. STUB SHAPE ASSUMPTIONS

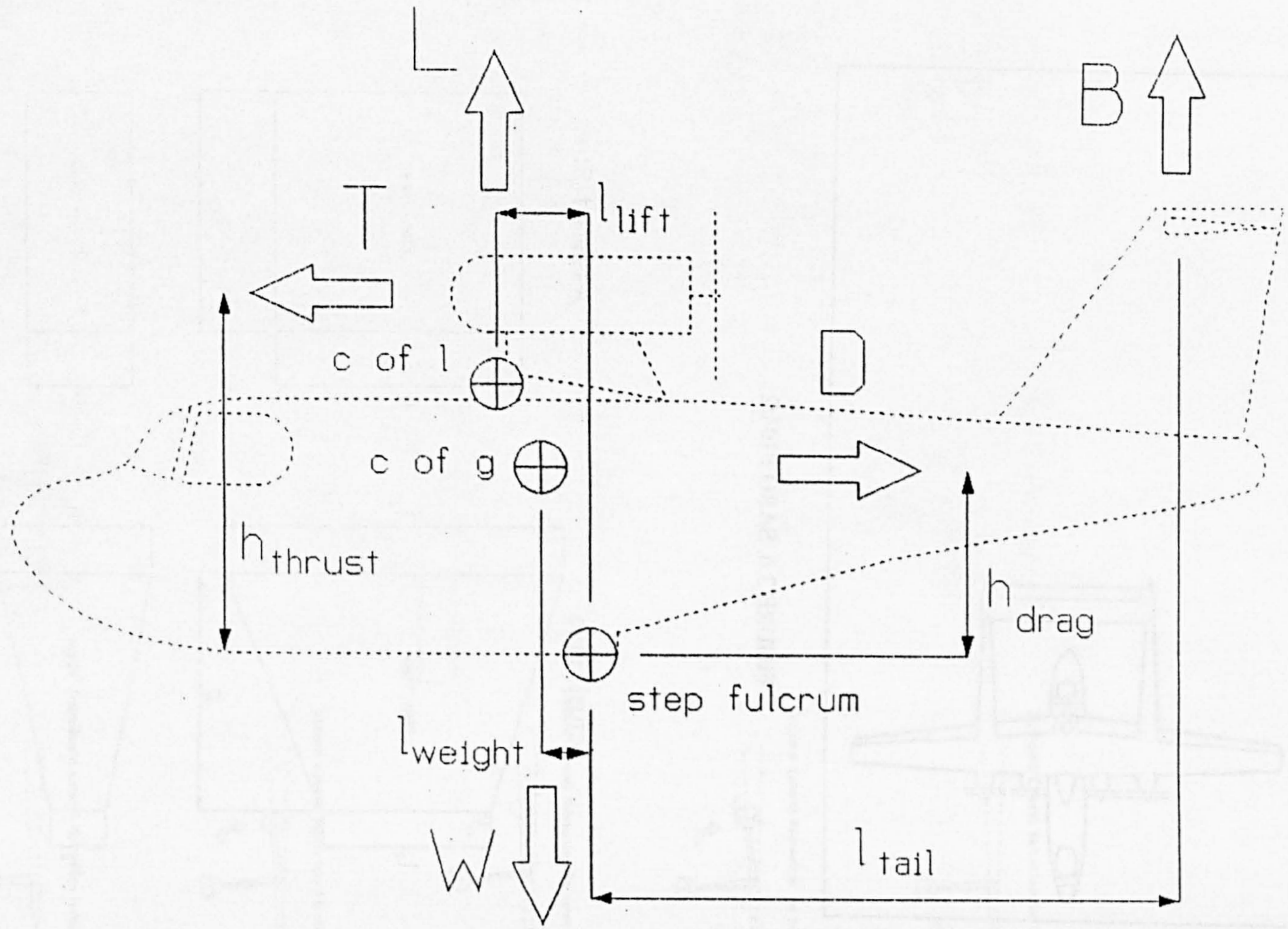


FIGURE 3.8. FLYINGBOAT BALANCE WHEN PLANING

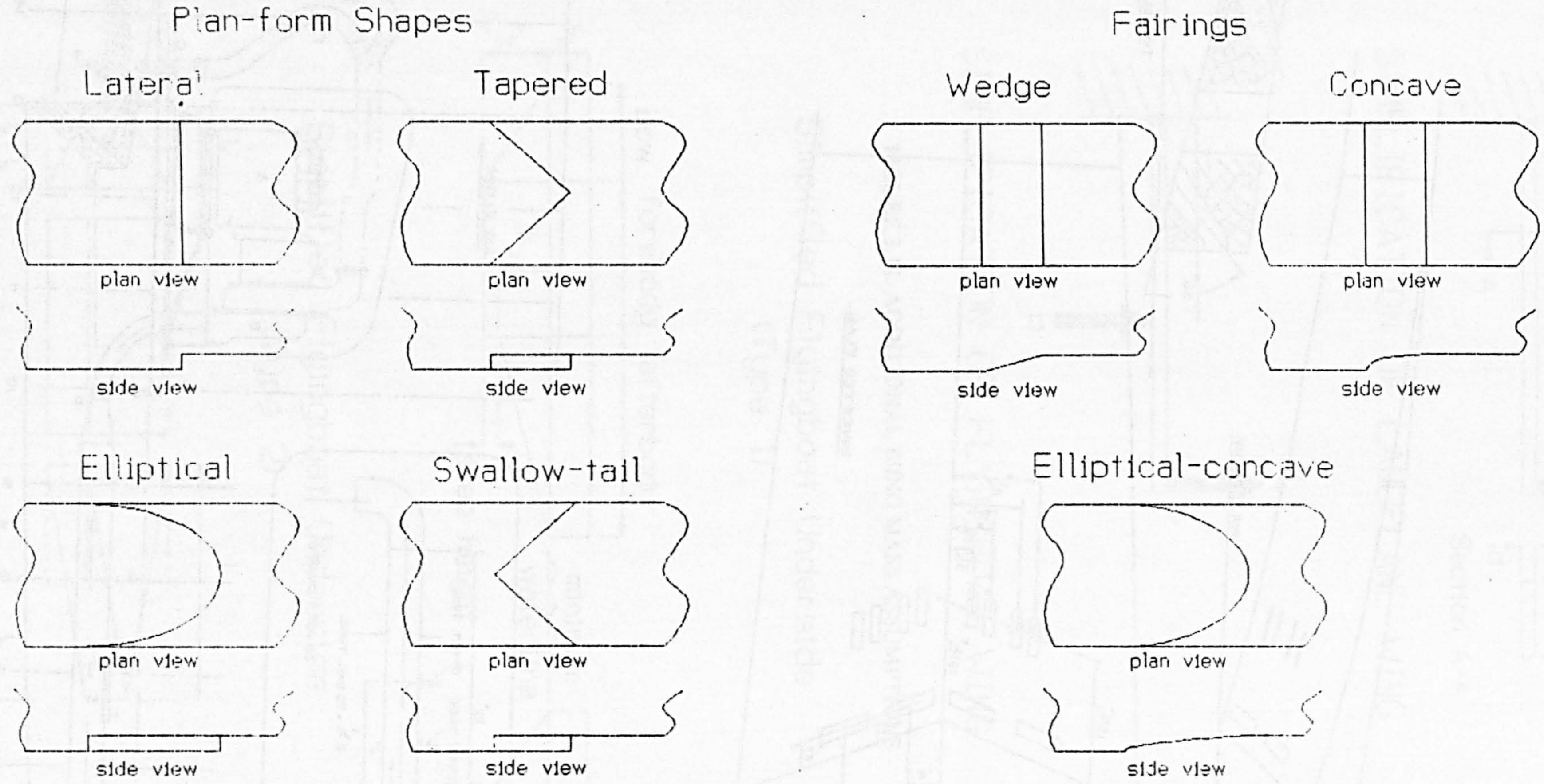


FIGURE 3.9. STEP FORMS

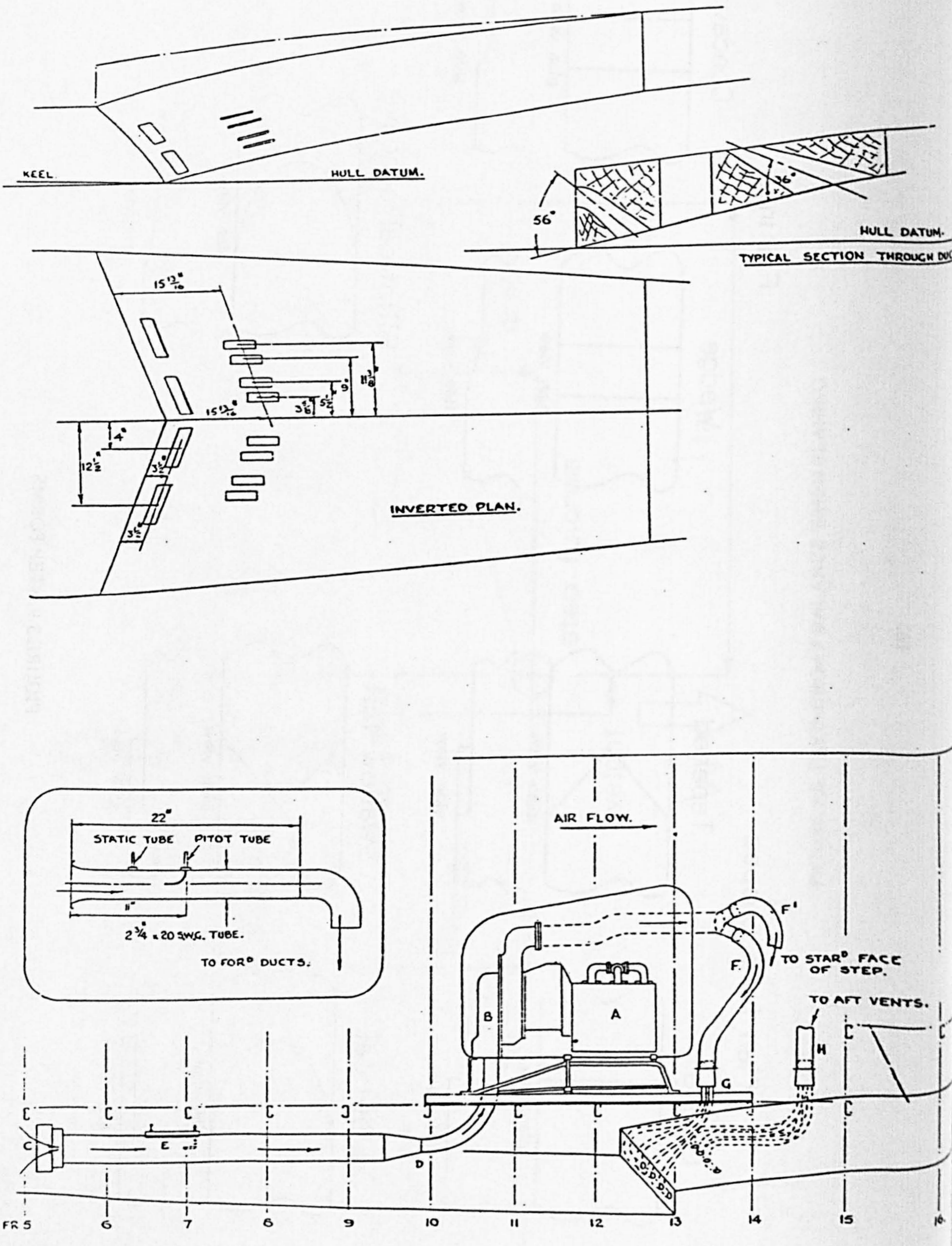


FIGURE 3.10. FORCED STEP VENTILATION METHOD

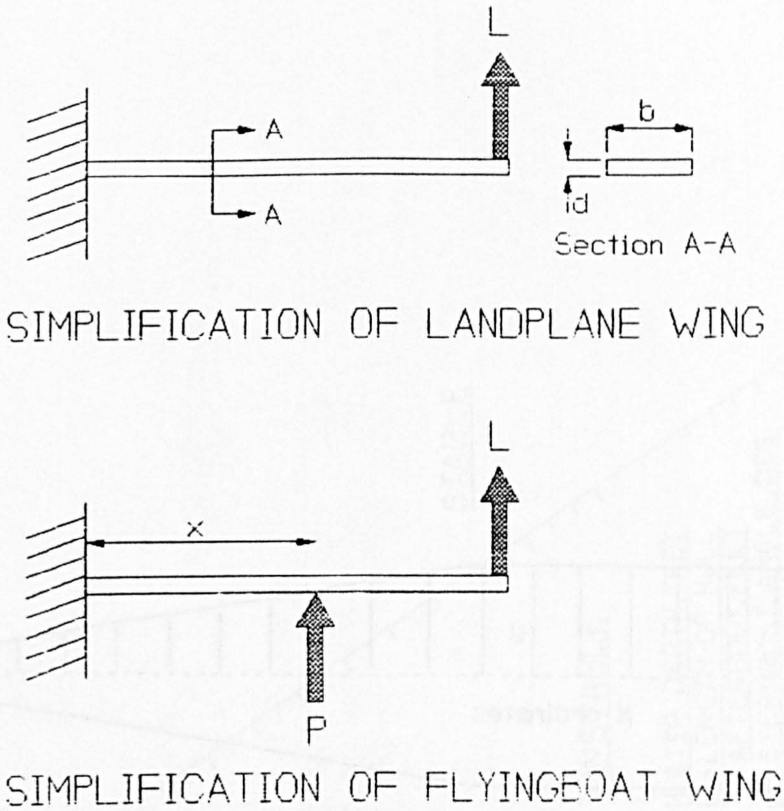


FIGURE 3.11. ADDITIONAL WING MASS ASSUMPTIONS

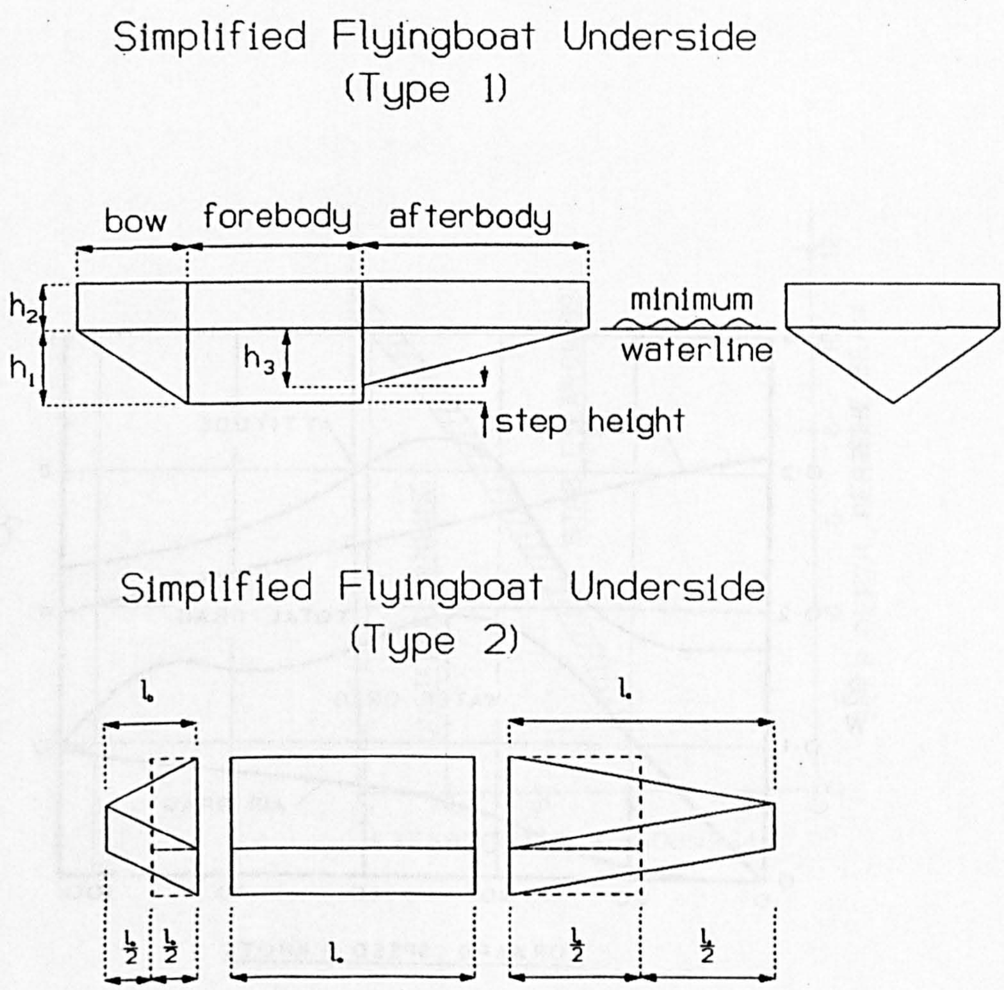


FIGURE 3.12. SIMPLIFIED FLYINGBOAT UNDERSIDE

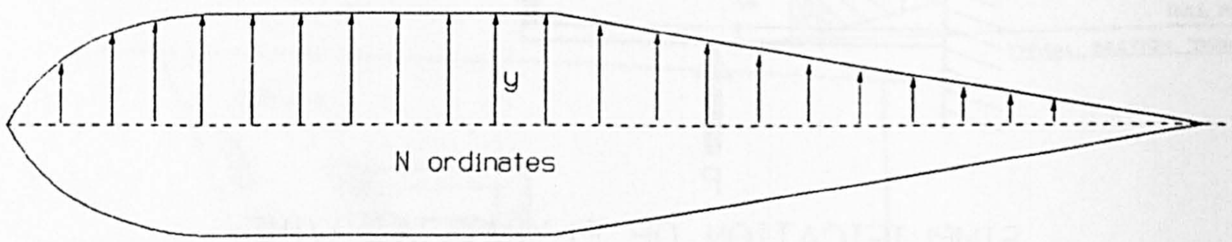


FIGURE 3.13 STATIC STABILITY ORDINATES

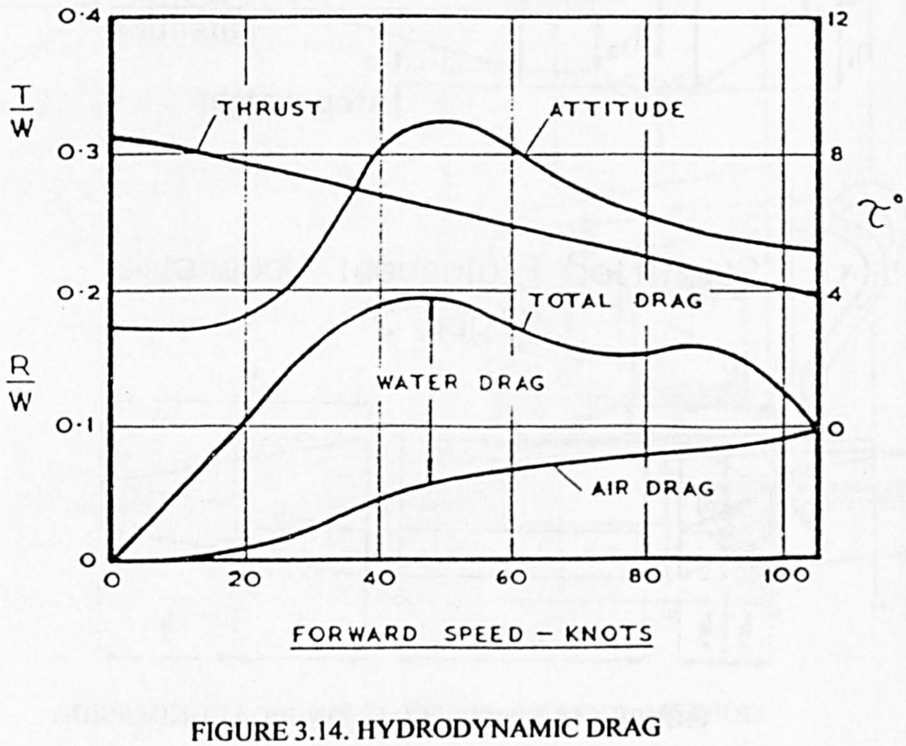
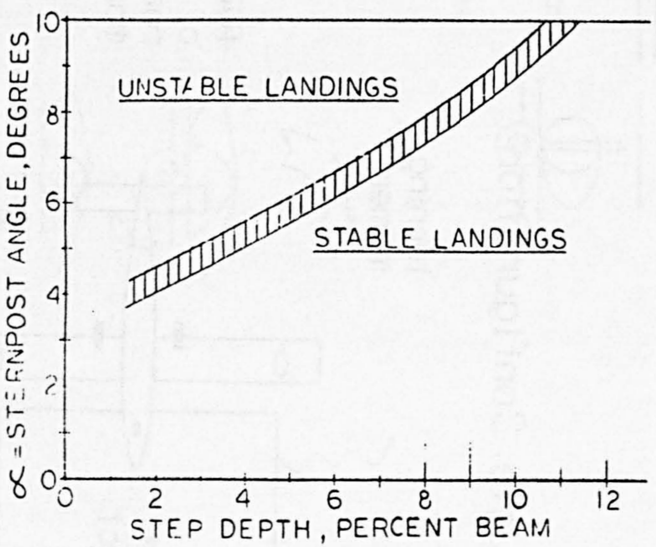


FIGURE 3.14. HYDRODYNAMIC DRAG



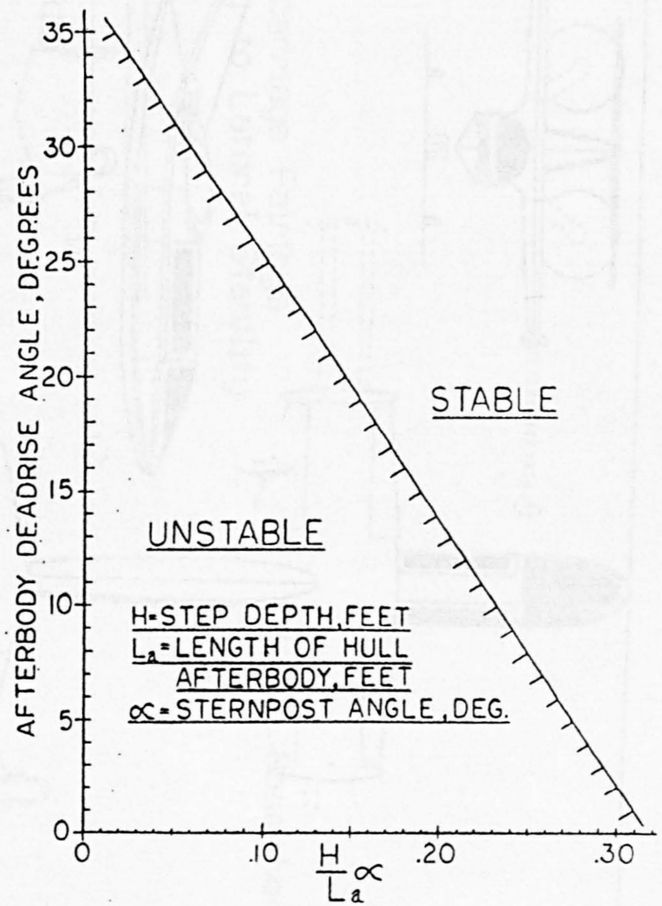


FIGURE 3.15. STABILITY DIAGRAMME

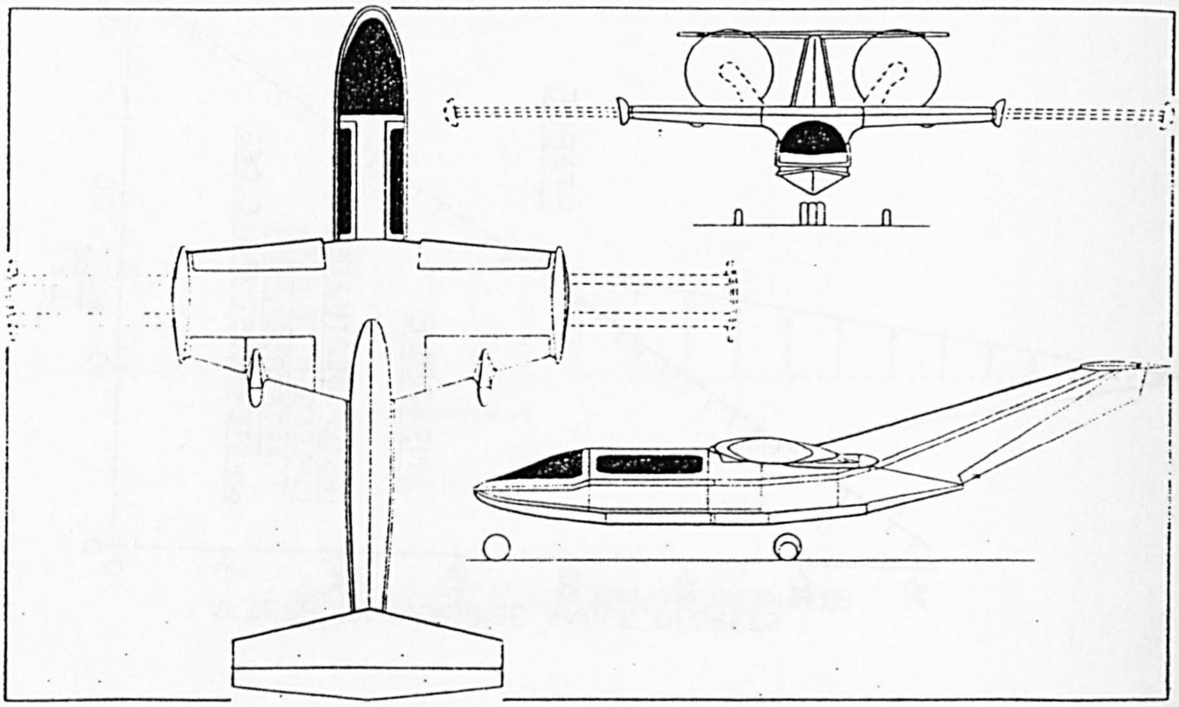


FIGURE 3.16 GEVERS GENESIS

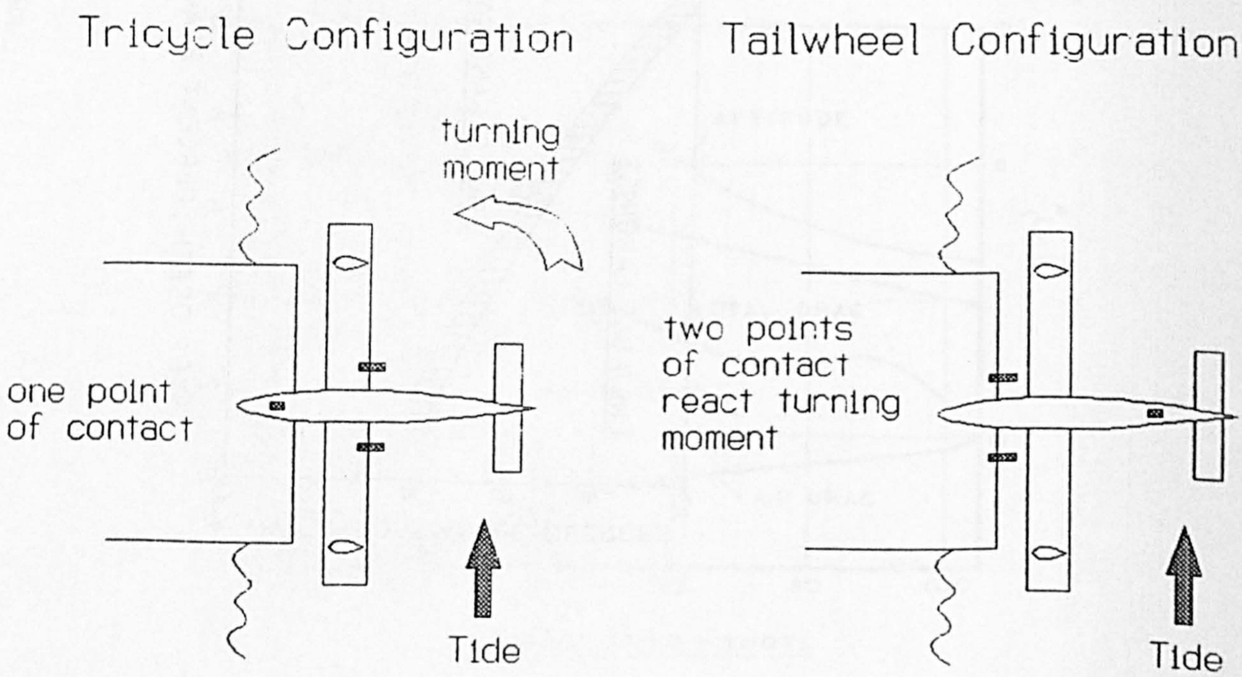


FIGURE 3.17 FLYINGBOAT JOINING A RAMP

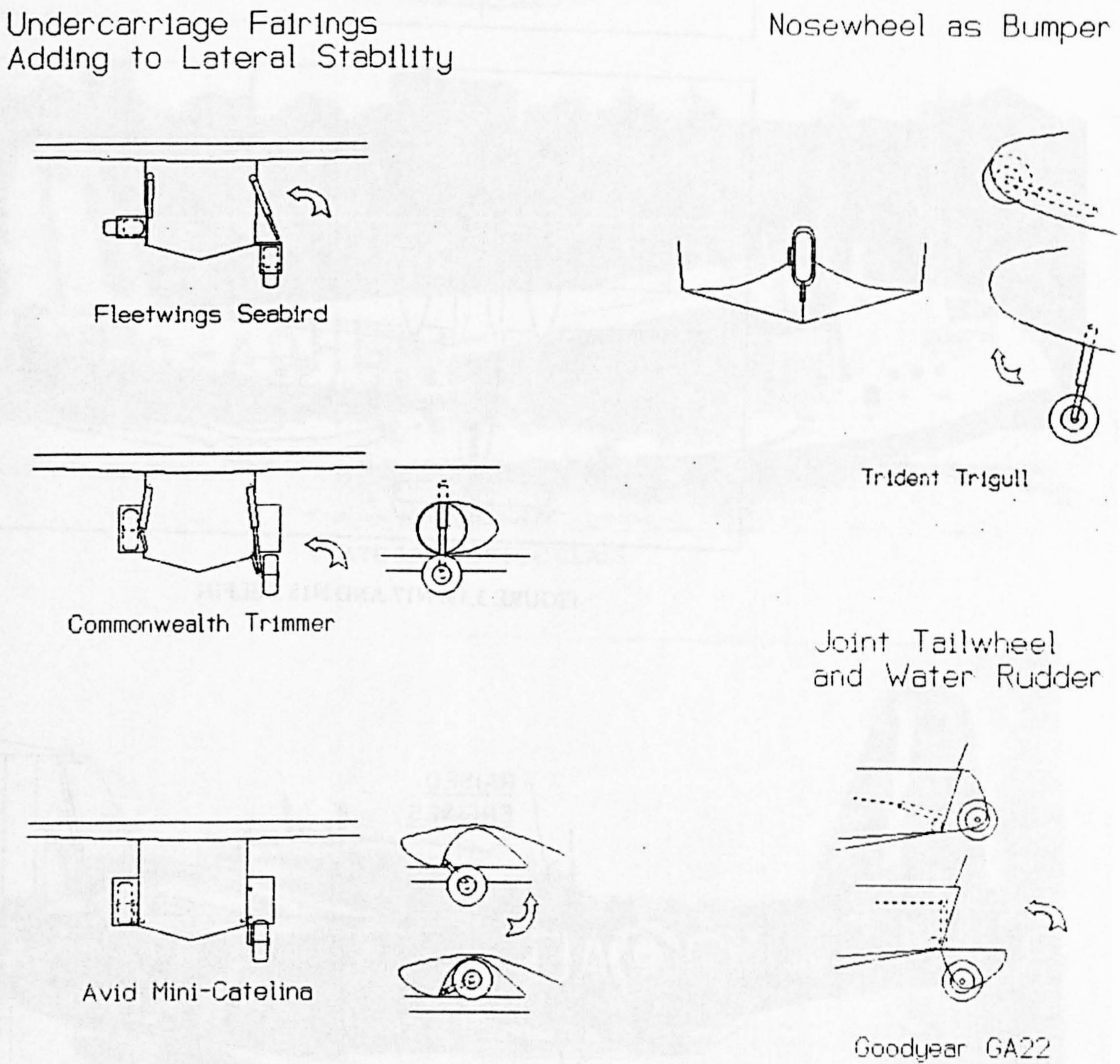
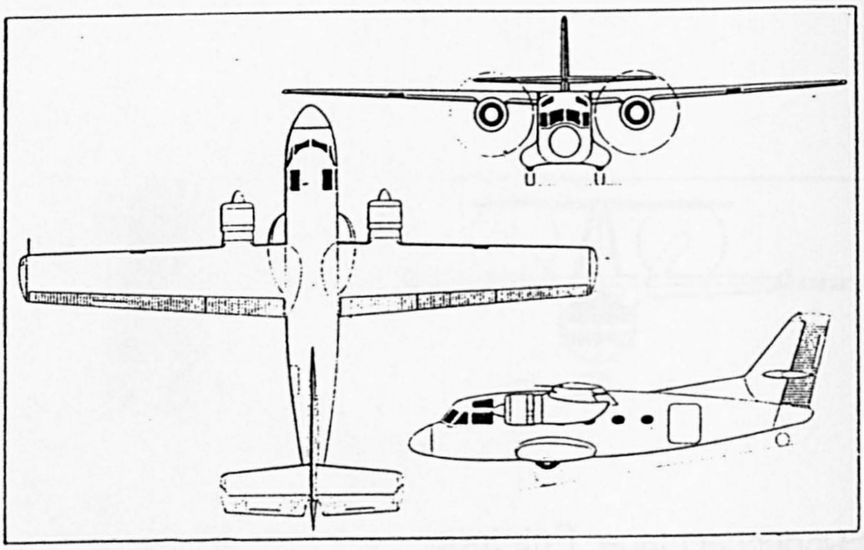


FIGURE 3.18. SYNERGY IN UNDERCARRIAGE DESIGN



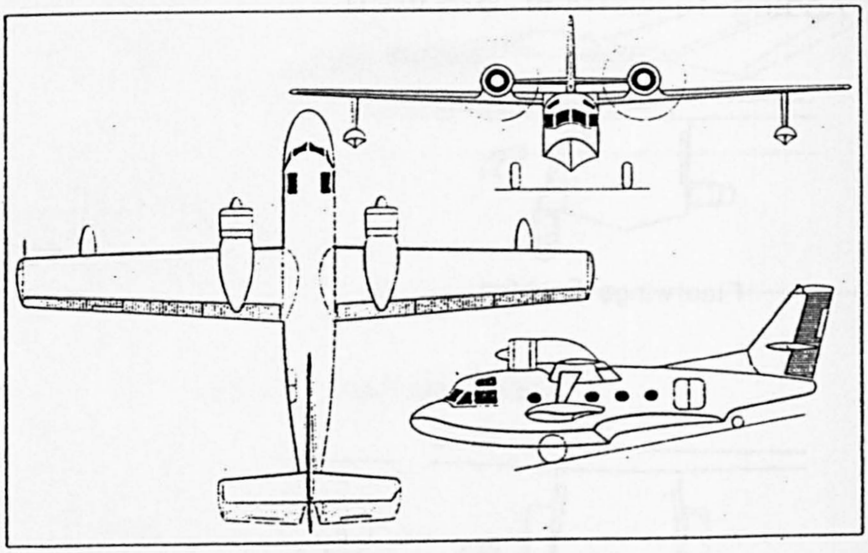


FIGURE 3.19. N17 AND N18 DELFIN

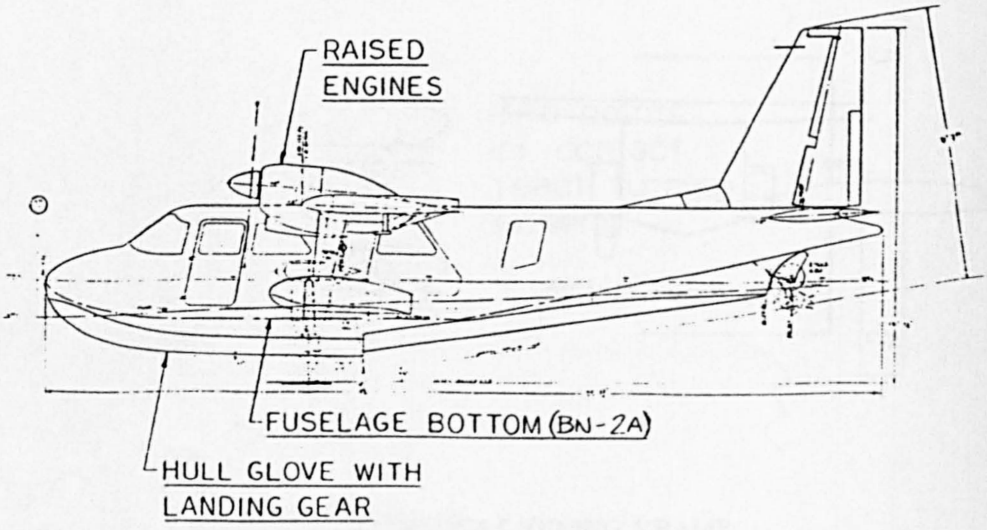


FIGURE 3.20. ISLANDER FLYINGBOAT CONVERSION

PLATE 3.1. CONSOLIDATED CATALINA

PLATE 3.2. SHORTS C CLASS

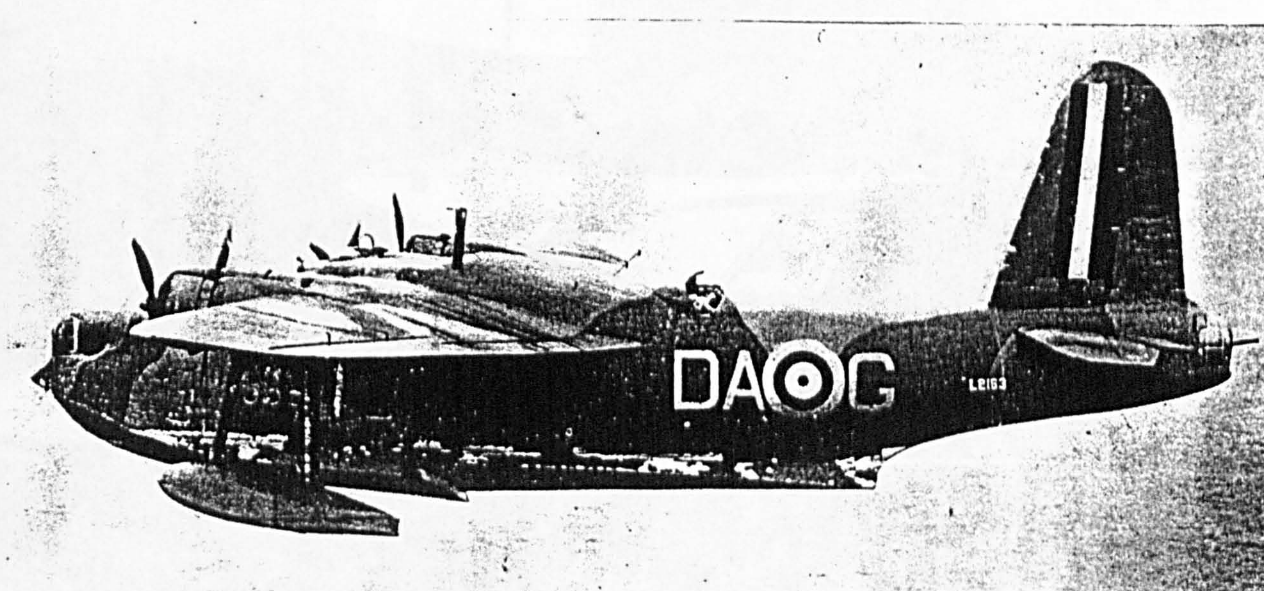


PLATE 3.3. SHORTS SUNDERLAND

PLATE 3.4. LAKE RENEGADE

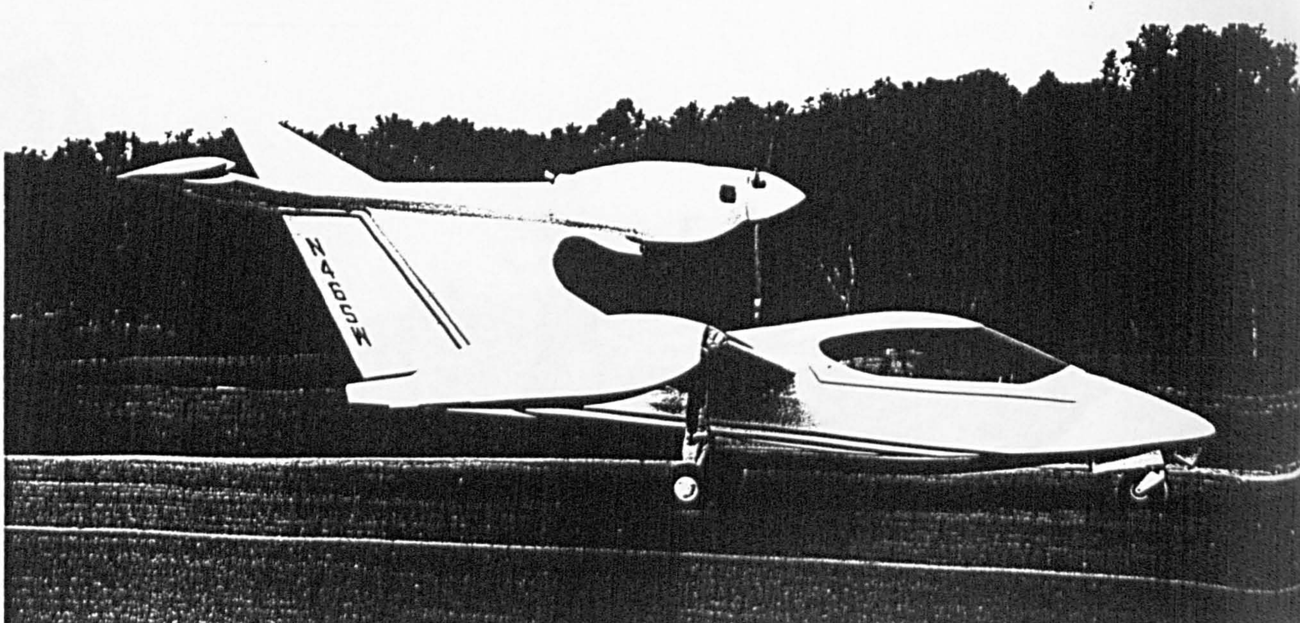


PLATE 3.5. SEAWIND 2000

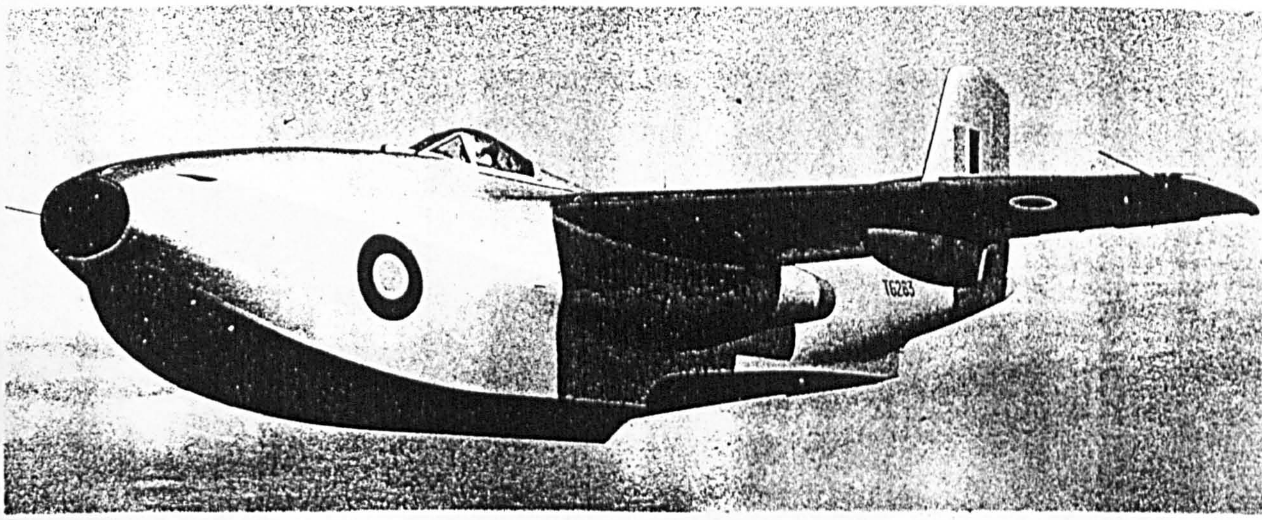
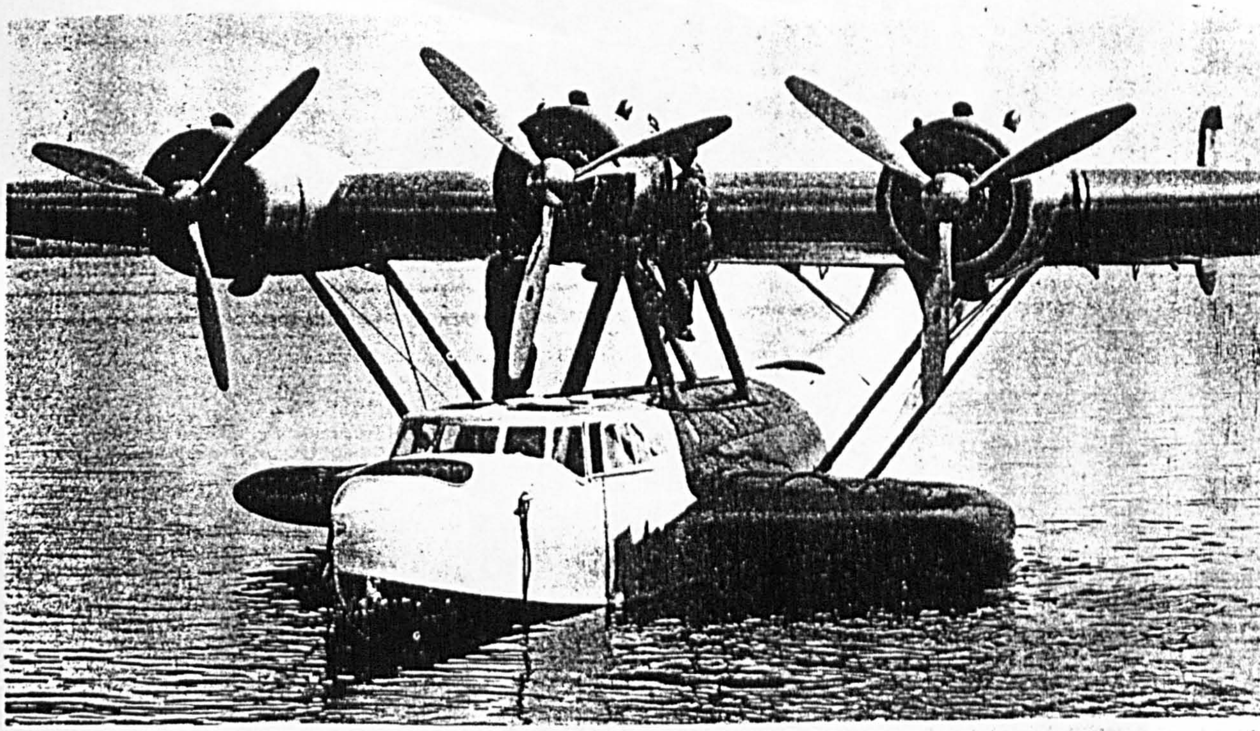


PLATE 3.6. SAUNDERS-ROE SR-A1 FLYINGBOAT FIGHTER



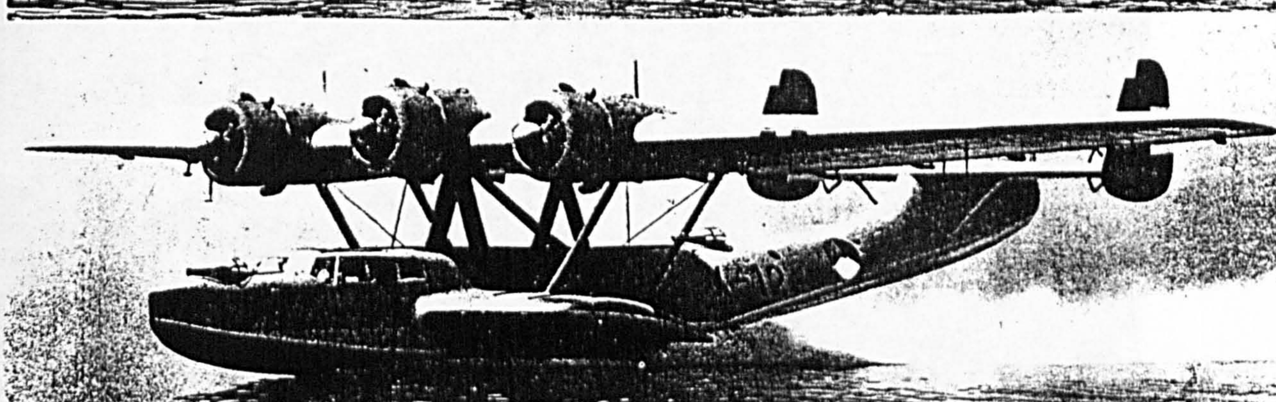


PLATE 3.7 DORNIER 24 STUBS

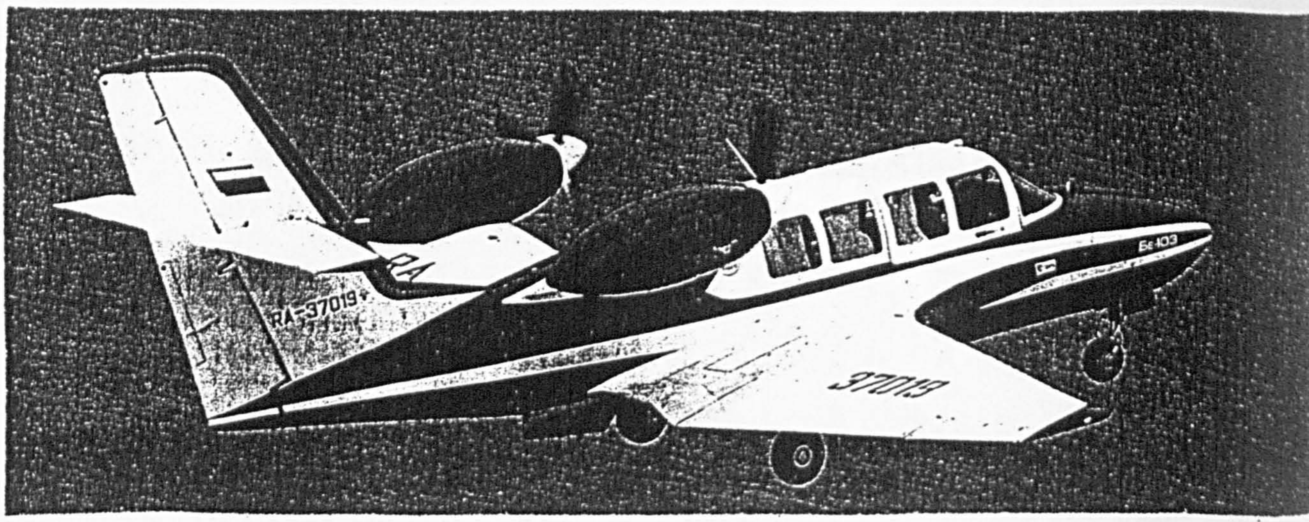


PLATE 3.8 BERIEV BE103

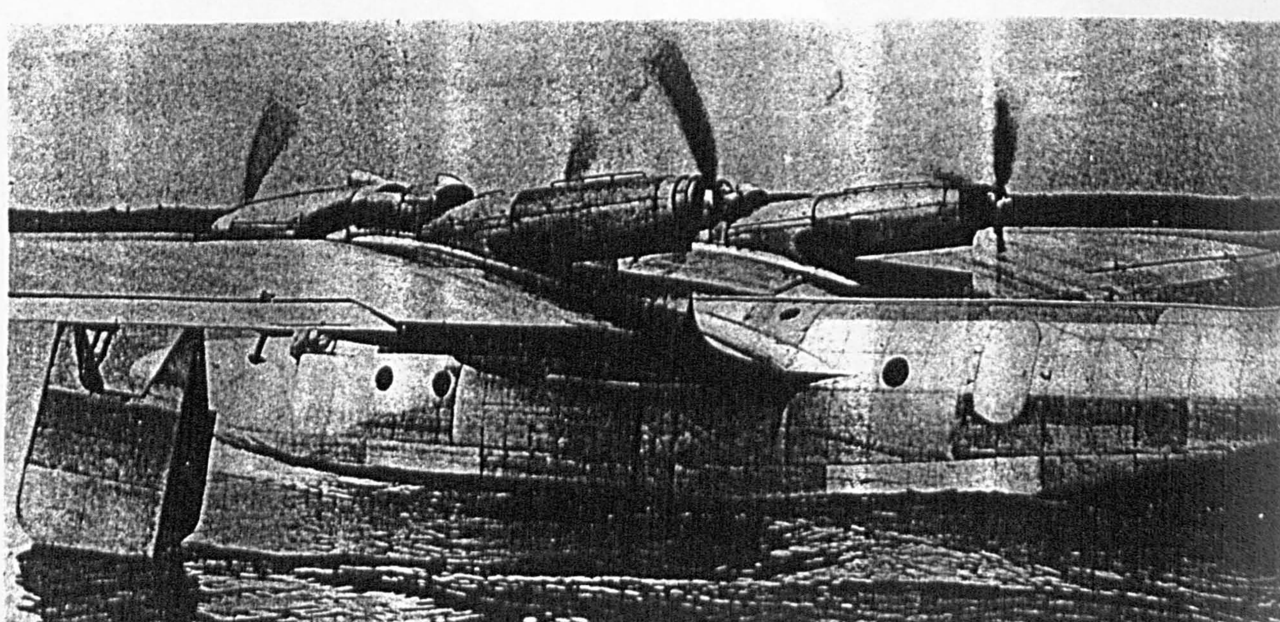


PLATE 3.9 DORNIER DO26

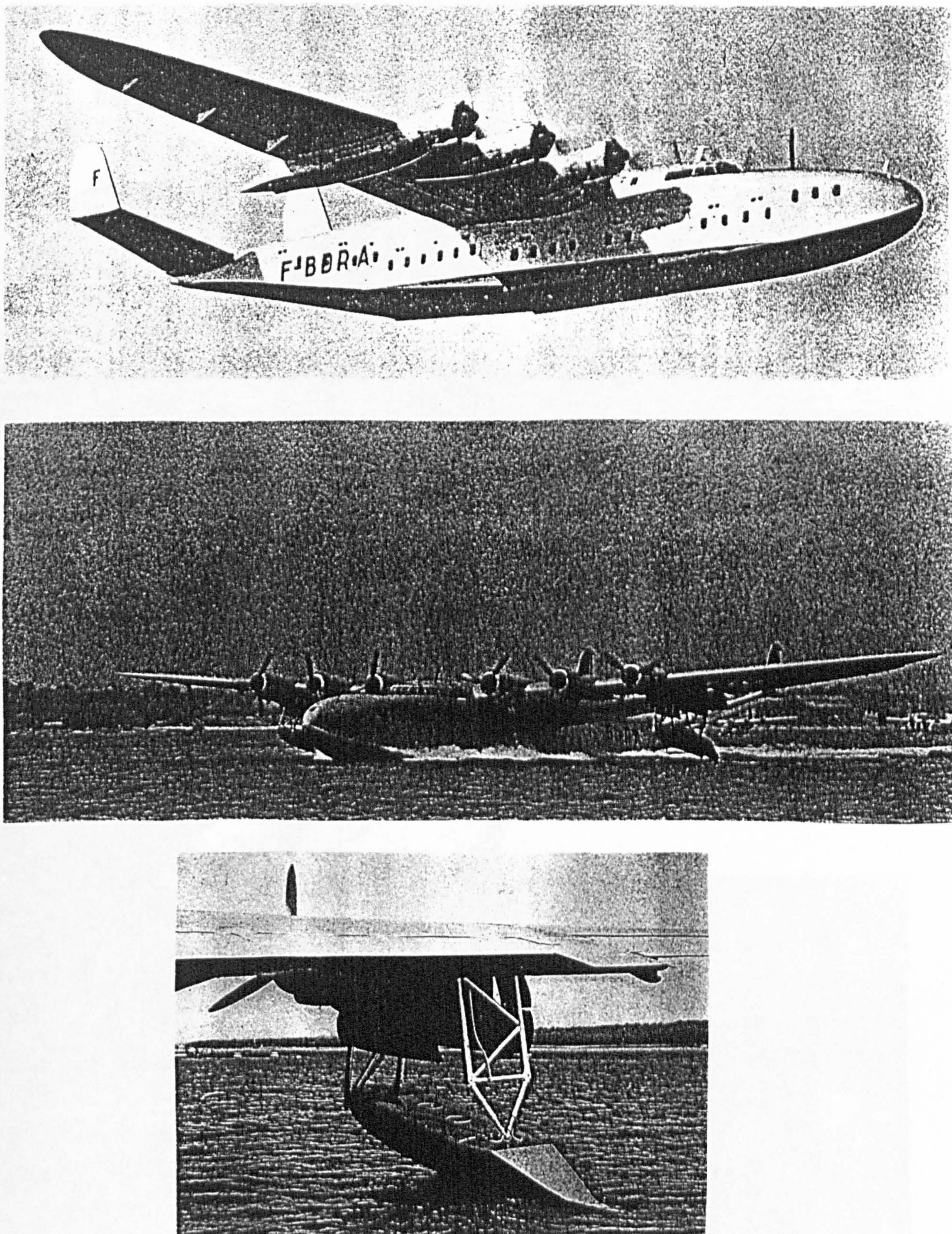


PLATE 3.10a-c. LATECOERE 631

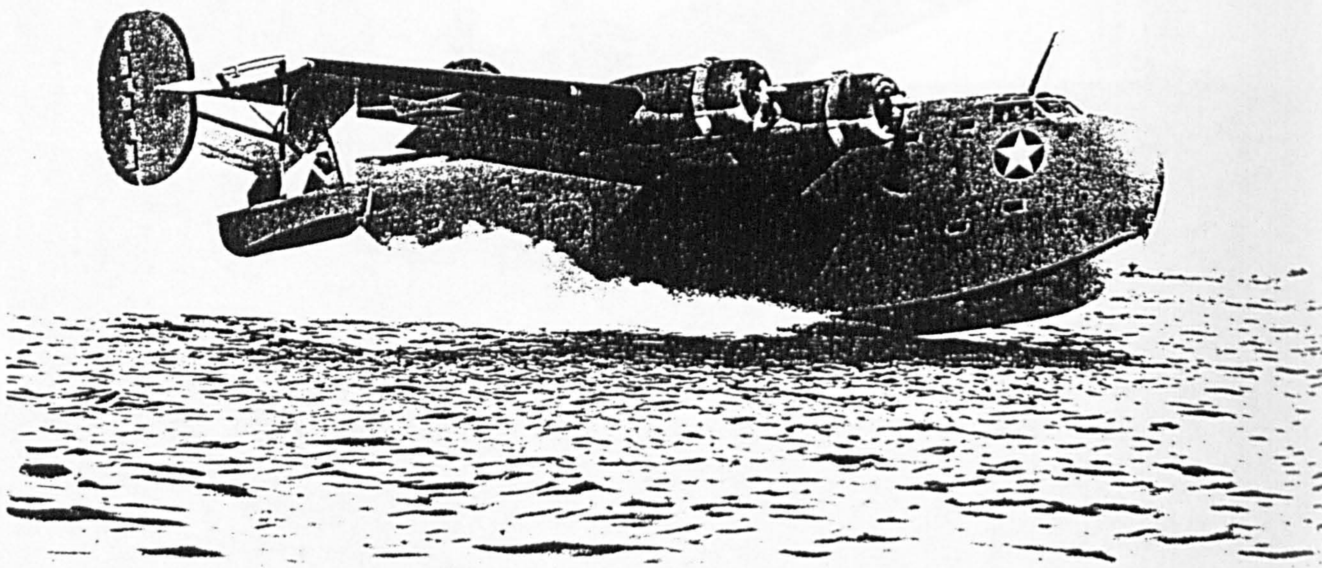


PLATE 3.11 CONSOLIDATED CORONADO

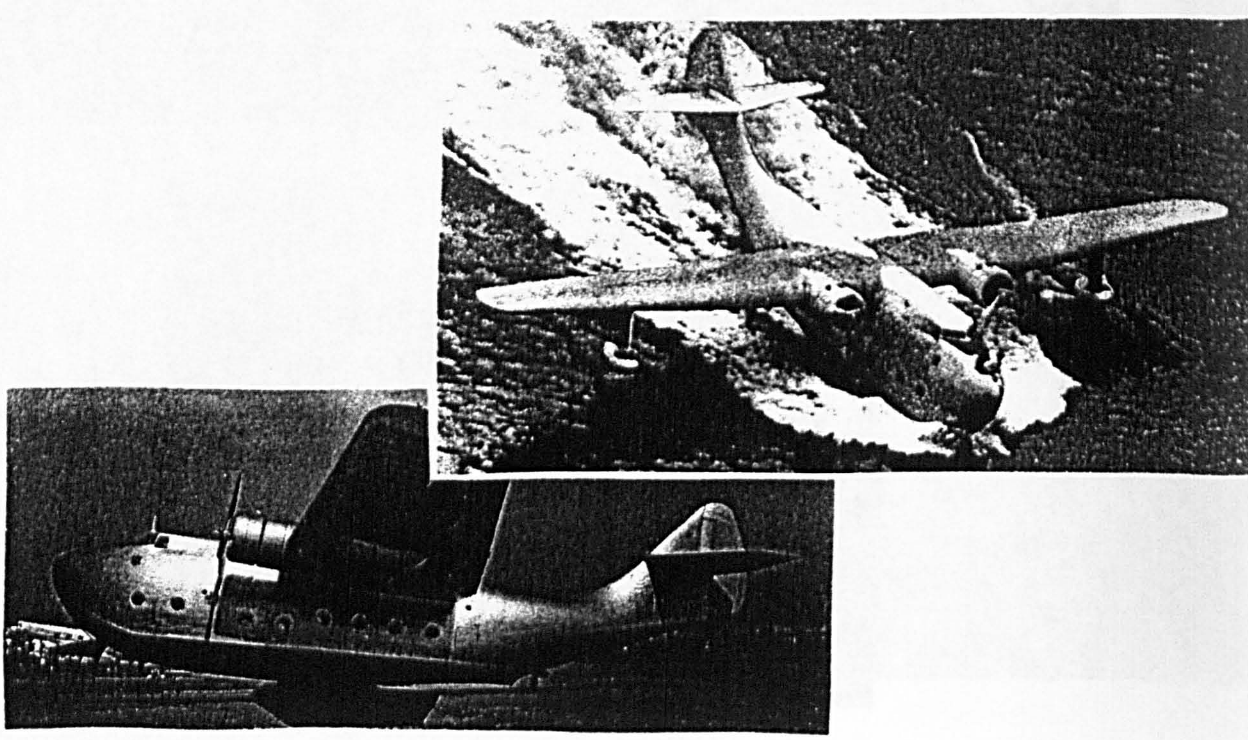


PLATE 3.12a-b. DOUGLAS DF

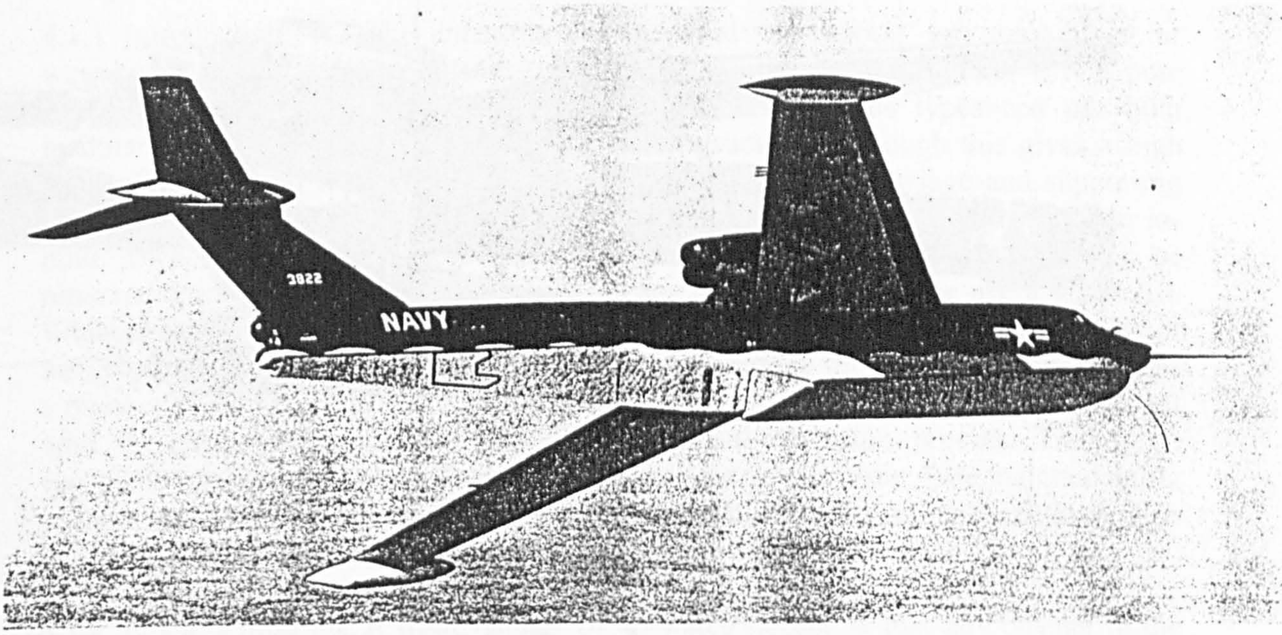


PLATE 3.13. MARTIN SEAMASTER

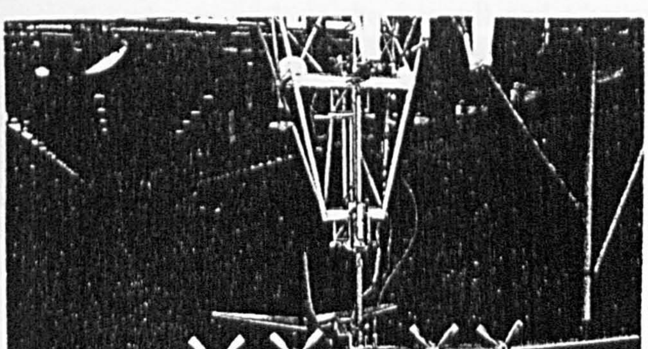


PLATE 3.14 TANK MODEL

PLATE 3.15 RADIO-CONTROLLED MODEL

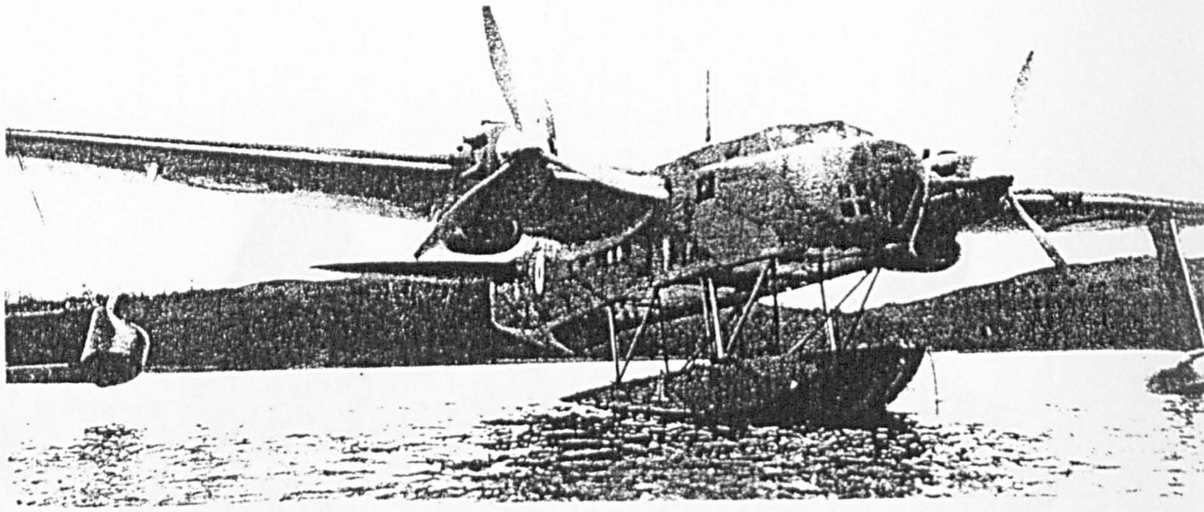


PLATE 3.16. BLACKBURN B20

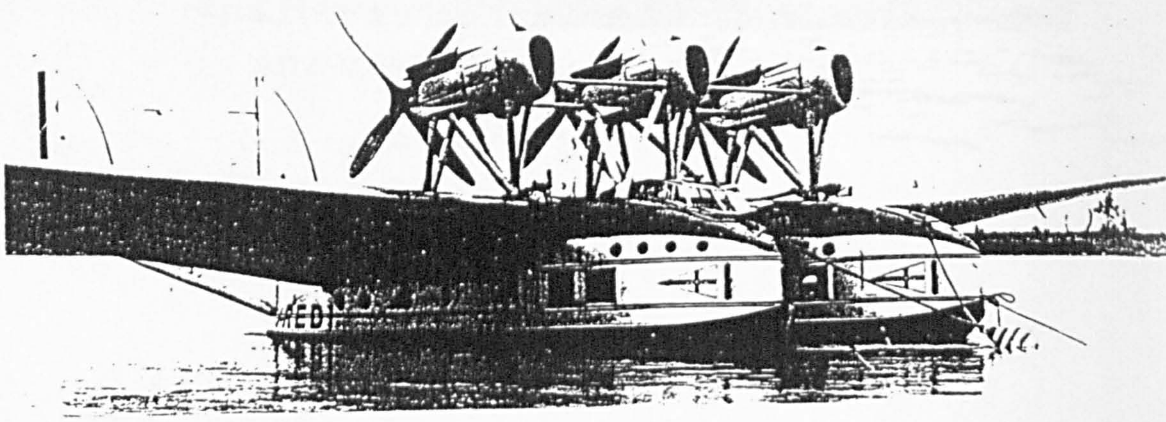


PLATE 3.17. SAVOIA MARCHETTI S55

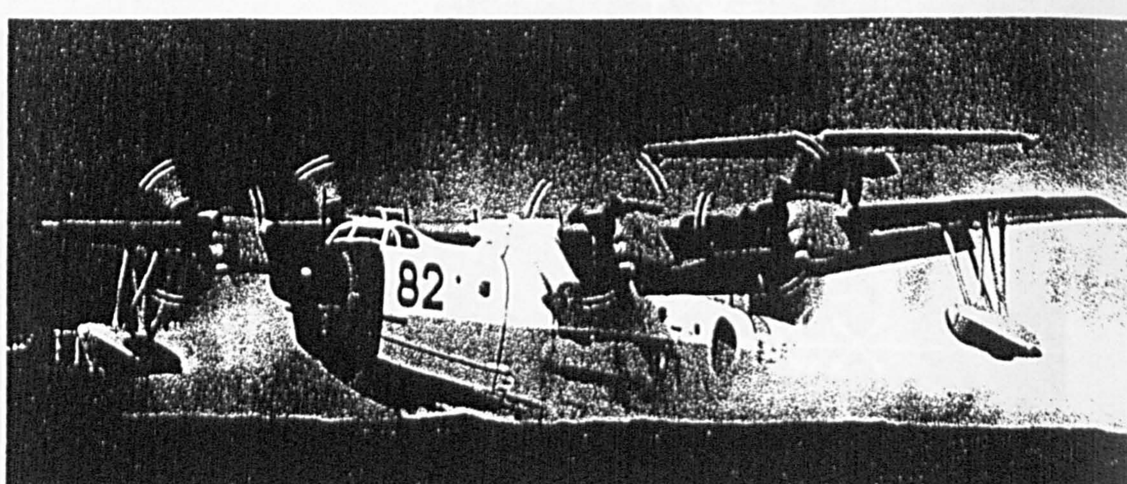


PLATE 3.18. SHIN MEIWA US1

4. OTHER FACTORS COMMON TO FLOATPLANES AND FLYINGBOATS.

4.1 INFRASTRUCTURE.

4.1.1 Introduction. The infrastructure required to support an amphibious or waterborne aircraft largely depends on the class of aircraft and whether it is a pure floatplane or flyingboat, or an amphibious type. Amphibious types can use both landplane and pure flyingboat or floatplane infrastructure. Although this gives a high level of operational flexibility, the mass penalty of the undercarriage and supporting structure must be accepted. However, as pure floatplanes and flying boats have no in-built wheels they must either be stored and serviced on the water at all times, be removed from the water using a distinct means of land transport or use a water lift. Whichever way is chosen by the end-user, an understanding of the types of infrastructure required is essential for the designer. Leaving the aircraft in the water has a number of disadvantages, not least of which is the fact that the structure is in contact with the prime electrolyte for the electro-chemical corrosion process. This is an especially important problem if the aircraft is moored in salt water. The maintainability costs of on-water parking are therefore high and are discussed in more detail in Section 4.3. Servicing and loading the aircraft is also more difficult on water.

4.1.2 In-shore Mooring. A disadvantage of on-water storage is that any change in the water level due to tides or waves (caused by weather or other water users) must be accounted for in the mooring of the aircraft. Thus, if the aircraft is tied to a jetty the hull or floats need to be protected by fenders. If the jetty is not in frequent use these may not be readily available and must therefore be carried in the aircraft - a non-revenue earning mass and volume requirement. The need to tie a flyingboat or floatplane to a jetty also adds the requirement to equip the hull or float with marine fittings such as mooring cleats, and mooring lines and anchors must be carried. Cleats must be fitted to load bearing structure if damage is not to be caused to less robust structure.

4.1.3 Off-shore Mooring. Alternatively, the aircraft can be moored off-shore and passengers or freight shipped out to it. This method is often used for those aircraft with deep drafts which cannot approach the shore without grounding. However, complex buoy systems are required $_{(133)}$ which must not only be quick to use but must also be strong enough to secure the aircraft in poor weather conditions. In some cases flyingboats such as the Seagull and Shetland have been designed with quick release fittings allowing the aircraft to be remotely disconnected from the buoy by operating a lever in the cockpit. However, all buoy systems require complex operations to initially connect the aircraft. Although off-shore mooring simplifies on-shore logistics, the whole range of normal ground-based support equipment must be provided in a floating form. For example, the Martin Mars flyingboats used by Forest Industries Flying Tankers (a firebombing organisation based on a large lake on Vancouver Island, Canada) have oil bowsers and maintenance stands fitted to floating rafts and use high powered tow-boats as aircraft tugs would be used on land. Note that to support only 2 Mars aircraft of Forest Industries Flying Tankers, 3 boats and 4 pontoons are required. Fuel is provided from specialist buoys connected to shore fuel tanks.

4.1.4 Jetties. Although floatplanes and flyingboats can use any sufficiently large jetty, aircraft which carry fare paying passengers or freight can gain in customer acceptance and ease of loading from more optimised jetties which are designed about the shape of the particular aircraft. In the case of relatively austere air taxi services this can be as simple as 2 parallel jetties, but for potential larger users a covered dock may be advantageous. For twin floatplanes or flyingboats with stubs, the width of the jetty is unimportant; however, for flyingboats with tip floats the width of the jetty is limited to the gap between the hull and the floats (see Figure 4.1). Although reversible propellers allow some degree of manoeuvrability, a method of either backing the aircraft into the dock or towing it out is an advantage. During the Second World War aircraft such as the Martin Mars transport used specially shaped, joined jetties known as U-docks to gain immediate access to the freight doors. Additionally, all maintenance could be carried out from these docks with the exception of planing bottom work. Reference 134 quotes a time of 7-8 minutes to dock a Mars. Projected schemes for large-scale post-war flyingboat centres envisaged boats taxiing into covered docks yet being towed out again using a system of lines. Equally ingenious was a method of docking jet transport flyingboats proposed by Stout $_{(92)}$ used an extendible pier and rotating buoy system allowed pilot control of all phases of the incoming and outgoing operation.

4.1.5 Leaving the Water. Although small-scale maintenance can be carried out whilst the aircraft is afloat, major servicing must usually be carried out on land. The simplest way for a floatplane or flyingboat to leave the water is via a ramp. This is a concrete or wooden incline leading from below low water level to above the high water level. Concrete ramps are more durable than wood, but wood is less liable to damage the aircraft. Wooden planks set into concrete is a compromise solution. Ramps are usually set at a slope of less than 1:8 $_{(16)}$. Amphibians can be taxied up and down ramps, but a pure flyingboat or floatplane must either be fitted with beaching units or taxied or pulled up the ramp. For light aircraft it may be possible to taxi up and down a gently sloped wooden (or wood planked concrete) ramp wetted to improve lubrication. In the past more complex ramps have included a turntable to allow the aircraft to be taxied onto the ramp, rapidly turned around and then taxied off again. These complex ramps could also alter their angle using controllable flotation tanks at their water end. In the case of small flyingboats and floatplanes cranes and forklift trucks can be used to hoist aircraft ashore. Similarly, trolleys mounted on tracks can be used to launch and recover aircraft from the water. Both cranes and tracks have also been used or planned in the past for large aircraft. For the largest flyingboats beaching units are required. These are wheeled units which are fitted to pure flyingboats or floatplanes to enable them to taxi up a ramp onto land. Beaching units are often equipped with floatation boxes to enable them to be towed out to the aircraft. If pure flyingboats are detached from their main operating base beaching units must be carried onboard as a mass and volume cost. A further disadvantage of beaching units is the time required to fit then in the water; the Martin Mars units take between 30 minutes to 1 hour to fit. Some aircraft such as the Consolidated Model 31 and the Shin Meiwa PS1 are equipped with retractable beaching units as part of the aircraft. These units are, in essence, lightly loaded undercarriages which allow the aircraft to taxi on land but which cannot be used as undercarriages on which the aircraft can be landed. If the aircraft is not to be taxied onto land a powerful tug or winch unit is required. A compromise between on and off-water storage is a water lift. This is a mechanism which is fitted beside a jetty and, usually using hydraulic power, lifts the aircraft out of the corrosive water, storing it just above high water level.

4.1.6 Support Boats. Although much of the operational flexibility of amphibious aircraft derives from their ability to take-off and land using any clear length of water, an optimised area is an ideal solution. A close approximation to the ideal is represented by one of the plans for the immediately post-War London airport which included a near circular flyingboat lake. In less well-served, utilitarian areas a water patrol may be required to keep landing and take-off areas clear of debris such a floating logs. In tropical regions local animals such as elephants, hippos and crocodiles can also be a hazard (135). For frequently used amphibian landing areas specialist fire-fighting boats may also be required. Such boats are already available for conventional airports with over-water approaches. Equally, the freight and passengers need transport to and from the aircraft in suitable boats or amphibious vehicles such as DUKWs or hovercraft.

4.1.7 Military Options. In the 1940s and 50s the US and UK military experimented with varying degrees of enthusiasm with deployable, mobile on-water servicing platforms to support the operation of flyingboat fighters, patrol and transport aircraft. Reference 136 postulates inflatable platforms, not unlike those used by Forest Industries Flying Tankers, linked to the shore by light metal gangways resting on evenly spaced inflatable pontoons. In order to simplify refuelling, fuel lines would form an integral part of the structure of the gangways, each section being joined by flexible joints. In addition to land-connected jetties of similar format to those described earlier, the US Navy used deep water seaplane support tenders during and immediately after the Second World War. Four such tenders were still in use in 1957. These ships provided full maintenance support to the aircraft, and in one case was a converted amphibious landing ship, the floodable rear deck designed to house landing craft proving ideal for flyingboats (9). Developing an idea first used between the wars, the US Navy also experimented with using a submarine as a flyingboat tender. Inflatable rubber cells were used as a bridge between the submarine and the aircraft. In an example exercise a Martin Marlin was able to come alongside, undertake simulated engine maintenance, take aboard spares and food, refuel and cast-off in 45 minutes (137).

4.2 DESIGN PERFORMANCE INDICATORS.

4.2.1 Introduction. Floatplane derivatives of current utility landplanes are normally afterthoughts to the basic design. Flyingboat designs are often targeted at inappropriate markets or result from individual design organisations' biases towards certain solutions. The overall result is that the waterborne aircraft may not be fulfilling its market potential and operators and governments may be investing in costly airport infrastructure projects when a more optimal solution is available. There was therefore a need to develop a method of quantifying important aspects of flyingboat and floatplane design in a manner which allows the confident completion of assessment and optimisation exercises

4.2.2 Relative Performance Ranking. Discussion with operators enabled an order of importance matrix to be drawn up for major design considerations (see Table 4.1). Note that the type classification of earlier sections has been repeated with the exception of the Private (P) section. Here the difference between the operators of the top-of-the-market, performance-orientated type of aircraft such as the Seawind (see Plate 3.5) and the more utilitarian and often home-built, hobby market was so great as to warrant separate sub-classes: P2 and P1 respectively.

a. STOL. Without exception the ability to take off from the water quickly was the most important factor for all operators. This reflects the desire to quickly leave the potentially damaging environment of waves, other water users and floating debris along with the ability to use short stretches of inland waterways.

b. Payload. Payload was understandably important to the more commercially-orientated operators, although these results are slightly suspect as all the commercial operators contacted were mainly involved in transporting relatively small numbers of passengers as opposed to freight, and therefore mass tended to be more important than volume as long as there was sufficient cabin height for standing. Similar logic applied to firebombers where volume was almost irrelevant compared to mass. Private operators put mass and volume on equal footing as a function of seating 2-6 people comfortably with room for luggage. For floatplane operators the ability to fully utilise the related landplanes AUM despite the addition of floats was paramount. It was implied, although never overtly stated, that many floatplane operators flew above the certified AUM limit of the floatplane in order to use the full seating capability of the landplane's cabin.

c. Water Handling. An equally common requirement was good handling on the water for similar reasons to those for STOL performance. Damaging or uncomfortable dynamic instability was very undesirable. Water handling was particularly important for private users who tended to use the most austere landing and take-off areas. Also, low speed on-water manoeuvrability in close proximity to docks was an important consideration for commercial operators.

d. Volume. Useable volume (ie cabin volume minus crew space) was valued by those operators transporting large goods or by those with small aircraft whose efficient use of available volume was essential. For example, a 4 seater with insufficient space to store 4 people's luggage was not useful. Equally, the ability to carry awkwardly-shaped loads (eg long and thin) was appreciated. Easy access to that useable volume was also very desirable and was allocated a separate, but related performance factor.

e. Maintainability. Maintainability was valued by those operators who were least likely to be able to park or load their aircraft on ramps or airports or would operate on minimal profit margins.

f. Range/Endurance. Range or endurance was only very important to MPA operators but was useful to fire bombers to maximise time in the fire area and add flexibility of basing.

g. Speed. Speed was only very important to the executive transport level of aircraft, although dash speed was viewed as a minor advantage to MPA and fire-fighters.

h. Environmental Impact. The impact of the water-borne aircraft on its environment was generally appreciated by all operators. There was an understanding that the acceptance of flyingboats and floatplanes as neighbours on lakes, rivers and the sea close to either wilderness zones or population centres demanded attention if these areas were to remain accessible to aircraft. The prime environmental impact was unanimously viewed as noise (138). This means not only considering propeller and engine noise for small aircraft, but also aerodynamic noise generated by the chines, step, tip floats and other discontinuities on faster flyingboats.

i. Ease of Loading. The availability of load volume and mass-carrying ability is academic if the payload cannot be actually manoeuvred into and out of the free volume. Equally, loading or unloading in a military scenario, a minimally-supported outback region or in rough water conditions can be vital to a flyingboat operator. The position and size of doorways is therefore an important design consideration.

4.2.2 Relative Ranking Values. Although useful for guidance, this very general relative ranking needed to be converted into a numeric performance indicator to allow alternative design solutions to be quantitatively compared. In this context the inverse order of the ranking becomes a weighting factor (ie the first ranking: 1, generated the highest weighting factor: 9). This results in a significant difference between the most important factor and the least and is therefore more severe than the opinions on which the rankings were based. However, based on the author's experience of using related techniques in industry, this system ensures a clear and meaningful result which concentrates the designer onto the most important factors (see Table 4.1).

4.2.3 Cost-related Performance Indicators. In many cases the performance indicator is relatively easy to derive; for example the take-off distance to 50ft is a well publicised aircraft data item. In many cases performance against these criteria can be related to empty mass/complexity and therefore cost. For example, it is easy to get good loading performance with a large nose door but the structural mass penalty, and therefore cost, is great. To account for this the main performance data item was divided by the empty mass, a sound indicator of cost $_{(44)}$, to produce an indicator relative to a cost function. However, if costs are known these can be used directly. Some difficulty was experienced in identifying suitable performance indicators for maintainability, ease of loading and water handling as these involved subjective viewpoints. Therefore a specific value was developed for these areas. The cost-related performance indicators are therefore as follows:

a. STOL: (1/TO distance)/M_e
b. Payload: Max payload/M_e
c. Range: Max range/M_e
d. Speed: Max level speed/M_e
e. Maintainability: Value/M_e
f. Volume: Useable cabin volume/M_e
g. Water handling: Value/M_e
i. Environmental: Noise level/M_e
h. Ease of loading: Value/M_e

4.2.4 Development of Subjective Indicators.

a. Maintainability. As accurate public domain maintenance costs for an adequate statistical sample of flyingboats and floatplanes were not available, a series of more qualitative factors which could be derived from the database, the specialist press and the author's personal experience were used. These took into account the complexity of systems, the likelihood of water and spray gaining access to critical engine and airframe components and the relative ease of access for pre and post flight maintenance. Ease of maintenance access is expressed in a very relative manner within the mass classes as, for example, access to an engine on a 44.2m span Tradewind cannot be reasonably compared to that for a 11.7m span Lake Renegade. The number and nature of flyingboat-specific mechanical parts such as retractable tip floats was accounted for, along with conventional aircraft parts operating in a water or spray environment such as the undercarriage and flaps. Although not strictly related to purely amphibious operation, the number of engines was included as this configuration choice often has a strong input from the water-borne aspects of the design. These aspects are described in detail in Table 4.2. Note that these factors are for those aspects of the design relating to the amphibious function of the aircraft. For example, the turboprop installation of the CL415 gains a lower, and therefore less good, maintenance score than the piston engined installation of the CL215. This is only due to the requirement to wash the compressor after salt water operations and does not account for the greater maintenance manhours/flying hour required to service piston engines compared to turbines. A similar complementary approach is needed if comparison between more general design aspects is required.

b. Water Handling. In developing a performance indicator for water handling it is assumed that for certification purposes the aircraft has adequate dynamic stability, that is it has no dangerous porpoising or skipping tendencies. The water handling values can therefore be defined by the cumulative importance of maximum operational wave height, wind speed and on-water manoeuvrability. The latter can be expressed in an easily measured term such as water turn radius. If turn radius is not available in a comparative exercise a more physical variable such as the presence of a water rudder, its product of area and moment arm, and the presence of reversible propellers is available for use.

c. Ease of Loading. Ease of loading and unloading freight or embarking and disembarking passengers while the aircraft is on the water was a related issue to payload and available cabin volume. Most aircraft could load easily on a seaplane ramp or conventional airport, although door size, sill height from ground and nature of opening (ie hinge position, shape etc) was important. However, on-water loading onto jetties significantly differentiates the tip float and stub-equipped flyingboats, the former being difficult to manoeuvre into a loading position in all except optimised U-jetties. An ease of loading performance indicator was therefore developed to account for door size and ability to side load straight from the main freight bay onto a jetty. Door sizes were represented as their area in m^2. To represent the ease of using the door, this area was multiplied by 1.5 if a straight path was available from the freight/passenger volume to a side or nose dock (see Figure 4.1a), no multiplier was used if a rotation action was required (see Figure 4.1b), but a multiplication factor of 0.75 was applied if a step was present requiring a lifting operation to load/unload freight from the bay onto a jetty or a specialist U-jetty was required (see Figure 4.1c). A further multiplication factor of 1.25 was applied if a mechanical aid to loading/unloading was built-in as part of the aircraft's design. For example, the Martin Mars had a 5000lb hoist built into the wing. In the case of multiple doors the best product of area and modifier is used. A worked example for the Martin Mars flyingboat is detailed in Appendix 15.

4.2.5 Reference-related Indicator. Whilst specific performance indicators can be used to provide a limited comparison between particular aspects of aircraft, there is a need to produce an overall rating which includes all the factors. When this overall rating is required the nature of the conventional parameters such as payload/M_e do not compare well with the more subjective types of indices such as maintainability. To enable both types of indices to be used together it was necessary to relate them to a known reference aircraft, thus producing a true non-dimensional performance indicator. This process is completed by defining the performance indicators of this reference aircraft as unity and thus any variance from unity be easily used to gain a quantitative indication of the design performance of the aircraft. The next stage was to decide on the reference aircraft in each class/role combination. Only those class/role combinations with 25% or more of the relevant part of the design database were considered to avoid nugatory work, although the technique can be applied to any combination. First, general information on the designs was reviewed and the overall "feel" of a successful aircraft gained. This extremely subjective method was used to identify a maximum of the best overall 5 designs in each class/role combination. These 5 were then awarded marks for numbers built, date of first flight, contemporary engine type and the quality of data held in the database. Details of the mark award technique are as follows:

Number:	prototype only = 0	n≤6 = 1	n>6 = 2
Date:	1936-45 = 0		
	1946-60 = 1		
	1960+ = 2		
Data:	Limited = 0	Good quality/quantity = 1	
Engine:	Obsolete = 0	Modern/relevant = 1	

Note that some aircraft can occur in more than one role, for example the Sunderland range of aircraft and Albatross appear in both T(V) and T(M) roles. The Albatross is assumed to be represented in its turboprop-engined version. In cases where the values produce equal results, for example between the CL415 and the Be12 Mail in the H/T(M) class/role combination, the more modern aircraft was always chosen. In the case of the UL aircraft where 4 from 5 gained a maximum mark of 6, the Glass Goose and Petral were not chosen as they were biplanes and were thus considered as the minority of the overall UL data set. In cases when dates were similar, for example in the UL class, the aircraft for which most information was available was chosen. The results are summarised as follows; note that the magnitude of the total value gives an indication of the validity of the reference aircraft. For example, the choice of the Sunderland range as the H/T(V) reference was gained from a poor score of 3 from a maximum of 6, whilst the CL415 represented the H/T(M) with an excellent score of 6 from a maximum of 6.

SH/T(V) = Convair Tradewind = 5/6
SH/T(M) = Shin Meiwa PS/US1 = 6/6
H/T(V) = Shorts Sunderland = 3/6
H/T(M) = Canadair CL415 = 6/6
M/T(V) = Grumman Albatross = 5/6
M/T(M) = Grumman Albatross = 5/6
LM/T(V) = Dornier Seastar = 4/6
L/U = Lake Renegade = 5/6
L/P = Seawind = 6/6
U/P = Pereira Osprey = 6/6

Having established the reference aircraft in each important class/role combination, the cost-related factors calculated earlier can be expresses as a relation of those of the reference aircraft.

4.2.6 Final PI Calculation. The reference-related indicators can be weighed by the relative ranking values to produce a final performance indicator. Example tables for the SH/T(V) class/role reference aircraft contenders are included in the full example calculation in Appendix 15.

4.3 COST OF OWNERSHIP.

4.3.1 Introduction. Three main factors add to the cost of ownership of an amphibious aircraft compared to that of a land-based machine. The factors of decreased performance and additional infrastructure have been discussed in Sections 2.11, 3.14 and 4.1 respectively. The third factor is the additional cost of maintenance due to the aircraft's operation from water. This additional cost is mainly centred about the inspection for and prevention and removal of corrosion. Little information could be found on actual details of this cost but general guidance from a variety of references are summarised in Appendix 16.

4.4 DESIGN FOR AMPHIBIOUS AIRCRAFT SAFETY.

4.4.1 Introduction. The data of Reference 139 was examined for any relationships where the design of the flyingboat or floatplane could have had an influence on the accident. The following statistics were extracted from the 195 flyingboat and floatplane accidents which occurred on or around the water during 1995 and 1996.

Cause	Flyingboat	Floatplane	TOTAL
Wheels down	10	19	29 (49%)
Hit submerged object	7	4	11 (19%)
Water in hull/float	3	1	4 (7%)
Passenger into prop	0	2	2 (3%)
Porpoising	1	0	1 (2%)
Glassy water	7	5	12 (20%)
TOTAL	28	31	59

Firstly note that of the 195 accidents only 59 (30%) were related to the design of the aircraft. All others were related to pilot factors.

4.4.2 Design Factors.

a. Wheels Down Landing. Inadvertent landing on water with the wheels down was the highest cause of accidents. These are particularly dangerous for amphibious aircraft as the sudden contact between the water and the wheels creates a strong moment which, in the case of a tail wheeled undercarriage, pivots the hull or floats towards the water at a much greater rate than normal, can tear off the undercarriage or if asymmetric, can spin the aircraft onto its side. For nose wheeled undercarriages the centre of gravity to water impact point is even greater, increasing the likelihood of a catastrophic somersault should the nosewheel touch the water first. There are many detailed ways that a pilot can be made aware of the undercarriage position including relatively inexpensive electrical indicators. Even more simple is the provision of small mirrors on flyingboat tip float structures which enable the pilot to see the undercarriage position. Both the Seabee and the Lake Renegade are fitted with these devices yet still occur frequently in the accident statistics.

b. Glassy Water. Although not strictly a design-related accident cause, the vertical disorientation caused by glassy water could be reduced by the development of a cheap radar altimeter. In particularly clear water the bottom of a lake can seem to be the water surface.

c. Submerged Objects. The third most common cause of accidents related to design was impact on submerged objects. Although design cannot result in the objects being avoided, the stiffness and strength of the planing bottom can make a big impact on the survivability of such events. The use of materials such as Kevlar in the construction of composite hulls or floats or as a covering on metal structures maybe a cost effective way of improving their impact resistance, although this may complicate repair and maintainability.

d. Water in Hulls or Floats. The presence of water in the hull or float caused accidents due to balance and trim problems. Although sometimes related to suspected impacts with submerged objects, water in the hull or floats can best be avoided by either good sealing or a minimisation of mechanical fasteners by the use of integrally machined skins or a bonded construction. Each of these options has an upward cost effect. Inspection holes and bilge pumps must have access to all hull and float compartments and bilge pump inlets must ideally be able to empty a compartment when the aircraft is at any attitude.

e. Propeller Accidents. The risk of passengers or crew inadvertently walking into the propeller disk during boarding, exit, mooring or maintenance activities can be minimised by using configurations which shield access routes from the disk.

f. Porpoising. Porpoising can be avoided by careful planing bottom design (see Section 3.15).

g. Inverted Egress. An additional safety related design feature for amphibious aircraft is the need to consider egress from the aircraft if inverted on water $_{(140)}$. The risk of fatalities due to this area of concern is particularly high for low wing aircraft as the normal exit routes are well underwater when the wing is floating on the surface. Water pressure can act to keep doors and canopies tightly shut and therefore some method of either breaking through the canopy, such as the fracture lever as found on the Petral or operating a window to equalise the pressure is required.

4.5 WATER LOADING ON FLOATS AND HULLS.

4.5.1 Introduction. Numerous studies have been carried out on the theory and practical effects of flyingboat and floatplane water impact loads. Reference 141 provides a summary of the research work since 1929, yet concludes that much of the theoretical and tank work did not relate well to actual measurements on real aircraft. It was therefore decided to rely upon the certification authorities' requirements to provide the basis for guidance on hull and float loading due to water forces. Moreover, the more academic references required a level of detailed design knowledge not usually available in the early stages of a float or flyingboat design. However, the certifying authorities' requirements are relatively practical and achievable in comparison, the only information required being mass, longitudinal centre of gravity, stall speed at landing and take-off flap settings and a concept of hull geometry. The most complex requirement is the pitch radius of gyration which needs to be estimated. The method of Reference 80 is used by the author. FAR23 and 25, BCAR Subsection D3, AvP 970 and TCO-C27 were examined at the latest amendment state which could be located. In particular, the BCAR and AvP references were dated in the mid 1950s as they have since become obsolete or have had mention of amphibious aircraft design removed. However, the TCO reference is also dated 1952 yet it is still regarded as the authoritative document by the FAA. The FAR references are dated in the late 1980s. This discrepancy of dates is not deemed important as the actual calculations required are identical between the references; only unit-related factors and clarity of expression vary. Indeed, the validity of old certification documents was discussed during the question session following the author's presentation on flyingboat design at ICAS '96. Knowledgeable members of the audience, including the ex-chief hydrodynamisist at Dornier, agreed that the references were equally valid now as they were in the 1950s. The required calculations are split into 2 main sections, single hull flyingboats (which can also be assumed to apply to single float floatplanes and individual floats of a twin float floatplane) and stabilising floats. Individual floats for twin float floatplanes are accounted for in accordance with FAR 25.525c by halving the AUM and treating them as flyingboat hulls. Note that FAR 25.537 requires that stub loading must be based on applicable test data. A full description of load calculations is at Appendix 17.

4.6 VERTICAL AND TILT FLOAT CONFIGURATIONS.

4.6.1 Introduction. In the early 1960's the US Navy was very concerned about the growth of the Soviet Navy submarine fleet and spent considerable resources investigating 'sea-sitting' dipping sonar-equipped anti-submarine aircraft as a possible solution. It was discovered during trials with a Marlin Marlin (9), that crew fatigue due to seasickness in conventional flyingboats severely reduced the time which an aircraft could remain floating on station. This was due to the high dynamic response of such shallow draft aircraft to even moderate wave patterns. Continuous power was also required to retain control which further reduced the operation's duration. The problem was therefore to develop a system whereby a flyingboat could land at a location in the open ocean, rest virtually motionless for a long period of time and then take-off again. The solution was to raise the hull above the wave system and support it on long, slender vertical floats of sufficient length to ensure that passing waves caused small changes in total displacement (142). The principle of vertical floats was trialed on an unpowered, life-expired Marlin Mariner flyingboat which was towed out to sea and stationed alongside a conventional Mariner. Motion of the vertical float Mariner were imperceptible to the crew, whilst the crew on the conventional aircraft soon became sea-sick. However, the vertical floats fitted to the Mariner were not retractable in any way. The problem of producing practical vertical float systems depended on the aircraft type to which they were to be fitted. Flyingboats needed a system which could be deployed once the aircraft had landed on the sea whilst VTOL and helicopters could use a system which deployed in the hover. Only the former will be considered here.

4.6.2 Rigid Floats. Two types of rigid float systems were postulated. The first, suggested by the Edo Corporation, involved the conversion of a conventional twin floatplane. Each float could be separated into 2 compartments which could rotate at the bow and stern to translate into a square configuration (see Figure 4.2). Similarly a single float floatplane configuration could convert into a diamond array of 2 large and 2 small vertical floats; the tip floats having inflatable vertical floats. The second type of rigid vertical float system was proposed by General Dynamics/Convair and involved the lower forebody and afterbody of a conventional hull being split into fore and aft segments. The forward segment would be hinged at the bow and the aft at the stern and, after landing, the segments would pivot down into vertical positions. Extremely long wing-tip floats were also pivoted to provide the lateral stabilisation. The operation of the configuration involved flooding the segments to lower them into position, then pumping them empty to raise the aircraft.

4.6.3 Inflatable Floats. To avoid the potentially high mass of fixed vertical float systems, inflatable vertical floats were also investigated. The technology was not significantly different from existing emergency flotation gear fitted to helicopters. The main difference was the requirement to frequently and efficiently re-stow the deflated float without damage. Goodyear proposed a design which maintained constant pressure throughout the extension/retraction cycle using a cord fastened to the interior of the float bottom. The cord passed axially upwards through the float to a winding drum. The float was retracted by winding the cord to pull the float into the housing while a relief valve permitted air to escape to atmosphere, thus keeping a fixed pressure inside the float and ensuring that the fabric stayed rigid. The float was extended by reversing the drum while inflating the float. This type of equipment could fit into a flyingboat tip float. The overall mass of this type of system is illustrated in estimates for a XC142A aircraft, the empty mass of which rose from 10462 kg to 12056 kg (9% AUM); this almost halved the payload. Yet for a projected Marlin Marlin vertical float conversion the theoretical time-on-station at a range of 600 nm from base was 80 hours compared to an endurance of 12 hours at that range for a conventional Marlin patrolling at economic cruising speed. The Marlin flyingboat was considered particularly suitable for conversion as its structure required so little potential modification. For example, the hull float deployment doors were not in areas with high hull loading, forward and rear bulkheads easily accommodated the float equipment, the beaching gear loads acting on the fuselage were higher than the calculated float loads and the hydrodynamic tip float loads were higher than the calculated vertical float loads. Based on this theoretical installation General Dynamics/Convair estimated that the additional mass of the system could be as little as 5% AUM.

4.6.4 Vertical Float System Design. The selection procedure for a vertical float design includes the choice of configuration (arrangement and spacing) determining the individual float geometry, estimating damping plate size and calculating vehicle motions for a range of parameters (wave details and aircraft masses). The 3 most practical configurations are diamond, rectangular and triangular. The diamond configuration is best suited to aircraft with 2 floats attached to the wings, for example most conventional flyingboat or single float floatplanes. For helicopters, twin float floatplanes or aircraft with no suitable large span lateral structures the rectangle configuration can be used. The triangle configuration is a modification of the rectangle with a single major vertical float replacing either the fore or aft pair. The exact position of the floats relative to the aircraft will be determined by its dimensions, structure and static stability requirements; it is usually best to maximise the distance between the floats but structural considerations may preclude this. The steadiness of the flyingboat on vertical floats depends on the floats' low degree of hydrodynamic stability. A very stable float such as a conventional, horizontally-orientated floatplane float will follow a wave contour as a large change in displacement is produced by a relatively small change in draft due to wave height. In contrast, vertical floats produce relatively small changes in displacement for even large waves. This instability is only an advantage if it does not become so exaggerated as to erase the restoring moments required to right the craft after it has rolled or pitched because of wave impacts, wind loads, motion through the water or other external forces. In the case of a cylindrical vertical float the degree of wave alleviation is a function of the ratio of the length to diameter. If float diameter is decreased to reduce the righting moment then the length must be increased to hold the volume, and hence displacement, fixed. The righting moment is also a function of float spacing; the greater the spacing the greater the moment. However, larger spacing increases loads on the supporting structure and therefore increases mass. Spacing will also be constrained by the configuration and dimension of the aircraft. Should there be a requirement for the vertical float aircraft to move through the water the cross-sectional shape of the float must be considered in terms of hydrodynamic resistance, structural stiffness, added mass and complexity and the effect of drift and weather-cocking tenancies. Details of damping plate design and simple roll and pitch stability equations are included in Reference 143.

TABLE 4.1

RELATIVE RANKING VALUES

	T(V)		T(M)		U		P1		P2	
	O	V	O	V	O	V	O	V	O	V
STOL	1	9	1	9	1	9	1	9	1	9
Payload	3	7	2	8	2	8	4	6	4	6
Range	5	5	3	7	8	2	7	3	6	4
Speed	9	1	8	2	9	1	8	2	2	8
Maintainability	7	3	5	5	4	6	3	7	9	1
Volume	2	8	7	3	5	5	5	5	5	5
Water Handling	4	6	4	6	3	7	2	8	3	7
Environmental	8	2	6	4	6	4	6	4	7	3
Loading	6	4	9	1	7	3	9	1	8	2

Key: O = order of importance V = ranking value

TABLE 4.2

MAINTAINABILITY FACTORS

Engine Related (E)	Airframe System Related (A)	Value	Column Example Cross Reference
Enclosure - Fully buried/remote actuation *1 Close fitting nacelle/enclosure Moderate protection/enclosure Slight protection/enclosure Open engine/systems		4 3 2 1 0	A
On Water - Very good access/easily reached from cabin Access Good access/access via close hatch *2 Moderate access/access via remote hatch Poor access/difficult access Access not possible		4 3 2 1 0	B
Compressor wash required	Retractable Tip Floats	Yes: 0 No: 2	C
-	Exotic systems for retracting steps etc	Yes: 0 No: 2	D
-	Undercarriage mechanism under water	Both: 0 One only: 1 None: 2 No u/c: 3	E
-	Flap - single/none Complexity - single slotted - double slotted - blown (with slats minus 1)	3/4 2 1 0	F
Number of 1 engines 2 (or gearboxes 3 whichever is the 4 greater) 5+	-	4 3 2 1 0	G

Notes:
1. Includes proximity to water/spray.
2. For airframe systems consider proportion of total (ailerons, elevators, rudder etc) which are accessible.

TABLE 4.3

REFERENCE AIRCRAFT CHOICE

Class	Role	Aircraft	Factors				Total	Choice
			Built	Date	Data	Engine		
SH	T(V)	Tradewind	2	1	1	1	5	✓
		Mars	1	0	1	0	2	
		Princess	0	2	1	1	4	
		Clipper	2	0	0	0	2	
	T(M)	Be200	0	2	0	1	3	
		Be42	0	2	0	1	3	
		Shetland	0	0	1	0	1	
		ShinMeiwa	2	2	1	1	6	✓
H	T(V)	G Class	1	0	0	0	1	
		C Class	2	0	0	0	2	
		Model 130/156	1	0	0	0	1	
		Sunderland	2	0	1	0	3	✓
	T(M)	Marlin	2	1	1	0	4	
		Emily	2	0	0	0	2	
		Sunderland	2	0	1	0	3	
		CL415	2	2	1	1	6	✓
		Mail	2	2	1	1	6	
M	T(V)	Albatross	2	1	1	(1)	5	✓
	T(M)	Albatross	2	1	1	(1)	5	✓
		Bv138	2	0	0	0	2	
LM	T(V)	Seastar	0	2	1	1	4	✓
		Sealand	2	1	1	0	4	
		Piaggio P136	2	1	1	0	4	
		Goose	2	0	1	0	3	
L	U	Seabee	2	1	1	0	4	
		Equator	0	2	1	1	4	
		Renegade	2	2	1	1	6	✓
		Flamingo	0	2	0	1	3	
		Be103	0	2	0	1	3	
	P	Seawind	2	2	1	1	6	✓
		Renegade	2	2	1	1	6	
		Equator	0	2	1	1	4	
UL	P	Petral	2	2	1	1	6	
		Osprey	2	2	1	1	6	✓
		Airshark	2	2	0	1	5	
		Glass Goose	2	2	1	1	6	
		Teal	2	1	1	1	5	

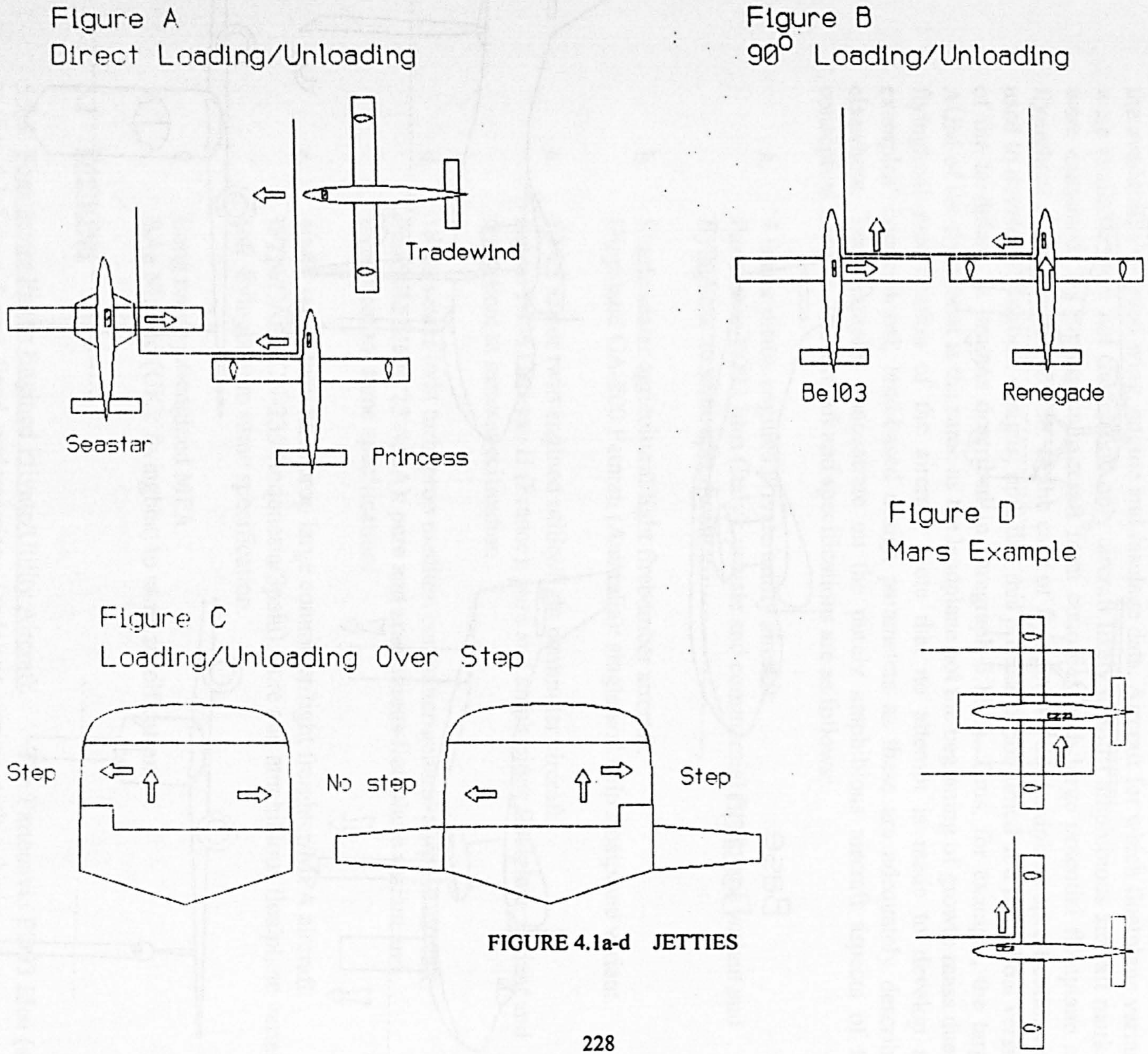


FIGURE 4.1a-d JETTIES

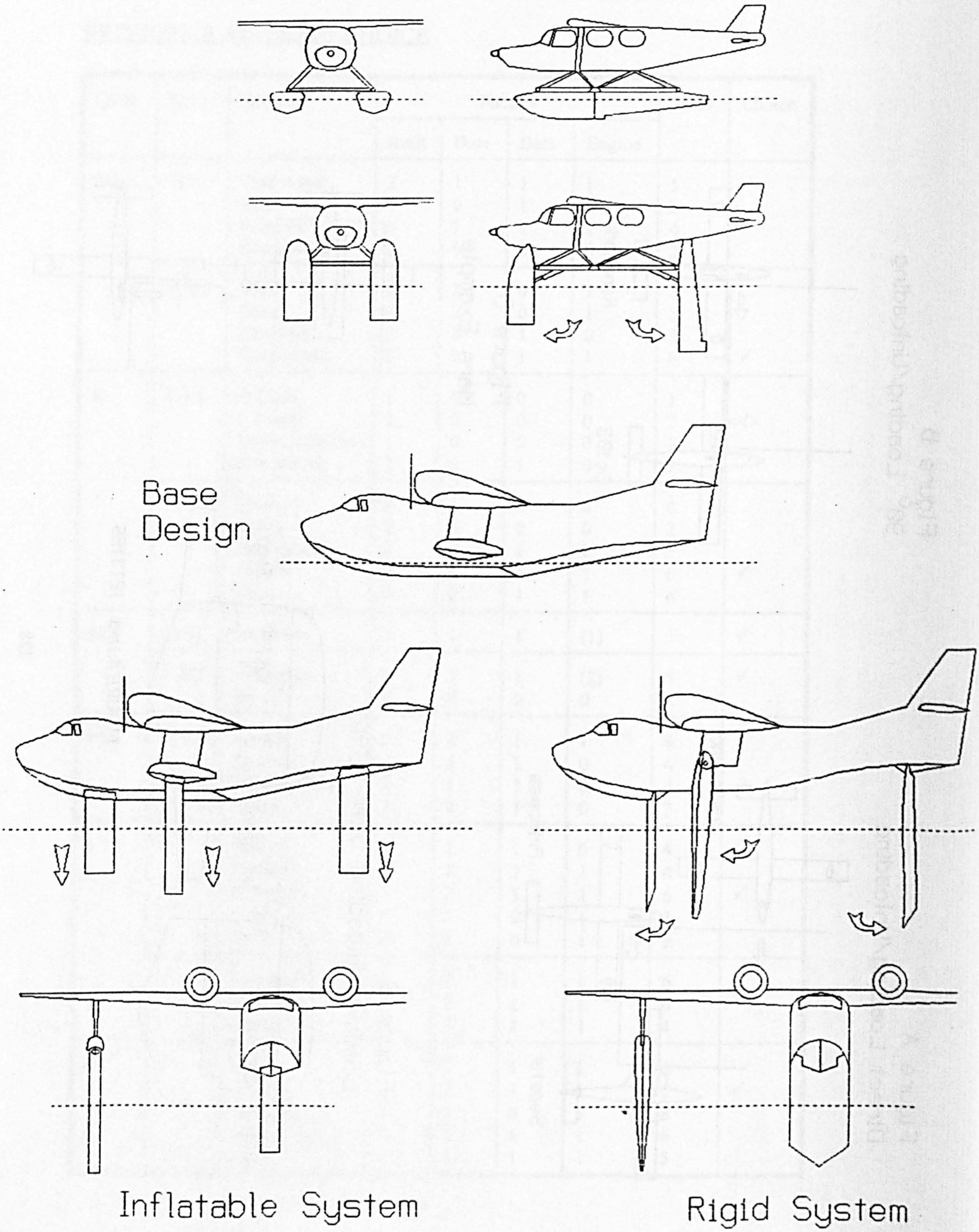


FIGURE 4.2 VERTICAL AND TILT FLOAT SYSTEMS

5. USING THE METHODOLOGIES

5.1 INTRODUCTION

This section of the study uses the methodologies to design floatplane versions of existing aircraft and flyingboats to similar specifications. The existing aircraft and specifications were chosen from Janes All the World's Aircraft 1996/7 $_{(144)}$ and were either recently produced aircraft or likely-to-materialise designs. Another input into aircraft/specification choice was the availability of good wing, engine and fuselage data. Aircraft for which floatplane variants were available were not chosen and only aircraft likely to fulfil amphibious aircraft markets were examined. By preference, aircraft from countries with large potential floatplane and flyingboat markets were chosen. In the case of flyingboats, the landplane specifications are used to develop flyingboat designs; note that this process is not aimed at a flyingboat version of the landplane (a process described in paragraph 3.18.6). Thus, for example, the target AUM of the flyingboat is the same as the landplane not the beginning of growth mass due to flyingboat modification of the aircraft. Note that no attempt is made to develop the examples' conventional, land-based design parameters as these are adequately described elsewhere. The examples concentrate on the purely amphibious aircraft aspects of the conceptual designs. The aircraft and specifications are as follows:

a. 4 seater piston engined private/utility aircraft:
Partenavia PD93 Idea (Italy): private and commercial floatplane variant and flyingboat to same specification.

b. Single seater agricultural/light firebomber aircraft:
Gippsland GA-200 Fatman (Australia): single and twin floatplane variant.

c. 10-12 seater twin engined utility/light commuter aircraft:
Reims F406 Caravan II (France): pure and amphibious floatplane variant and flyingboat to same specification.

d. 18-20 seater twin turboprop medium commuter/general purpose aircraft:
Fairchild Metro 23 (USA): pure and amphibious floatplane variant and flyingboat to same specification.

e. 40-44 seater twin turboprop large commuter/light freighter/MPA aircraft:
IPTN/CASA CN-235 (Indonesia/Spain): pure and amphibious floatplane variant and flyingboat to same specification.

f. Long range jet-engined MPA:
BAe Nimrod (UK): flyingboat to same specification.

5.2 DESIGNS

5.2.1 Four-seater Piston Engined Private/Utility Aircraft. The Partenavia PD93 Idea (see Figure 5.1a) is a 4 seat fixed undercarriage landplane design with a high wing currently under study in Italy. The aircraft will be powered by a Textron Lycoming IO-360-A1B6 (200hp) piston engine. The PD93 is developed into both a pure and amphibious private and commercial utility floatplane and amphibious utility flyingboat using the methodologies.

Relevant specifications are as follows:

wing span = 11m
overall length = 8m
V_{max} = 370km/hr
cabin volume = 2.5m^3
fin area = 1.6m

wing area = 17.05m^2
empty mass = 770kg
$V_{stall\ (flaps\ up)}$ = 104km/hr
door size = 0.89m^2
fin arm = 4.25m

fuselage width = 1.2m
AUM = 1250kg
range(75%power)=1400km
ROC = 289m/min

Conceptual design calculations in accordance with the relevant parts of the thesis were undertaken and the results are summarised below. Design A is a private floatplane with pure composite floats, Design B is a commercial floatplane with metal amphibious floats and Design C is a flyingboat. The results are reviewed in the Discussion chapter. Detailed calculations are included in Appendix 18.

a. Common Design Outcomes.

	Basis Design	Design A	Design B	Design C
structural mass change (kg)	-	-8.5	+23	+40
anchor mass (kg)	-	3.1		
change in payload	-	+1%	-5.4%	-9%

b. Floatplane Specific Outcomes.

	Basis Design	Design A	Design B
float length (m)	-	5.25	
float beam (m)	-	0.7	
float height (m)	-	0.6	
float forebody length (m)	-	2.6	
minimum(spray) height (m)	-	0.69	
maximum (stability) height (m)	-	1.69	
float separation (m)	-	1.95	
float purchase price ($)	-	6625	17000
max speed (km/hr)	370	321	
range (km)	1400	1218	
ROC (m/min)	289	246	

c. Flyingboat Specific Outcomes.

	Design C
flyingboat configuration	HE-P
tip float dimensions	$v = 0.1m^3$ $l = 0.96m$ $b = 0.32m$
planing bottom dimensions	$l = 7.1m$ $b = 1.2m$ $l_{fb} = 4.2m$ $l_{ab} = 2.9m$ $area = 3.3m^2$ $\beta = 16°$
masses (kg)	$m_{pb} = 37.5$ $m_{add} = 25.5$ $m_{tip} = 14.8$
draft (m)	0.34
spray height (m)	0.91m
take-off distance (m)	329
take-off time (sec)	19
landing distance (m)	500
C_{D0}	0.03897

The final configuration is shown in Figures 5.1b and c.

5.2.2 Single-seater Agricultural/Light Firebomber. The Gippsland GA-200 Fatman (see Figure 5.2a) is a 2-seat agricultural aircraft powered by a Textron Lycoming O-540-H2A5 flat 6 piston engine. The Fatman is a good potential amphibious light firebomber as it is already equipped for laying liquid crop sprays. In addition, it has a corrosion-resistant structure and its 2-seat layout increases safety and control in the firebombing role. The Fatman is developed into both a single and twin pure float floatplane to illustrate the use of these methodologies. Relevant specifications are as follows:

wing span = 11.93m	wing area = $19.6m^2$	overall length = 7.48m
empty mass = 770kg	AUM = 1315kg	TO run = 340m
V_{max} = 185km/hr	ROC = 295m/min	range = unknown

Conceptual design calculations in accordance with the relevant parts of the thesis were undertaken and the results are summarised below. Design A is a twin float configuration and Design B is a single float design. The results are reviewed in the Discussion chapter. Detailed calculations are included in Appendix 18.

a. Common Design Outcomes.

	Basis Design	Design A	Design B
structural mass change (kg)	-	+97	+81
anchor mass (kg)	-	3.6	
change in payload	-	-18%	-16%

b. Floatplane Specific Outcomes.

	Basis Design	Design A	Design B
float length (m)	-	5.37	6.55
float beam (m)	-	0.72	0.95
float height (m)	-	0.61	0.74
float forebody length (m)	-	2.7	3.64
minimum(spray) height (m)	-	0.7	0.61
maximum (stability) height (m)	-	2	-
float separation (m)	-	1.98	-
float purchase price ($)	-	26059	-
max speed (km/hr)	185	161	
range (km)	not known	-	
ROC (m/min)	295	251	

The final configurations are shown in Figures 5.2b and c.

5.2.3 Twin Piston Engined Utility/Light Commuter. The Reims F406 Caravan II (see Figure 5.3a) is an unpressurised light aircraft carrying up to 12 passengers. It has a low wing, retractable undercarriage and is powered by twin Pratt & Whitney Canada PT6A-112 turboprops. The methodologies were used to design an amphibious floatplane and a commuter/utility flyingboat. Relevant specifications (including optional cargo door) are as follows:

wing span = 15.08m	wing area = 23.48m^2	overall length = 11.89m
empty mass = 2460kg	AUM = 4468kg	fuselage width = 1.6m
V_{max} = 424km/hr	ROC = 564m/min	range = 2135km
cabin volume = 8.64m^3	door size = 1.57m^2	TO run = 526m
tailplane arm = 5.84m	$V_{TO(flaps\ up)}$ = 174km/hr	

Conceptual design calculations in accordance with the relevant parts of the thesis were undertaken and the results are summarised below. Design A is a pure floatplane, Design B is an amphibious floatplane and Design C is a flyingboat. The results are reviewed in the Discussion chapter. Detailed calculations are included in Appendix 18.

a. Common Design Outcomes.

	Basis Design	Design A	Design B	Design C
structural mass change (kg)	-	+265.3	+471.3	+94.2
anchor mass (kg)	-		4.3	
change in payload	-	-13%	-24%	-6%

b. Floatplane Specific Outcomes.

	Basis Design	Design A	Design B
float length (m)	-	8.9	
float beam (m)	-	1.2	
float height (m)	-	1.01	
float forebody length (m)	-	4.5	
minimum(spray) height (m)	-	1.1	
maximum (stability) height (m)	-	10.76	
float separation (m)	-	2.06	
float purchase price ($)	-	123944	248696
max speed (km/hr)	424	331	
range (km)	2135	1665	
ROC (m/min)	564	429	

c. Flyingboat Specific Outcomes.

	Design C
flyingboat configuration	HW
tip float dimensions	v = 026m^3 l = 1.33m b = 0.44m
planing bottom dimensions	l = 10.8m b = 1.6m l_{fb} = 5.6m l_{ab} = 5.2m area = 8.1m^2 β = 16°
masses (kg)	m_{pb} = 97 m_{add} = 68.2 m_{tip} = 46
draft (m)	0.54
spray height (m)	1.38
take-off distance (m)	879
take-off time (sec)	30
landing distance (m)	1336
C_{D0}	0.03982

The final configurations are shown in Figures 5.3b and c.

5.2.4 Twin Turboprop Medium Commuter/General Purpose Aircraft. The Fairchild Metro 23 (see Figure 5.4a) is a medium sized, low-winged 20 seater commuter aircraft powered by 2 Allied Signal TPE331-11U-6 turboprops. It has a retractable undercarriage and is available in a variety of civil and military variants including commuter, freighter, medivac, surveillance and airborne early warning roles. It is therefore suitable for modification as a floatplane or as the basis for a flyingboat to either extend its commercial operations into austere or coastal/lake areas or to increase military flexibility, especially in the surveillance role. Relevant specifications are as follows:

wing span = 17.37m	wing area = 28.71m^2	overall length = 18.09m
empty mass = 4309kg	AUM = 7484kg	
V_{max} = 455km/hr	ROC = 243m/min	range = 2065km
cabin volume = 16.62m^3	door size = 1.755m^2	TO run = unknown
tailplane arm = 8.58m	$V_{TO(flaps\ up)}$ = 191km/hr	fuselage width = 1.76m

Conceptual design calculations in accordance with the relevant parts of the thesis were undertaken and the results are summarised below. Design A is a pure floatplane, Design B is an amphibious floatplane and Design C is a flyingboat. The results are reviewed in the Discussion chapter. Detailed calculations are included in Appendix 18.

a. <u>Common Design Outcomes</u>.

	Basis Design	Design A	Design B	Design C
structural mass change (kg)	-	781.4	1077.9	151.1
anchor mass (kg)	-	7.2		
change in payload	-	-16%	-25%	-4%

b. <u>Floatplane Specific Outcomes</u>.

	Basis Design	Design A	Design B
float length (m)	-	9.5	
float beam (m)	-	1.27	
float height (m)	-	1.08	
float forebody length (m)	-	4.75	
minimum(spray) height (m)	-	1.23	
maximum (stability) height (m)	-	2.9	
float separation (m)	-	3.05	
float purchase price ($)	-	239251	465848
max speed (km/hr)	455	350	
range (km)	2065	1590	
ROC (m/min)	243	185	

c. Flyingboat Specific Outcomes.

	Design C
flyingboat configuration	HW
tip float dimensions	v = 43m^3 l = 1.57m b = 0.52m
planing bottom dimensions	l = 14.2m b = 1.76m l_{fb} = 6.2m l_{ab} = 8.01m area = 14.6m^2 β = 16°
masses (kg)	m_{pb} = 150.4 m_{add} = 71.1 m_{tip} = 80
draft (m)	0.54
spray height (m)	1.2
take-off distance (m)	1296
take-off time (sec)	41
landing distance (m)	1970
C_{D0}	0.0418

The final configurations are shown in Figures 5.4b and c.

5.2.5 Twin Turboprop Large Commuter/Light Freighter/MPA. The Airtech (IPTN/ CASA) CN-235 (see Figure 5.5a) is a medium sized military and civil freighter which is also used as a maritime patrol aircraft. The CN-235 is powered by 2 General Electric CT7-9C turboprop engines, can seat up to 44 passengers, a variety of freight containers or can be equipped with a 360° surveillance radar and weapons in the patrol role. It has a high wing and a rear loading ramp. It is therefore suitable for a floatplane modification or as the basis for a flyingboat to either extend its commercial operations into austere or coastal/lake areas or to increase military flexibility, especially in the surveillance role. In common with similar types of freighter it can also use palletised firebombing equipment. Relevant specifications (military version) are as follows:

wing span = 25.81m	wing area = 59.1m^2	overall length = 21.40m
empty mass = 8800kg	AUM = 16000kg	TO run (Srs 200) = 1051m
V_{max} = 445km/hr	ROC = 465m/min	range (with max payload) = 1528km
cabin volume = 43.24m^3		door size (aperture) = 4.465m^2
tailplane arm = 11.25m	$V_{TO(flaps\ up)}$ = 186km/hr	fuselage width = 2.7m

Conceptual design calculations in accordance with the relevant parts of the thesis were undertaken and the results are summarised below. Design A is a pure floatplane, Design B is an amphibious floatplane and Design C is a flyingboat. The results are reviewed in the Discussion chapter. Detailed calculations are included in Appendix 18.

a. Common Design Outcomes.

	Basis Design	Design A	Design B	Design C
structural mass change (kg)	-	+1025	+1577	+413.8
anchor mass (kg)	-	15.3		
change in payload	-	-14%	-22%	-6%

b. Floatplane Specific Outcomes.

	Basis Design	Design A	Design B
float length (m)	-	11.2	
float beam (m)	-	1.5	
float height (m)	-	1.27	
float forebody length (m)	-	5.6	
minimum(spray) height (m)	-	1.6	
maximum (stability) height (m)	-	-3.2*	
float separation (m)	-	-	
float purchase price ($)	-	630355	1079000
max speed (km/hr)	445	347	
range (km)	1528	1192	
ROC (m/min)	465	353	

* see Appendix 18

c. Flyingboat Specific Outcomes.

	Design C
flyingboat configuration	HW
stub dimensions	$v = 13.98m^3$ $l_1 = 5.48m$ $l_2 = 3.78m$ $b = 2.54m$ $t = 0.74m$
planing bottom dimensions	$l = 18.89m$ $b = 2.7m$ $l_{fb} = 9.45m$ $l_{ab} = 9.44m$ $area = 19.3m^2$ $\beta = 20°$
masses (kg)	$m_{pb} = 252.8$ $m_{add} = 155.3$ $m_{tip} = 243.2$
draft (m)	1.28
spray height (m)	2.9
take-off distance (m)	1257
take-off time (sec)	40.5
landing distance (m)	1911
C_{D0}	0.0391

The final configurations are shown in Figures 5.5b and c.

5.2.6 Long Range Jet-engined MPA. The BAe Nimrod MR2 (see Figure 5.6a) is a large, jet-powered, long range maritime patrol aircraft. The Nimrod is powered by 4 Rolls Royce Spey low by-pass ration turbojets each of 54KN thrust. Relevant specifications are as follows:

wing span = 35.0m	wing area = $197m^2$	overall length = 39m
empty mass = 39000kg	AUM = 87090kg	TO run = 1463m
V_{max} = 817km/hr	range = 9200km	fuselage width = 2.95m
cabin volume = $73.1m^3$	tailplane arm = 19.5m	$V_{TO(flaps\ up)}$ = 150km/hr

Conceptual design calculations in accordance with the relevant parts of the thesis were undertaken and the results are summarised below. The results are reviewed in the Discussion chapter. Detailed calculations are included in Appendix 18.

a. Common Design Outcomes.

	Basis Design	Flyingboat Design
structural mass change (kg)	-	+1340
change in payload	-	-3%

b. Flyingboat Specific Outcomes.

flyingboat configuration	HW-J
tip float dimensions	$v = 2.74m^3$ $l = 2.91m$ $b = 0.97m$
planing bottom dimensions	$l = 39m$ $b = 2.95m$ $l_{fb} = 23.45m$ $l_{ab} = 15.55m$ $area = 60.5m^2$ $\beta = 22°$
masses (kg)	$m_{pb} = 906$ $m_{add} = 383$ $m_{tip} = 918$
draft (m)	1.5
spray height (m)	3.25
take-off distance (m)	2186
take-off time (sec)	44
landing distance (m)	3323
C_{D0}	0.02122

The final configuration is shown in Figures 5.6b.

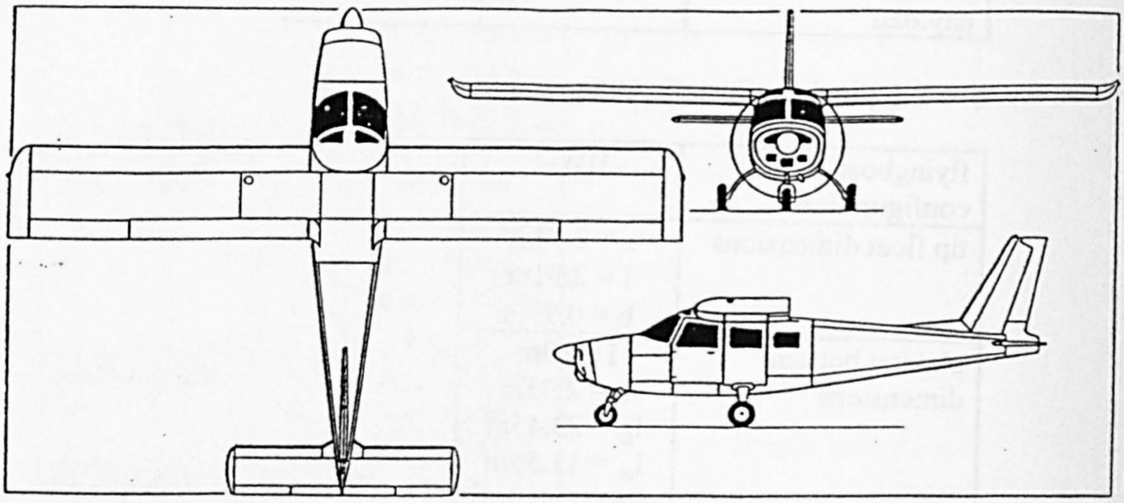


FIGURE 5.1a PARTENAVIO P93 IDEA LANDPLANE

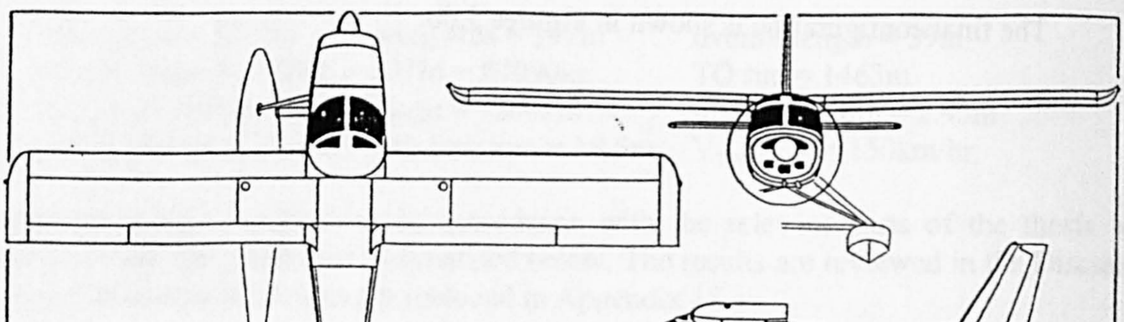


FIGURE 5.1b PARTENAVIO P93 IDEA FLOATPLANE

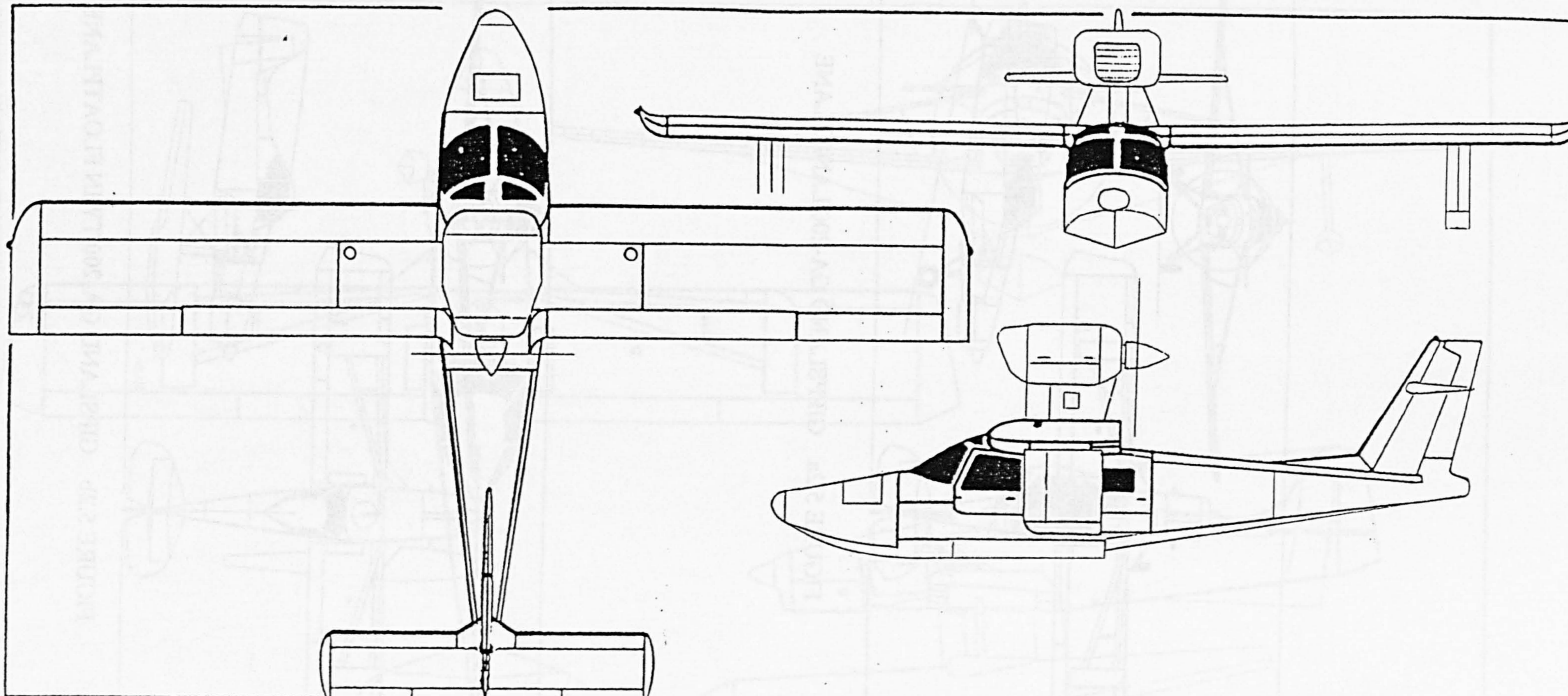


FIGURE 5.1c PARTENAVIO P93 IDEA FLYINGBOAT

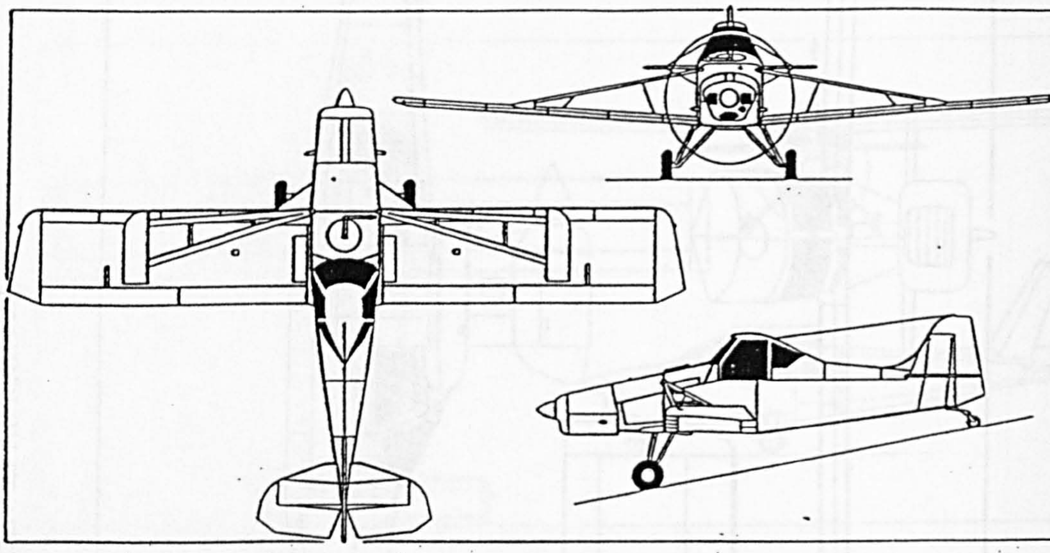


FIGURE 5.2a GIPPSLAND GA-200 LANDPLANE

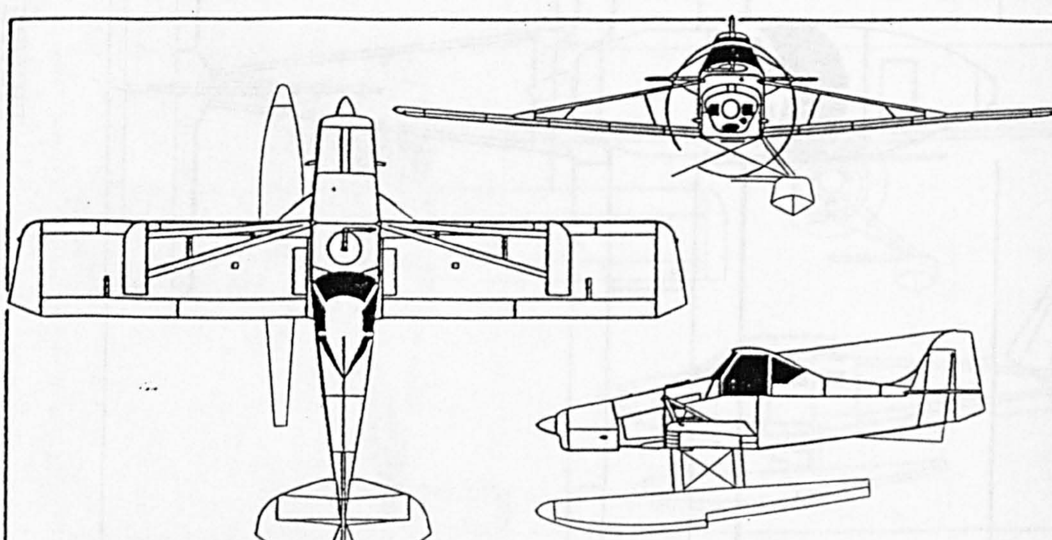


FIGURE 5.2b GIPSLAND GA-200 TWIN FLOATPLANE

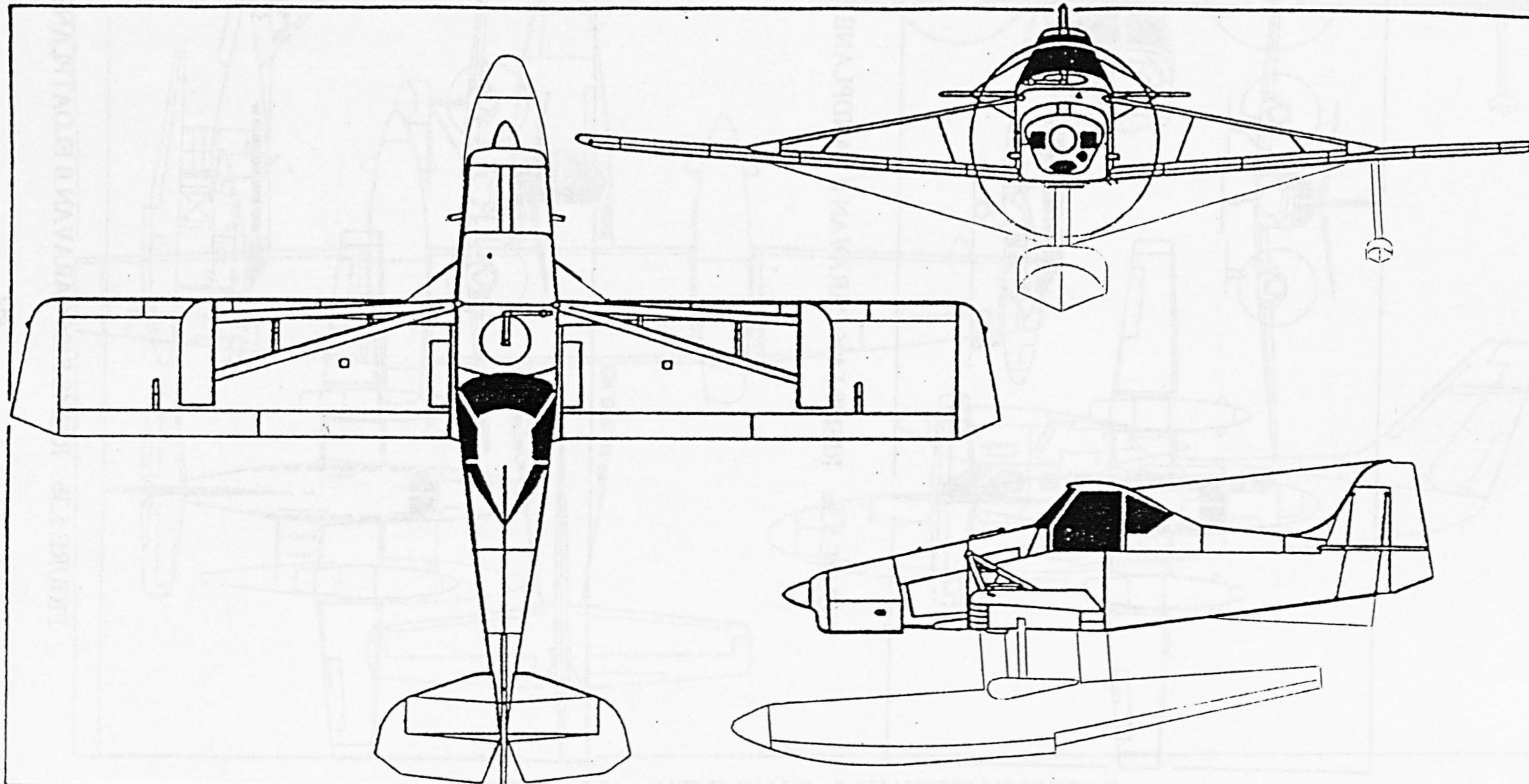


FIGURE 5.2c GIPPSLAND GA-200 SINGLE FLOAT FLOATPLANE

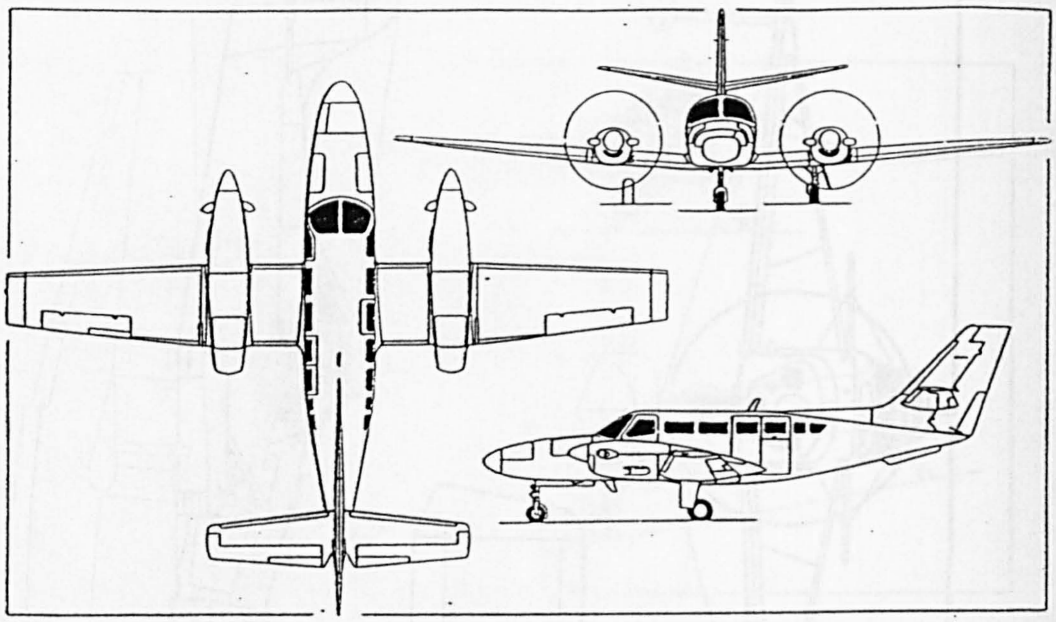


FIGURE 5.3a RIEMS F406 CARAVAN II LANDPLANE

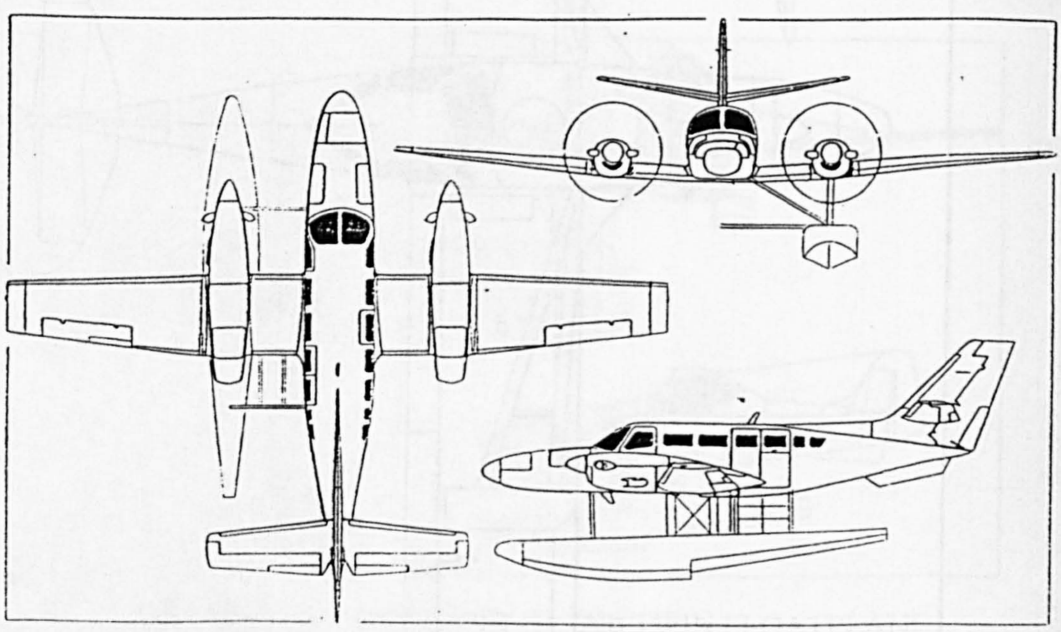


FIGURE 5.3b RIEMS F406 CARAVAN II FLOATPLANE

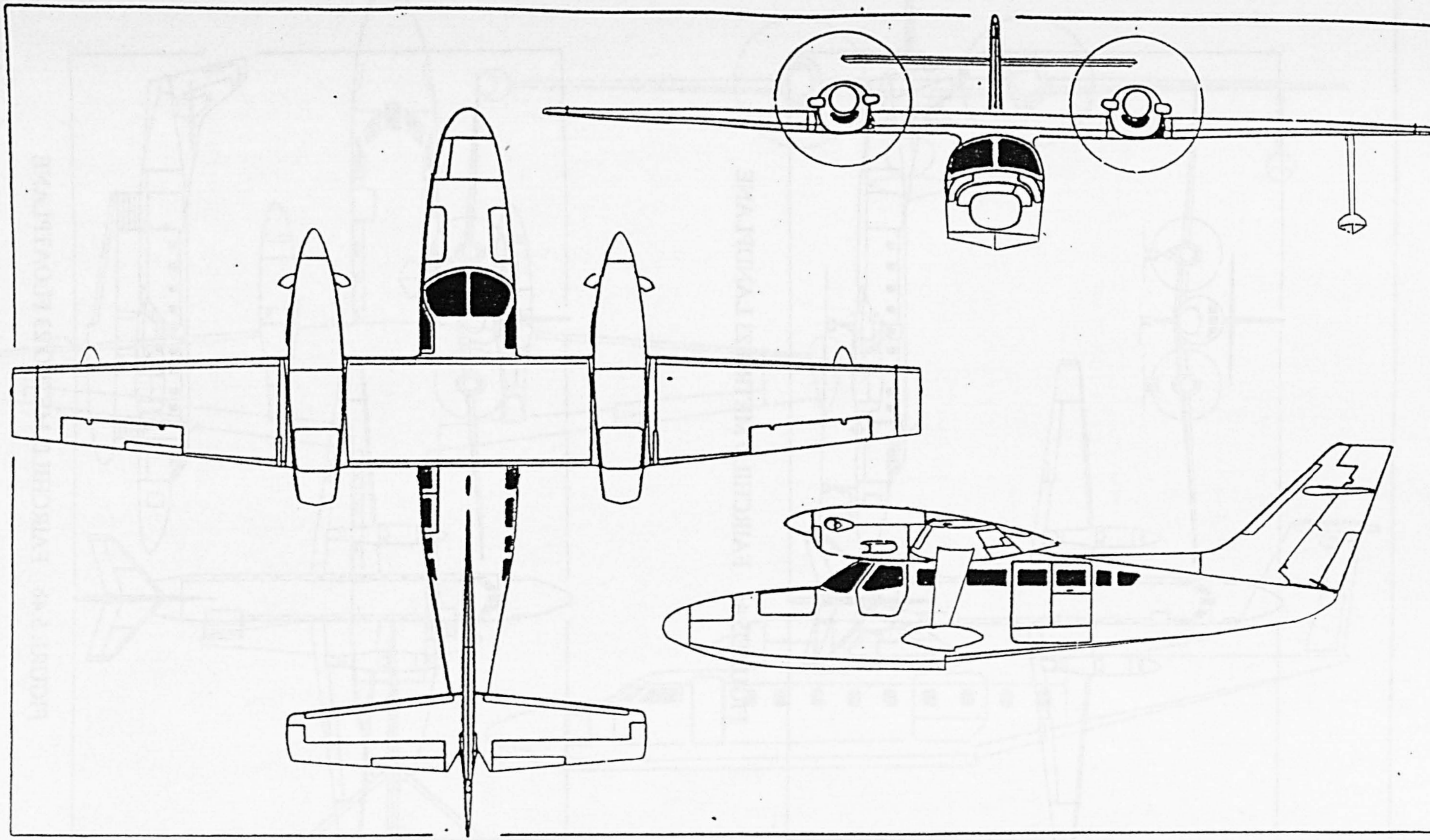


FIGURE 5.3c RIEMS F406 CARAVAN II FLYINGBOAT

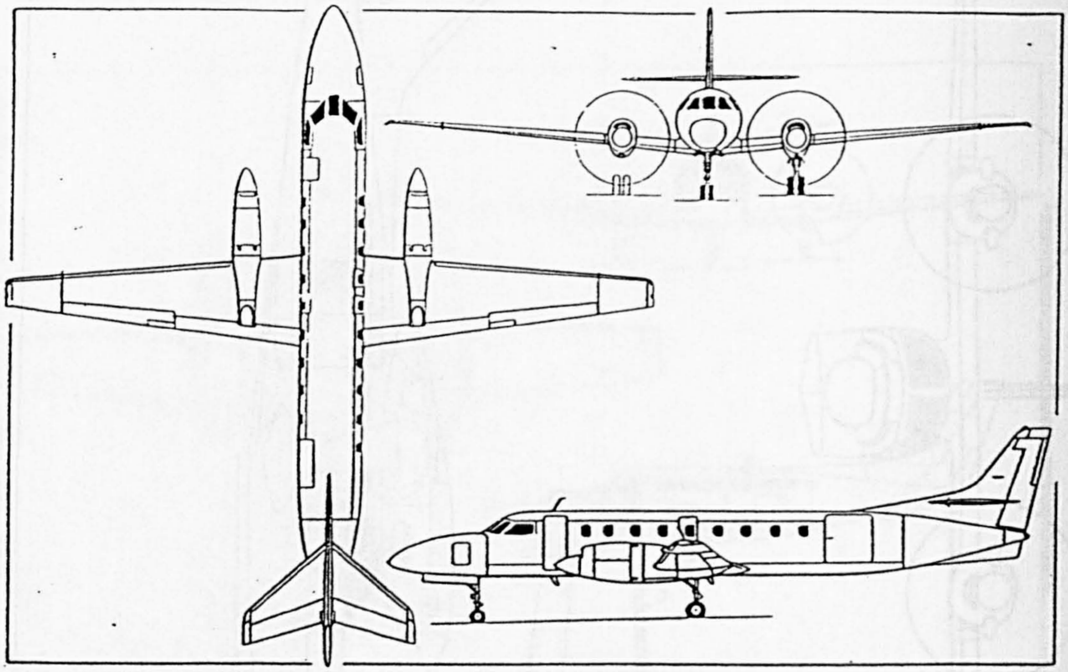


FIGURE 5.4a FAIRCHILD METRO 23 LANDPLANE

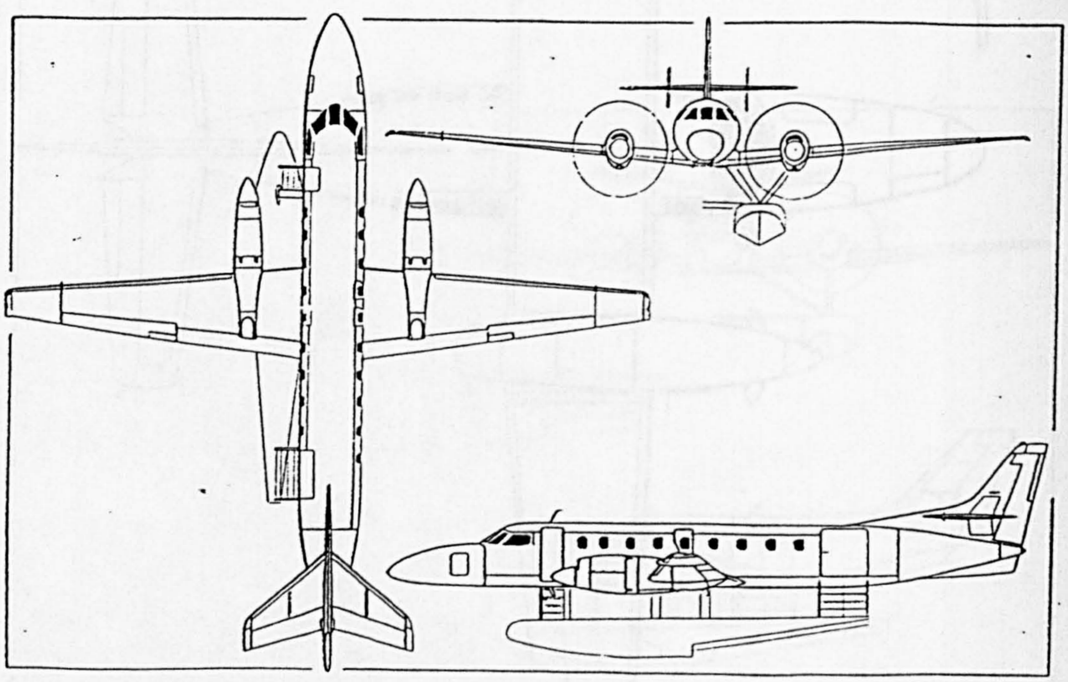


FIGURE 5.4b FAIRCHILD METRO 23 FLOATPLANE

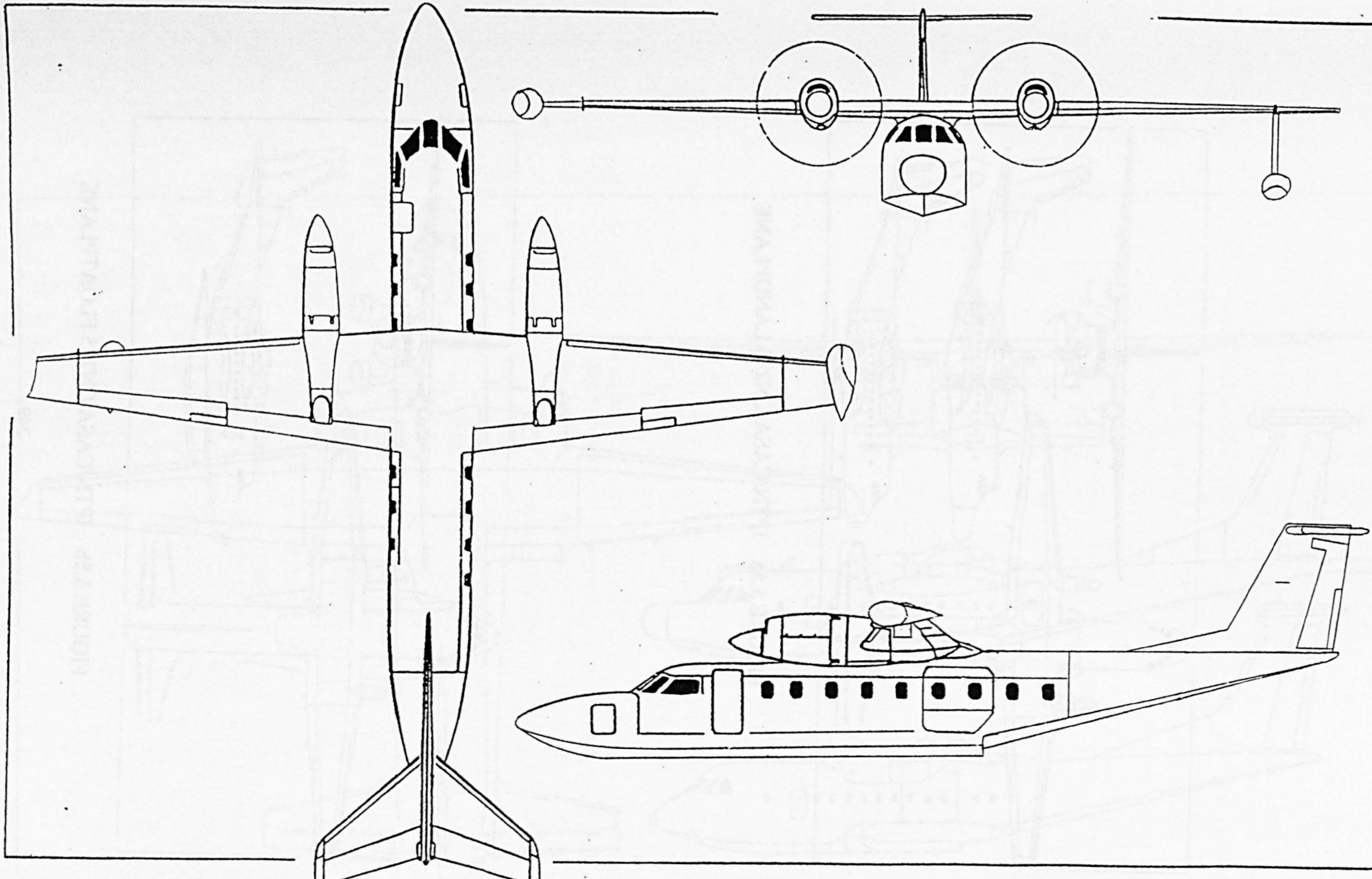


FIGURE 5.4c FAIRCHILD METRO 23 FLYINGBOAT

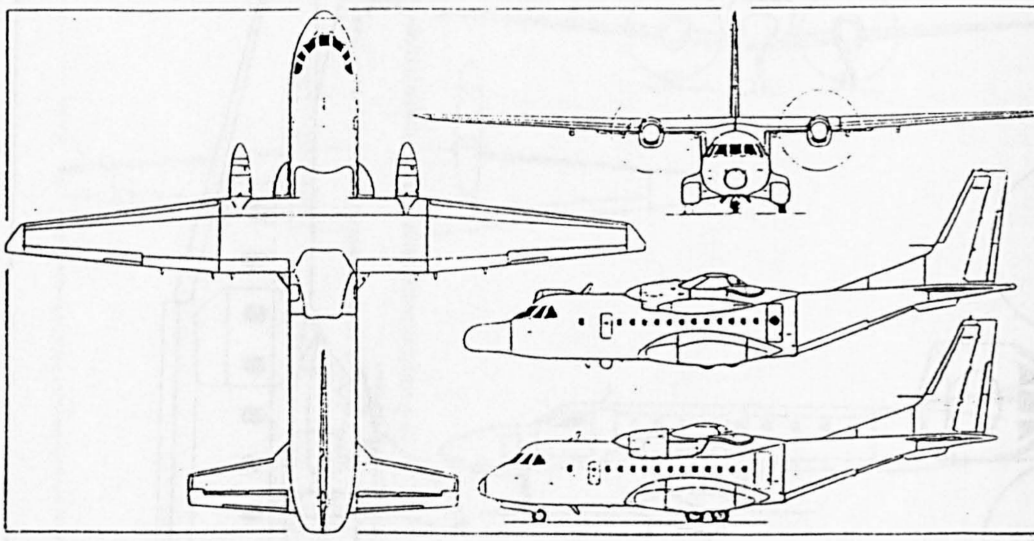


FIGURE 5.5a IPTN/CASA CN235 LANDPLANE

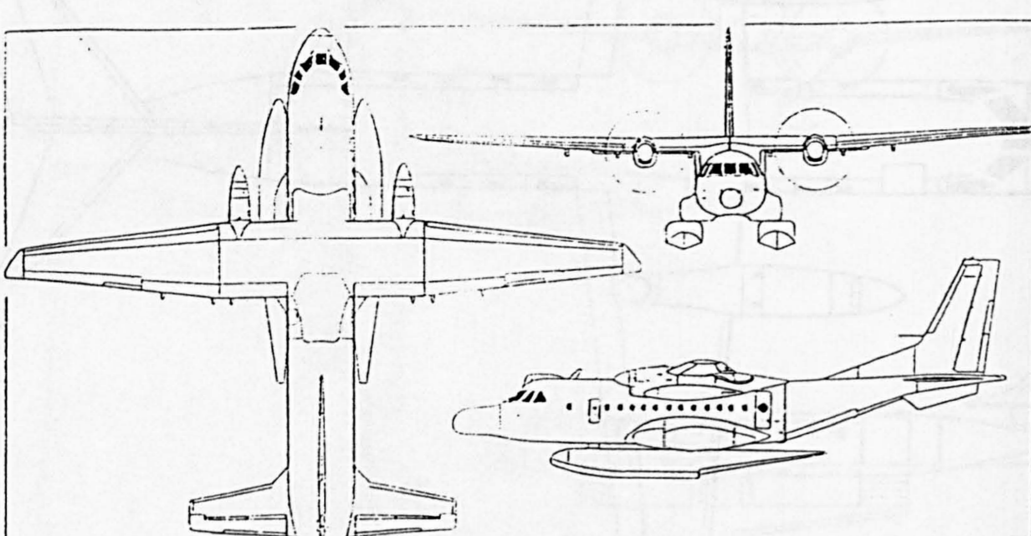


FIGURE 5.5b IPTN/CASA CN235 FLOATPLANE

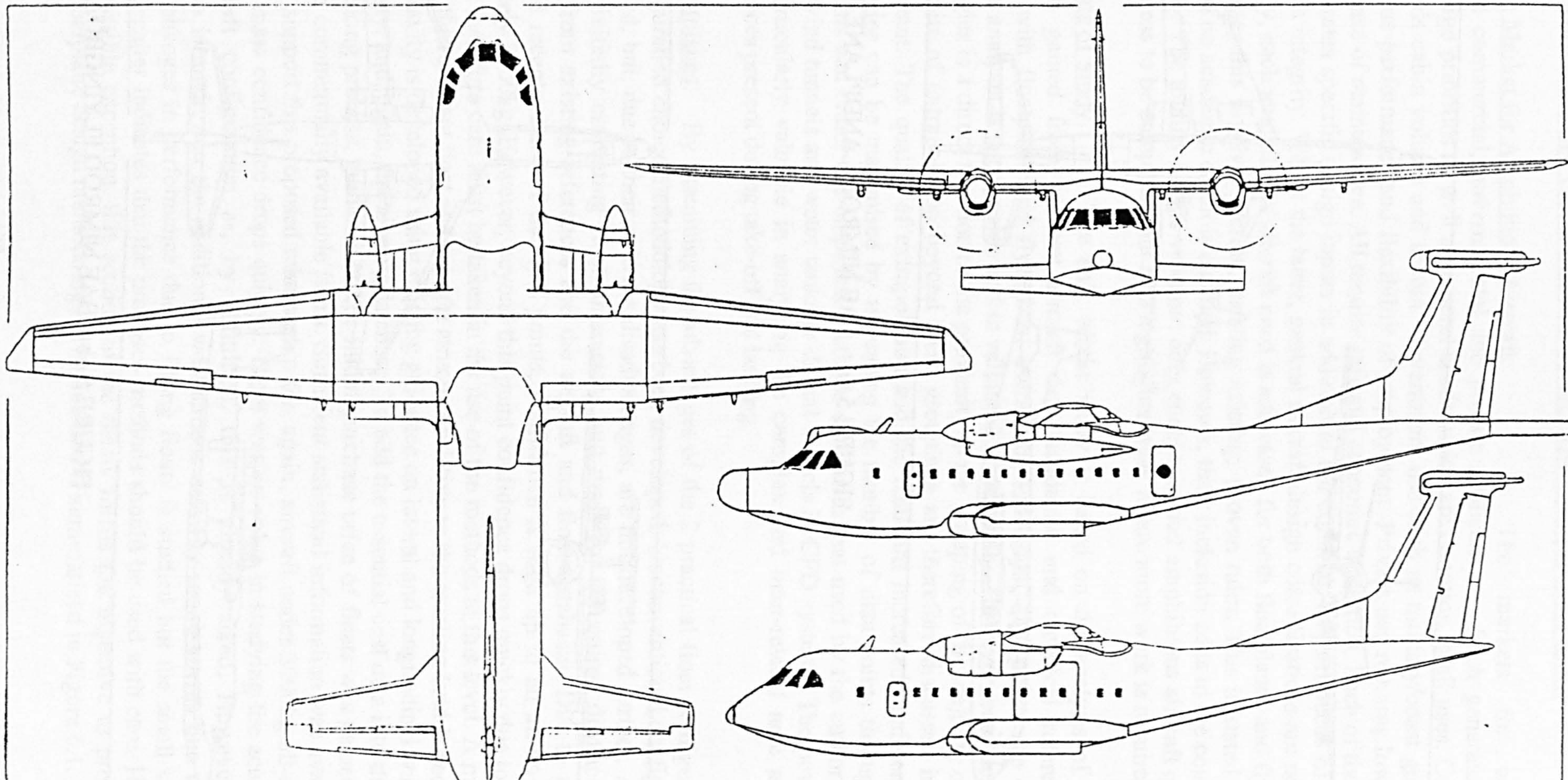


FIGURE 5.5c IPTN/CASA CN235 FLYINGBOAT

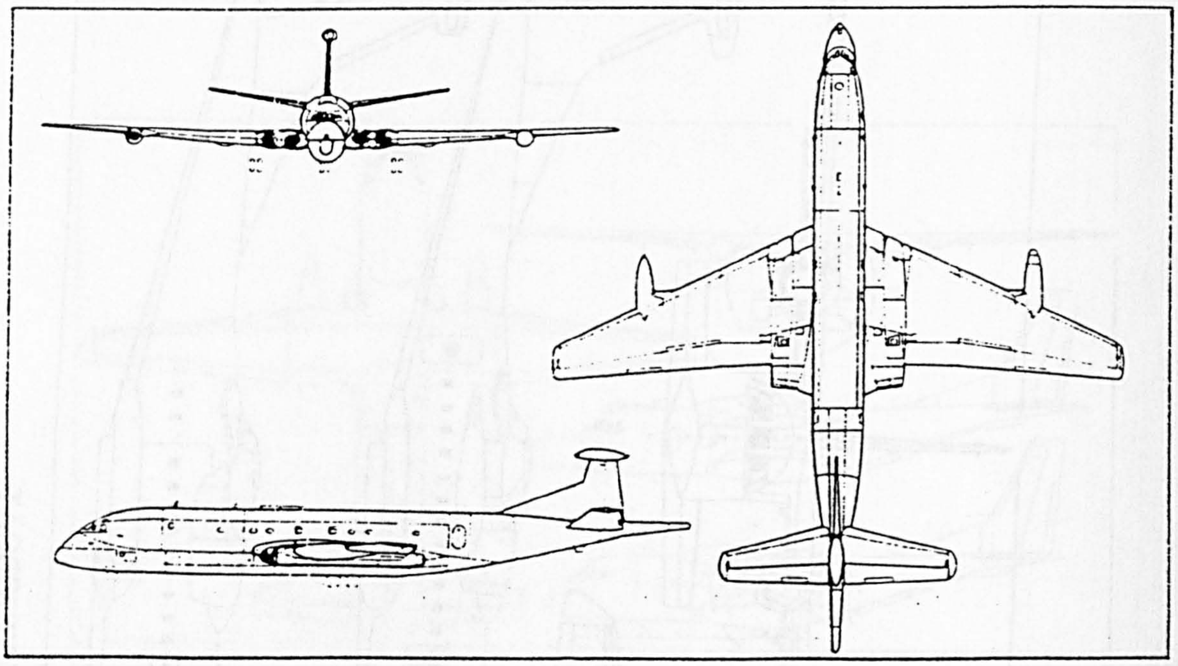


FIGURE 5.6a BAE NIMROD LANDPLANE

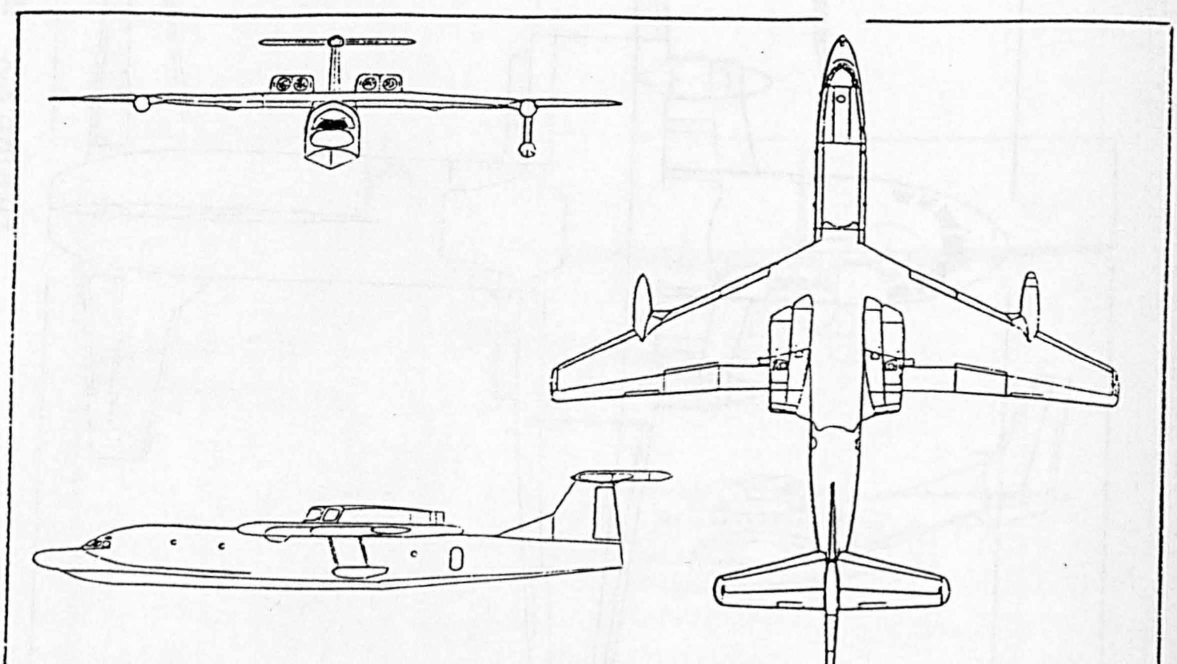


FIGURE 5.6b BAE NIMROD FLYINGBOAT

6. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 The Market for Amphibious Aircraft. The markets for amphibious aircraft are commercial, governmental and private applications. Each generates its own special design priorities as well as general needs which are common to all uses. Commercial use demands cabin volume and access. Government use such as military/coast guard patrol tend to value performance and flexibility of employment. Private use requires low purchase price and ease of maintenance. All require safe and economic operation. Each of these market needs generates specific design inputs in addition to the common aircraft needs of structural and systems integrity. Whilst the latter, general aircraft design considerations are not covered in this study, each amphibious aircraft need is addressed for both floatplanes and flyingboats. In some cases this involves merely restating existing, proven rules. This is stated clearly in the text and no academic credit is claimed. However, their inclusion adds to the completeness of the study. The totality of this view not only enables a total amphibious aircraft conceptual design process to be completed but also highlights areas where more work is required.

6.2 Basis of Study. The bulk of the study is based on the analysis of empirical information gained from relevant aircraft data, academic and technical references and interviews with floatplane and flyingboat users. The individual data points are of a high quality, the analysis is supportable and is validated in the study. However, confidence in the methodologies is a direct function of the proximity to the grouping of the majority of the data points. Limits of extrapolation beyond these groupings are therefore discussed in the text where relevant. The quality of extrapolation and the resultant increased confidence in the methodologies can be maximised by increasing the number of data points through further research. This can either use empirical methods similar to that used by the author, physical models in wind tunnels and water tanks or digital models in CFD systems. The power of the latter is particularly valuable in analysing the complex and inter-related aero and hydro dynamic forces present during take-off and landing.

6.3 Floatplanes. By examining the advantages of the 2 practical float configurations a basic configuration choice methodology has been developed. Unconventional configurations are identified, but, due to their extreme disadvantages, are not developed further. A simple method of initially estimating float dimensions and mass for a required displacement is developed from existing references and the aircraft and float databases. Due to the large number and recent nature of the data points, confidence is high up to an all-up mass of approximately 3000kg. However, beyond this point confidence drops quickly due to the lack of data and therefore care must be taken in the use of the methods at this level. A method of positioning the resultant float and support structure relative to the existing land-based aircraft centre-of-gravity is developed using existing guidance on lateral and longitudinal waterborne static stability, and, again, the aircraft database. To add the essential cost data into the design decision making process, guidance on the initial purchase price of floats was gained from a study of the commercially available items. Sufficient statistical information was available to confidently support this proposed relationship for, again, aircraft under 3000kg all-up mass. Above this mass confidence drops quickly. There was no value in studying the actual land-based aircraft configuration as, by definition, this is already fixed. However, some investigation is made into the additional weathercock stability requirements due to fitting floats. The changes in performance due to fitting floats is studied but the small statistical sample and scatter indicates that the proposed methods should be used with care. However, with this possible exception, this section of the thesis fulfils the objective to produce an integrated floatplane design methodology. This method is summarised in Figure 6.1.

6.4 Flyingboats. In a similar method to floatplanes, work on flyingboats begins with the development of a configuration choice methodology. This is based on a configuration classification system which enabled generalistic characteristics to be applied to any size or role of flyingboat. Again, unconventional configurations are noted but not studied further. Having decided on the overall configuration, tools are developed to choose the method of providing on-water lateral stability and to complete the initial sizing of that choice. A method of estimating initial planing bottom dimensions is developed along with step position and configuration. These methods are based on an adequate quality of information from the flyingboat database. Less confident methods are developed to estimate tailplane sizing and flyingboat-specific mass. Statistical scatter and a lack of data, particularly regarding mass, result in care having to be taken when using these methodologies. Knowing the mass and configuration of the flyingboat allows spray estimation and detailed on-water static stability calculations to be completed to check the acceptability of the initial configuration and dimensions. Again, the lack of a broad band of data limits the initial establishment of the methodology, but validation across the database proved successful. Performance estimation methods including take-off and landing and aerodynamic drag are developed based on methods from references. In particular, an empirical flyingboat drag factor is developed for an existing, general purpose drag estimation equation. Undercarriage configurations, dynamic on-water stability and dynamically similar test models are briefly discussed for completion. Insufficient information was available to confidently develop a cost estimation methodology. Excepting the areas noted above, this section of the thesis fulfils the objective to produce an integrated flyingboat design methodology. This method is summarised in Figure 6.2.

6.5 Factors Common to Floatplanes and Flyingboats. To ensure that the amphibious aircraft designer considers the totality of his product, infrastructure, cost of ownership and safety aspects are discussed based on existing references. References regarding water loading and tilt float technology are reviewed and summarised. Unique work is documented on weighted design performance indicators, generating a method which enables aspects of the design of the aircraft to be quantitatively reviewed based on end-user requirements.

6.6 Designs. Using the methodologies to produce conceptual designs for a variety of specifications not only proved the completeness of the study but also produced some overall guidance on amphibious aircraft design.

a. Single Engined Private/Light Floatplane. The Partenavio P93 Idea light twin floatplane unsurprisingly proved the validity of the float methodologies in the most popular commercial and private applications. All aspects of the study fitted readily onto the P93 design and the resultant floatplane is a confident and practical design. The greatest lesson this example illustrates is the significant mass and cost implications of a STCed commercial amphibious float (only available in metal) over a non-certified private use "experimental" composite float. The commercial floats are 2.5 times the cost of the private floats and deduct 5.4% of payload compared with a gain of 1% for the private floats. This factor must always be borne in mind when studying commercial floatplane derivatives of landplanes.

b. Single Engined Private/Light Flyingboat. The light flyingboat based on the P93 specification illustrates the 3 key factors in this size of design. Firstly, the design is dominated by engine position; this emphasises the importance of this conceptual design choice. It is in this ultralight/light mass area that there is most variety in configuration choice and therefore the advantages and disadvantages discussed in the text should be explored in detail before a configuration is chosen. The second issue is the size of the tip floats. On such a small aircraft their size and additional mass and drag input is high. Detailed cost-benefit analysis using the sizing tools would be a valuable addition to any light flyingboat design process. The conceptual fuselage depth illustrated an area not covered in detail in the text: door design. When the water level at rest is such a high proportion of the fuselage depth, and deadrise angle is low to allow the use of shallow beach approaches, any passenger or freight door is bound to be close to, or even partially under, the water. A small project on amphibious door functionality options would prove useful in optimising this part of the aircraft. A more powerful engine/propellor combination was required to achieve adequate take-off performance for the flyingboat. The greatest lesson learnt from this design was the payload effect compared to the landplane and floatplane options. Compared to the light floatplane, the flyingboat showed a loss of payload of almost double that of the light amphibious floatplane.

c. Light Single Engined Floatplane Firebomber. The Gippland GA200 Fatman light agricultural aircraft-based firebomber was chosen for study as an example of the only practical application of the single float configuration. The analysis proved that a single float configuration is practical and had no significant performance differences from the twin float configuration. Even availability of a float is unlikely to be a problem as the single float for a small aircraft can be one of the pair for a larger aircraft. For example, the idealised single float for the GA200 is not dissimilar to one of the twin floats used on the Beaver. However, no certification details could be found for single float designs and therefore widespread use is unlikely. The twin float specification produced an equally practical solution but would be a more commercially acceptable due to its well accepted configuration. Airflow around the twin floats may, however, interfere with the water dump pattern.

d. Twin Engined Utility/Light Commuter Floatplane. The Reims F406 Caravan II was chosen as a representative light twin commuter aircraft. The resultant floatplane was practical and successfully proved the methodologies, but illustrated the difficulty in mounting floats onto a low winged aircraft. In particular, the length of the float struts to give adequate propeller-to-float clearance would give structural problems. A high wing aircraft is a far more suitable configuration as is illustrated later in the CN235 example. However, the greatest lesson learned from this example is the growing loss of payload compared to the lighter float-equipped aircraft. In the case of the pure floatplane version the loss is 13% rising to 24% for amphibious floats. The cost of floats also rises steeply with size, the amphibious floats costing almost $1/4M. Serious thought must therefore be given to the economics of this size of floatplane compared to other solutions such as a dedicated flyingboat. This size of floatplane therefore tends to define the top end of the quantity floatplane marketplace.

e. Twin Engined Utility/Light Commuter Flyingboat. Using the Reims F406 specification as the basis for a flyingboat involved changing to a high wing/high tail configuration. In particular, the fuselage and spray height matched well, resulting in the wing fitting onto the fuselage top with no requirement for more exotic parasol or gull wing solutions. The resultant configuration was a practical and elegant design which produced no problems for the methodologies. Compared to the floatplane version of the Reims 406, the flyingboat design added only 114.2kg to the empty mass, less than half of that added by the pure floats. An engine/propellor combination giving greater power at take-off was needed to give adequate performance in this area. Although clearly an operational advantage, the development costs of a flyingboat are significantly more than those for a floatplane. The inability to develop a reliable purchase price estimation tool for flyingboats is therefore a large disadvantage in undertaking flyingboat to floatplane comparisons and should be addressed by further research.

f. Twin Turbo-prop Medium Commuter Floatplane. The all-up mass of the twin turbo-prop medium commuter Metro 23 was outside the majority of the float database and only limited confidence can therefore be placed in the use of the tools. Again, however, the low wing configuration dominated the resulting design. No floats of this size have been built for over 30 years and the performance and payload reductions well illustrate why. It is unlikely that such an aircraft would be commercially viable, although a military or pseudo-governmental customer may be willing to pay for the flexibility of amphibious operation with this size of aircraft. This assumption is supported by the low numbers of operational float-equipped aircraft of this size, the only significant design being TwinOtters operating in Canada.

g. Twin Turbo-prop Medium Commuter Flyingboat. The Metro 23's fuselage height was sufficient for a high wing to keep the engines and wing out of the spray envelope. This pattern almost inevitably defines the overall configuration of the flyingboat at and above this all-up mass level. Some difficulties were found in using the forebody planing bottom sizing methodology for this all-up mass and fuselage width (and therefore beam) of aircraft. No particular reason could be discovered for this as the Metro specification is not significantly difference from, say, the CL415 flyingboat. However, iterating both the fore and afterbody dimensions through the methodologies produced an acceptable planing bottom solution. Empty mass increase over the land-based aircraft is acceptable, especially when compared to the floatplane. Again, the lack of a confident cost tool makes direct comparison between the flyingboat and floatplane options difficult.

h. Twin Turbo-prop Large Transport/Patrol Floatplane. A floatplane version of the size and mass of the CN235 was considered in light of the recent research into a floatplane version of the C130. The CN235 design proved practical as long as the floats are mounted onto the undercarriage sponsons. This also opens up the opportunity for the floats to be easily removeable/refittable if fixed onto the undercarriage mountings. The high wing and engines ensure that spray would not impact on these structures, although, like the C130, spray would impact on the lower fuselage between the floats. However, on a pressurised aircraft of this size the skin thickness is likely to be sufficient to absorb this impact. Although the floats significantly reduced the payload of the CN235, the amphibious operational flexibility of a large, rear door-equipped transport or maritime patrol aircraft would make it valuable to a military or pseudo-governmental customer.

i. Twin Turbo-prop Large Transport/Patrol Flyingboat. A CN235-based flying boat was used to prove the large flyingboat design methodologies. The high wing configuration of the land-based aircraft proved acceptable, but a high tail would be required to move that structure out of the spray envelope. The main disadvantage in producing a flyingboat based on a large transport aircraft-type specification is the difficulty in gaining a cost-effective freight door as the rear fuselage must also fulfil the critical hydrodynamic function of the afterbody. Sponsons are therefore used to aid access to a large side freight door in the CN235-based flyingboat design. However, this design also illustrates the mass and volume of the sponsons required for this size of flyingboat. This is illustrated by the increased loss of payload (6%) compared to the Metro 23 example (4%). Again, the fore and afterbody needed an iteration to produce a practical planing bottom form.

j. Large Jet MPA. The Nimrod specification was chosen as the basis of a large jet maritime patrol aircraft flyingboat. The resultant design illustrates the need to mount the jet intakes well above the waterline and also shows the high tail which is almost always required on a flyingboat of this size. Fairing-in a large, nose-mounted search radar is difficult and would cause challenging detailed aero and hydrodynamic investigations. A fore-aft retractable float system is illustrated which combines the advantages of a retractable tip float with little use of fuel-carrying internal wing volume. Again, the fore and afterbody needed an iteration to produce a practical planing bottom form. The length-to-beam ratio and speed of this type of design puts it at the extreme edge of the empirically-based techniques, yet its closeness to the existing Seamaster and Mermaid designs make it a practical military niche design. The greatest difference between the Nimrod-derived flyingboat and the Mermaid is the formers very long take-off run. This would require either a significant increase in take-off C_L or a decrease in wing, or more likely power loading to gain an acceptable performance.

k. Overall Lessons from the Design Exercises. The most important lesson learned from the floatplane and flyingboat design exercises was the rapid loss of performance and payload when floats were added to the larger aircraft. This was matched with increasing difficulty in attaching floats to low-winged aircraft. It is therefore likely that floatplanes are not generally commercially viable - although they may be engineering practicalities - above approximately 4000kg all-up mass. Military or pseudo-governmental operators may be willing to accept the compromise of a floatplane version of an existing landplane. However, a dedicated flyingboat is more likely to be cost-effective above this mass if it can be built in sufficient quantities. The flyingboat examples illustrated the increase in take-off distance with increasing power and wing loading. This well illustrates the severe conflict between cruise and take-off performance for flyingboats and is probably the single most significant reason why large flyingboats have been unsuccessful in modern times. The weighted design performance indicator technique is a good tool to illustrate both the strengths and weaknesses of floatplane, flyingboat and landplane designs needed to fulfil a customer specification.

6.7 Conclusions

The flow charts at Figures 6.1 and 6.2 graphically illustrate this thesis's success in fulfilling the aim to develop a series of integrated conceptual design methodologies for amphibious aircraft. The methodologies are based on an extensive review of past work and a comprehensive database of relevant technical details, yet are simple enough to be completed by hand if desired. The methodologies are compatible with a wide range of more conventional design tools, thus allowing them to be used easily in any commercial or academic application. This is illustrated in the use of the methodologies to develop floatplane and flyingboat "derivatives" of existing aircraft. These designs well illustrate the limited economic possibilities of floatplanes above 4000kg AUM and the take-off performance problems of large flyingboats having a wing loading above 250kg/m^2. Both of these issues underline the need for a well researched niche cost-benefit analysis based on the conceptual design parameters available using the methodologies from this thesis. Particular areas of this thesis which contribute to new areas of knowledge are as follows:

a. a comprehensive database of amphibious aircraft technical details.

b. float mass, dimensions and purchase cost estimation equations for all configurations, aircraft masses and float construction methods.

c. a landplane to floatplane performance estimation method.

d. a method of generalising flyingboat mass, role and configuration to allow the confident application of conceptual design tools.

e. an overall configuration choice methodology for any flyingboat mass or role.

f. an initial sizing method for the planing bottom, tip floats, stubs and horizontal and vertical tailplanes of a flyingboat.

g. mass estimation tools for the planing bottom and lateral stability methods of a flyingboat.

h. a simple flyingboat configuration-based safe spray height estimation method.

i. a flyingboat empirical factor to add into an existing drag estimation equation.

j. a design performance indicator method based on end-user requirements.

k. a comprehensive study of alternative landplanes, floatplanes and flyingboats with numerical values against key design performance indicators.

6.8 Recommendations

Recommendations for further work include:

a. Ongoing additions to the float, floatplane and flyingboat database to ensure the continuing validity of the empirical methods.

b. Development of a single float certification method to enable this configuration to be developed to the full.

c. The discovery of more landplane to floatplane performance data points to improve the confidence in that methodology.

d. Aerodynamic stability modelling of a variety of float sizes and configurations to validate the approximate methodology.

e. Detailed structural design analysis of more planing bottoms, stubs and tip floats to gain more confident methodologies.

f. Specialist stability analysis of flyingboat tailplane performance and sizing.

g. More empirical information on modern flyingboat costs, spray heights and hydrodynamic drag to improve the confidence in these empirical relationships.

h. A detailed study be undertaken into amphibious aircraft door design.

i. The collation of all these methodologies into a simple to use computer programme.

j. A systematic aero and hydrodynamic CFD, wind tunnel and water tank analysis to help define the tools beyond empiricism.

Much of the empirical data collection aspects of these recommendations could be best fulfilled by access to relevant records from the ex-USSR.

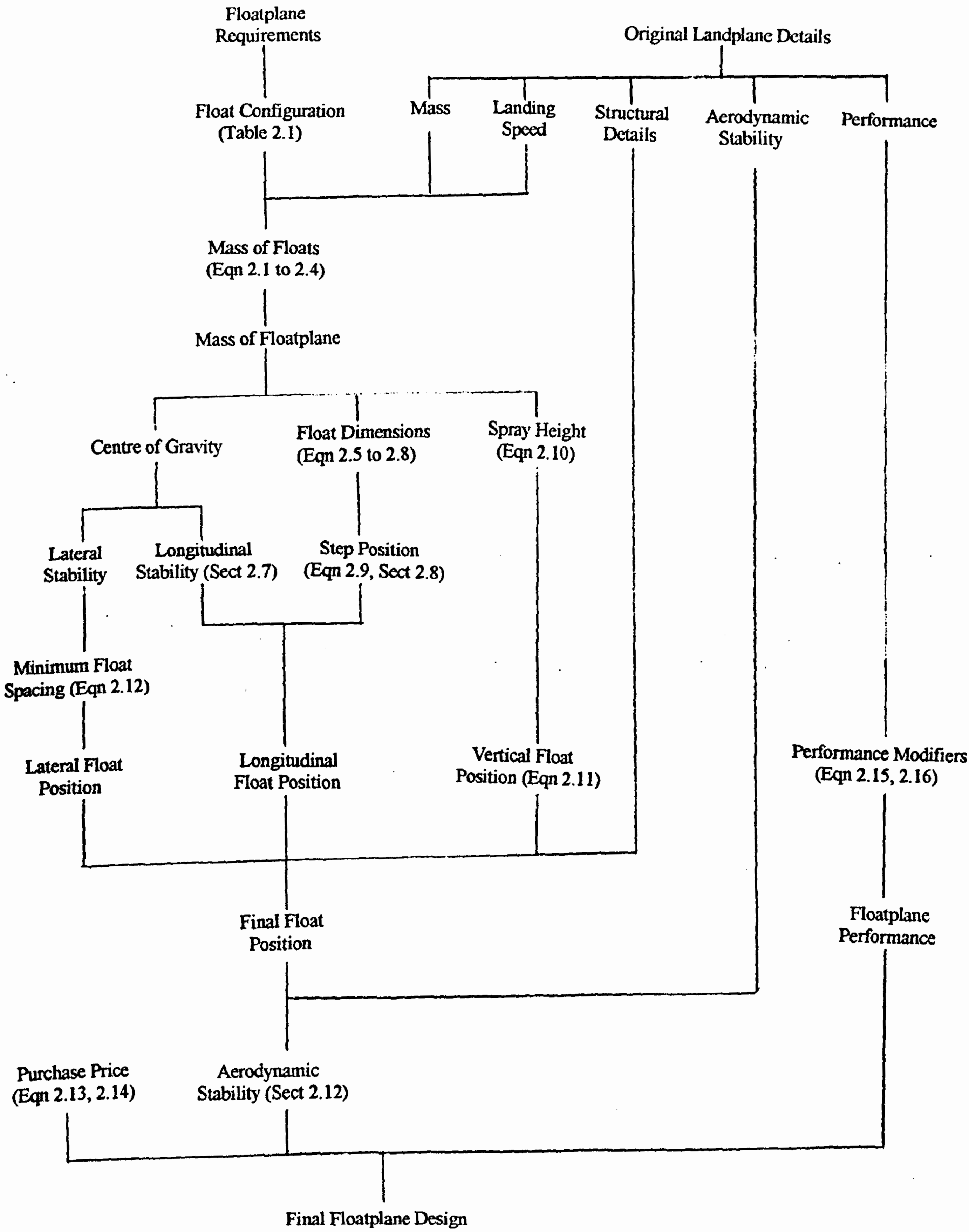


FIGURE 6.1 INTEGRATED FLOATPLANE DESIGN FLOWCHART

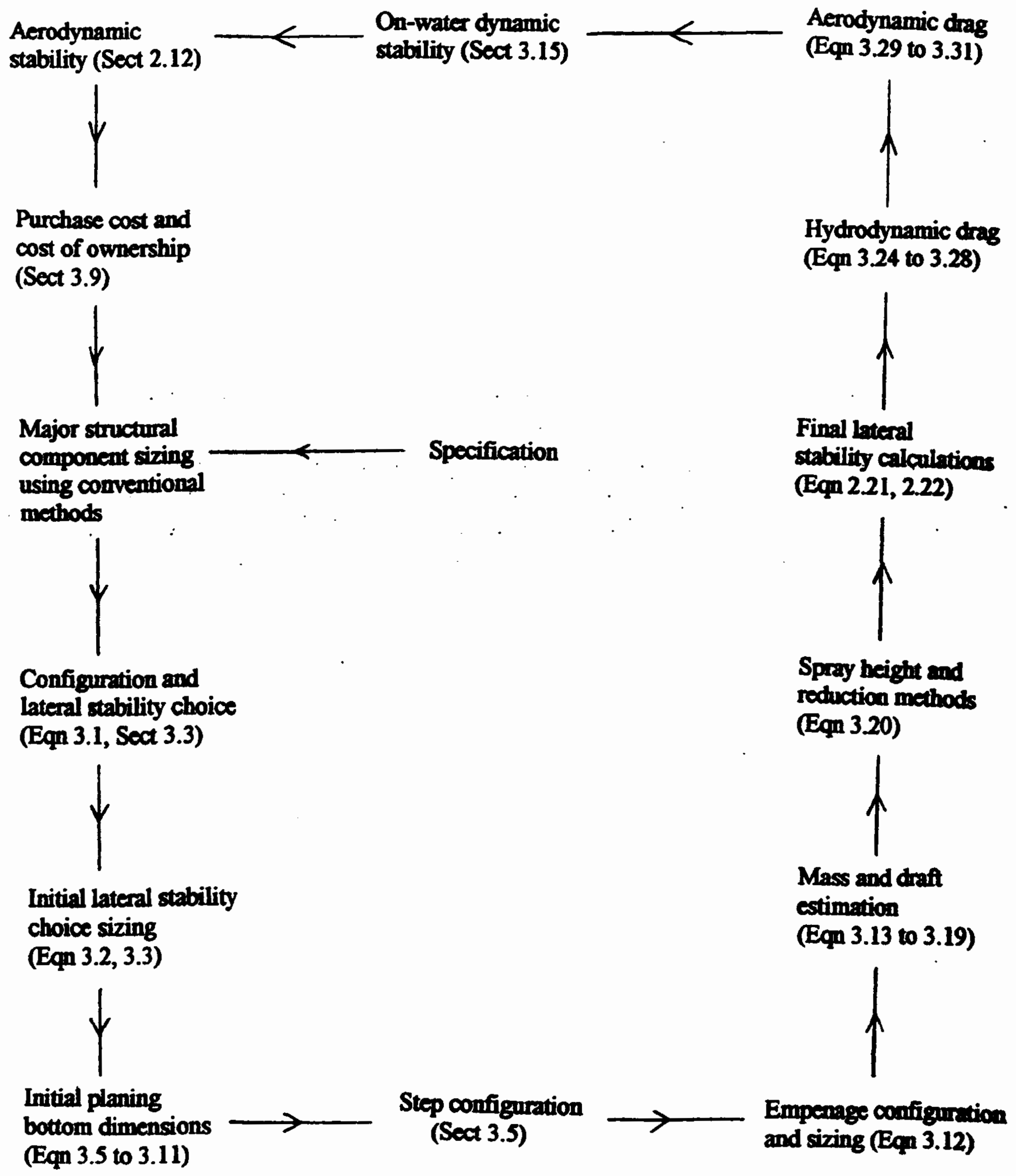


FIGURE 6.2 INTEGRATED FLYINGBOAT DESIGN FLOWCHART

APPENDICES

APPENDIX 1

FLYINGBOAT DATBASE

The Flyingboat Database is presented as a series of linked tables which include all the relevant information found on the particular aircraft. For ease of presentation the database is split into nationalities. The main reference is quoted in Table 4 of each nationality.

Nationality: Italy and UK 1

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
S66 (twin-hull)	Siai-Marchetti	1932	10950	?	M	T(V)dT(M)	HW-P
C94 (amphib)	Macchi	1935	8250	?	M	T(V)	HW-T
C100	Macchi	1939	13100	?	H	T(V)	HW-T
P136 (L2)	Piaggio	1948	2722	2126	LM	T(V)	GW-P
FN333	Siai-Marchetti	1952	1485	976	L	T(V)	HE-CO-P
Princess	Saro	1952	143000	86260	SH	T(V)	HW-T
SRA1	Saro	1947	7264	5113	LM	T(M)	nose intake twin jet
Seagull	Supermarine	1948	6585	4770	LM	T(M)	PW-P
Sealand	Shorts	1948	4130	3190	LM	T(V)	HW-T
Lerwick	Saro	1939	12894		M	T(M)	HW-T
Shetland II	Shorts	1944	59000	34440	SH	T(V)dT(M)	HW-T
Solent III (mil=Seaford)	Shorts	1946	35700	221870	H	T(V)dT(M)	HW-T
C Class	Shorts	1936	24200	12320	H	T(V)	HW-T
G Class	Shorts	1939	33800	17100	H	T(V)	HW-T
Sunderland V (civ=Sandringham)	Shorts	1937	29482	16783	H	T(M)d T(V)	HW-T
A33	Saro	1938	18841	?	H	T(M)	PW-T
B20	Blackburn	1940	15890	?	H	T(M)	HW-T

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Nationality: Italy and UK 2

Aircraft	Tail Config	Range (km)	U/c Type	Wing Area (m^2)	Planing Bottom Dimensions				
					L (m)	L_f (m)	b (m)	β (°)	Draft (m)
S66 (twin-hull)	triple	1290	nil	?	?	?	?	?	?
C94 (amphib)	mid	1380	nil	76.0	11.17	6.03	2.35	?	?
C100	twin	1400	nil	100.0	12.33	6.71	2.94	?	?
P136 (L2)	low	1440	tail	24.0	6.91	3.8	1.34	7	0.48
FN333	boom	?	tri	15.14	6.21	3.1	1.1	13	0.35
Princess	mid	8850	nil	466.0	35.62	18.55	4.82	25	2.41
SRA1	mid	?	nil	38.6	12.62	6.23	2.28	?	?
Seagull	high	1410	tri	?	12.54	5.61	2.03	?	?
Sealand	mid	792	tri	32.8	10.22	5.4	1.56	25	0.72
Lerwick	low	2464	nil	78.0	17.34	7.84	2.63	?	?
Shetland II	low	4830	nil	223.5	27.0	13.5	3.9	25	1.8
Solent III (mil=Seaford)	low	3540	nil	138.1	22.0	11.0	3.0	?	?
C Class	low	2090	nil	139.5	17.86	9.99	3.0	26	1.16
G Class	low	5120	nil	201.0	23.32	11.24	3.5	29	1.57
Sunderland V (civ=Sandringham)	low	4630	nil	138.1	19.35	9.44	3.0	25	1.06
A33	low	?	nil	111.0	17.22	9.42	2.6	?	?
B20	low	2400	nil	99.0	14.8	?	?	?	?

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Nationality: Italy and UK 3

Aircraft	Speed s (kts)		Lateral Stability						
	max	stall	b/2 (m)	posn	synergy	form	retract	L_{float} (m)	B_{float} (m)
S66 (twin-hull)	121	?	16.5	-	-	twin	-	-	-
C94 (amphib)	136	?	11.5	70%	-	C1	-	2.35	0.59
C100	156	?	12.2		-	C1	-	2.33	0.55
P136 (L2)	143	?	6.8	78%	-	B1	-	1.22	0.48
FN333	143	?	?	82%	tip	B3	*	1.7	0.32
Princess	267	?	14.95	?	tip	B4	*	5.66	1.21
SRA1	445	?	7.0	72%	-	C1	*	?	?
Seagull	226	62	8.0	75%	-	C1	-	2.38	0.85
Sealand	163	67	9.0	63%	-	C1	-	2.06	0.56
Lerwick	186	81	12.4	67%	-	C1	-	3.36	0.54
Shetland II	229	?	23.4	67%	-	C1	-	4.66	1.38
Solent III (mil=Seaford)	232	?	17.2		-	C1	-	?	?
C Class	174	?	17.4	56%	control	C1	-	4.53	1.03
G Class	182	69	20.5	67%	-	C1	-	5.2	1.3
Sunderland V (civ=Sandringham)	185	68	17.2	63%	-	C1	-	4.62	1.1
A33	174	?	14.5	-	-	-	-	-	-
B20	266	?	12.5		-	?	*	?	?

continued next page

Nationality: Italy and UK 4

Aircraft	Spray Method					Production	References
	c f	f w	t a	d	ex		
S66 (twin-hull)	*	-	-	-	-	**	World Encyclopedia of Civil Aircraft.
C94 (amphib)	?	-	-	-	-	**	World Encyclopedia of Civil Aircraft. Janes 39.
C100	?	-	-	-	-	**	World Encyclopedia of Civil Aircraft. Janes 39.
P136 (L2)	-	-	-	-	-	**	Airplane Monthly Apr 94. Janes 49. Aircraft Engineering Apr 52.
FN333	-	-	-	*	-	**	Observers Book of Aircraft. Janes 56 and 64.
Princess	*	*	*	-	-	0	Saro Aircraft. Flight 26 Sep 52.
SRA1	*	-	-	-	intake guard	*	Saro Aircraft. Aeronautics Nov 47.
Seagull	*	-	*	-	-	**	Janes 48.
Sealand	-	-	-	-	-	**	Janes 48 and 53/4. Aeroplane Monthly Aug 93. Shorts Aircraft.
Lerwick	*	-	-	-		**	Saro Aircraft. Air Pictorial Feb 96.
Shetland II	*	-	-	-	-	*	Shorts Aircraft. Janes 47. The Aeroplane Dec 45.
Solent III (mil=Seaford)	*	-	-	-	-	**	Janes 1948. Shorts Aircraft. Aeroplane Monthly June 93.
C Class	*	-	-	-	-	**	Shorts Aircraft. Janes 40.
G Class	*	-	-	-	-	**	Shorts Aircraft. Janes 41.
Sunderland V (civ=Sandringham)	*	-	-	-	-	**	Shorts Aircraft. Janes 41.
A33	-	-	-	-	stub	*	Saro Aircraft.
B20	*	-	-	-	-	*	Warplanes of the 2nd WW.

Nationality: France and Others 1

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
Petral	SMAN	1986	450	195	UL	P	HE-P
Explorer	Wilson	1991	3402	1950	LM	T(V)	HW-T
730/731	Breguet	1938	35000	18700	H	T(M)	HW-T
Lat 631	Latecoere	1942	71414	32361	SH	T(V)	HW-T
SE200	Sud-Est	1943	72000	32746	SH	T(V)	HW-T
160	Potez-CAMS	1938	?	?	LM	1:3 scale	HW-T
141	Potez-CAMS	1938	23120	15013	H	T(M)	PW-T
Noroit	Nord (1402 varient)	1949	20430	?	H	T(M)	GW-T
20	SCAN	1947	2500	?	LM	T(M)	HE-P
Lat 582	Latecoere	1938	11302	6913	M	T(M)	PW-P
H47	LeO	1936	17900	10079	H	T(V)	PW-T/P
H246	LeO	1937	14973	9809	M	T(V)	PW-T
130	Loire-Neuport	1938	3300	2005	LM	T(M)	HE-CO-P
Lat 611	Latecoere	1938	26523	16014	H	T(M)	HW-T
SE1210	Sud-Est	1949	5740	4542	LM	1:1.3 scale	HW-T
790	Breguet	1939	3603	2702	LM	T(M)	HE-P
Lat 523	Latecoere	1935	37533	20859	SH	T(V)	HW-T
Lat 300	Latecoere	1931 (stub info)	24021	14323	H	T(M)	PW-T/P
FSRW-1	Smith	1983	907	670	UL	P	HE-T
Finmark	Honningstad	1949	5804	4035	LM	T(V)	HW-T
Seabird	SEFA	1993	405	200	UL	P	HE-P
SH5	HAMC	1973	45000	25000	SH	T(M)	HW-T
CJ59	Johansen	1967	1984	1278	L	P	HW-T
TE1A	Eckholm	1949	335	220	UL	P	HE-CO-T

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Nationality: France and Others 2

Aircraft	Tail Config	Range (km)	U/c Type	Wing Area (m^2)	Planing Bottom Dimensions				
					L (m)	L_f (m)	b (m)	β (°)	Draft (m)
Petral	M	?	tri	17.3	?	?	?	?	?
Explorer	M	?	tri	46.92	?	?	?	?	?
730/731	Tw	4850	nil	172	?	?	?	?	?
Lat 631	Tw	6035	nil	350	43.46	18.7	4.1	24	1.37
SE200	Tw	6060	nil	340	26.17	16.7	4.19	23	1.4
160	Tw	?	nil	?	?	?	?	?	?
141	Tw	?	nil	171	?	?	?	?	?
Noroit	Tr	2500	tail	100	15.54	10.3	2.94	?	?
20	Tw	1000	nil	32	8.56	5.2	1.5	16	0.48
Lat 582	M	1800	nil	112	14.56	7.8	2.74	?	?
H47	M	4000	nil	134.6	14.5	8.8	2.64	19	1.17
H246	M	1984	nil	131	16.0	8.75	2.75	?	?
130	Tr	1115	nil	38.17	?	?	?	?	?
Lat 611	Tw	4224	nil	195	?	?	?	?	?
SE1210	L	900	nil	45.9	?	?	?	?	?
790	M	893	nil	33	?	?	?	?	?
Lat 523	L	5914	nil	237	?	?	?	?	?
Lat 300	M	3280	nil	256	?	?	?	?	?
FSRW-1	M	370	tricycle	12.1	?	?	?	?	?
Finmark	L	1003	tail	45.5	9.32	5.2	1.89	22	0.5
Seabird	H	?	tail	17.5	5.4	2.5	0.9	17	0.33
SH5	Twin	4750	tricycle	144	28.95	14.9	3.17	15	1.21
CJ59	M	450	tricycle	12.8	?	?	?	?	?
TE1A	H	?	tricycle	5.6	4.42	2.0	0.89	16	0.31

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Nationality: France and Others 3

Aircraft	Speed s (kts)		Lateral Stability						
	max	stall	b/2 (m)	posn	synergy	form	retract	L_{float} (m)	B_{float} (m)
Petral	81	30	4.25	100	tip	C1	-	?	?
Explorer	86	43	10.0	-	uc	stub	-	-	-
730/731	163	?	20.2	38	section	?	-	?	?
Lat 631	200	71	28.7	46	engine	C1	*	?	?
SE200	190	?	26.1	47	engine	C1	*	?	?
160	?	?	?	?	engine	B1	*	?	?
141	140	54	20.5	50	-	?	-	?	?
Noroit	218	?	16	69	-	C1	-	2.35	0.55
20	109	?	7.5	63	-	C1	-	4.41	1.07
Lat 582	149	?	14.0	35	engine	C1	-	5.71	1.18
H47	180	?	16.0	46	controls	C1	-	4.62	1.0
H246	140	?	16.0	45	-	C1	-	3.91	0.93
130	88	53	8.0	43	-	C1	-	?	?
Lat 611	188	?		34	?	?	*	?	?
SE1210	150	?	10.45	?	engine	?	*	?	?
790	81	?	8.8	53	engine	?	-	?	?
Lat 523	114	?	24.6	-	controls	stub	-	-	-
Lat 300	87	?	22.5	-	-	stub	-	-	-
FSRW-1	105	50	?	?	?	E1	?	?	?
Finmark		?	-	-	uc	stub	-	-	-
Seabird	92	33	6	94	?	C2	*	?	?
SH5	300	92	18	83	-	C1	-	?	/
CJ59	?	?	4.7	?	-	B1	-	?	?
TE1A	?	?	3.75	84	-	B1	-	?	?

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Nationality: France and Others 4

Aircraft	Spray Method					Production	References
	c f	f w	t a	d	ex		
Petral	*	-	-	-	wing	**	Janes 90/1. Company booklet.
Explorer	-	-	-	-	stub	*	Janes 93/4.
730/731	*	-	-	-	-	**	Janes 47.
Lat 631	*	-	-	-	-	**	Janes 47 and 48. The Aeroplane Jan 45. Aeroplane Monthly Jan 93. Aeronautics Jan 48.
SE200	*	-	-	-	-	**	Janes 47.
160	*	?	?	?	-	*	Janes 38.
141	?	?	?	?	-	**	Janes 38. Warplanes of the 2nd WW.
Noroit	*	-	-	-	-	**	Janes 50/1 and 51/2.
20	*	-	-	-	-	**	Janes 47 and 50/1.
Lat 582	*	-	-	-	-	**	Janes 38.
H47	*	-	-	-	-	**	Janes 38. Aeroplane Monthly Jan 92. Warplanes of the 2nd WW.
H246	*	-	-	-	-	**	Janes 38. Warplanes of the 2nd WW. Aeroplane Monthly Jan 92.
130	*	-	-	-	-	**	Janes 38. Warplanes of the 2nd WW.
Lat 611	*	-	-	-	-	**	Warplanes of the 2nd WW.
SE1210	?	?	?	?	?	*	Janes 49/50.
790	-	-	-	-	-	**	Warplanes of the 2nd WW.
Lat 523	*	-	-	-	stub	**	Warplanes of the 2nd WW.
Lat 300	-	-	-	-	stub	**	Warplanes of the 2nd WW. World Encyclopedia of Civil Ac.
FSRW-1	?	-	-	*	-	*	Janes 87/8. AUSTRALIA
Finmark	-	-	-	-	stub	*	Aeroplane Monthly Aug 93 NORWAY
Seabird	-	-	-	-	low wing	*	Janes 93/4 PHILIPINES
SH5	*	*	*	*	slots	**	Janes 93/4 CHINA
CJ59	-	-	*	*	-	*	Janes 69/70 DENMARK
TE1A	-	-	-	-	-	*	Janes 51/2 FINLAND

Nationality: Germany, Japan and Canada 1

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
Equator	-	-	2000	1070	L	U	HE-P
DoX	Dornier	1929	56000	32675	SH	T(V)	HW-T+P
Bv138C-1	Blohm & Voss	1937	14513	11780	M	T(M)	HW-T
Seastar	Dornier	1986	4600	2800	LM	T(V)	PW-T+P
Do26K	Dornier	1937	20000	10200	H	T(M)	GW-T+P
Do18E	Dornier	1935	10805	5800	M	T(M)	PW-T+P
Do24T-1	Dornier	1937	16215	9408	H	T(M)	PW-T
Do24TT	Dornier	1983	18600	10407	H	T(M)	PW-T
Bv222A	Blohm & Voss	1940	45640	28575	SH	T(V)d T(M)	HW-T
Bv238	Blohm & Voss	1943	95085	55629	SH	T(V)d T(M)	HW-T
H6K5 (Mavis)	Kawanishi	1936	23000	12380	H	T(M)	PW-T
H8K2 (Emily)	Kawanishi	1940	32500	18380	H	T(M)	HW-T
SMG III	Mukai Olive	1980	575	430	UL	P	HE-CO-T
US1	Shin Meiwa	1968	45000	25500	SH	T(M)	HW-T
H9A1	Aichi	1940	7577	4900	LM	T(M)	PW-T
H5Y1	Kawanishi	1936	11510	7061	M	T(M)	PW-T
E11K1	Yokosuka	1937	3303	2722	LM	T(M)	HE-P
CL215	Canadair	1967	19278	11793	H	T(M)	HW-T
CL415	Canadair	1992	19731	12333	H	T(M)	HW-T
2000	Seawind	1982	12270	771	L	P	HE-Fin-T
Teal	Falconair	1967	680	476	UL	P	HE-CO-T
Drake	Frizzle	1977	726	454	UL	P	HE-P
Blue Teal	Crowder	1967	795	476	UL	P	HE-CO-P
Trigull	Trident	1973	1791	1134	L	U	HE-CO-P

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Nationality: Germany, Japan and Canada 2

Aircraft	Tail Config	Range (km)	U/c Type	Wing Area (m^2)	Planing Bottom Dimensions				
					L (m)	L_f (m)	b (m)	β (°)	Draft (m)
Equator	mid	10926	tricycle	18.0	5.74	3.9	1.65	12	0.49
DoX	mid	2200	nil	?	24.69	16.5	4.4	14	1.04
Bv138C-1	boom	4272	nil	122.0	15.79	6.63	2.52	11	0.84
Seastar	mid	1581	tricycle	30.6	8.23	5.3	1.9	7	0.29
Do26K	mid	9000	nil	12.0	16.56	10.0	2.5	11	0.94
Do18E	mid	5800	nil	111.2	12	7.8	2.5	8	0.52
Do24T-1	twin	4672	nil	108	13.66	9.0	2.93	7	0.61
Do24TT	twin	3200	tricycle	?	13.66	9.0	2.93	7	0.61
Bv222A	mid	7408	nil	255.1	26.88	14.8	2.88	15	1.34
Bv238	mid	7000	nil	365.1	33.46	17.46	3.4	16	1.46
H6K5 (Mavis)	twin	6733	nil	170.0	19.6	9.98	3.09	14	1.13
H8K2 (Emily)	low	6179	nil	160.0	20.4	10.4	3.06	15	1.13
SMG III	high	400	nil	16.8	7.5	6.1	1.23	14	0.37
US1	high	4207	tricycle	135.8	26.9	12.38	2.57	24	1.57
H9A1	mid	2136	tricycle	63.3	11.9	6.63	2.3	?	?
H5Y1	twin	4768	nil	107.7	13.35	8.9	3.0	?	?
E11K1	mid	?	tail	38.0	7.92	4.44	1.44	?	?
CL215	mid	2400	tricycle	100.33	19.37	8.62	2.57	25	1.1
CL415	mid	2427	tricycle	100.33	19.37	8.62	2.57	25	1.1
2000	mid	1493	tricycle	14.86	6.37	3.6	1.32	8	0.37
Teal	mid	1125	tricycle	14.86	?	?	?	?	?
Drake	mid	?	tricycle	12.08	?	?	?	?	?
Blue Teal	boom	?	tail	?	?	?	?	?	?
Trigull	mid	1609	tricycle	22.78	6.54	3.55	1.22	?	0.3

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Nationality: Germany, Japan and Canada 3

Aircraft	Speed s (kts)		Lateral Stability						
	max	stall	b/2 (m)	posn	synergy	form	retract	L_{float} (m)	B_{float} (m)
Equator	426	51	?	-	wing	-	-	-	-
DoX	210	?	?	-	stub	-	-	-	-
Bv138C-1	154	?	13.5	71%	control	B4	-	2.96	0.99
Seastar	180	65	8.9	-	stub	-	-	-	-
Do26K	335	109	15	52%	control	D1	*	1.7	0.51
Do18E	250	85	13.15	-	stub	-	-	-	-
Do24T-1	179	?	13.5	-	stub	-	-	-	-
Do24TT	224	?	?	-	stub	-	-	-	-
Bv222A	210	67	23.0	70%	-	B4	*	2.19	1.1
Bv238	219	?	30.0	77%	-	D1	*	2.44	0.87
H6K5 (Mavis)	208	58	20.0	60%	control	C1	-	4.34	1.08
H8K2 (Emily)	252	70	19.0	78%	-	C1	*	3.03	1.01
SMG III	81	30	7.0	57%	control	C2	-	1.14	0.4
US1	268	40	16.4	78%	-	C1	-	4.86	1.33
H9A1	176	?	12.0	51%	-	C4	-	3.18	0.8
H5Y1	163	?	15.8	60%	-	C3	-	3.78	1.0
E11K1	125	?	8.09	77%	tip	A1	*	1.92	0.67
CL215	164	73	14.3	92%	-	C1	-	3.54	0.85
CL415	203	66	14.3	92%	-	C1	-	3.54	0.85
2000	163	51	5.33	100%	tip	B2	-	?	?
Teal	113	32	5.0	?	fuselage	?	-	?	?
Drake	122	?	4.11	?	uc	?	-	?	?
Blue Teal	65	51	4.7	?	fuselage	?	-	?	?
Trigull	165	50	5.92	87%	tip	B1	*	1.78	0.32

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Nationality: Germany, Japan and Canada 4

Aircraft	Spray Method					Production	References/Notes
	c f	f w	t a	d	ex		
Equator	-	-	-	-	wing	0	Janes 82.
DoX	-	-	-	-	stub	*	The Monster from the Lake.
Bv138C-1	*	-	-	-	-	**	Warplanes of the 3rd Reich. Janes 39.
Seastar	-	-	-	-	stub	*	Company booklet. Janes 94/5.
Do26K	*	-	-	-	-	**	Aircraft Engineering Sep 39. Janes 38.
Do18E	-	-	-	-	stub	**	Warplanes of the 3rd Reich. Janes 38.
Do24T-1	*	-	-	-	stub	**	Warplanes of the 3rd Reich.
Do24TT	*	-	-	-	stub	*	Flyingboats and Amphibians since 1945.
Bv222A	*	-	-	-	-	**	Aeroplane Monthly Jul 94. Warplanes of the 3rd Reich.
Bv238	*	-	-	-	-	**	Aeroplane Monthly Jul 96.
H6K5 (Mavis)	*	-	-	-	-	**	Japanese Ac of the Pacific War. Ac Profile 233.
H8K2 (Emily)	*	-	-	*	-	**	Japanese Ac of the Pacific War. Ac Profile 233.
SMG III	*	-	-	-	-	*	Janes 82/3.
US1	*	-	*	*	channels	**	Janes 79/80
H9A1	*	-	-	-	-	**	Japanese Ac of the Pacific War. Warplanes of the 2nd WW.
H5Y1	*	-	-	-	-	**	Warplanes of the 2nd WW.
E11K1	*	-	-	-	-	**	Warplanes of the 2nd WW.
CL215	-	-	-	*	-	**	Janes 68/9. Canadian Ac. Canadair paper.
CL415	-	-	-	*	-	**	Flight 2-8 Jun 93. Company booklet.
2000	-	-	-	*	-	**	Company booklet.
Teal	?	?	-	?	stub	*	Janes 70/1.
Drake	?	?	?	*	?	*	Janes 79/80.
Blue Teal	?	?	?	?	?	*	Janes 68/9.
Trigull	-	-	-	*	-	**	Canadian Ac. Janes 75/6 and 80/1.

Nationality: Russia 1

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
Pony	REDA	1994	750	545	UL	P	HE-P
Be10	Beriev	1956	46500	26523	SH	T(M)	HW-J
Be R1	Beriev	1952	17015	?	H	T(M)	GW-J
Be 103	Beriev	1994	1760	1210	L	U	HE-T
Be 12	Beriev	1960	31000	18015	H	T(M)	GW-T
Be 42	Beriev	1986	86000	?	SH	T(M)	HE-J
Be 200	Beriev	1997	36000	?	SH	T(V)	HE-J
Flamingo	ROKS-Aero	1995(?)	2050	1470	LM	U	HE-P
Yamal	Aviaspetstrans	1998(?)	?	?	LM(?)	T(V)	HE-Fin-P
Be 112	Beriev	1998(?)	?	?	LM(?)	T(V)	HE-F-T
Be 6	Beriev	1949	28112	18827	H	T(M)	GW-T
ANT 44D	Tupolev	1937	19017	13011	H	T(M)	GW-T
MDR-5	Beriev	1938	9200	6083	M	T(M)	HW-T
MDR-6B5	Chyetverikov	1945	10080	5610	M	T(M)	GW-T
MDR-6	Chyetverikov	1937	7206	4104	LM	T(M)	GW-T
MBR-7	Beriev	1939	3168	2418	LM	T(M)	HE-T
Be 4	Beriev	1941	2760	2082	LM	T(M)	PW-T
Be 8	Beriev	1947	3624	2815	LM	U	PW-T
TA-1	Chyetverikov	1948	6255	4658	LM	T(V)	PW-T
Fregat	ROKS-Aero	1998(?)	2080	1251	LM	T(V)	HE-T+P
R-50	Robert	1998(?)	1820	1212	L	U	HE-P
A25M	Aeropract	1995	1225	630	L	U	HE-CO-P
11	Unikomtranso	1996	600	300	UL	P	PW-T
S202K	SGAU	1994	600	360	UL	P	HE-P
Prize	REDA	1998(?)	1700	1300	L	U	HE-P

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Nationality: Russia 2

Aircraft	Tail Config	Range (km)	U/c Type	Wing Area (m^2)	Planing Bottom Dimensions				
					L (m)	L_f (m)	b (m)	β (°)	Draft (m)
Pony	mid	680	tail	16.5	-	-	-	-	?
Be10	mid	?	nil	130	26.43	18.87	2.9	?	?
Be R1	mid	2000	nil	58	25.06	14.04	3.7	?	0.44
Be 103	mid	2600	tricycle	25.1	7.24	4.35	1.0	?	?
Be 12	twin	4000	tail	105	20.82	11.28	2.89	17	1.33
Be 42	high	5500	tricycle	200	28.56	19.45	2.8	23	1.45
Be 200	high	4500	tricycle	117.4	28.48	15.0	2.4	24	1.41
Flamingo	mid	1100	tricycle	20.68	10.9	4.1	1.6	18	0.56
Yamal	high	?	tail	51.9	16.82	9.25	2.15	?	?
Be 112	twin	?	tail	?	16.27	9.38	2.0	?	?
Be 6	twin	4800	nil	120	19.4	10.25	2.79	?	?
ANT 44D	mid	4500	tail	144.7	17.16	9.3	3.0	?	?
MDR-5	mid	2415	nil	78.5	11.27	6.4	2.2	?	?
MDR-6B5	twin	3000	nil	49.4	11.86	6.86	2.2	?	?
MDR-6	mid	2650	nil	59.4	12.05	6.99	1.9	?	?
MBR-7	mid	1215	nil	26	8.82	5.05	1.56	?	?
Be 4	mid	550	nil	25.5	7.83	4.52	1.48	?	?
Be 8	mid	1205	tail	40	11.36	5.8	1.73	?	?
TA-1	mid	1200	tail	43.6	10.69	5.68	1.74	?	?
Fregat	low	1320	tricycle	25.14	7.28	4.65	1.24	?	?
R-50	mid	?	tricycle	28.8	6.93	4.56	1.6	?	?
A25M	mid	1000	tricycle	14.7	?	?	?	?	?
11	low	?	tail	?	3.9	2.4	1.14	?	?
S202K	high	440	tail	?	?	?	?	?	?
Prize	high	750	tail	?	-	-	-	-	?

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Nationality: Russia 3

Aircraft	Speed s (kts)		Lateral Stability						
	max	stall	b/2 (m)	posn (%)	synergy	form	retract	L_{float} (m)	B_{float} (m)
Pony	81	38	5.5	-	-	-	-	-	-
Be10	496	120	14.3	100	tip	B1	-	4.93	0.58
Be R1	413	?	10.7	85	tip	B1	*	3.08	0.64
Be 103	156	54	6.36	-	wing	-	-	-	-
Be 12	330	?	14.9	88	-	B1	-	4.25	0.83
Be 42	413	?	16	100	tip	B3	-	5.48	0.82
Be 200	?	?	16	80	controls	B3	-	4.08	0.82
Flamingo	132	?	7.1	70	controls	B1	-	1.85	0.46
Yamal	235	?	10.7	85	-	B1	-	1.6	0.3
Be 112	?	?	9.4	70	controls	B1	-	2.97	0.51
Be 6	205	?	16.5	70	-	C1	-	3.88	1.11
ANT 44D	193	71	18.2	60	-	B3	-	5.0	1.07
MDR-5	154	65	12.5	72	-	C3	-	3.22	0.83
MDR-6B5	206	81	8.4	74	-	B1	-	2.81	0.77
MDR-6	196	54	10.5	50	-	?	-	3.23	0.54
MBR-7	168	?	6.5	68	-	?	-	2.25	0.7
Be 4	169	?	6.0	67	-	C3	-	2.09	0.61
Be 8	145	?	9.5	74	-	B3	-	2.22	0.62
TA-1	178	?	8.6	76	-	?	*	1.84	0.67
Fregat	124	?	5.7	-	stub	-	-	-	-
R-50	124	?	7.7	-	wing	-	-	-	-
A25M	140	52	5.3	100	tip	D2	-	?	?
11	91	38	5	83	tip	D3	*	1.29	0.29
S202K	68	33	6	100	tip	?	-	?	?
Prize	121	44	7.68	-	-	-	-	-	-

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Nationality: Russia 4

Aircraft	Spray Method					Production	References
	c f	f w	t a	d	ex		
Pony	-	-	-	-	-	0	Janes 96/7. Company booklet.
Be10	*	*	*	*	-	*	Janes 64. Osprey Russian Ac.
Be R1	*	-	-	-	-	*	Osprey Russian Ac. History of Soviet Ac.
Be 103	*	-	-	-	wing	*	Osprey Russian Ac.
Be 12	*	-	-	*	-	**	Janes 73. Osprey Russian Ac.
Be 42	*	-	*	*	-	*	Janes 94/5. Osprey Russian Ac.
Be 200	*	-	*	*	-	*	Janes 94/5. Osprey Russian Ac. Company booklet.
Flamingo	-	-	*	-	-	0	Janes 93/4.
Yamal	*	-	-	-	stub	0	Janes 94/5.
Be 112	*	-	-	-	-	0	Dwg only
Be 6	*	-	-	*	-	**	Osprey Russian Ac. History of Soviet Ac.
ANT 44D	-	-	-	*	-	*	Osprey Russian Ac.
MDR-5	*	-	-	-	-	*	Osprey Russian Ac. History of Soviet Ac.
MDR-6B5	-	-	-	-	-	*	Osprey Russian Ac. History of Soviet Ac.
MDR-6	*	-	-	-	-	**	Osprey Russian Ac. History of Soviet Ac.
MBR-7	*	-	*	-	-	**	Osprey Russian Ac. History of Soviet Ac.
Be 4	*	-	-	-	-	**	Osprey Russian Ac. History of Soviet Ac.
Be 8	*	-	-	-	-	*	Osprey Russian Ac. History of Soviet Ac.
TA-1	*	-	-	-	-	0	Osprey Russian Ac.
Fregat	-	-	-	-	stub	0	Osprey Russian Ac.
R-50	-	-	-	-	wing	0	Janes 96/7.
A25M	?	?	-	*	-	*	Janes 96/7.
11	-	-	-	*	-	*	Janes 96/7.
S202K	-	-	-	*	-	*	Janes 96/7.
Prize	-	-	-	-	-	0	Janes 96/7.

Nationality: USA 1

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
Airshark	Freedom Master	1985	1270	680	L	P	HE-P
SooperCoot A	Aerocar	1971	884	499	UL	P	HE-P
Dipper	Collins	1982	798	481	UL	P	HE-P
Merganser	Van Dine	1985	453	211	UL	P	HE-CO-P
Glass Goose	Quickkit	19822	726	476	UL	P	HE-CO-P
Osprey II	Pereira	1973	707	440	UL	P	HE-P
Seafire (TA16)	Thurston (IAC)	1982	1451	885	L	P	HE-T
Teal III	Thurston	1991	1043	680	L	P	HE-P
BCA 1-3	Baker	1968	929	?	UL	P	PW-T
Kingfisher	Anderson	1969	680	468	UL	P	HE-CO-P
Spectra IV	Island	1972	1535	881	L	P	HE-Fin-T
Seabee	Republic	1947	1361	884	L	P	HE-CO-P
Renegade (LA250)	Lake	1983	1383	839	L	U	HE-P
VJ22	Volmer	1958	658	430	UL	P	HE-P
GA22	Goodyear	1950	1305	851	L	U	HE-P
Sportsman (BAX-4)	Bunyard	1947	1247	769	L	U	HE-P
W-6	Aqua	1949	1635	1000	L	U	HW-T
Clipper (314)	Boeing	1941	37455	22040	SH	T(V)	HW-T
SeaRanger (XPBB-1)	Boeing	1942	45912	16972	SH	T(M)	HW-T
Turbo-Goose	McKinnon	1978	5670	3039	LM	T(V)	HW-T
Mini-Catelina	Avid	1995(?)	545	295	UL	P	HE-CO-P
LA4-200	Lake	1970	1220	705	L	U	HE-P
Trimmer	Commonwealth	1947	998	689	UL	U	HW-T
Seabird	Fleetwings	1938	1700	1111	L	P	HE-CO-T

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Nationality: USA 2

Aircraft	Tail Config	Range (km)	U/c Type	Wing Area (m^2)	Planing Bottom Dimensions				
					L (m)	L_f (m)	b (m)	β (°)	Draft (m)
Airshark	high	2735	tricycle	13.24	?	?	?	?	?
SooperCoot A	mid	?	tricycle	16.72	4.48	2.42	1.03	14	0.36
Dipper	low	926	tricycle	14.86	?	?	?	?	?
Merganser	twin	?	?	6.91	?	?	?	?	?
Glass Goose	mid	1600	tricycle	20.91	4.23	3.15	1.24	?	?
Osprey II	mid	579	tricycle	12.08	4.6	2.44	1.14	16	0.24
Seafire (TA16)	high	1609	tricycle	17.0	7.42	3.55	1.1	?	?
Teal III	high	804	tricycle	16.44	6.8	3.0	1.1	?	?
BCA 1-3	boom	720	tail	?	?	?	?	?	?
Kingfisher	mid	322	tail	?	6.01	2.66	1.1	?	?
Spectra IV	high	?	tricycle	18.6	?	?	?	?	?
Seabee	mid	901	tail	18.2	5.92	3.4	1.26	?	?
Renegade (LA250)	mid	1668	tricycle	15.8	7.02	3.7	1.25	13	0.34
VJ22	mid	545	tail	16.3	?	?	?	?	?
GA22	mid	?	tail	19.4	8.92	3.84	1.16	10	0.49
Sportsman (BAX-4)	high	?	tricycle	?	?	?	?	?	?
W-6	mid	?	tricycle	19.9	?	?	?	?	?
Clipper (314)	triple	4960	nil	266.45	21.0	13.3	3.84	16	1.12
SeaRanger (XPBB-1)	mid	6792	nil	169.7	19.7	10.65	3.15	15	1.28
Turbo-Goose	mid	2575	tail	35.08	8.31	4.56	1.52	18	?
Mini-Catelina	mid	582	tail	13.94	?	?	?	?	?
LA4-200	mid	1327	tricycle	15.8	?	?	?	?	?
Trimmer	mid	805	tail	15.09	5.05	2.87	1.23	18	0.34
Seabird	mid	864	tail	21.8	?	?	?	?	?

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Nationality: USA 3

Aircraft	Speed s (kts)		Lateral Stability						
	max	stall	b/2 (m)	posn	synergy	form	retract	L_{float} (m)	B_{float} (m)
Airshark	191	51	5.8	100%	tip	-	-	?	?
SooperCoot A	113	39	5.5	-	root	-	-	-	-
Dipper	130	45	5.1	?	?	D2	-	?	?
Merganser	143	47	5.33	100%	fins	-	-	-	-
Glass Goose	140	45	4.11	-	stub/uc	-	-	-	-
Osprey II	113	53	4.0	77%	-	E1	-	0.8	0.2
Seafire (TA16)	152	52	5.64	?	?	D2	-	?	?
Teal III	101	48	5.5	69%	controls	D2	-	0.9	0.2
BCA 1-3	?	77	5.5	?	?	B1	-	?	?
Kingfisher	104	39	5.5	?	?	B1	-	?	?
Spectra IV	188	53	5.7	100%	tip	-	-	-	-
Seabee	104	48	5.74	69%	-	B1	-	1.15	0.28
Renegade (LA250)	139	48	5.8	64%	controls	D2	-	0.91	0.31
VJ22	82	39	5.56	?	?	D2	-	?	?
GA22	115	47	5.8	75%	-	B1	-	1.34	0.27
Sportsman (BAX-4)	115	50	5.23	?	?	B1	-	?	?
W-6	108	44	5.56	-	stub/uc	-	-	-	-
Clipper (314)	165	70	23.18	-	stub	-	-	-	-
SeaRanger (XPBB-1)	190	?	21.3	72%	-	B1	-	4.28	0.86
Turbo-Goose	211	?	7.75	?	tip	B1	*	1.88	0.47
Mini-Catelina	65	33	5.5	?	?	B1	-	?	?
LA4-200	126	39	5.8	?	?	D2	-	?	?
Trimmer	117	42	5.4	70%	-	B1	-	1.26	0.31
Seabird	130	?	6.18	?	?	B1	-	?	?

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Nationality: USA 4

Aircraft	Spray Method					Production	References
	c f	f w	t a	d	ex		
Airshark	-	-	-	-	low wing	**	Janes 82/3, 84/5 and 94/5.
SooperCoot A	-	-	-	*	low wing	**	Janes 74/5.
Dipper	-	-	-	-	-	**	Janes 87/8.
Merganser	?	?	?	*	-	*	Janes 85/6.
Glass Goose	-	-	-	*	stub	**	Company booklet.
Osprey II	-	-	-	*	low wing	**	Janes 87/8. Company booklet.
Seafire (TA16)	-	-	-	*	-	**	Janes 94/5.
Teal III	-	-	-	*	-	**	Janes 92/3.
BCA 1-3	?	?	?	?	-	*	Janes 69/70.
Kingfisher	-	-	-	*	-	**	Janes 79/80.
Spectra IV	?	?	?	*	-	*	Janes 73/3.
Seabee	-	-	-	*	-	**	Janes 47.
Renegade (LA250)	-	-	-	*	-	**	Janes 90/1.
VJ22	-	-	-	*	-	*	Janes 61/2.
GA22	-	-	-	-	-	*	Janes 51/2.
Sportsman (BAX-4)	-	-	-	-	-	*	Janes 47.
W-6	-	-	-	*	stub	*	Janes 49/50.
Clipper (314)	*	-	-	-	stub	**	Janes 40. Boeing Ac.
SeaRanger (XPBB-1)	*	-	-	-	-	*	Boeing Ac.
Turbo-Goose	*	-	-	*	-	**	Janes 79/80.
Mini-Catelina	-	-	-	-	stub	*	Company booklet.
LA4-200	-	-	-	*	-	**	Janes 79/80.
Trimmer	-	-	-	-	-	**	Aero Digest 15 Sep 45. Janes 47.
Seabird	-	-	-	-	-	*	Janes 38.

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Nationality: USA 5

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
Tradewind (R3Y-2)	Convair	1956	74910	?	SH	T(V)d T(M)	HW-T
Goose (G21A)	Grumman	1941	3629	2461	LM	T(V)	HW-T
Mallard (G64)	Grumman	1947	5789	4245	LM	T(V)	HW-T
Albatross (UF-1)	Grumman	1947	12270	9125	M	T(M)	HW-T
Widgeon (G44)	Grumman	1941	2053	1470	LM	T(V)	HW-T
Avalon 680	Airmaster	1983	2631	1587	LM	T(V)	HE-CO-P
Catalina (PBY-5A)	Consolodated	1935	16080	9493	H	T(M)	PW-T
Corregador (Model 31, XP4Y-1)	Consolodated	1939	22884	13318	H	T(V)	HW-T
Coronado (PB2Y-3)	Consolodated	1937	30872	18584	H	T(M)	HW-T
XP3D-2	Douglas	1936	10391	6858	M	T(M)	HW-T
130	Martin	1935	23133	10478	H	T(V)	HW-T
Mars (JRM-2)	Martin	1941	74910	36461	SH	T(V)d T(M)	HW-T
Marlin (P5M-2)	Martin	1950	33166	21310	H	T(M)	GW-T
Seamaster (P6M)	Martin	1955	68100	36320	SH	T(M)	HW-J
Mariner (PBM-3)	Martin	1939	26330	18000	H	T(M)	GW-T
Adventurer	Adventure Air	1989	1498	908	L	P	HE-P
DF	Douglas	1936	12927	7854	M	T(V)	HW-T
Avocet	Aerowood	?	1498	912	L	P	HE-CO-P
Spruce Goose (H-3)	Hughes	1947	136200	?	SH	T(V)	HW-T
VS-42-B	Sikorsky	1936	19051	10886	H	T(V)	PW-T
VS-43-B	Sikorsky	1937	8845	5783	M	T(V)	PW-T
XPBS-1 (VS-44)	Sikorsky	1937	22037	11989	H	T(M)	HW-T

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Nationality: USA 6

Aircraft	Tail Config	Range (km)	U/c Type	Wing Area (m^2)	Planing Bottom Dimensions				
					L (m)	L_f (m)	b (m)	β (°)	Draft (m)
Tradewind (R3Y-2)	low	6400	nil	195.23	30.39	18.23	3.3	14	1.66
Goose (G21A)	mid	1287	tail	34.8	8.31	4.56	1.52	18	0.65
Mallard (G64)	mid	2410	tricycle	41.24	?	?	?	?	?
Albatross (UF-1)	mid	4320	tri/nil	77.5	15.2	7.6	2.43	14	1.16
Widgeon (G44)	mid	1150	tail	22.72	6.71	3.83	1.19	19	0.47
Avalon 680	twin	1770	tricycle	24.53	?	?	?	?	?
Catalina (PBY-5A)	mid	3760	tri/nil	130.11	13.0	7.74	3.03	14	1.07
Corregador (Model 31, XP4Y-1)	twin	5248	nil/tri	97.4	15.22	8.12	2.74	25	1.12
Coronado (PB2Y-3)	twin	2384	nil	165.43	16.0	8.86	3.2	20	1.92
XP3D-2	mid	3300	nil	?	14.1	8.0	2.4	?	?
130	mid	6437	nil	201.6	17.14	11.59	3.4	15	1.01
Mars (JRM-2)	low	?	nil	342.57	27.45	14.64	4.1	18	1.68
Marlin (P5M-2)	high	4630	nil	130.65	24.24	10.58	2.85	17	1.22
Seamaster (P6M)	high	12800	nil	176.5	33.23	2.48	14.95	?	?
Mariner (PBM-3)	twin	4828	nil/tri	130.85	18.2	9.83	2.9	15	1.27
Adventurer	mid	2700	tail	16.63	6.98	3.17	1.27	?	?
DF	mid	5310	nil	120.3	13.54	8.35	2.83	?	?
Avocet	mid	1314	tricycle	?	5.35	3.64	?	?	?
Spruce Goose (H-3)	mid	4825	nil	1029.0	47.6	24.3	7.6	?	?
VS-42-B	twin	1930	nil	124.5	?	?	?	?	?
VS-43-B	twin	1247	tail	72.51	?	?	?	?	?
XPBS-1 (VS-44)	low	6448	nil	?	17.04	9.48	3.05	?	1.12

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Nationality: USA 7

Aircraft	Speed s (kts)		Lateral Stability						
	max	stall	b/2 (m)	posn	synergy	form	retract	L_{float} (m)	B_{float} (m)
Tradewind (R3Y-2)	304	?	22.1	71%	-	B1	-	6.4	1.65
Goose (G21A)	174	?	7.5	67%	-	B1	-	2.0	0.5
Mallard (G64)	187	61	?	?	?		-	?	?
Albatross (UF-1)	299	69	12.2	71%	-	C1	-	3.34	0.85
Widgeon (G44)	139	44	6.1	71%	-	B1	-	1.53	0.43
Avalon 680	139	56	?	-	stub/uc	-	-	-	-
Catalina (PBY-5A)	152	60	15.9	85%	tip	A1	*	2.78	0.62
Corregador (Model 31, XP4Y-1)	215	77	16.77	73%	-	B1	*	3.04	0.81
Coronado (PB2Y-3)	185	?	17.5	92%	tip	A1	*	3.4	0.64
XP3D-2	159	?	14.5	64%	-	A1	*	?	?
130	206	61	20.0	-	stub	-	-	-	-
Mars (JRM-2)	207	86	30.5	70%	-	C1	-	5.58	1.11
Marlin (P5M-2)	213	85	18.0	81%	-	C2	-	4.6	0.73
Seamaster (P6M)	596	72	15.24	100%	tip	C2	-	5.7	0.71
Mariner (PBM-3)	174	71	18.0	71%	-	C1	-	4.39	1.04
Adventurer	137	47	5.5	77%	-	D2	-	1.08	0.32
DF	154	?	14.48	65%	-	?	*	2.36	1.26
Avocet	135	47	6.0	?	?	?	*	?	?
Spruce Goose (H-3)	203	90	48.8	70%	?	?	-	6.21	1.86
VS-42-B	163	56	18.0	?	?	C1	-	?	?
VS-43-B	165	56	13.1	58%	-	C1	-	?	?
XPBS-1 (VS-44)	193	57	19.0	63%	-	C1	-	?	?

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Nationality: USA 8

Aircraft	Spray Method					Productio n	References
	c f	f w	t a	d	ex		
Tradewind (R3Y-2)	*	*	-	-	-	**	Janes 56/7. Aero Digest Mar 51. USN AN 01-5MRA-2.
Goose (G21A)	*	-	-	*	-	**	Janes 38.
Mallard (G64)	*	?	*	-	-	**	Janes 48.
Albatross (UF-1)	*	-	*	-	-	**	Janes 53/4.
Widgeon (G44)	-	-	-	-	-	**	Janes 48.
Avalon 680	-	-	-	*	stub	*	Janes 85.
Catalina (PBY-5A)	*	-	-	-	-	**	USN AN 01-5MC1. Consolidated Ac.
Corregador (Model 31, XP4Y-1)	*	-	-	-	-	*	Janes 39. The Aeroplane 4 Apr 47.
Coronado (PB2Y-3)	*	-	-	-	-	**	Consolidated Ac. Janes 41.
XP3D-2	?	?	?	?	-	*	The American Flyingboat. McDonnel Douglas Aircraft.
130	*	-	-	-	stub	**	The Aeroplane 23 Jan 35.
Mars (JRM-2)	*	-	*	-	-	**	Airplane Monthly Apr 77. USN Datasheet.
Marlin (P5M-2)	*	*	*	-	-	**	Janes 56/7. NAVWEPS 01-35EJA-2.
Seamaster (P6M)	*	-	*	-	-	**	The American Flyingboat. USN Datasheet. Janes 58/9.
Mariner (PBM-3)		-	*	-	-	**	USN AN-01-35EG-2/1. Janes 48.
Adventurer	-	-	-	*	-	*	Company booklet.
DF	-	-	-	-	-	**	Douglas Ac.
Avocet	-	-	-	-	-	*	Company booklet.
Spruce Goose (H-3)	*	?	?	?	-	*	McDonnell Douglas Ac. Aero Digest 1 Sep 45.
VS-42-B	?	?	?	?	-	**	Janes 40.
VS-43-B	*	?	?	?	-	**	Janes 39.
XPBS-1 (VS-44)	*	?	?	?	-	*	USN Data Sheet. Janes 38.

Project Aircraft 1

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
Boeing 320	Boeing	-	60781	?	SH	T(M)	HW-T
Genisis	Gevers	-	2722	1542	LM	U	Special
USP-1 (tilt-wing)	NASA	-	102150	?	SH	T(M)	HW-J
USP-2 (6-engine)	NASA	-	99880	?	SH	T(M)	HW-J
Shearwater	NACA	-	54480	?	SH	T(V)	HW-T
Gannet	NACA	-	136200	?	SH	T(V)	HW-T
Albatross	NACA	-	217920	?	SH	T(V)	HW-T
Cormoranto	Siai-Marchetti	-	?	?	H(?)	T(V)	HW-T
P115	Piaggio	-	?	?	H	T(M)	GW-T
Dutchess	Saro	-	68040	?	SH	T(V)	HW-J
Tribian	-	-	1910	1313	L	T(V)	HW-T
S38A	Saro	1938	24940	-	H	T(M)	HW-T
P162B	Saro		52210	-	SH	T(M)	HW-T
P105	Saro	1951	22700	-	H	T(M)	PW-T
P208	Saro	1958	33142	-	H	T(M)	PW-T
SE1200	Sud-Est	1949	140000	78000	SH	T(V)	HW-T
SE4000	Sud-Est	1949	2757	1941	LM	T(V)	HE-CO-P
2000 (6 engine)	Hydro	1995	1000000	360000	SH	T(V)	HW-J
Freighty	NIAT	1995	?	?	M(?)	T(V)	HW-T
Corvette	Khrunichev	1995	2150	1440	LM	T(V)	HW-P
Brigantine	Khrenichev	1995	2530	1630	LM	T(V)	PW-P
Corvette R2	Hydroplan	1989	650	360	UL	U	HE-CO-T
AAA	-	-	23000	12200	H	T(M)	HW-T
Delfin	UTVA		5780	4034	LM	T(V)	HW-T

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Project Aircraft 2

Aircraft	Tail Config	Range (kg)	Uc Type	Wing Area (m^2)	Planing Bottom Dimensions			
					L (m)	L f (m)	b (m)	β (°)
Boeing 320	low	11345	nil	410.17	?	?	?	?
Genisis	high	3540	tricycle	28.61	9.83	?	1.5	
USP-1 (tilt-wing)	high	?	nil	139.4	49.1	26	2.3	?
USP-2 (6-engine)	high	?	nil	170.54	40.9	26.3	2.8	?
Shearwater	low	?	nil	265.52	?	?	?	?
Gannet	low	?	nil	663.85	?	?	?	?
Albatross	low	?	nil	1062.27	?	?	?	?
Cormorant o	mid	?	tri	?	?	?	?	?
P115	mid	3700	nil	?	?	?	?	?
Dutchess	?	?	nil	?	35.62	17.62	2.62	30
Triban	mid	1290	tri	26.3	8.55	4.8	1.57	?
S38A	twin	?	nil	?	?	?	?	?
P162B	mid	?	nil	?	?	?	?	?
P105	twin	?	nil	?	?	?	?	?
P208	high	?	nil	?	?	?	?	?
SE1200	low	10000	nil	385	45.5	23.0	5.63	23
SE4000	mid	1000	tri	31	8.87	4.5	1.18	17
2000 (6 engine)	high	?	nil	1300	?	?	?	?
Freighty	twin	1500	tricycle	?	?	?	?	?
Corvette	boom	1820	tricycle	?	8.86	5.17	1.4	?
Brigantine	mid	2080	tricycle	20.97	7.65	5.27	1.27	?
Corvette R2	low	430	tail	16.4	?	?	?	?

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Project Aircraft 3

Aircraft	Speeds		Lateral Stability						
	max	stall	b/2 (m)	posn	synergy	form	retract	L_{float} (m)	B_{float} (m)
Boeing 320	172	?	30.5	-	twin hull	-	-	-	-
Genisis	267	55	7.62	-	special	-	*	-	-
USP-1 (tilt-wing)	M=1.8	?	11.0	84%	-	?	-	?	?
USP-2 (6-engine)	M=1.8	?	11.3	?	?	?	-	?	?
Shearwater	?	?	24.4	73%	-	C1	-	4.9	0.9
Gannet	?	?	38.6	75%	-	C1	-	6.7	1.3
Albatross	?	?	48.8	75%	-	C1	-	7.6	1.4
Cormorant o	?	?	?	-	uc	-	-	-	-
P115	190	?	?	66%	-	C1	-	-	-
Dutchess	?		21.0		tip	C1	*	?	?
Triban	133	48	6.7	-	-	-	-	-	-
S38A	?	?	16.8	?	?	?	*	?	?
P162B	?	?	23.6	?	?	?	-	?	?
P105	?	?	?	?	?	?	-	?	?
P208	?	?	22.9	?	?	?	-	?	?
SE1200	182	?	30.5	?	tip	C1	*	6.57	1.4
SE4000	149	?	8.3	100	tip	B1	*	1.71	0.36
2000 (6 engine)	500	?	55	-	-	stub	-	-	-
Freighty	215	?	10	-	stub	-	-	-	-
Corvette	162	?	6.65	35	booms	C4	-	1.89	0.5
Brigantine	145	?	6.9	-	-	-	-	-	-
Corvette R2	91	33	5.85	100	tip	?	-	?	?

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Project Aircraft 4

Aircraft	Spray Method					Nationality	References
	cf	fw	ta	d	ex		
Boeing 320	-	-	-	-	-	USA	Boeing Ac.
Genisis	-	-	-	*	-	USA	Janes 94/5. Company booklet.
USP-1 (tilt-wing)	*	?	*	-	-	USA	NASA TM X-249.
USP-2 (6-engine)	*	?	*	-	-	USA	NASA TM X-246.
Shearwater	*	-	-	-	-	USA	NACA AAR L4I12.
Gannet	*	-	-	-	-	USA	NACA AAR L4I12.
Albatross	*	-	-	-	-	USA	NACA AAR L4I12.
Cormoranto	-	-	*	*	stub	Italy	Roskam.
P115	*	-	*	-	-	Italy	Janes 57.
Dutchess	?	?	?	?	?	UK	Saunders Roe Aircraft
Triban	-	-	-	-	stub	UK	The Airplane
S38A	?	?	?	?	?	UK	Saunders Roe Aircraft
P162B	?	?	?	*	?	UK	Saunders Roe Aircraft
P105	?	?	?	?	?	UK	Saunders Roe Aircraft
P208	?	?	?	?	?	UK	Saunders Roe Aircraft
SE1200	*	-	*	-	-	France	Janes 49/50.
SE4000	*	-	-	-	-	France	Janes 49/50.
2000 (6 engine)	?	?	?	?	stub	France	Janes 95/6.
Freighty	-	-	-	-	stub	Russia	Janes 96/7.
Corvette	-	-	-	-	-	Russia	Janes 96/7.
Brigantine	?	-	-	-	stub	Russia	Janes 96/7.
Corvette R2	?	*	-	-	-	Russia	Janes 96/7.

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Project Aircraft 5

Aircraft	Manufacturer	General Information					
		Date	AUM (kg)	M_{empty} (kg)	Class	Role	Config
RAE 1	RAE	1945	72640	?	SH	T(V)	HW-T
RAE 2	RAE	1945	108960	?	SH	T(V)	HW-T
RAE 3	RAE	1945	163440	?	SH	T(V)	HW-T
RAE 4	RAE	1945	245160	?	SH	T(V)	HW-T
RAE 5	RAE	1945	72640	?	SH	T(V)	HW-T
RAE 6	RAE	1945	108960	?	SH	T(V)	HW-T
RAE 7	RAE	1945	163440	?	SH	T(V)	HW-T
RAE 8	RAE	1945	245160	?	SH	T(V)	HW-T

Project Aircraft 6

Aircraft	Tail Config	Range (km)	Uc Type	Wing Area (m^2)	Planing Bottom Dimensions			
					L (m)	L f (m)	b (m)	β (°)
RAE 1	low	6436	nil	283.41	?	?	?	23
RAE 2	low	6436	nil	396.77	?	?	?	23
RAE 3	low	6436	nil	586.53	?	?	?	23
RAE 4	low	6436	nil	778.76	?	?	?	23
RAE 5	low	6436	nil	403.85	?	?	?	23
RAE 6	low	6436	nil	628.43	?	?	?	23
RAE 7	low	6436	nil	887.19	?	?	?	23
RAE 8	low	6436	nil	1158.28	?	?	?	23

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Project Aircraft 7

Aircraft	Speeds (kts)		Lateral Stability						
	max	stall	b/2 (m)	posn	synergy	form	retract	L_{float} (m)	B_{float} (m)
RAE 1	?	?	25.53	?	?	?	*	?	?
RAE 2	?	?	31.09	?	?	?	*	?	?
RAE 3	?	?	37.75	?	?	?	*	?	?
RAE 4	?	?	43.85	?	?	?	*	?	?
RAE 5	?	?	31.64	?	?	?	*	?	?
RAE 6	?	?	37.75	?	?	?	*	?	?
RAE 7	?	?	44.41	?	?	?	*	?	?
RAE 8	?	?	52.18	?	?	?	*	?	?

Project Aircraft 8

Aircraft	Spray Method					Nationality	References
	cf	fw	ta	d	ex		
RAE 1	?	?	?	?	?	UK	RAE TN(Aero)1724
RAE 2	?	?	?	?	?	UK	RAE TN(Aero)1724
RAE 3	?	?	?	?	?	UK	RAE TN(Aero)1724
RAE 4	?	?	?	?	?	UK	RAE TN(Aero)1724
RAE 5	?	?	?	?	?	UK	RAE TN(Aero)1724
RAE 6	?	?	?	?	?	UK	RAE TN(Aero)1724
RAE 7	?	?	?	?	?	UK	RAE TN(Aero)1724
RAE 8	?	?	?	?	?	UK	RAE TN(Aero)1724

APPENDIX 2

FLOATPLANE LONGITUDINAL AND LATERAL ON-WATER STATIC STABILITY

1. Longitudinal On-Water Stability. From the theory of metacentric heights (see Figure 2.5):

$$BM = I/V$$

where I is the moment of inertia of the waterplane area and V is the volume of displacement. therefore:

$V = AUM/1025$ as $\rho_{H2O} = 1025\ kg/m^3$

in the longitudinal sense:

$I = (n/12)b_f l_{wl}^{\ 3}$ where n is the number of floats

from inspection of the seaplane database the float waterline length (l_{wl}) is approximately 90% of the float length less water rudder (l_f). However, note that small changes of waterline height due to floatplane mass can result in relatively large changes in waterline length and therefore the accuracy of this method is potentially suspect. However, accepting this caveat:

$$I = (n/12)\ b_f\ (0.9l_f)^3$$

substituting gives:

$$BM = (1025/AUM)(n/12)b_f(0.9l_f)^3$$

from Figure 2.5:

$$GM = BM - h$$

where h is the height of the float centre of buoyancy from the floatplane centre of gravity. Therefore substituting gives:

$$h = [\{85.4\ nb_f\ (0.9\ l_f)^3\ \}/AUM] - GM$$

In the past, floatplane references have approximated GM to a function of AUM. Specifically, for longitudinal stability (note Imperial units):

(1) Aircraft Engineering Nov 1933: $GM\ (ft) > 1.75(AUM)^{1/3}\ (lb)$
(2) Aircraft Engineering Feb 1933: $1.4(AUM)^{1/3} < GM\ (ft) < 1.8\ AUM^{1/3}\ (lb)$

Converting to SI units gives:

(1) $GM\ (m) > 0.305(1.75\ (AUM)^{1/3}) = 0.53AUM^{1/3}$
(2) $0.305(1.4\ (AUM)^{1/3}) < GM\ (m) < 0.305(1.8\ (AUM)^{1/3})$
$= 0.43AUM^{1/3} < GM < 0.55AUM^{1/3}$

The GM values of 40 floatplanes were estimated using this method (see Table 2.11). This confirmed that the 1.75 value was a sound factor. Failures were examined and it was noted that the greatest were where large values of GM (ie high AUM) were matched with low values of BM (ie high AUM and/or short floats). Therefore, it was not surprising that the inconsistencies for twin floats mainly occurred for large military floatplanes. In the case of single float aircraft, failures occurred when the actual height was greater than expected due to factors such as propeller diameter. This may also be a factor for twin float, twin engined aircraft. This method must be therefore used with care in these areas. A relationship is proposed as follows: with a variety of factors applied.

single floats: $h_{max} = [\{85.4\, b_f (0.9\, l_f)^3\}/AUM] - [0.53(AUM)^{1/3}]$

twin floats: $h_{max} = [\{170.8\, b_f (0.9\, l_f)^3\}/AUM] - [0.53(AUM)^{1/3}]$

2 Lateral On-Water Static Stability. Using the same method as above but in a lateral sense:

$$I = 1/12\,((s + b)^3 - (s - b)^3) = 1/12\,(6s^2b + 2b^3)$$

therefore, substituting gives:

$$BM = (1025/12)(1/AUM)(6s_f^2b_f + 2b_f^3)$$

therefore, substituting gives:

$$GM = [85.4\,(1/AUM)\,(6s_f^2b_f + 2b_f^3)] - h$$

From previous estimation methods l_f, h and b_f are known. The remaining unknowns are the matacentric height and the float spacing. Numerous references (145, 146) quote a safe approximation of metacentric height as follows:

$GM\,(ft) = 1 \text{ to } 1.4(AUM)^{1/3}\,(lb)$ converting to SI units gives:

$GM = 0.305K\,(AUM/0.454)^{1/3}$ where K lies between 1 and 1.4.

therefore substituting and rearranging gives

$$s_{min} = [([0.305K\,(AUM/0.454)^{1/3} + h]\,[12AUM/1025l_f] - 2b_f^3)(1/6b_f)]^{1/2}$$

Floatplanes with known values of float spacing were taken from the database and s_{min} with various values of K compared to these actual values (see Table 2.12). The same 75% success criteria used to define a value of K when the estimated spacing was greater than the actual measured spacing. As the majority of multi-engined floatplanes used engine mountings as float strut supports it was concluded that this design synergy would have a significant influence over float spacing in addition to pure lateral stability considerations. Thus the multi-engined seaplanes were deleted from the relevant data and the 75% criteria applied to the remaining data points. The value of K required to produce 75% estimated float spacings which were greater than the measured value of s was 1.4. Substituting, this gives:

$$s_{min} = [([0.43\,(AUM/0.454)^{1/3} + h]\,[12AUM/1025l_f] - 2b_f^3)(1/6b_f)]^{1/2}$$

APPENDIX 3

FLOAT INSTALLATION CENTRE OF GRAVITY/BUOYANCY POSITION ESTIMATION

1. Introduction. Assumption-based techniques produced estimated centre of gravity and (fully immersed) buoyancy positions which were close to the validation example but similar methods for longitudinal positions failed. Empirical methods based on the floatplane database were therefore used for these estimation methods.

2. Vertical Centre of Gravity. The relative position of float structure and struts in the vertical sense was common in most floats and therefore an assumption-based estimation technique could be used to estimate the centre of gravity position as follows (see Figure A3.1):

Assume vertical centre of gravity of float = M_{float} h/2

Assume vertical centre of gravity of struts = M_{struts} [(h*-h)/2]+h = M_{struts}(h*-h)/2

To find M_{struts} consider the Full Lotus inflatable floats, the only floats in the database with both float and strut mass data:

Float mass (kg)	Strut mass (kg)	%
17.2	5.00	29
16.8	4.67	28
22.7	7.38	33
17.7	6.54	37
26.8	12.16	45
22.7	11.63	51
	AVERAGE	37%

Therefore M_{struts} = 0.37 M_{float}

Considering the average of this small and possibly unrepresentative sample as a proportion of the AUM of the aircraft:

from Eqn 2.1: 0.37(0.1AUM + 33) = 0.037AUM +12

This compares well with the 3%AUM recommendation of Langley (see Para 2.3.8). Therefore use above equation confidently.

Substituting gives:

Vertical c of g position of installation = {[M_{float}]+[M_{struts} (h*-h)/2]}/{M_{float}+M_{struts}}

Validate using Twin Otter on Wipline 13000 floats (see Figure A3.2) taken from Reference 147.

$M_{float\ installation} = 939kg$ therefore: $M_{float} = 685kg$ $M_{struts} = 254kg$

From Figure A3.2: h = 1.26m h* = 1.71m

Therefore vertical c of g = 0.86m Actual vertical c of g = 0.77m Error = 11%

2. <u>Vertical Centre of Buoyancy Position.</u> Assume that the cross-section of a float is as described in Figure A3.1:

Vertical c of b of a fully submerged float (measured from the top downwards)
= [(2h/3)/2] + [(h/6)/2] = 5h/12 = 0.42h

Validate using Twin Otter on Wipline 13000 floats example (see Figure A3.2):

Centre of Buoyancy = 0.6m down, float h = 1.4 therefore = 0.43 error = 2%

3. <u>Longitudinal Centres of Gravity and Buoyancy Position</u>. As there were significantly different forms of longitudinal configurations of both struts, float internal structural components and float form, an empirical rather than assumption-based technique was used to approximate the longitudinal centre of gravity position. With the exception of the Twin Otter example (which was used as validation) the only floats for which longitudinal centre of gravity positions were available were in relatively old references, the NACA ones being research model floats and the R&M ones being Schneider Trophy racer floats; all were pure floats. However, their close statistical grouping was such that a relationship could be confidently proposed.

Reference	c of g position (% float length)	c of b position (% float length)
NACA TN 563. Mar 1936 (145)	49%	-
NACA TN 473. Oct 1933 (146)	48% 45%	47% 48%
NACA TN 656. May 1938 (148)	47% 49%	- -
NACA TN 716. Jun 1939 (149)	45%	-
ARC R&M 1300 (extract from ARC R&M 1296). Jan 1931 (150)	45%	-
ARC R&M 1300 (extract from ARC R&M 1297). Jan 1931 (150)	45% -	48% 48%
Note on the Design of Twin Seaplane Floats (151)	-	49%
AVERAGE	47%	48%

Longitudinal c of g position (measured from float bow) = 0.47 l_{float}

Longitudinal c of b position (measured from float bow) = 0.48 l_{float}

The Twin Otter validation example had a longitudinal centre of gravity and buoyancy position at 44% and 46% of float length respectively. Although both were only 2% in error, possibly due to the fact that the Twin otter floats were amphibious, it was noted that small errors in these positions could significantly influence the float position relative to the aircraft centre of gravity. Therefore this method should be used with care. A more detailed calculation when detailed design has finalised float and strut structure is advisable.

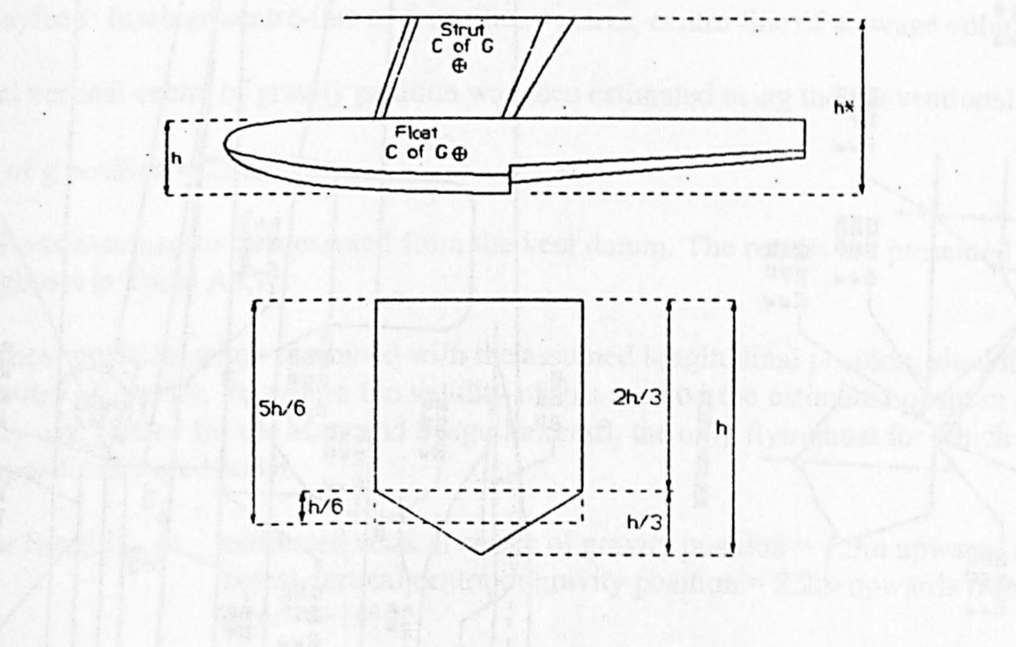


FIGURE A3.1 CENTRE OF GRAVITY AND BUOYANCY ASSUMPTIONS

POINT	CONDITION	STA	WL	LOC	B.L.
A	FULL UP	240.33	-88.95	AXLE	
	"	"	-92.76	TIRE	
	STRUT COLLAPSED	241.715	-86.40	AXLE	
	"	"	-93.20	TIRE-FLAT	
	STATIC	243.35	-90.80	AXLE	
	"	"	-100.20	TIRE	
	25%	240.69	-91.676	AXLE	
	"	"		TIRE	
	EXTENDED	238.58	-95.046	AXLE	
		"	-103.871	TIRE	
B	MAX DEFLE.	50.00	-82.77	AXLE	
			-88.57	TIRE-FLAT	
	STATIC	45.00	-93.30	AXLE	
		"	-100.20	TIRE	
	EXTENDED	44.00	-93.93	AXLE	
		"	-102.80	TIRE	

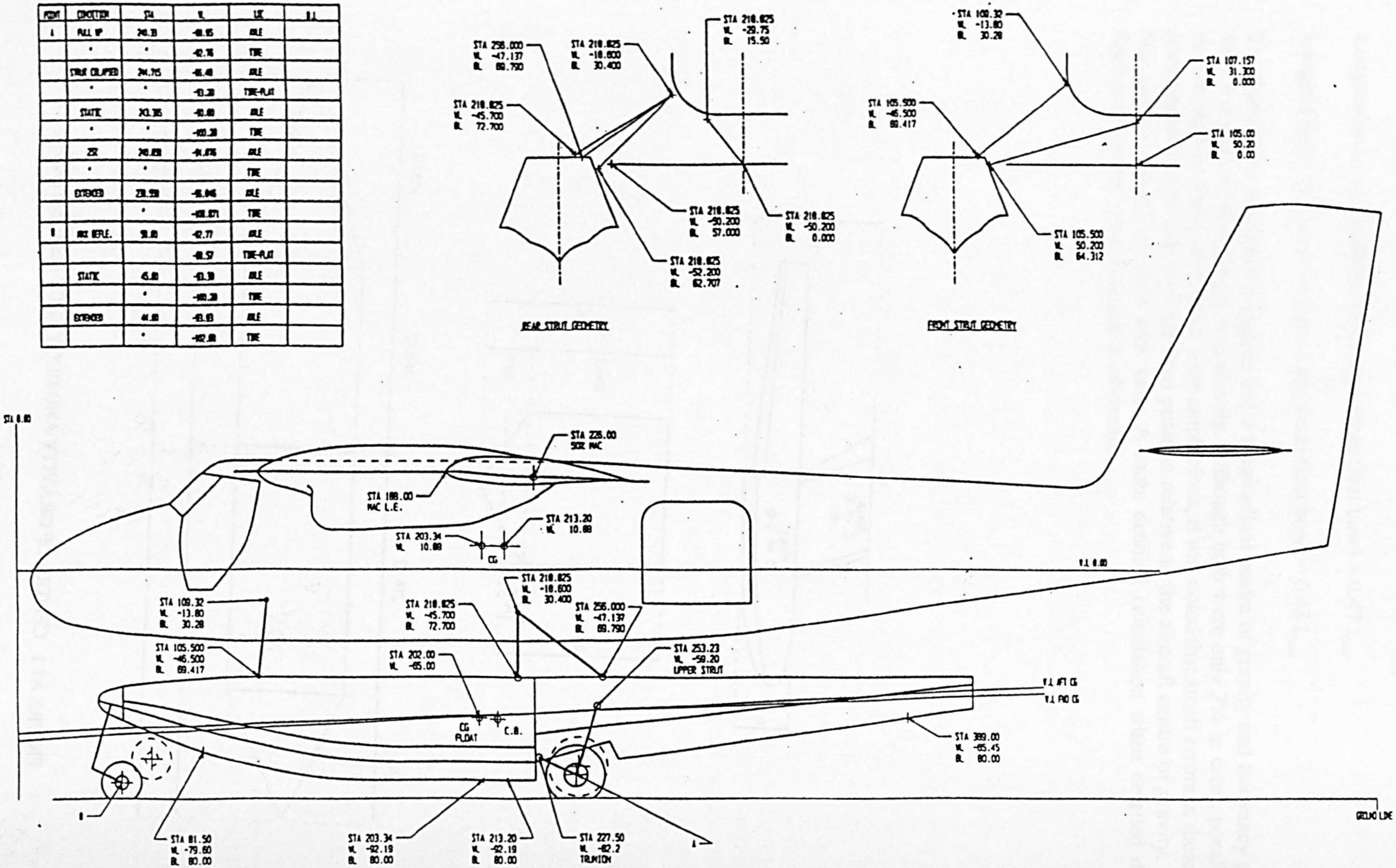


FIGURE A3.2 TWIN OTTER WITH WIPLINE 13000 FLOATS

APPENDIX 4

ESTIMATION OF AIRCRAFT VERTICAL CENTRE OF GRAVITY POSITION

1. It was concluded that the major components making up the vertical centre of gravity position were the fuselage, wings, engines, fin, tailplane, undercarriage, payload and fuel. The position of these are often design variables for flyingboats. For example, fuel can be positioned in the hull, wings or stubs. Masses for each structural component were estimated using the method of Reference 74. In many cases the total estimated mass did not equate to the known empty mass due to the generalities inherent in the assumptions. The total estimated empty mass was therefore compared with the known empty mass and the difference grouped as a point mass at the fuselage centre-line. Payload and fuel masses were taken from the database. For large aircraft where a significant payload/fuel trade-off was possible a 50/50 split was assumed. The centre of gravity of each structural component was then assumed to be vertically positioned as follows:

fuselage: centre-line — engine: centre-line
wing: mid-thickness — tailplane: mid-thickness
fin: 2/3 span — undercarriage: centre-line of stowage volume
fuel: centre-line of wing or fuselage or stub mid-thickness
payload: fuselage centre-line or for military stores, centre-line of stowage volume

The total vertical centre of gravity position was then estimated using the conventional method:

$$\text{c of g position} = \Sigma Mz \,/\, \Sigma M$$

where z was assumed to be measured from the keel datum. The results are presented for a variety of flyingboats in Table A4.1.

This vertical position, when combined with the assumed longitudinal position, sited the flyingboat AUM centre of gravity. To ensure the validity of this method the estimated position of the centre of gravity was plotted for the Mars and Seagull aircraft, the only flyingboat for which actual AUM vertical positions were known.

for $\text{Seagull}_{(152)}$: estimated vertical centre of gravity position = 1.9m upwards from keel
actual vertical centre of gravity position = 2.2m upwards from keel
error = +14%

for $\text{Mars}_{(153)}$: estimated vertical centre of gravity position = 2.9m upwards from keel
actual vertical centre of gravity position = 2.63m upwards from keel
error = 10%

Both plots resulted in the estimated position occurring close to 10% of the actual individual longitudinal and vertical position which is an acceptable error bearing in mind the accuracy of measurement from the database drawings.

Example calculations are as follows:

For Seagull (AUM = 6585kg)

component	Estimation Eqn	mass	arm	Mz
wing	0.03 $AUM^{1.1}$	476	3.15	1499
fuselage	0.0144 $AUM^{1.18}$	461	1.0	461
fin	0.33x0.15$AUM^{0.85}$	73	3.61	264
tail	0.66x0.15$AUM^{0.85}$	146	3.1	453
main uc	0.9x0.048AUM	286	1.0	286
nose uc	0.1x0.048AUM	25	1.0	25
engine(s)	known x 1	964	3.3	3181
payload	Known	850	1.0	850
fuel	Known	965	3.15	3040
			TOTAL =	10059

empty mass estimate = 476+461+73+146+286+25+964 = 2431
actual empty mass = 4770 therefore difference = 2339 at a 1m arm

therefore vertical centre of gravity = (10059 + 2339)/6585 = 1.9m

For Martin Mars (AUM = 74910kg)

component	Estimation Eqn	mass	arm	Mz
wing	0.03 $AUM^{1.1}$	6904	5.38	37143
fuselage	0.0144 $AUM^{1.18}$	4511	3.10	13984
fin	0.33x0.15$AUM^{0.85}$	550	10.24	5632
tail	0.66x0.15$AUM^{0.85}$	1100	7.68	8448
main uc	Nil	0	0	0
nose uc	Nil	0	0	0
engine(s)	known x 4	5520	5.38	29698
payload	Known	19224	3.1	59594
fuel	Known	19225	0.63	12112
			TOTAL =	166611

empty mass estimate = 6904+4511+550+1100+5520 = 18585kg
actual empty mass = 36461 therefore difference = 17876kg at a 3.1m arm = 55416

therefore vertical centre of gravity = (166611+55416)/74910 = 2.9m

TABLE A4.1

VERTICAL CENTRE OF GRAVITY POSITION

aircraft	Position from keel (m)	aircraft	position from keel (m)
Princess	5.85	LeO H47	2.54
Dutchess	3.33	LeO H24-6	2.64
SE1200	5.18	Albatross	2.38
SE200	3.20	G21A	1.75
SE4000	1.13	Widgeon	1.30
Bv238	4.47	Be12	2.67
Bv222	3.37	Be6	2.95
Bv138	2.28	Noroit	1.91
Tradewind	3.35	VS44	2.27
Coronado	3.22	Lat631	3.57
Catelina	2.46	CL215	2.39
Mars	2.85	Seagull	2.53
Marlin	3.45	Finmark	1.86
Model 130	3.49	Delfin	2.03
Mariner	3.04	P136	0.86
Do26	1.98	Flamingo	1.33
Do24	1.85	Equator	0.71
DoX	4.09	Trigull	1.04
Do18	1.49	Riviera	1.07
Seastar	1.27	Renegade	1.03
Ranger	3.60	Goodyear	1.47
Clipper	3.39	Seawind	0.91
SH-5	3.05	Trimmer	1.10
ShinMeiwa	3.27	Coot	0.65
Emiliy	2.34	Teal	1.13
Mavis	2.07	Osprey	0.68
Shetland	3.92	SMG III	1.16
Seaford	3.49	Seabird	0.81
G Class	3.75	Eckholm	0.92
Sunderland	2.38		
C Class	2.54		
Sealand	1.82		

APPENDIX 5

FLOATPLANE PERFORMANCE EXAMPLE CALCULATION

Taking the Piper Cub as an example:

(Piper Cub $C_{D0})_{landplane}$ = 0.0373 (from Reference 114)

AUM $_{landplane}$ = 794kg

from Eqn 2.6: l_{float} = 0.0027AUM + 3 = 5.1m

from Eqn 2.7: b_{float} = l_{float} /7.5 = 0.68m

from Eqn 2.8: h_{float} = l_{float} /8.8 = 0.58m

therefore square cross-sectional area = b x h = 0.39m^2

therefore float shape cross-sectional area (see Figure A5.1) = 0.8925 x 0.39 = 0.34m^2

$(C_{D0})_{float}$ = 0.22 based on cross-sectional area of 0.34m^2

for Piper Cub: s = 16.58m^2

$(C_{D0})_{float}$ = 0.22 (0.34/16.58) = 0.0045 based on wing area

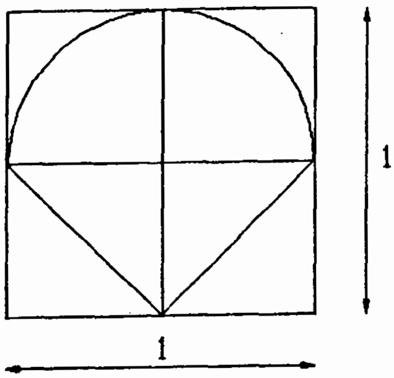
2 x floats therefore C_{D0} = 0.009

$(C_{D0})_{wheels}$ = 0.0013 based on 1m^2

therefore $(C_{D0})_{wheels}$ = 2 x 0.0013 (1/16.58) = 0.00015 based on wing area

therefore $(C_{D0})_{floatplane}$ = (0.0373 - 0.00015) + 0.009 = 0.04615

FLOAT CROSS-SECTIONAL AREA



area of triangle - 0.5 x 1 x 0.5 - 0.25

area of semi-circle - 0.5 x pi x 0.5 x 0.5 - 0.3925

total area = 0.25 + 0.3925 = 0.8925

FIGURE A5.1 FLOAT CROSS SECTIONAL AREA

APPENDIX 6

DERIVATION OF FLOAT DRAG COMPARISONS BASED ON AREAS

1 Wetted Area. The wetted area of each configuration was estimated using the fuselage method of Torenbeek(44).

$$A_w = \pi D_{fus} l_{fus} (1-2/\lambda)^{2/3}(1+1/\lambda^2)$$

where D_{fus} = diameter of fuselage (assume to become float)
λ = length/diameter ratio
l_{fus} = length of fuselage (assume to become float)

first define λ as an average of float length to beam and length to height ratios using Eqns 2.7 and 2.8:

for twin floats:	$l/b = 7.5$	$l/h = 8.8$	therefore $\lambda = 8.15$
for single float:	$l/b = 6.9$	$l/h = 8.8$	therefore $\lambda = 7.85$

then define D as follows:

$\lambda = l/D$ therefore $D = l/\lambda$

for twin floats: $D = l/8.15$
for single floats: $D = l/7.85$

therefore for a single, twin float:

$$A_w = \pi\,(l^2/8.15)(1-2/8.15)^{2/3}(1+1/8.15^2) = 0.31l^2$$

and for the twin float set (ie 2 floats)

$$A_w = 0.61l^2$$

therefore for a single main float:

$$A_{wm} = \pi\,(l^2/7.85)(1-2/7.85)^{2/3}(1+1/7.85^2) = 0.341l^2$$

Now consider the single float configuration's tip/auxiliary floats. By examination of the floatplane database:

$b_{tip} = h_{tip} = 0.75\, b_{main}$ and $l_{tip} = 0.25\, l_{main}$

therefore: $\lambda = (0.25\, l_{main})/(0.75\, b_{main})$

substituting gives: $\lambda = 2.6$

therefore for a single tip float:

$D = l/\lambda$ therefore:

$A_{wt} = \pi\ (0.09\ l_{main})(0.25\ l_{main})(1\text{-}2/2.6)^{2/3}(1+1/2.6^2) = 0.03l^2$

and for both tip floats:

$A_{wt}\ = 0.06l^2$

therefore for single float set:

$A_w = A_{wm} + A_{wt} = 0.34l^2 + 0.06l^2 = 0.4l^2$

2 <u>Cross Sectional Area.</u> For twin floats (using Eqns 2.7 and 2.8):

$A_x = b.h = (l/7.5)(l/8.8) = 0.015l^2$

therefore for 2 floats:

$A_x = 0.03l^2$

For a single main float (using Eqn 2.7 and 2.8):

$A_{xm} = b.h = (l/6.9)(l/8.8) = 0.017l^2$

for tip floats:

$A_{xt} = b.h = (0.75\ b_{main})(0.75\ b_{main}) = 0.5625b_{main}^{\ 2}$

$= 0.5625(l/6.9)(l/6.9) = 0.012l^2$

for tip floats:

$A_{xt} = 0.024l^2$

therefore $A_x = A_{xm} + A_{xt} = 0.041l^2$

APPENDIX 7

FLOATPLANE VALIDATION EXAMPLE CALCULATIONS

Example 1 - Twin Float, Single Engined Aircraft. The Baumann BF2100 float fitted to the Piper PA18 Super Cub was not included in the development of the float methodologies and can therefore be used for validation purposes.

BF2100 float displacement = 953kg therefore AUM of aircraft = (2x953)/1.8 = 1059kg

ie <1500kg therefore from Eqn 2.2: $(M_f)_{metal} = 0.14AUM - 24 = 124$kg

actual mass = 112kg therefore error = +10%

AUM<2500kg therefore from Eqn 2.5:

$l_f = 3 + 0.0018AUM = 4.91$m

actual length = 5.14m therefore error = -4%

from Eqn 2.7: $b_f = l_f/7.5 = 0.65$m

actual beam = 0.72m therefore error = -9%

from Eqn 2.8: $h_{float} = l_f/8.8 = 0.56$m

actual height = 0.55m therefore error = +2%

from Eqn 2.9: $l_{fb} = l_f/2 = 2.45$m

actual forebody length = 2.55m therefore error = -4%

from Eqn 2.10: $z = 0.54 + (1.x10^{-4}\ AUM) = 0.65$m

actual height from float to structure = 0.65m therefore error = 0%

from Eqn 2.13 $cost = 2.75AUM^{1.275} = \$19773$

actual cost = \$18500 pair therefore error = +7%

from Eqn 2.11: $h_{max} = [\{170.8\ b_f\ (0.9\ l_f)^3\ \}/AUM] - [0.6(AUM/0.454)^{1/3}] = 1.11$m

actual height from centre of gravity to centre of buoyancy = 1.2 m therefore error = 7%

from Eqn 2.12: $s_{min} = [\{[0.43\ (AUM/0.454)^{1/3} + h_f]\ [12AUM/1025l_f] - 2b_f^3\}/6b_f]^{1/2}$

$s_{min} = 2.1$m

actual float separation = 2.1 therefore error = 0%

Example 2 - Single Float, Multi-engined Aircraft. In 1939 a Short Scion Senior transport aircraft was fitted with a half-scale representation of a Sunderland hull under its fuselage for experimental work (see Plate 2.11) (50). This is the closest to a large single float civilian floatplane available for validation work, although some care must be taken in using the figures as the dimensions would have been driven more by the requirement to represent the Sunderland rather than by efficiently supporting the Scion. However, the design still had to be safe to operate.

AUM = 2607kg

from Eqn 2.6: $l_f = 8 + 0.0003\ AUM = 8.8m$

actual $l_f = 9.0m$ therefore error = -5%

from Eqn 2.7: $b_f = l_f/6.9 = 1.3m$

actual beam = 1.49m therefore error = -8%

from Eqn 2.8: $h_f = l_f/8.8 = 1.0m$

actual height = 0.95m therefore error = +5%

from Eqn 2.9: $l_{fb} = l_f/1.8 = 4.9m$

actual forebody length = 5.1m therefore error = -4%

Example 3 - Large Twin Float Multi-engined Aircraft. The DC3 Dakota aircraft was modified to become an amphibious floatplane primarily to serve the Pacific theatre during World War 2 (see Plate 2.12).

AUM = 11793kg (>2500kg) therefore

from Eqn 2.5: $l_f = 8 + 0.0002AUM = 10.4m$

actual float length = 13.0m therefore error = -20%

from Eqn 2.7: $b_f = l_f/7.5 = 1.4m$

actual float beam = 1.50m therefore error = -7%

from Eqn 2.8: $h_f = l_f/8.5 = 1.22m$

actual float height = 1.31m therefore error = -7%

from Eqn 2.9: $l_{fb} = l_f/2 = 5.2m$

actual forebody length = 4.8m therefore error = +8%

from Eqn 2.10: $z = 0.9 + 4.4\times10^{-5}AUM = 1.4m$

actual spray height = 1.4m therefore error = 0%

from Eqn 2.11: $h_{max} = [\{170.8\ b_f\ (0.9\ l_f)^3\ \}/AUM] - [0.6(AUM/0.454)^{1/3}]$

using estimated l_f from above: $h_{max} = -1.11m$ ie unstable

using actual l from above: $h_{max} = 9.23$ ie stable

actual height from centre of gravity to centre of buoyancy = 3.24m therefore stable

from Eqn 2.12: $s_{min} = [\{[0.43\ (AUM/0.454)^{1/3} + h]\ [12AUM/1025l_f] - 2b_f^3\}/6b_f]^{½}$

$s_{min} = 5.8m$

actual float spacing = 5.8m therefore stable and error = 0%

from Eqns 2.15 and 2.16:

estimated floatplane speed = 0.78 x landplane speed = 0.78 x 370 = 289 km/hr

actual maximum speed = 309 km/hr therefore error = -6%

est floatplane rate of climb = 0.76 x landplane rate of climb = 0.76 x 366 = 278 m/min

actual rate of climb = 228 m/min therefore error = -18%

The floatplane DC3 had additional fuel tanks in the floats and therefore a range comparison with the landplane is not valid.

APPENDIX 8

PLANING BOTTOM MASS ESTIMATION - EXAMPLE CALCULATION

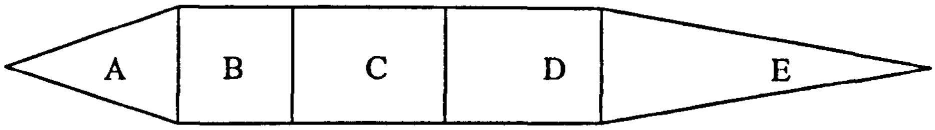
Taking details of the Martin Marlin (133) as an example calculation and calculating actual and estimated masses:

1. Actual Mass.

a. Skin.

Area length: 6.2m 1.2m 1.9m 2.4m 14.3m

Area:



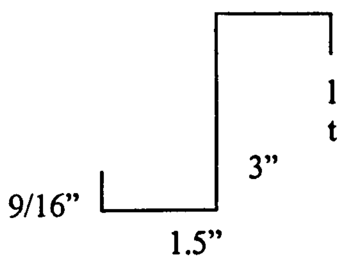
Thickness: $1.3\text{x}10^{-3}$ $1.6\text{x}10^{-3}$ $2.0\text{x}10^{-3}$ $2.6\text{x}10^{-3}$ $1.0\text{x}10^{-3}$

beam = 3.05m $\beta = 20°$ therefore width of bottom plate = 3.24m

Mass of area A = 2770 ($1.3\text{x}10^{-3}$) (0.5 x 3.24 x 6.2) = 36.2kg
Mass of area B = 2770 ($1.6\text{x}10^{-3}$) (1.2 x 3.24) = 17.2kg
Mass of area C = 2770 ($2.0\text{x}10^{-3}$) (1.9 x 3.24) = 34.1kg
Mass of area D = 2770 ($2.6\text{x}10^{-3}$) (2.4 x 3.24) = 56.0kg
Mass of area E = 2770 ($1.0\text{x}10^{-3}$) (0.5 x 3.24 x 14.3) = 64.2kg
Total Skin Mass = 207.7kg

b. Frames.

Z-section

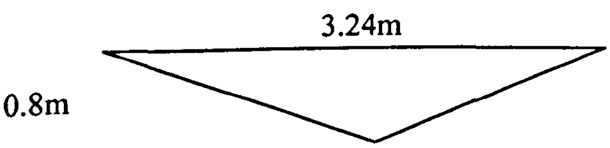


l = 3.24m
t = 0.064" = $1.6\text{x}10^{-3}$ m

3 + 1.5 + 1.5 + 9/16 + 9/16 = 7.125" = 0.18m

therefore mass = 2770 x 0.18 x $1.6\text{x}10^{-3}$ x 3.24 = 2.6 kg per frame
number of frames = 46 of which 12 are bow and 23 are stern therefore:
[0.5(12 + 23) x 2.6] + [11 x 2.6] = 74.1 kg = Total Frame Mass

c. Bulkheads.



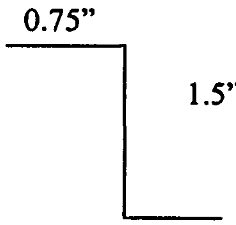
t = 0.051" = $1.3\text{x}10^{-3}$ m
n = 11 (including 3 bow and 4 afterbody)

therefore mass = $2770[(0.5 \times 0.8 \times 3.24)1.3\times10^{-3}]4 + (0.5 \times 7)[(0.5 \times 0.8 \times 3.24)1.3\times10^{-3}]$

$= 35kg$

multiply by 1.1 to account for stiffeners = 38.5kg = Total Bulkhead Mass

d. Stringers.



$t = 0.04" = 1\times10^{-3}m$
$l = 26mw = 1.5" + 0.75" + 0.75" = 0.0762m$

therefore single stringer mass = $2770 \times 1\times10^{-3} \times 0.0762 \times 26 = 5.5kg$

n = 20 assume chine strap = 2 x stringers

therefore mass of all stringers = 22 x 5.5 = 121kg = Total Stringer Mass

e. Summation.

Sum of all masses = 207.7 + 74.1 + 38.5 + 121 = 441.3kg

assume additional mass due to fasteners = 10%

therefore 1.1 x 441.3 = 485.4kg = Total Planing Bottom Mass

AUM = 78000lb = 35334kg therefore 485.4/35334 = 0.0137

1.37% = Planing Bottom Mass as Proportion of AUM

2. Estimated Mass. Using the method of Reference 74.

a. Skin.

skin mass = $0.0542\ S_F^{1.07}\ V_D^{0.743}\ k_l$

where $k_l = 0.22 + 0.36\ [L_T/(B + H)]$

$S_F = k_2\ 2.56\ L\ [(B + H)/2]$

$L_T = 13m$ $B = 3.04m$ $H = 4.55m$
$L = 26.78m$ $k_2 = 1.1$ $V_D = 276mph = 123m/sec$

therefore $k_l = 0.2 + 0.36[13/(3.04 + 4.55)] = 0.84$

therefore $S_F = 1.1 \times 2.56 \times 26.78\ [(3.04 + 4.55)/2] = 286.2$

therefore skin mass = $0.0542 \times 286.2^{1.09} \times 123^{0.743} \times 0.84 = 691.4kg$

assume planing bottom is approximately 20% of total skin area

therefore = 691.4/5 = 138.28kg = skin mass

b. Stringers.

stringer mass = $0.012\ S_F^{1.45}\ V_D^{0.39}\ N^{0..316}\ k_1$ where N = 4.125

stringer mass = 0.012 x $286.2^{1.45}$ x $123^{0.39}$ x $4.125^{0..316}$ x 0.84 = 376.0kg

assume planing bottom is approximately 20% of total skin area

therefore = 376.0/5 = 75.2kg = stringer mass

c. Frames.

frame mass = k_3 (skin mass + stringer mass)$^{1.07}$ where k_3 = 0.18

frame mass = 0.18 $(691.4 + 376.0)^{1.07}$ = 313kg

assume planing bottom is approximately 20% of total skin area

therefore = 313/5 = 62.6kg = frame mass

d. Summation.

Sum of all masses = 138.28 + 75.2 + 62.6 = 276kg = Total Planing Bottom Mass

AUM = 78000lb = 35334kg therefore 276/35334 = 0.0078

0.78% = Planing Bottom Mass as Proportion of AUM

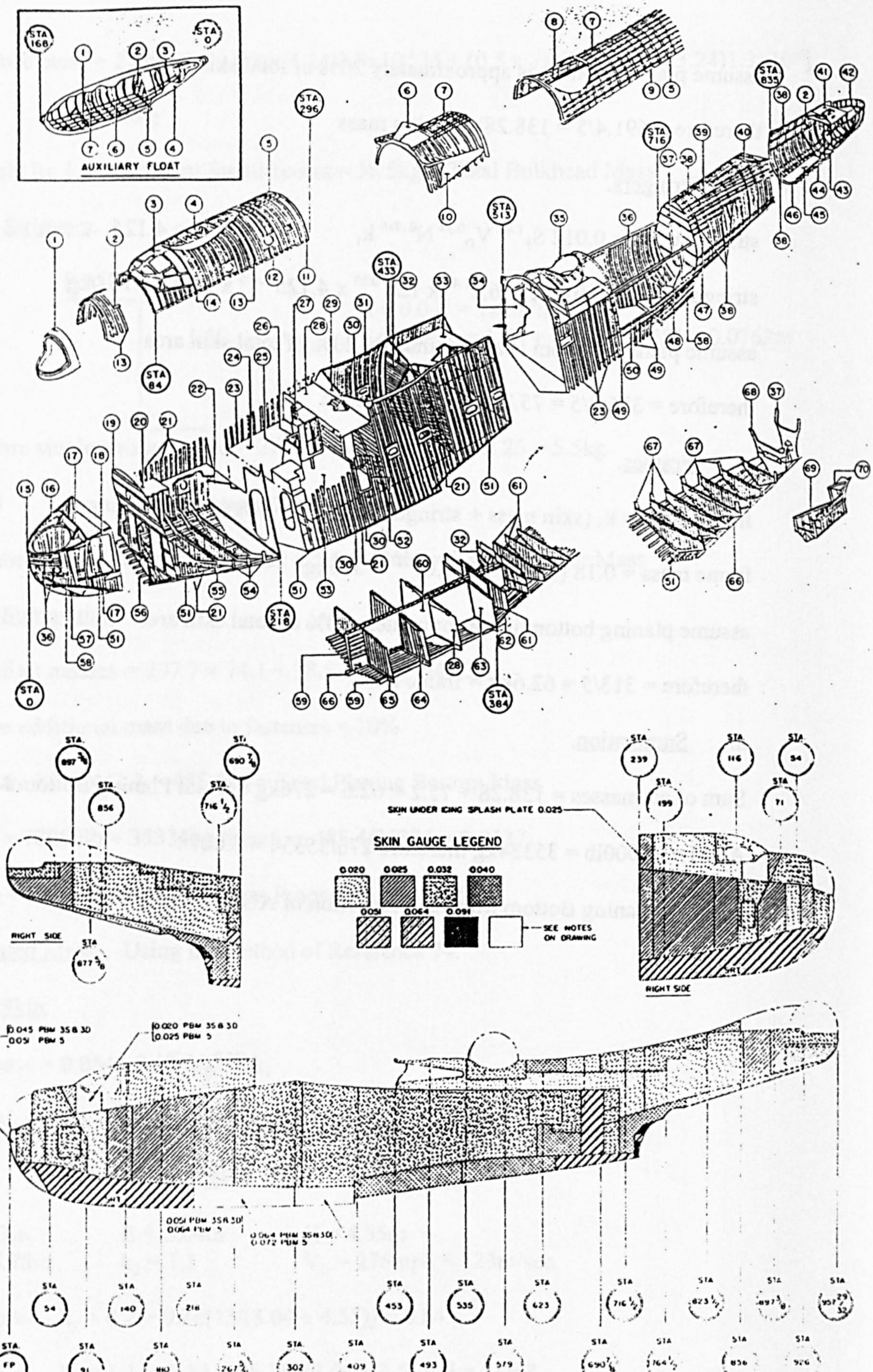


FIGURE A8.1 MARTIN MARINER PLANING BOTTOM

APPENDIX 9

DERIVATION OF ANCHOR MASS EQUATIONS

Anchors are required to withstand the force applied to the flyingboat or seaplane from both wind and current/tide. Cross $_{(75)}$ provides an approximate expression for the latter as:

$$\text{Water Drag} = (1.2 \text{ displacement } v^3_{water})/10000 \quad \text{(lb)}$$

converting to SI units gives:

$$D_{water} = 5.5\text{x}10^{-5}\,(AUM)(v_{water})^3$$

Note that V_{water} is in kts. Drag due to the wind can be derived for the aircraft's zero lift drag coefficient.

$$D_{air} = C_{DO}\,0.5\,v^2 S$$

Assuming that the average flyingboat zero lift drag coefficient is 0.03 (see Table 52) then:

$$D_{air} = 0.018\,v^2_{air}\,S$$

Note the V_{air} is in m/sec. Thus the drag required of an anchor can be calculated knowing the aircraft AUM and wing area and the wind and water velocity. A relationship between drag force and anchor mass is now required. Cross $_{(75)}$ defines a 'holding factor' term as the ratio between the drag force and the anchor mass and states that a modern anchor (remember the reference is dated 1928) should have a holding factor of 12 for a steel MkXIIA Felixtow flyingboat anchor. Four years later Reference 78 provides experimental data of a minimum value holding factor of 34.3 for an aluminium alloy anchor of the same form. Fluteless anchors performed less well having holding factors of as low as 2. The Felixtow MkXIIA anchor was a conventional stocked anchor. However, this form required a large amount of stowage volume if assembled, and a finite assembly time if disassembled. The latter could prove unacceptable in an emergency. It is for this reason that more modern flyingboats use stockless 'danforth' style anchors. These have the advantages of the almost 2 dimensional stowage of a fluteless anchor but have some of the stability of the stocked anchor. No data was available to calculate the holding factor of such an anchor so an average between the best performance of an aluminium stockless and stocked anchors from Reference 78 was taken as 24.75. Substituting above gives:

$$(\text{anchor mass})_{tide} = (5.5\text{x}10^{-5}\,AUM\,v^3_{tide})/24.74 = 2.2\text{x}10^{-6}\,AUM\,v^3_{tide} \qquad \text{(kg)}$$

If C_{DO} is known:

$$(\text{anchor mass})_{wind} = (0.61\,C_{DO}\,v^2_{air}\,S)/24.74 = 0.024\,C_{DO}\,v^2_{air}\,S \quad \text{(kg)}$$

If C_{DO} is unknown:

$$(\text{anchor mass})_{wind} = (0.018\,v^2_{air}\,S)/24.74 = 7.4\text{x}10^{-4}\,v^2_{air}\,S \text{ (kg)}$$

This holding factor was then applied to 2 known aircraft/anchor cases for verification.

Example 1. Saunders Roe Princess

$S = 453m^2$ AUM = 330,000lb = 149,820 kg Anchor mass = 100lb = 45.4 kg

Holding Factor = 24.75 therefore drag force = 24.75 x 45.4 = 1124N

For wind effect:

$D = 0.018\, v^2 S$ therefore $v = (D/0.0185)^{1/2}$ = 12m/sec = 25 mph

For current/tide effect:

$D = 5.5x10^{-5}\, AUM\, v^3$ therefore $v = [D/(5.5x10^{-5}\, AUM)]^{1/3}$ = 5 kts

Thus this assumed holding factor seems to give approximately valid results.

Example 2 Cessna 150

$S = 14.6m^2$ AUM = 1650 kg Anchor mass = 7 lb = 3.2 kg

Holding Factor = 24.75 therefore drag force = 79.2N

For wind effect:

$D = 0.018\, v^2 S$ therefore $v = (D/0.185)^{1/2}$ = 17 m/sec = 38 mph

Force current/tide effect:

$D = 5.5x10^{-5}\, AUM\, v^3$ therefore $v = [D/(5.5x10^{-3}\, AUM)]^{1/3}$ = 3 kts

Thus this assumed holding factor seems to give approximately valid results.

APPENDIX 10

DERIVATION OF EXTRA WING MASS EQUATION

Referring to Figure 3.13:

For wing without tip float: (bending moment$_{root}$)$_1$ = Ll
For wing with tipfloat: (bending moment$_{root}$)$_2$ = Ll + Px

We know:

$L = K_1Mg$ where K_1 = normal accel factor
$P = K_2V_F \rho_{H2O} g$ where V_F = immersed float volume
ρ_{H2O} = water density
K_2 = rough weather factor above pure stability load

$$(BM_{root})_1 = K_1Mgl$$

$$(BM_{root})_2 = K_1Mgl + V_F \rho_{H20} gx$$

For safety assume that the root bending stress of a flyingboat must be the same as the equivalent landplane. Therefore the beam representing the flyingboat wing must be larger.

$$\sigma = My/I$$

$$\sigma_1 = (K_1Mg\,l\,d_1/2)/(b_1d_1^3/12)$$

$$\sigma_2 = (K_1Mg\,l + K_2V_F\,\rho_{H2O}\,g\,x)(d_2/2)/(b_2d_2^3/12)$$

Equate σ_1 and σ_2 and assume d remains constant.

$$(K_1Mg\,l)/b_1 = (K_1Mgl + K_2V_F\,\rho_{H20}\,g\,x)/b_2$$

Simplify by grouping known factors:

$$K_1Mg\,l = A$$

$$K_2\,\rho_{H2O}\,g = B$$

Therefore:

$$A/b_1 = A + BV_Fx / b_2$$

Therefore:

$$b_2 = b_1\,(A + BV_Fx)$$

Assume wing mass of landplane M_{W1} and flyingboat M_{W2} are:

$$M_{W1} = l\,b_1\,d\,\rho_{material}$$

$$M_{W2} = l\, b_l\, d\, \rho_{material} + x(b_2 - b_l)\, d\, \rho_{material}$$

$$M_{W2} / M_{W1} = d\, \rho_{material}\, (l\, b_l + x[b_2 - b_l])/l\, b_l\, d\, \rho_{material}$$

$$M_{W2} / M_{W1} = l\, b_l + x(b_2 - b_l)/l\, b_l$$

$$M_{W2} / M_{W1} = 1 + x(b_2 - b_l)/l\, b_l$$

Substituting gives:

$$M_{W2} / M_{W1} = 1 + [b_l(A + BV_F x/A) - b_l]x / l\, b_l$$

$$M_{W2} / M_{W1} = 1 + x[(A + BV_F x/A) - 1]/ l$$

$$M_{W2} / M_{W1} = 1 + x\, [[(A + BV_F x)/A] - 1]/ l$$

The method was used on the data from a Sunderland flyingboat:

$l = 34.39/2 = 17.2$ m $\quad x = 0.63\, l = 10.8$ m
$V_F = 0.4\ m^3$ (assume full displacement)

Therefore

$A = 3.75 \times (22750/2) \times 9.81 \times 17.2 = 7.2\text{x}10^6$
$B = 1025 \times 9.81 = 10055$

Therefore

$$M_2 / M_1 = 1 + (12.9/17.2)\, [\{(7.2\text{x}10^6 + 10055 \times 0.4 \times 12.9)/ 7.2\text{x}10^6\} - 1] = 1.0054$$

Using the mass estimate technique from Reference 74:

$$M_{wing} = C_1\, \{ [bS/\cos\phi]\, [(1 + 2\lambda)/(3+3\lambda)]\, [(MN)^{0.3}/S]\, [(V_D^{0.5}/ \tau)] \}^{0.9}$$

where:

$b = 34.39$	$\tau = 0.175$	$N = 3.75$	$S = 138$	$\phi = 0$
$C_1 = 0.026$	$V_D = 336$ km/hr $= 112$ m/s		$\tau = 0.4$	$M = 22750$

Therefore

$M_{wing} = 2565$ kg

Therefore extra mass of Sunderland flyingboat wing over that of the same sized landplane is:

$0.0054 \times 2565 = 14$ kg $= 0.06\%$ AUM = negligible

APPENDIX 11

DERIVATION OF DRAFT ESTIMATION EQUATIONS

See Figure 3.14.

1. Method 1.

$v_{bow} = (h_2\, l_{bow}\, b)/2 + (h1\, l_{bow}\, b)/4$

note that * indicates partial forebody, ie conventional forebody - bow.

$v_{fb}^* = h_2\, l_{fb}^* b + (h_1\, l_{fb}^*\, b)/2$

$v_{ab} = (h_2\, l_{ab}\, b)/2 + (h_3\, l_{ab}\, b)/4$

where $h_3 = h_1 - h_{step}$

therefore:

$v_{total} = [(h_2\, l_{bow}\, b)/2 + (h1\, l_{bow}\, b)/4] + [h_2\, l_{fb}^*\, b + (h_1\, l_{fb}^*\, b)/2] + [(h_2\, l_{ab}\, b)/2 + (h_3\, l_{ab}\, b)/4]$

substituting from Archimedes' Principle and simplifying:

$M/\rho = h_2[(l_{bow}\, b)/2 + l_{fb}^*\, b + (l_{ab}\, b)/2] + h_1[(l_{bow}\, b)/4 + (l_{fb}^*\, b)/2 + (l_{ab}\, b)/4] - h_{step}\, [(l_{ab}\, b)/4]$

therefore:

$h_2 = \{M/\rho - [h_1 b(l_{bow}/4 + l_{fb}^*/2 + l_{ab}/4) + h_{step}\, l_{ab}/4]\}/\{b(l_{bow}/2 + l_{fb}^* + l_{ab}/2]\}$

if $h_{total} = h_1 + h_2$ then $h_2 = h_{total} - h_1$ therefore:

$h_{total} = \{M/\rho - [h_1 b(l_{bow}/4 + l_{fb}^*/2 + l_{ab}/4) + h_{step}\, l_{ab}/4]\}/\{b(l_{bow}/2 + l_{fb}^* + l_{ab}/2]\} + h_1$

2. Method 2.

$l_{total} = l_{fb}^* + ½\,(l_{bow} + l_{ab})$

volume of displaced water = AUM/1025 (m^3)

area of load water plane = b l_{total}

draft = volume/area therefore:

$h_{total} = AUM/\ 1025\, b\, [l_{fb}^* + ½\,(l_{bow} + l_{ab})]$

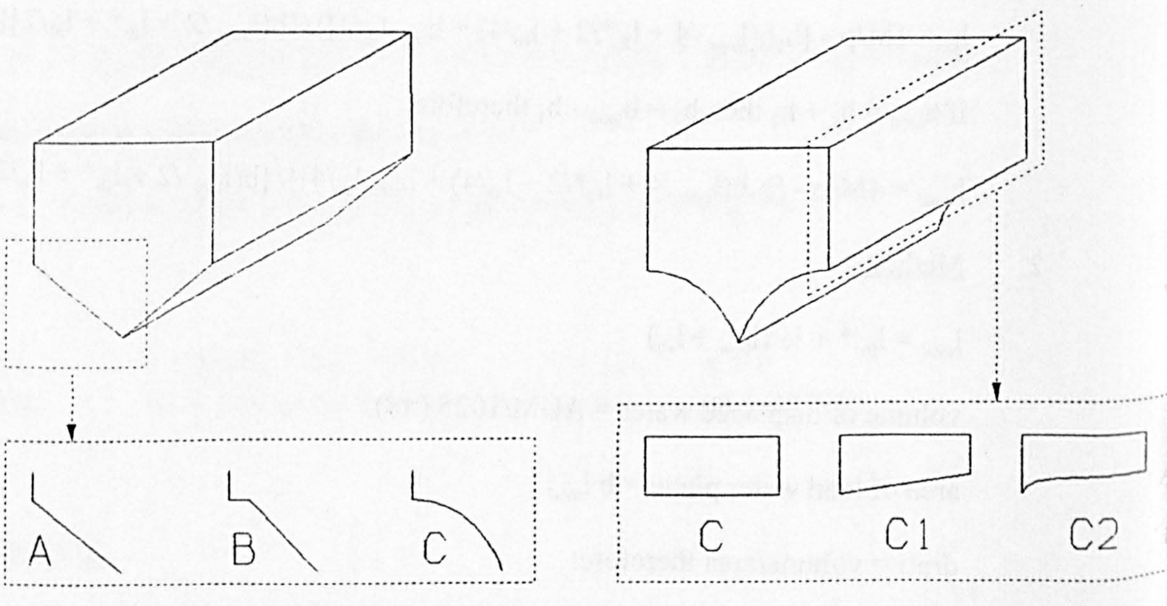
APPENDIX 12

CONSTRUCTION COST FACTORS

Many of the design decisions regarding the need for complex spray reduction methods involve the balance between aerodynamic and hydrodynamic properties and their single or double curvature surfaces and the practicality and cost of such forms. To aid in making such trade-off decisions a cost appraisal task was set on the RAF's jobbing factory at RAF St Athan. The task required a cost increase factor to be applied to a variety of increasingly complex fore and afterbody shapes based on an initial, simple shape with a unit cost. It was assumed that the shapes would be constructed from metal using conventional mechanical methods. The shapes are shown below and the results are as follows:

Shape A: 1 Shape B: 1.1 Shape C: 1.4 Shape C1: 2 Shape C2: 3.5

These simple relationships can be used as part of a Quality Functional Deployment (QFD) or similar technique to value spray reduction methods.



APPENDIX 13

WORKED EXAMPLE FOR ON-WATER STATIC STABILITY - MARTIN MARINER

1. This worked example follows the process of para 3.12.3, Reference 154 and Figure 3.15.

a. Hull BM.

Draft = 1.11m AUM = 26330kg

$V = AUM/\rho_{H20} = 26330/1000 = 26.33\ m^3$

$b = l_{bow} = 2.9m \quad l = 18.2m \quad l_{forebody} = 9.83m$

therefore $l_{forebody}* = l_{forebody} - l_{bow} = 9.83 - 2.9 = 6.93m$

$l_{afterbody} = l - l_{forebody} = 18.2 - 9.83 = 8.37m$

$y_{bow} = x / 2$

$y_{forebody}* = b / 2 = 2.9 / 2 = 1.45m$

$y_{afterbody} = [\ b\ (l_{afterbody} - x + l_{bow} + l_{forebody}*)\ ] / (2\ l_{afterbody})$

$= [\ 2.9\ (8.37 - x + 2.9 + 6.93)] / (2 \times 8.37) = 2.9(18.2 - x)/16.74$

$\Sigma My^3 = 248.59$ (from spread sheet attached)

$I = (2/3)(1/3)(l/N)(\ \Sigma My^3) = (2/3 \times 1/3)(18.2/50)(248.59) = 20.09m^4$

$BM = I/V = 20.09 / 26.33 = 0.76m$

b. Fuselage Fuel BM.

Assume $l_{tank} = 6.1m$ $r_{fuel} = 719.7kg/m^3$

$I_{fuel} = (n/12)(l_{tank} b^3) = (1/12)(6.1 \times 2.9^3) = 12.4m^4$

$\Delta BM_{fuel} = (\rho_{fuel}\ I)/(AUM) = (719.7 \times 12.4) / 26330 = 0.34m$

Therefore $BM_{total} = 0.76 - 0.34 = 0.42m$

c. Vertical Centre of Gravity Position.

Vertical centre of gravity = 3.04m (see Table A4.1)

d. Hull GM.

GM = KG - (KB + BM)

Assume KB = 2/3 x draft = 2/3 x 1.11 = 0.73

Therefore GM = 3.04 - (0.73 + 0.42) = 1.89m

e. Tip Float righting Moment Arm.

Use US method to determine safety factor:

$\Delta y > (AUM)[(GM \sin\theta)+(0.1b/(AUM/S))+0.06\ {}^3\sqrt{W}]$

Converting dimensions to Imperial:

AUM = 57996lb   GM = 6.17ft   b = 118ft   S = 1408ft^2

$\Delta y = 57996[(6.17 \sin 7°)+(0.1 \times 118/(57996/1408))+0.06\ {}^3\sqrt{57996}]$

Δy = 190227lbft

Validate by comparison with actual aircraft:

y = 41ft   volume = 126ft^3

therefore actual Δ = 64 x 126 = 8064 and Δy = 330624lbft

therefore safety factor = 330624/190227 = 1.74

Use UK method to determine safety factor:

$\Delta y^3\ K(AUM)\ (GM + {}^3\sqrt{W}) \sin\theta$

$\Delta y^3\ 1 \times 57996\ (6.17 + {}^3\sqrt{57996}) \sin 7° = 316195$lbft

therefore safety factor = 330624/316195 = 1.04

f. Additional Check.

$RF = (\Delta y_{float})/(AUM\ GM \sin\theta)$

For US method: RF = (190227)/(57996 x 6.17 x 0.12) = 4.4 = safe

For UK method: RF = (330624)/(57996 x 6.17 x 0.12) = 7.6 = safe

Therefore the process produces a correct result.

Calculation of Hull Only BM - Mariner Ans= 245.91

Ord	b	L	Lf	Lab	Lfb*	x	^x	y	y^3	M	My^3	
0	2.9	18.2	9.83	8.37	6.93	.364	.00	.00	.00	1	.00	
1	2.9	18.2	9.83	8.37	6.93	.364	.36	.18	.01	4	.02	
2	2.9	18.2	9.83	8.37	6.93	.364	.73	.36	.05	2	.10	
3	2.9	18.2	9.83	8.37	6.93	.364	1.09	.55	.16	4	.65	
4	2.9	18.2	9.83	8.37	6.93	.364	1.46	.73	.39	2	.77	
5	2.9	18.2	9.83	8.37	6.93	.364	1.82	.91	.75	4	3.01	
6	2.9	18.2	9.83	8.37	6.93	.364	2.18	1.09	1.30	2	2.60	
7	2.9	18.2	9.83	8.37	6.93	.364	2.55	1.27	2.07	4	8.27	
8	2.9	18.2	9.83	8.37	6.93	.364	2.91	1.46	3.09	2	6.17	end of
9	2.9	18.2	9.83	8.37	6.93	.364	3.28	1.45	3.05	4	12.19	bow
10	2.9	18.2	9.83	8.37	6.93	.364	3.64	1.45	3.05	2	6.10	
11	2.9	18.2	9.83	8.37	6.93	.364	4.00	1.45	3.05	4	12.19	
12	2.9	18.2	9.83	8.37	6.93	.364	4.37	1.45	3.05	2	6.10	
13	2.9	18.2	9.83	8.37	6.93	.364	4.73	1.45	3.05	4	12.19	
14	2.9	18.2	9.83	8.37	6.93	.364	5.10	1.45	3.05	2	6.10	
15	2.9	18.2	9.83	8.37	6.93	.364	5.46	1.45	3.05	4	12.19	
16	2.9	18.2	9.83	8.37	6.93	.364	5.82	1.45	3.05	2	6.10	
17	2.9	18.2	9.83	8.37	6.93	.364	6.19	1.45	3.05	4	12.19	
18	2.9	18.2	9.83	8.37	6.93	.364	6.55	1.45	3.05	2	6.10	
19	2.9	18.2	9.83	8.37	6.93	.364	6.92	1.45	3.05	4	12.19	
20	2.9	18.2	9.83	8.37	6.93	.364	7.28	1.45	3.05	2	6.10	
21	2.9	18.2	9.83	8.37	6.93	.364	7.64	1.45	3.05	4	12.19	
22	2.9	18.2	9.83	8.37	6.93	.364	8.01	1.45	3.05	2	6.10	
23	2.9	18.2	9.83	8.37	6.93	.364	8.37	1.45	3.05	4	12.19	
24	2.9	18.2	9.83	8.37	6.93	.364	8.74	1.45	3.05	2	6.10	
25	2.9	18.2	9.83	8.37	6.93	.364	9.10	1.45	3.05	4	12.19	
26	2.9	18.2	9.83	8.37	6.93	.364	9.46	1.45	3.05	2	6.10	
27	2.9	18.2	9.83	8.37	6.93	.364	9.83	1.45	3.05	4	12.19	
28	2.9	18.2	9.83	8.37	6.93	.364	10.19	1.45	3.05	2	6.10	end of
29	2.9	18.2	9.83	8.37	6.93	.364	10.56	1.32	2.32	4	9.29	forebody
30	2.9	18.2	9.83	8.37	6.93	.364	10.92	1.26	2.01	2	4.01	
31	2.9	18.2	9.83	8.37	6.93	.364	11.28	1.20	1.72	4	6.88	
32	2.9	18.2	9.83	8.37	6.93	.364	11.65	1.14	1.46	2	2.92	
33	2.9	18.2	9.83	8.37	6.93	.364	12.01	1.07	1.23	4	4.93	
34	2.9	18.2	9.83	8.37	6.93	.364	12.38	1.01	1.03	2	2.05	
35	2.9	18.2	9.83	8.37	6.93	.364	12.74	.95	.85	4	3.39	
36	2.9	18.2	9.83	8.37	6.93	.364	13.10	.88	.69	2	1.38	
37	2.9	18.2	9.83	8.37	6.93	.364	13.47	.82	.55	4	2.20	
38	2.9	18.2	9.83	8.37	6.93	.364	13.83	.76	.43	2	.87	
39	2.9	18.2	9.83	8.37	6.93	.364	14.20	.69	.33	4	1.33	
40	2.9	18.2	9.83	8.37	6.93	.364	14.56	.63	.25	2	.50	
41	2.9	18.2	9.83	8.37	6.93	.364	14.92	.57	.18	4	.73	
42	2.9	18.2	9.83	8.37	6.93	.364	15.29	.50	.13	2	.26	
43	2.9	18.2	9.83	8.37	6.93	.364	15.65	.44	.09	4	.34	
44	2.9	18.2	9.83	8.37	6.93	.364	16.02	.38	.05	2	.11	
45	2.9	18.2	9.83	8.37	6.93	.364	16.38	.32	.03	4	.13	
46	2.9	18.2	9.83	8.37	6.93	.364	16.74	.25	.02	2	.03	
47	2.9	18.2	9.83	8.37	6.93	.364	17.11	.19	.01	4	.03	
48	2.9	18.2	9.83	8.37	6.93	.364	17.47	.13	.00	2	.00	
49	2.9	18.2	9.83	8.37	6.93	.364	17.84	.06	.00	4	.00	
50	2.9	18.2	9.83	8.37	6.93	.364	18.20	.00	.00	1	.00	
											>>>>>	

APPENDIX 14

DERIVATION OF RETRACTABLE UNDERCARRIAGE COST FACTOR

As many of the lighter landplanes used in the cost comparison exercise had fixed undercarriages and the comparison flyingboats inevitably had retractable undercarriages, an empirical factor was required to account for the additional cost of retracting an undercarriage.

Aircraft	Date	Variant	Cost ($)	Factor
Cessna 182	1978	Skylane	47600	1.35
		RG	64125	
Cessna	1965	336	57965	1.10
		337	63896	
Piper PA28-180	1970	-	21405	1.35
		Arrow II	28920	
Beechcraft	1973	24R	21500	1.42
		23	30500	
			AVERAGE	1.305

APPENDIX 15

EXAMPLE PERFORMANCE INDICATOR CALCULATIONS

Martin Mars Flyingboat.
Class/Role = SH/T(V) therefore reference Aircraft: Tradewind (R3Y-2 version)

Reference Aircraft: M_e = 34050 kg
Payload = P = 38590 kg therefore cost-related PI = P/M_e =1.13
Range = R = 6400 km therefore cost-related PI = R/M_e = 0.19
Speed = S = 621 km/hr therefore cost-related PI = S/M_e = $1.8x10^{-2}$
Maint Value = M = 21 therefore cost-related PI = M/M_e = $6.2x10^{-4}$
Volume = V =144.7 m^3 therefore cost-related PI = V/M_e = $4.2x10^{-3}$
Loading = L = 7.64 therefore cost-related PI = L/M_e = $2.2x10^{-4}$

Note no information available on TO distance, water handling or noise.

Example Aircraft: Martin Mars M_e = 36461 kg
Payload = P = 38449 kg therefore cost-related PI = P/M_e =1.05
therefore reference-related PI =1.05/1.13 = 0.93
Relative ranking = 7 therefore final PI = 6.51

Range = R = 7040 km therefore cost-related PI = R/M_e = 0.19
therefore reference-related PI = 0.19/0.19 = 1.0
Relative ranking = 5 therefore final PI = 5.0

Speed = S = 382 km/hr therefore cost-related PI = S/M_e = $1.0x10^{-2}$
therefore reference-related PI = 1.0/1.8 = 0.55
Relative ranking = 1 therefore final PI = 0.55

Maintainability Study (for layout see Table 4.2):

A	A	3
	E	2
B	A	2
	E	3
C	A	2
	E	2
D		2
E		3
F		2
G		1
Total 22		

Maint Value = M = 22 therefore cost-related PI = M/M_e = $6.5x10^{-4}$
therefore reference-related PI = 6.5/6.2 = 1.05
Relative ranking = 3 therefore final PI = 3.15

Volume = V = 174.4m^3 therefore cost-related PI = V/M_e = $5.1x10^{-3}$
therefore reference-related PI = 5.1/4.2 = 1.21
Relative ranking = 8 therefore final PI = 9.68

Main cargo door area = 5.91m^2 but U-jetty required (see Figure 4.1d) and in-built crane
therefore factored area = 0.75 x 1.25 x 5.91 = 5.54m^2
Second cargo door = 2m^2 but no U-jetty required (see Figure 4.1d)
therefore factored area =1 x 2 = 2m^2 therefore use main cargo door value
Loading = L = 5.54 therefore cost-related PI = L/M_e = 1.63x10^{-4}
therefore reference-related PI = 1.63/2.2 = 0.74
Relative ranking = 4 therefore final PI = 2.96

Therefore total PI = sum of final PIs = 27.85

EXAMPLE PERFORMANCE INDICATORS - SH/T(V)

Aircraft	Tradewind (R3Y-2)	Martin Mars	Saro Princess
M_e (kg)	34050	36461	86260
Payload (kg)	38590	38449	62200
P/M_e	1.13	1.05	0.72
PI/PI_{ref}	1	0.93	0.64
Range (km)	6400	7040	9200
R/M_e	0.19	0.19	0.11
PI/PI_{ref}	1	1	0.58
Speed (km/hr)	621	382	611
S/M_e	0.018	0.01	0.007
PI/PI_{ref}	1	0.55	0.39
Maint (value)	21	22	18
M/M_e	6.2x10^{-4}	6.5x10^{-4}	2.1x10^{-4}
PI/PI_{ref}	1	1.05	0.34
Volume (m^3)	144.7	174.4	392
V/M_e	4.2x10^{-3}	5.1x10^{-3}	4.5x10^{-3}
PI/PI_{ref}	1	1.21	1.07
Loading (value)	7.64	5.54	1
L/M_e	2.2x10^{-4}	1.63x10^{-4}	0.11x10^{-4}
PI/PI_{ref}	1	0.74	0.05

EXAMPLE PERFORMANCE INDICATORS - SH/T(V) cont

	Tradewind (R3Y-2)	Martin Mars	Saro Princess
Payload PI	1	0.93	0.64
Weight	7	7	7
Total	7	6.51	4.48
Range PI	1	1	0.58
Weight	5	5	5
Total	5	5	2.9
Speed PI	1	0.55	0.39
Weight	1	1	1
Total	1	0.55	0.39
Maint PI	1	1.05	0.34
Weight	3	3	3
Total	3	3.15	1.02
Volume PI	1	1.21	1.07
Weight	8	8	8
Total	8	9.68	8.56
Loading PI	1	0.74	0.05
Weight	4	4	4
Total	4	2.96	0.2
Grand Total	28	27.85	17.55

APPENDIX 16

CORROSION THEORY

1. Introduction. Corrosion is an electrochemical process which causes metals to be transformed into oxides and salts. The driving force behind the corrosive process involves the intrinsic difference between the electrical potential of metallic elements, or how easily the elements give up electrons in the presence of other materials. Metals such as magnesium and zinc give up electrons easily and thus are corrosion-prone whilst copper and silver do not give up electrons easily and are therefore corrosion-resistant. This process is quantified via the electromotive or galvanic series where the differences in electrical potentials are measured in terms of volts of electromotive force (EMF). Common engineering materials are included below:

Material	EMF (volts)	Material	EMF (volts)
Magnesium	-1.73	Cadmium	-0.82
Magnesium alloys	-1.63	Steel	-0.64
Zinc	-1.10	Tin	-0.49
Beryllium	-0.97	Brass	-0.38
7072 Al alloy	-0.96	Copper	-0.20
7075 Al alloy	-0.82	Titanium	-0.15
2024-T4 Al alloy	-0.67	Monel	-0.10

If materials with greatly different EMF values are brought together there is a strong corrosive potential. Although it is not impossible to keep these metals apart, their presence in similar alloys can undermine design choices. Also, the complexity of an aircraft structure is such that fasteners, welds and bonding processes can add corrosion initiation points. It is also important to note that corrosion can take place between small variations in the same material due to grain boundaries or slight irregularities in chemical composition. For the corrosive process to work a final part is usually required: an electrolyte to pass the current between the metals. Pure water is actually an insulator, but salt or polluted water makes an exceptionally good electrolyte. Thus if one of the elements of the anode, cathode or electrolyte can be removed or isolated corrosion will not occur. By the nature of their operation amphibious aircraft work in the most challenging corrosion environment. Not only are many flyingboats and floatplanes routinely taking off and landing in salt water but also they are operating with corrosive fire-fighting foams and in smoky carbon-heavy atmospheres. Soot is not only corrosive, but is also hydroscopic, in that it attracts water, forming a corrosive poultice on the aircraft $_{(155)}$.

2. Corrosion Prevention. From an aircraft customer's perspective all down-time due to maintenance is lost revenue and therefore if a flyingboat or floatplane is to be commercially successful its design must minimise the specialised water-operation element of this cost. Moreover, if the life of an aircraft can be increased by corrosion prevention methods its initial purchase price can be spread across more time, thus further enhancing its value. Corrosion costs can be reduced by good prevention methods built into the design and manufacturing stage and by adequate maintenance.

a. Design. Minimising the effects of corrosion via prevention and ease of cure must be factored into the initial design. This not only includes configuration and detailed design but also and material selection and access considerations. It cannot be assumed that a good corrosion control programme can be used in lieu of good corrosion resistant design, although the cost to the customer may seem to be hidden. This is particularly important for carbon fibre composite materials as carbon is a very "noble" material and reacts as a strong cathode when put next to a strong anode such as aluminium. Structurally significant items are usually chosen on the basis of good static or fatigue performance. In the case of amphibious aircraft the effect of corrosion must enter into the equation and may, in some cases, actually prove to be the defining parameter. Having produced a corrosion-resistant design, specifying adequate manufacturing procedures also reduces the likelihood of serious corrosion problems.

b. Manufacture. The use of sealants, corrosion prevention compounds and surface finishes are the most effective and versatile manufacturing methods to preventing corrosion. Sealants can exclude moisture and separate joined materials. Exterior joints can be sealed to prevent any electrolyte entering and sealant can be used to wet-assemble fasteners. Corrosion prevention compounds can provide permanent and temporary protection. There are 2 types: water displacing and non-water displacing. The latter provide long term protection as they contain a more viscous grease than the former. However, water displacing compounds which contain lighter grades of oil can better penetrate tight joints. Adequate anodising, priming and applying surface finish is the final corrosion protection method relevant to manufacture and is arguably the most important as it is the surface finish which actually contacts the salt water.

c. Maintenance. Much of the content of anti-corrosion maintenance will be targeted versions of conventional structural inspection, such as clearing blocked airframe drains to reduce the chance of salt water remaining in contact with the structure. Technician training in corrosion-related maintenance is an important additional factor. The major addition for flyingboat or floatplane maintenance is the significant importance of washing the aircraft after operation from salt water. The 2 major maintenance reasons for washing an aircraft are to remove corrosion-causing contaminants and provide a clean surface for anti-corrosion inspections. A wash also improves the appearance of the aircraft. RAF experience (156) with fresh water wash-down rigs for aircraft operating in maritime environments is that salt can be washed off a clean aircraft but not off a dirty one. Additionally, it was found that a wash-down could actually force salt deposits (as part of a diluted wash water/deposited salt mix) into areas where it had not been previously. However, fresh water rinsing was felt to be generally beneficial. Rinse water pressure is not as important as the volume of water. As a rule of thumb, Lockheed recommend that, in relation to the C130 (157), adequate pressure is available when the top of the fin can be rinsed by a worker standing on the ground. The volume of water used should be sufficient to provide a free-flowing action over the surface being rinsed: this requires a minimum flow of about 8 gallons per minute. Dehumidification is generally accepted to increase mean time between failure of avionic and electrical components but has also been used in the RAF transport fleet to reduce structural corrosion on aircraft which are parked outside for long periods. This could equally well be applied to amphibious aircraft.

3. Engines. Some degree of spray is always present around flyingboat and floatplane engines and can cause a number of problems, particularly for turbine power plants operating in a salt water environment. Much work was done by Convair during design, development and operation of the Tradewind and Seadart turbo-prop and pure jet aircraft (158)

a. The Problems. Salt remains in engines have 3 main effects: deposits on compressor and stator blades, physical interference and corrosion. Deposits on blades change the aerodynamic shape and therefore effect efficiency. At low levels of deposit this effect is noticeable in a loss of power, for example the Seadart could suffer 300lb of lost thrust due to salt deposits. Deposits could also lead to compressor stall at higher levels of deposition. Physical interference has been experienced in the binding together of close tolerance gaps in the engine such as the compressor blade to casing gap. Corrosion can be particularly extensive if magnesium alloys are used in the engine.

b. Prevention and Maintenance. Prevention of salt water spray ingestion into engines should be the prime design driver in the initial flyingboat configuration choice (see Section 3.2). In some cases this may be influenced by other factors and alternative air intakes may be required. Where possible internal engine parts should be made of materials close together in the electrolytic series. For example, steel stator rings embedded in magnesium compressor casings should be avoided. The Convair aircraft mentioned above had a cured surface treatment applied to engine parts which not only produced a corrosion barrier but also added a glass-like surface onto which salt had difficulty depositing. Steam cleaning Tradewind engines was found to have little effect on salt build-up and eventually walnut shells were injected into the engines during ground runs to remove the deposits. In the case of the Seadart an internal fresh water injection system was developed. An 18 gallon tank was included in the fairing behind the pilot and an electric pump delivered fresh water at 3.5 gallons per minute at 15 psi to the intake approximately 25cm inside the duct. It was found that 1 gallon of water per engine after each take-off and landing was sufficient to ensure that engine performance was maintained.

APPENDIX 17

HULL AND FLOAT LOADS

1. Single Hull Flyingboats. The loading on single hull flyingboats is split into 2 sections, hull load factors and water pressure distribution. The limit load factors and water loads calculated from the former are used when designing the flyingboat or float structure as a whole. It is acceptable to distribute the resultant loads over the hull bottom so as to avoid excessive shear and bending moments at the point where the resultant water load is located as long as that pressure is not lower than that calculated for hull pressure distribution. Hull pressure distribution is that pressure occurring during highly localised impacting of the water on the hull and need not be applied over an area large enough to result in the development of frame or general structural loads.

a. Limit Load Factors. There are 3 cases to derive hull loading factors and one to derive a wing attachment load factor as follows (note units):

(i) Symmetric Step Landing Case.

$$n_{W1} = (C_1 \,.\, V_{so}^2) / (\tan^{2/3}\beta \,.\, W^{1/3})$$

(ii) Symmetric Bow and Stern Landing Case.

$$n_{W2} = (n_{W1} \,.\, K_1) / (1 + r_x^2)^{2/3}$$

where: $n_{W1 \text{ or } W2}$ = limit load factor (water reaction/weight of aircraft)
W = weight of aircraft (lb)
V_{S0} = stall speed in landing configuration (kts)
β = deadrise angle at longitudinal station at which force is acting
K_1 = empirical hull station factor (see Figure A17.1a)
r_x = ratio of {distance from c of g (parallel to hull axis) to longitudinal station at which force is acting } over {pitch radius of gyration.
C_1 = empirical operations factor = 0.012

Note that in no case may n_{W1} be less than 2.33. Also, note that the empirical operations and hull station factors are based on empirical tests undertaken in the 1940s and 50s and therefore can only be confidently applied to the speed, size and configuration of aircraft from that period. For the symmetric step loading case the resultant water load is applied at the keel through the centre of gravity perpendicular to the keel line. In the case of the bow loading the resultant water load is applied at the keel at 20% of the forebody length (measured from the bow) whilst for the stern loading case it is applied at 85% of the afterbody length measured from the step. Both bow and stern loading is reacted perpendicular to the keel line.

(iii) Asymmetric Landing Cases. Asymmetric landing cases should be investigated. These are the same as the symmetric step, bow and stern cases except that the loading in each case consists of an upward and inward side force component equal to 0.75 and (0.25tanβ) times the relevant symmetric load. The point of application of the upward component is identical to that for the symmetric cases but acts at a point midway between the keel and the chine.

(iv) Wing Attachment Factor. The remaining load factor is the take-off case which specifies that for the wing and its attachment to the hull a downward inertia load corresponding to the following load factor exists:

$$n = (C_{TO} \cdot V_{S1}^2) / (\tan^{2/3} \beta_S \cdot W^{1/3})$$

where: C_{TO} = empirical take-off factor = 0.004
V_{S1} = stall speed in take-off configuration (kts)
β_S = deadrise angle at step

Note that the aerodynamic wing lift is assumed to be zero.

b. Hull Pressure Loading. There are 3 hull pressure loading cases: symmetric landing, symmetric take-off and the asymmetric landing case. The symmetric pressure distribution is also expressed in terms for both straight bottom lines and chine flare. Note that these pressures are uniform and must be applied simultaneously over the entire hull or float bottom. The loads should be carried into the sidewall structure of the float or hull but need not be transmitted in a fore or aft direction as shear and bending loads.

(i) Symmetric Take-off Pressure Loading Case.

$$p = (C_2.K_2.V_{S1}^2) / (\tan\beta)$$

where: p = pressure at keel (psi)
K_2 = empirical hull station factor (see Figure A17.1b)
C_2 = empirical factor = 0.00216

For a straight keel-to-chine line the pressure varies linearly along the line with the pressure at the chine being 0.75 times that at the keel. For a hull with chine flare additional pressure due to the flare is added onto the pressure distribution assuming the bottom is unflared (see Figure A17.1c). The additional pressure distribution is as follows:

$$p = (C_3.K_2.V_{S1}^2) / (\tan\beta)$$ where: C_3 = empirical factor = 0.0016

This additional pressure varies linearly from the chine to the unflared pressure at the start of the flare. A degree of assumed straight and flared geometry may be required for complex hull and float forms.

(ii) Symmetric Landing Pressure Loading Case

$$p = (C_4.K_2.V_{S1}^2) / (\tan\beta)$$ where: C_4 = empirical factor = 0.078

Chine flare assumptions apply again to this calculation for a straight bottom transverse line.

(iii) Asymmetric Landing Pressure Loading Case The asymmetric landing pressure loading case involves the pressure distribution for the symmetric landing described above being applied to one side of the hull or float centreline and 50% of that pressure being applied to the other side.

2. Tip or Auxiliary Floats. Six types of load are applied to tip or auxiliary floats: symmetric and asymmetric step loads, symmetric and asymmetric bow loads, immersed float loading and float bottom pressures. The loads are used to design the float attachments and support structures. Excessive local shear and bending moments at the defined application points can be avoided by distributing the loads over the float bottom, except that the calculated bottom pressure cannot be exceeded using this method. The wing support structure should have a sufficient margin of strength to ensure that the failure of the float attachment structure occurs before the wing is damaged.

a. Symmetric Step Loading. The symmetric step loading is applied in a direction perpendicular to a tangent to the keel line in the plane of the of symmetry of the float at a point 75% of the forebody length measured from the bow. The limit load is as follows:

$$L = (C_5.V_{S0}^2.W^{2/3})/(\tan^{2/3}\beta_S(1+r_y^2)^{1/3}$$

where: L = limit load (lb)
C_5 = empirical factor = 0.0053
β_S = deadrise angle at the load point (but need not be less than 15°)
r_y = ratio of (lateral distance between the centre of gravity and the plane of symmetry of the float) over radius of gyration in roll

Note that the value of L need not exceed three times the weight of the displaced water when the float is completely submerged.

b. Asymmetric Step Loading. The load of a. above is applied asymmetrically as described in 1a(iii).

c. Symmetric Bow Loading. The magnitude of the bow loading is the same as calculated in a. above, but is applied at a point 25% of the forebody length measured from the bow.

d. Asymmetric Bow Loading The loading of c. above is applied as described in 1a(iii).

e. Immersed Float Loading. The immersed float loads have upward, side and aft components and act at the centroid of the float cross-section at a point 33% of the forebody length measured from the bow. The vertical component acts perpendicular to the float reference axis, the side component acts perpendicular to the plane of symmetry of the float and the aft component acts parallel to the float axis.

$$L_{vertical} = \rho\ g\ v \quad \text{(lb)}$$

$$L_{side} = C_y\ (\rho/2)\ v^{2/3}\ (K\ V_{S0})^2 \quad \text{(lb)}$$

$$L_{aft} = C_x\ (\rho/2)\ v^{2/3}\ (K\ V_{S0})^2 \quad \text{(lb)}$$

where: ρ = density of water = 1.98 (slugs/ft^3)
v = volume of float (ft^3)
C_x = empirical drag force coefficient = 0.133
C_y = empirical side force coefficient = 0.106
K = empirical factor = 0.8
g = acceleration due to gravity (ft/sec^2)

Note that lower values of K may be used if it can be shown that the floats are incapable of being submerged at a speed of $0.8V_{S0}$. This may be the case if the displacement of the tip float has been defined by a design case such as fuel and mechanic on a wing scenario or the tip float is of the vertical column type.

f. Float Bottom Pressure. The float bottom pressure is calculated in the same way as in 1b above except that K_2 = 1.0 and the deadrise angle is taken at a point 75% of the forebody length measured from the bow.

3. Additional Requirements. All relevant references included the factors discussed above. However, the long obsolete aspects of Chapter 306 of AvP 00-970 also includes a 2 wave landing requirement for flyingboats and floatplanes. For flyingboats, 2 equal reactions summing to 3.5W acting downwards at the centre of gravity are assumed to exist at points close to the bow and the stern of the hull. The rear point of application is assumed to be either at the rear step of a 2 stepped hull or at the point where the full load waterline at rest cuts the rear portion of the hull in profile for a single stepped design. The bow position of application of the reaction load is at a length forward of the stern application equal to the full load waterline at rest (see Figure A17.1d). For floatplanes the centre of gravity load is assumed to be 5.0W and the reactions are applied at l/6 from the bow and stern respectively.

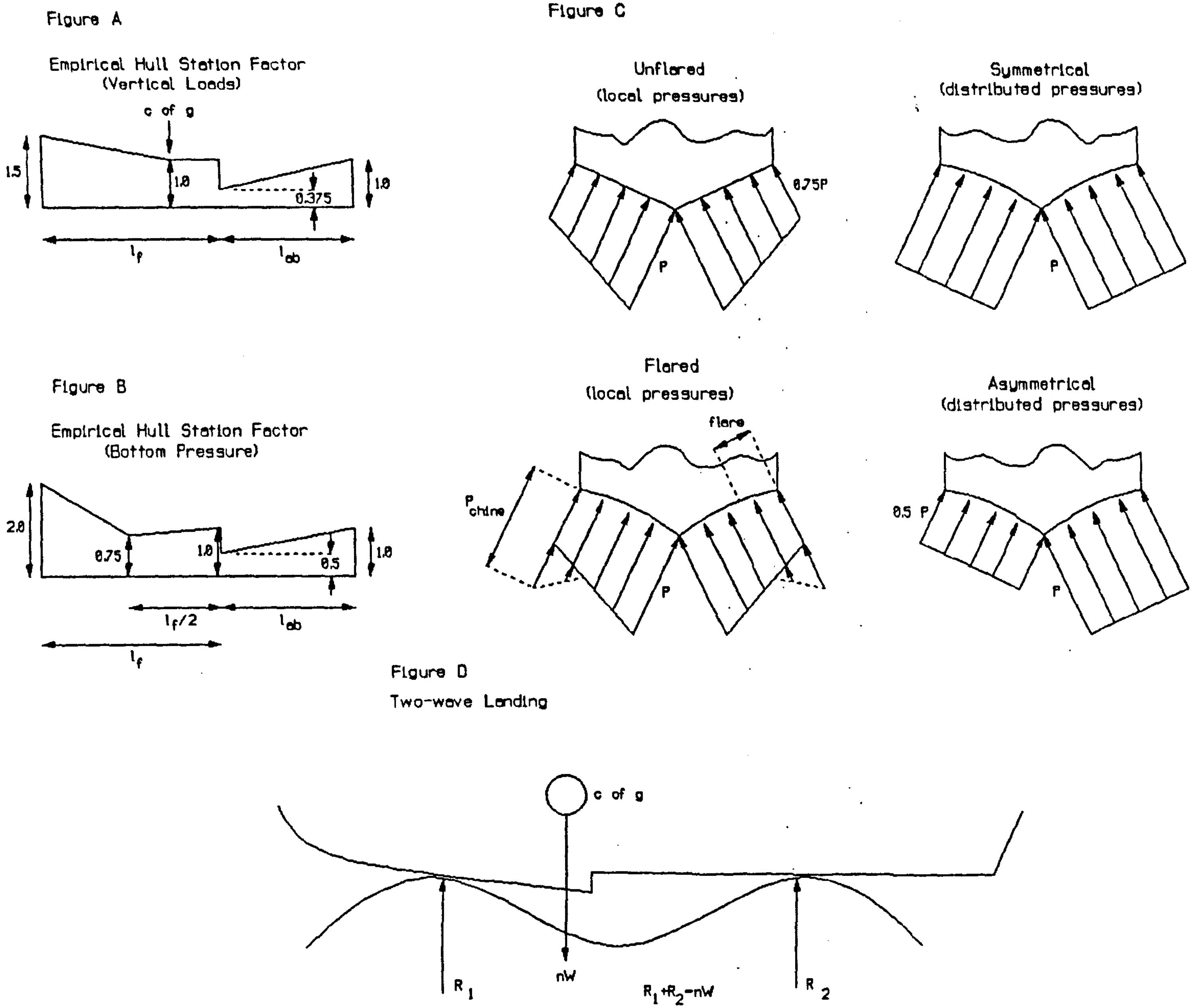


FIGURE A17.1 HULL LOADING

APPENDIX 18

EXAMPLE AMPHIBIOUS AIRCRAFT DESIGN CALCULTIONS

1. Four-seater Piston Engined Private/Utility Aircraft. The Partenavia PD93 Idea (see Figure 5.1a) is a 4 seat fixed undercarriage landplane design with a high wing currently under study in Italy. The aircraft will be powered by a Textron Lycoming IO-360-A1B6 (200hp) piston engine. The PD93 is developed into both a pure and amphibious private and commercial utility floatplane and amphibious utility flyingboat using the methodologies. Relevant specifications are as follows:

wing span = 11m	wing area = 17.05m^2	fuselage width = 1.2m
overall length = 8m	empty mass = 770kg	AUM = 1250kg
V_{max} = 370km/hr	$V_{stall\ (flaps\ up)}$ = 104km/hr	range (75%power) = 1400km
cabin volume = 2.5m^3	door size = 0.89m^2	ROC = 289m/min
fin area = 1.6m	fin arm = 4.25m	

Floatplane Design Calculations.

a. Mass Change and Effect on Payload.

i. For use as a private aircraft with pure floats:

for lowest purchase price choose composite floats

from Eqn 2.2: $M_{floats} = 0.38AUM + 4 = 51.5kg$

from Reference 24: $M_{undercarriage} = 0.048AUM = 60kg$

therefore mass change due to fitting floats is -8.5kg

ii. For use as commercial aircraft with amphibious floats:

for legality and maintainability choose STCed metal amphibious floats:

from Eqn 2.2: $M_{floats} = 13 + 0.056AUM = 83kg$

from Reference 24: $M_{undercarriage} = 0.048AUM = 60kg$

therefore mass change due to fitting floats is +23kg

from Eqns 3.14 and 3.15 assuming specified tide and wind speeds are 4.5 kts and 35mph (15.7m/sec) respectively:

$$(M_{anchor})_{tide} = 1.05x10^{-5}AUM\ v^3_{tide} = 1.2kg$$
$$(M_{anchor})_{wind} = 7.4x10^{-4}\ v^2_{wind}\ S = 3.1kg$$

therefore anchor mass = 3.1kg

therefore change in payload due to floats and anchor is:

pure float equipped private aircraft = +5.4kg = +1%
amphibious float equipped commercial aircraft = -26.1kg = -5.4%

b. Float Dimensions.

From Eqn 2.5: $l_f = (3 + 0.0018AUM) = 5.25m$

From Eqn 2.7: $b_f = l_f /7.5 = 0.7m$

From Eqn 2.8: $h_f = l_f /8.8 = 0.6m$

From Eqn 2.9: $l_{fb} = l_f /2 = 2.6m$

From Eqn 2.10: $z_{min} = 0.54 + (1.2x10^{-4}\ AUM) = 0.69m$

From Eqn 2.11: $h_{max} = \{[170.8b_f (0.9l_f)^3] /AUM\} - \{0.6[AUM/0.454]^{1/3}\} = 1.6m$

From Eqn 2.12: $S_{min} = (\{[0.43(AUM/0.454)^{1/3} + h][(12AUM/1025l_f) - 2b_f^3]\}/6b_f)^{1/2}$
$= (\{[0.43(1250/0.454)^{1/3} + 1.6][(12x1250/1025x5.25) - 2(0.7)^3]\}/6x0.7)^{1/2} = 1.95m$

c. Purchase Price.

i. For use as a private aircraft with pure, composite floats:

from Eqn 2.13: cost = (4.5xAUM) + 1000 = $6625

ii. For use as commercial aircraft with amphibious, metal STCed floats:

from Eqn 2.13: cost = (72xAUM) - 73000 = $17000

d. Performance.

From Eqn 2.15: speed and range ratio = 0.9 therefore:

floatplane max speed = 0.87 x 370 = 321km/hr
floatplane range = 0.87 x 1400 = 1218km

From Eqn 2.16: rate of climb ratio = 0.85 therefore:

floatplane rate of climb = 0.85 x 289m/min = 246m/min

e. Floatplane Configuration. See Figure 5.1b. Note that the float strut synergy is the engine bulkhead/rear spar frame configuration which equates to the most popular of the single engine, twin float types from Table 2.14a. Similarly, the float/aircraft relative positions were established using the method of paragraph 2.7 and directional stability ventral fin area from paragraph 2.12.3.

Flyingboat Design Calculations.

a. General Configuration. For use as a utility (U) aircraft and an AUM of 1250kg (mass classification L) then from Eqn 3.1 the configuration is HE-P.

b. Initial Static Stability Sizing. Using the guidance of paragraph 3.3.1.fixed tip floats of C1 form at 75% semi-span is the simplest and most cost-effective lateral stability method. However, to show a spread of examples, a Lake Renegade-type vertical column float is used.

From Eqn 3.2: $(v_{float}\, a)/b^3 = 0.23$ therefore $v_{float} = 0.23\, b^3/a$

b = fuselage width = 1.2m $a = 75\%\,(span/2) = 0.75(11/2) = 4.125m$

therefore $v_{float} = 0.23(1.2^3)/4.125 = 0.1m^3$

from C1 proportions: $b_{float} = h_{float} = l_{float}/3$

therefore $v = l_{float}^3/9$ and $l_{float} = (9v_{float})^{1/3} = 0.96m$

$b_{float} = h_{float} = l_{float}/3 = 0.96/3 = 0.32m$

c. Step Configuration.

From paragraph 3.5.4: $V_{max} < 250kts$ therefore step form = lateral

From Eqn 3.5: $l_{ab} = 2.9/1.2 = 2.4$

which is just outside the parameters of the eqn. However, use recommendation of 4-8% beam for step depth: specifically 6%.

step depth = 0.06x1.2 = 0.072m

d. Planing Bottom Dimensions.

From Eqn 3.6: $l/b = 5.9$ $b = 1.2$ therefore $l = 5.9 \times 1.2 = 7.1m$

AUM<8000kg therefore from Eqn 3.7:

$(\text{forebody area})_{min} = 1.4 + 1.5\text{x}10^{-3}AUM = 1.4 + 1.5\text{x}10^{-3}(1250) = 3.3m^2$

From Eqn 3.8: $l_{fb}/b = 3.5$ therefore $l_{fb} = 3.5\text{x}1.2 = 4.2m$

Therefore $l_{ab} = l - l_{fb} = 7.1 - 4.2 = 2.9m$

Check that linear dimensions match AUM-based forebody area method using simple "flattened" model (see Appendix 8):

forebody area = $l_{fb}^* \times b$ where $l_{fb}^* = l_{fb} - l_{bow} = l_{fb} - b$ for low speed flyingboats forebody area = $(l_{fb} - b)b = (4.4-1.2)1.2 = 3.6m^2 > 3.3$ therefore design is OK

$C_{\Delta max} = AUM /(\rho_{H2O} x b^3) = 1250/(1025x1.2^3) = 0.71$

From Eqn 3.9: $C_{\Delta max} < 4.36$ therefore design is acceptable

From Eqn 3.10: deadrise angle = 16° From Eqn 3.11: afterbody angle = 7°

e. Tail Configuration and Sizing. The overall configuration id HE-P therefore based on the guidance of para 3.7.1 the fin should be single and in-line with the propeller centre-line. Similarly, the horizontal tailplane should be mid-mounted, again in-line with the propeller centre-line.

From Eqn 3.12: $FVC_{flyingboat} = 1.19\ FVC_{landplane}$

$FVC_{landplane} = (s_v\ l_v)/(s\ b) = (1.6x4.25)/(11x17.05) = 0.036$

therefore $FVC_{flyingboat} = 1.19x0.036 = 0.043$

assuming l_v remains the same as the P93: $(s_v)_{flyingboat} = 2.26m^2$

From para 3.7.3 $HVC_{flyingboat} = HVC_{landplane}$

f. Mass Estimation.

From Eqn 3.13: $M_{planing\ bottom}$ (%AUM) = $17.8AUM^{-0.25} = 17.8x1250^{-0.25} = 3\%$

AUM = 1250kg therefore $M_{planing\ bottom} = 37.5kg$

From Appendix 8: assuming planing bottom approximately = 0.25 surface area

mass of equivalent area of landplane fuselage = $0.25x0.0542(S_F^{1.07}V_D^{0.743}k_1)$

where $S_F = k_2 2.56\ L[(b + h)/2] = 1.1x2.56x8[(1.2 + 1.2)/2] = 27m^2$
$k_1 = 0.22 + 0.36[L_T/(b + h)] = 0.22 + 0.36[4.25/(1.2 + 1.2)] = 0.86$
$V_D = 230mph = 102m/sec$

$M = 0.25x0.0542(27^{1.07}x102^{0.743}x0.86) = 12.3kg$

Therefore additional mass = 37.5 - 12.3 = 25.2kg

anchor mass = 3.1kg (see floatplane example)

From Eqn 3.16: $M_{tip\ float}$ (%AUM) = $2.4AUM^{-0.1} = 2.4x1250^{-0.1} = 1.18\%$

(note caveat in para 3.8.3 to use this method with care)

AUM = 1250kg therefore $M_{tip\ float} = 0.0118x1250 = 14.8kg$

Therefore $(M_{empty})_{flyingboat} = (M_{empty})_{landplane} + 25.2 + 3.1 + 14.8 = 813.1kg$

Therefore payload = 1250 - 813.1 = 436.9kg

g. Draft.

From the method of para 3.9.1

$$\text{draft} = 1.2\left(h_l + \left\{\frac{(M/\rho) - h_l b\,[\,l_b/4 + l_{fb}^*/2 + l_{ab}/4\,] + h_s b\,[\,l_{ab}/4\,]}{b\,[\,l_b/2 + l_{fb}^* + l_{ab}/2\,]}\right\}\right)$$

consider cross-section of lower hull: tan(deadrise angle) = $(h_l)/(b/2)$
deadrise portion of hull = $h_l = (1.2/2)\tan 16° = 0.17$

assume step depth is negligible therefore:

$$\text{draft} = 1.2\left(0.17 + \left\{\frac{(1250/1025) - 0.17 \times 1.2[1.2/4 + 3/2 + 2.9/4]}{1.2[\,1.2/2 + 3 + 2.9/2\,]}\right\}\right) = 0.34\text{m}$$

From the simplified method of para 3.9.2:

$$\begin{aligned}\text{draft} &= 1.55AUM/(\rho_{H2O}\,b)(\,l_{fb}^* + 0.5[l_{bow} + l_{ab}])\\ &= 1.55 \times 1250/(1025 \times 1.2)(\,3 + 0.5[1.6 + 2.9]) = 0.30\text{m}\end{aligned}$$

use most conservative figure: draft = 0.34m

check using guidance of para 3.9.3: draft/h_l < 2.56

draft/h_l = 0.34/0.17 = 2 < 2.56 therefore design is OK

h. Spray.

As l_{fb}/b = 4.2/1.2 = 3.5 < 5 use Eqn 3.20:

$z = 2.1b(C_{\Delta 0})^{2/3}/(l_{fb}/b) = (2.1 \times 1.2 \times 0.71^{2/3})/(4.2/1.2) = 0.57$m from waterline
= 0.57 + 0.34 = 0.91m from keel

height of fuselage = 1.2m therefore spray height will not exceed top of fuselage meaning wings, engine and propeller positions can be as required by HE-P configuration.

Some spray/waves are likely to hit the windscreen at low speed therefore include dams.

i. Power Loading.

From Eqn 3.24: power loading < 5.86

power of P93's Lycoming engine = 200hp therefore power loading = 1250/200 = 6.25 kg/hp

Therefore design is unacceptable and a more powerful engine would be needed.

j. Take-off Distance and Time.

From Eqn 3.26: d_{TO} = 4.7(wing loading) - 15

where wing loading = 1250/17.05 = 73.3kg/m^2

Therefore d_{TO} = 4.7(73.3) - 15 = 329m

From Eqn 3.28: $t_{TO} = d_{TO}/0.6V_{TO}$ = 329/(0.6x29) = 19 sec

From Eqn 3.29: $d_{landing} = 1.52\ d_{TO}$ = 1.52x329 = 500m

All are acceptable for this role and will allow the flyingboat to operate on small lakes, inland waterways and busy harbours.

k. Drag.

From Eqn 3.28: $C_{D0} = 0.005S^{-0.1}RT$ where R = 4.5 (Eqn 3.29) and T = 2.3 (Eqn 3.30)

Therefore $C_{D0} = 0.005(17.05)^{-0.1}(4.5x2.3)$ = 0.03897

l. Undercarriage. From Section 3.6 the advantages of a nosewheel undercarriage exceed those for a tailwheel.

m. Performance Indicator Calculation. Examined for L mass classification and U role therefore from Table 4.3 the reference aircraft is the Lake Renegade.

For reference aircraft: M_{empty} = 839kg

Payload = 544kg therefore PI = (payload/M_{empty})rating = (544/839)8 = 5.19
Range = 1668km therefore PI = (range/M_{empty})rating = (1668/839)2 = 3.98
Speed = 245km/hr therefore PI = (speed/M_{empty})rating = (245/839)1 = 0.29
TO distance = 381m therefore PI = (TO^{-1}/M_{empty})rating = ($2.62x10^{-3}$/839)9 = $2.81x10^{-5}$
Cabin volume = 1.7m^3 therefore PI = (vol/M_{empty})rating = (1.7/839)5 = $1.01x10^{-2}$

Door area = 1.78m^2
Loading: no direct path = no factor
lifting operation required = 0.75
therefore modified door area = 0.75x1.78 = 1.335

Loading = 1.335m^2 therefore PI = loading/M_{empty})rating = (1.335/839)3 = $4.8x10^{-3}$

Maintainability Values

A	A = 2	D = 2
	E = 3	E = 0
B	A = 2	F = 3
	E = 3	G = 1
C	A = 2	
	E = 2	Total = 20

Maintainability = 20 therefore PI = maint/M_{empty})rating = (20/839)6 = 0.14

For P93 flyingboat: M_{empty} = 813kg (assume range and speed remain same as landplane)

Payload = 435kg therefore PI = (payload/M_{empty})rating = (435/813)8 = 4.28
Range = 1668km therefore PI = (range/M_{empty})rating = (1668/813)2 = 4.10
Speed = 245km/hr therefore PI = (speed/M_{empty})rating = (245/813)1 = 0.30
TO distance = 329m therefore PI = (TO^{-1}/M_{empty})rating = ($3.04x10^{-3}$/813)9 = $3.36x10^{-5}$
Cabin volume = $2.5m^3$ therefore PI = (vol/M_{empty})rating = (2.5/813)5 = $1.54x10^{-2}$

Door area = $0.89m^2$
Loading: no direct path = no factor
no lifting operation required = no factor
therefore modified door area = 1x 0.89 = 0.89

Loading = $0.89m^2$ therefore PI = loading/M_{empty})rating = (0.89/813)3 = $3.28x10^{-3}$

Maintainability Values

A	A = 2	D = 2
	E = 3	E = 1
B	A = 1	F = 3
	E = 1	G = 1
C	A = 2	
	E = 2	Total = 18

Maintainability = 18 therefore PI = maint/M_{empty})rating = (18/813)6 = 0.13

Comparing with reference aircraft gives:

	Renegade	P93	ratio
Payload	5.19	4.28	0.82
Range	3.98	4.10	1.03
Speed	0.29	0.30	1.03
TO dist	$2.81x10^{-5}$	$3.36x10^{-5}$	1.19
Volume	$1.01x10^{-2}$	$1.54x10^{-2}$	1.52
Loading	$4.8x10^{-3}$	$3.3x10^{-3}$	0.69
Maint	0.14	0.13	0.93

This illustrates the key areas the P93-based flyingboat design would have to develop to challenge the Renegade, ie loading and payload.

The final configuration is shown in Figure 5.1c.

2. Single-seater Agricultural/Light Firebomber Floatplane. The Gippsland GA-200 Fatman (see Figure 5.2a) is a 2-seat agricultural aircraft powered by a Textron Lycoming O-540-H2A5 flat 6 piston engine. The Fatman is a good potential amphibious light firebomber as it is already equipped for laying liquid crop sprays. In addition, it has a corrosion-resistant structure and its 2-seat layout increases safety and control in the firebombing role. The Fatman is developed into both a single and twin pure float floatplane to illustrate the use of these methodologies. Relevant specifications are as follows:

wing span = 11.93m	wing area = 19.6m^2	overall length = 7.48m
empty mass = 770kg	AUM = 1315kg	TO run = 340m
V_{max} = 185km/hr	ROC = 295m/min	range = unknown

a. Mass Change and Effect on Payload.

i. Twin float configuration:

for ease of repair choose metal floats in both cases therefore:

from Eqn 2.2: $M_{floats} = 0.14AUM - 24 = 160.1kg$

from Reference 24: $M_{undercarriage} = 0.048AUM = 63.1kg$

therefore mass change due to fitting floats is +97kg

ii. Single float configuration:

from Eqn 2.4: $M_{floats} = 0.11AUM = 144.6kg$

from Reference 24: $M_{undercarriage} = 0.048AUM = 63.1kg$

therefore mass change due to fitting floats is +81.5kg

from Eqns 3.14 and 3.15 assuming specified tide and wind speeds are 4.5kts and 35mph (15.7m/sec) respectively:

$$(M_{anchor})_{tide} = 1.05x10^{-5}AUM\ v^3_{tide} = 1.26kg$$
$$(M_{anchor})_{wind} = 7.4x10^{-4}\ v^2_{wind}\ S = 3.6kg$$

therefore anchor mass = 3.6kg

therefore change in payload due to floats and anchor is:

twin float configuration	= -100.6kg = -18%
single float configuration	= -85.1kg = -16%

b. Float Dimensions.

i. Twin float configuration:

From Eqn 2.5: $l_f = (3 + 0.0018AUM) = 5.37mm$

From Eqn 2.7: $b_f = l_f/7.5 = 0.72m$

From Eqn 2.8: $h_f = l_f/8.8 = 0.61m$

From Eqn 2.9: $l_{fb} = l_f/2 = 2.7m$

From Eqn 2.10: $z_{min} = 0.54 + (1.2x10^{-4}$ AUM) = 0.7m

From Eqn 2.11: $h_{max} = \{[170.8b_f(0.9l_f)^3]/AUM\} - \{0.6[AUM/0.454]^{1/3}\}$

$= \{[170.8x0.72(0.9x5.37)^3]/1315\} - \{0.6[1315/0.454]^{1/3}\} = 2m$

From Eqn 2.12: $S_{min} = (\{[0.43(AUM/0.454)^{1/3} + h][(12AUM/1025l_f) - 2b_f^3]\}/6b_f)^{1/2}$

$= (\{[0.43(1315/0.454)^{1/3} + 2][(12x1315/1025x5.37) - 2(0.72)^3]\}/6x0.72)^{1/2}$
= 1.98m

ii. Single float configuration:

From Eqn 2.6: $l_f = (3 + 0.0027AUM) = 6.55m$

From Eqn 2.7: $b_f = l_f/6.9 = 0.95m$

From Eqn 2.8: $h_f = l_f/8.8 = 0.74m$

From Eqn 2.9: $l_{fb} = l_f/1.8 = 3.64m$

From Eqn 2.10: $z_{min} = 0.35 + (2.0x10^{-4}$ AUM) = 0.61m

c. Purchase Price.

Twin float configuration: from Eqn 2.23: cost = $2.75AUM^{1.275}$ = \$26059
No methodology available for single float configuration.

d. Performance.

For both the twin and single float configurations (see paragraph 2.11.5):

From Eqn 2.15: speed ratio = 0.87 therefore:

floatplane max speed = 0.87 x 185 = 161km/hr
Note: no range data for GA-200

From Eqn 2.16: rate of climb ratio = 0.85 therefore:

floatplane rate of climb = 0.85 x 295m/min = 251m/min

e. Floatplane Configuration. See Figure 5.2b. Note that the float strut synergy is the front/rear spar frames configuration which equates to the most popular of the single engine, single float types from Table 2.14a. Similarly, the float/aircraft relative positions were established using the method of paragraph 2.7 and directional stability ventral fin area from paragraph 2.12.3.

3. Twin Piston Engined Utility/Light Commuter Aircraft. The Reims F406 Caravan II (see Figure 5.3a) is an unpressurised light aircraft carrying up to 12 passengers. It has a low wing, retractable undercarriage and is powered by twin Pratt & Whitney Canada PT6A-112 turboprops. The methodologies were used to design an amphibious floatplane and a commuter/utility flyingboat. Relevant specifications (including optional cargo door) are as follows:

wing span = 15.08m	wing area = 23.48m^2	overall length = 11.89m
empty mass = 2460kg	AUM = 4468kg	fuselage width = 1.6m
V_{max} = 424km/hr	ROC = 564m/min	range = 2135km
cabin volume = 8.64m^3	door size = 1.57m^2	TO run = 526m
tailplane arm = 5.84m	$V_{TO(flaps\ up)}$ = 174km/hr	

Floatplane Design Calculations.

a. Mass Change and Effect on Payload.

i. With pure floats:

from Eqn 2.1: $M_{floats} = (0.1xAUM) + 33 = 479.8kg$

from Reference 24: $M_{undercarriage} = 0.048AUM = 214.5kg$

therefore mass change due to fitting floats is +265.3kg

ii. With amphibious floats:

from Eqn 2.2: $M_{floats} = (0.13xAUM) + 105 = 685.8kg$

from Reference 24: $M_{undercarriage} = 0.048AUM = 214.5kg$

therefore mass change due to fitting amphibious floats is +471.3kg

from Eqns 3.14 and 3.15 assuming specified tide and wind speeds are 4.5 kts and 35mph (15.7m/sec) respectively:

$$(M_{anchor})_{tide} = 1.05x10^{-5}AUM\ v^3_{tide} = 4.3kg$$
$$(M_{anchor})_{wind} = 7.4x10^{-4}\ v^2_{wind}\ S = 4.3kg$$

therefore anchor mass = 4.3kg

therefore change in payload due to floats and anchor is:

pure float equipped aircraft	= -269.6kg = -13%
amphibious float equipped aircraft	= -475.6kg = -24%

b. Float Dimensions.

From Eqn 2.5: $l_f = (8 + 0.0002AUM) = 8.9m$

From Eqn 2.7: $b_f = l_f /7.5 = 1.2m$

From Eqn 2.8: $h_f = l_f /8.8 = 1.01m$

From Eqn 2.9: $l_{fb} = l_f /2 = 4.5m$

From Eqn 2.10: $z_{min} = 0.9 + (4.4x10^{-5} AUM) = 1.1m$

From Eqn 2.11: $h_{max} = \{[170.8b_f(0.9l_f)^3] /AUM\} - \{0.6[AUM/0.454]^{1/3}\} = 10.76m$

From Eqn 2.12: $S_{min} = (\{[0.43(AUM/0.454)^{1/3} + h][(12AUM/1025l_f) - 2b_f^3]\}/6b_f)^{1/2}$
$= (\{[0.43(4468/0.454)^{1/3} + 10.76][(12x4468/1025x8.9) - 2(1.2)^3]\}/6x1.2)^{1/2} = 2.06m$

c. Purchase Price.

i. With pure floats:

from Eqn 2.13: $cost = 2.75AUM^{1.275}$ = \$123944

ii. With amphibious floats:

from Eqn 2.14: cost = (72xAUM) - 73000 = \$248696

d. Performance.

From Eqn 2.15: speed and range ratio = 0.78 therefore:

floatplane max speed = 0.78 x 424 = 331km/hr
floatplane range = 0.78 x 2135 = 1665km

From Eqn 2.16: rate of climb ratio = 0.76 therefore:

floatplane rate of climb = 0.76 x 564m/min = 429m/min

e. Floatplane Configuration. See Figure 5.3b. Note that the float strut synergy is the front spar/rear spar/fuselage frame configuration which equates to the most popular of the twin engine, twin float types from Table 2.14a. Similarly, the float/aircraft relative positions were established using the method of paragraph 2.7 and directional stability ventral fin area from paragraph 2.12.3.

Flyingboat Design Calculations.

a. General Configuration. For use as a commuter/utility (T(V)) aircraft and an AUM of 4468kg (mass classification LM) then from Eqn 3.1 the configuration is HW.

b. Initial Static Stability Sizing. Using the guidance of para 3.3.1.fixed tip floats of C1 form at 70-79% semi-span is the simplest and most cost-effective lateral stability method. However, examination of the relevant drawing shows an aileron hinge rib at 82.5% semi-span and for synergy reasons this is used.

From Eqn 3.2: $(v_{float}\, a)/b^3 = 0.39$ therefore $v_{float} = 0.39b^3/a$

b = fuselage width = 1.6m $a = 82.5\%(\text{span}/2) = 0.825(15.08/2) = 6.2\text{m}$

therefore $v_{float} = 0.39(1.6^3)/6.2 = 0.26\text{m}^3$

from C1 proportions: $b_{float} = h_{float} = l_{float}/3$

therefore $v = l_{float}^3/9$ and $l_{float} = (9v_{float})^{1/3} = (9\text{x}0.26)^{1/3} = 1.33\text{m}$

$b_{float} = h_{float} = l_{float}/3 = 1.33/3 = 0.44\text{m}$

c. Step Configuration.

From para 3.5.4: V_{max}<250kts therefore step form = lateral

From Eqn 3.5: $l_{ab}/b = 5.2/1.6 = 3.25$

which is inside the parameters of Eqn 3.5. Therefore use recommendation of 4-8% beam for step depth: specifically 6%.

step depth = 0.06x1.6 = 0.096m

d. Planing Bottom Dimensions.

From Eqn 3.6: $l/b = 5.29$ $b = 1.6$ therefore $l = 5.29 \text{ x } 1.6 = 8.5\text{m}$

AUM<8000kg therefore from Eqn 3.7:

$(\text{forebody area})_{min} = 1.4 + 1.5\text{x}10^{-3}\text{AUM} = 1.4 + 1.5\text{x}10^{-3}(4468) = 8.1\text{m}^2$

From Eqn 3.8: $l_{fb}/b = 3.5$ therefore $l_{fb} = 3.5 \text{ x } 1.6 = 5.6\text{m}$

Therefore $l_{ab} = l - l_{fb} = 8.5 - 5.6 = 2.9\text{m}$

Check that linear dimensions match AUM-based forebody area method using simple "flattened" model (see Appendix 8):

forebody area = $l_{fb}^* \text{ x } b$ where $l_{fb}^* = l_{fb} - l_{bow} = l_{fb} - b$ for low speed flyingboats

forebody area = $(l_{fb} - b)b = (5.6 - 1.6)1.6 = 6.4\text{m}^2 < 8.1$ indicating too small a forebody. Therefore increase forebody length to 6.7m to generate 8.1m² forebody area. Recalculating afterbody length gives:

$l_{ab} = l - l_{fb} = 8.5 - 6.7 = 1.8\text{m}$

which is, by examination, far too low. Comparing the total length of the fuselage (11.89m) with the estimated length of the planing bottom (8.5m) illustrates the additional length available for a sensible afterbody. The length of the afterbody is therefore extended to:

$l_{ab} = (11.89 - 8.5) + 1.8 = 5.2m$

$C_{\Delta max} = AUM /(\rho_{H2O}\, xb^3) = 4468/(1025x1.6^3) = 1.06$

From Eqn 3.9: $C_{\Delta max} < 4.36$ therefore design is acceptable

From Eqn 3.10: deadrise angle = 16° From Eqn 3.11: afterbody angle = 7°

e. Tail Configuration and Sizing. The overall configuration is HW therefore based on the guidance of para 3.7.1 the fin could be single or twin to keep the rudder/s in line with the propeller centre-lines. Similarly, the horizontal tailplane should be mounted high, again in-line with the propeller centre-line.

From Section 3.7: $FVC_{flyingboat} = FVC_{landplane}$ and $HVC_{flyingboat} = HVC_{landplane}$

f. Mass Estimation.

From Eqn 3.13: $M_{planing\ bottom}$ (%AUM) = $17.8AUM^{-0.25} = 17.8x4468^{-0.25} = 2.18\%$

AUM = 4468kg therefore $M_{planing\ bottom} = 0.0218 \times 4468 = 97kg$

From Appendix 8: assuming planing bottom approximately = 0.25 surface area

mass of equivalent area of landplane fuselage = $0.25x0.0542(S_F^{1.07}V_D^{0.743}k_l)$

where $S_F = k_2 2.56\, L[(b + h)/2] = 1.1x2.56x11.89[(1.6+1.6)/2] = 53.4m^2$
$k_l = 0.22 + 0.36[L_T/(b + h)] = 0.22 + 0.36[5.84/(1.6+1.6)] = 0.877$
$V_D = 263mph = 117m/sec$

$M = 0.25x0.0542(53.4^{1.07}x117^{0.743}\ x0.877) = 28.8kg$

Therefore additional mass = 97 - 28.8 = 68.2kg

anchor mass = 4.3kg (see floatplane example)

From Eqn 3.16: $M_{tip\ float}$ (%AUM) = $2.4AUM^{-0.1} = 2.4x4468^{-0.1} = 1.03\%$

(note caveat in para 3.8.3 to use this method with care)

AUM = 4468kg therefore $M_{tip\ float} = 0.0103x4468 = 46kg$

Therefore $(M_{empty})_{flyingboat} = (M_{empty})_{landplane} + 68.2 + 4.3 + 46 = 2578.5kg$

Therefore payload = 4468 - 2578.5 = 1889.5kg

g. Draft.

From the method of para 3.9.1

$$\text{draft} = 1.2\left(h_l + \left\{\frac{(M/\rho) - h_l b\,[\,l_b/4 + l_{fb}^*/2 + l_{ab}/4\,] + h_s b\,[\,l_{ab}/4\,]}{b\,[\,l_b/2 + l_{fb}^* + l_{ab}/2\,]}\right\}\right)$$

consider cross-section of lower hull: tan(deadrise angle) = $(h_l)/(b/2)$
deadrise portion of hull = h_l = (1.6/2)tan16° = 0.23

assume step depth is negligible therefore:

$$\text{draft} = 1.2\left(0.23 + \left\{\frac{(4668/1025) - 0.23 \times 1.6[1.6/4 + 5.1/2 + 5.2/4]}{1.6[\,1.6/2 + 5.1 + 5.2/2\,]}\right\}\right) = 0.54\text{m}$$

From the simplified method of para 3.9.2:

$$\begin{aligned}\text{draft} &= 1.55\text{AUM}/(\rho_{H2O}\,b)(\,l_{fb}^* + 0.5[l_{bow} + l_{ab}]) \\ &= 1.55\text{x}4668/(1025\text{x}1.6)(\,5.1 + 0.5[1.6 + 5.2]) = 0.52\text{m}\end{aligned}$$

use most conservative figure: draft = 0.54m

check using guidance of para 3.9.3: draft/h_l < 2.56

draft/h_l = 0.54/0.24 = 2.25 < 2.56 therefore design is OK

h. Spray.

As l_{fb}/b = 6.7/1.6 = 4.2 < 5 use Eqn 3.20:

$z = 2.1b(C_\Delta)^{2/3}/(l_{fb}/b) = (2.1\text{x}1.6\text{x}1.06^{2/3})/(6.7/1.6) = 0.84\text{m}$ from waterline
= 0.84 + 0.54 = 1.38m from keel

height of fuselage = 1.6m therefore spray height will not exceed wing root meaning wings, engine and propeller positions can be as required by HW configuration.

Some spray/waves are likely to hit the windscreen at low speed therefore include dams.

i. Power Loading.

From Eqn 3.24: power loading < 4.55

power of 2x Pratt & Whitney PT6 engines = 1000hp therefore power loading = 4668/1000
= 4.7kg/hp

Therefore design is just above the acceptable limit and requires slightly more power.

j. Take-off Distance and Time.

From Eqn 3.26: d_{TO} = 4.7(wing loading) - 15 where wing loading = 4468/23.48 = 190.3kg/m^2

Therefore $d_{TO} = 4.7(190.3) - 15 = 879$m

From Eqn 3.28: $t_{TO} = d_{TO}/0.6V_{TO} = 879/(0.6x48.33) = 30$sec

From Eqn 3.29: $d_{landing} = 1.52\ d_{TO} = 1.52x879 = 1336$m

All are acceptable for this role and will allow the flyingboat to operate on medium sized lakes, inland waterways and harbours.

k. Drag.

From Eqn 3.29: $C_{D0} = 0.005S^{-0.1}RT$ where R = 5.2 (Eqn 3.30) and T = 2.1 (Eqn 3.31)

Therefore $C_{D0} = 0.005(23.48)^{-0.1}(5.2x2.1) = 0.03982$

l. Undercarriage. From Section 3.6 the advantages of a nosewheel undercarriage exceed those for a tailwheel.

m. Performance Indicator Calculation. Examined for LM mass classification and T(V) role therefore from Table 4.3 the reference aircraft is the Dornier Seastar.

For reference aircraft: M_{empty} = 2800kg

Payload = 1800kg therefore PI = (payload/M_{empty})rating = (1800/2800)7 = 4.50
Range = 1581km therefore PI = (range/M_{empty})rating = (1581/2800)5 = 2.82
Speed = 180km/hr therefore PI = (speed/M_{empty})rating = (180/2800)1 = 0.06
TO distance = 543m therefore PI = (TO^{-1}/M_{empty})rating = ($1.84x10^{-3}$/2800)9 = $5.91x10^{-6}$
Cabin volume = 8.23m^3 therefore PI = (vol/M_{empty})rating = (8.23/2800)8 = $2.35x10^{-2}$

Door area = 1.09m^2
Loading: direct path = 1.5 factor
lifting operation required = 0.75 factor
therefore modified door area = 1.5x0.75x1.09 = 1.23m^3

Loading = 1.23m^2 therefore PI = loading/M_{empty})rating = (1.23/2800)4 = $1.76x10^{-3}$

Maintainability Values

A	A = 3	D = 2
	E = 3	E = 0
B	A = 3	F = 2
	E = 3	G = 3
C	A = 2	
	E = 0	Total = 21

Maintainability = 21 therefore PI = maint/M_{empty})rating = (21/2800)3 = $7.5x10^{-3}$

For Caravan II based flyingboat: M_{empty} = 2579kg (assume range and speed remain same as landplane)

Payload = 1890kg therefore PI = (payload/M_{empty})rating = (1890/2579)7 = 5.13
Range = 2135km therefore PI = (range/M_{empty})rating = (2135/2579)5 = 4.14
Speed = 424km/hr therefore PI = (speed/M_{empty})rating = (424/2579)1 = 0.16
TO distance = 879m therefore PI = (TO^{-1}/M_{empty})rating = ($1.14x10^{-3}$/2579)9 = $3.98x10^{-6}$
Cabin volume = 8.64m^3 therefore PI = (vol/M_{empty})rating = (8.64/2579)8 = $2.68x10^{-2}$

Door area = 1.57m^2
Loading: direct path = 1.5 factor
no lifting operation required = no factor
therefore modified door area = 1.5x 1.57 = 2.35m^2

Loading = 2.35m^2 therefore PI = loading/M_{empty})rating = (2.35/2579)4 = $3.64x10^{-3}$

Maintainability Values

A	A = 3	D = 2
	E = 2	E = 1
B	A = 2	F = 2
	E = 2	G = 3
C	A = 2	
	E = 0	Total = 19

Maintainability = 19 therefore PI = maint/M_{empty})rating = (19/2579)3 = $7.3x10^{-3}$

Comparing with reference aircraft gives:

	Seastar	Caravan II	ratio
Payload	4.50	5.13	1.14
Range	2.82	4.14	1.47
Speed	0.06	0.16	2.67
TO dist	$5.91x10^{-6}$	$3.98x10^{-6}$	0.67
Volume	$2.35x10^{-2}$	$2.68x10^{-2}$	1.14
Loading	$1.76x10^{-3}$	$3.64x10^{-3}$	2.07
Maint	$7.5x10^{-3}$	$7.3x10^{-3}$	0.97

This illustrates the key areas the Reims F406 Caravan II-based flyingboat design would have to develop to challenge the Seastar, ie take-off distance, probably at the expense of speed.

The final configuration is shown at Figure 5.3c.

4. Twin Turboprop Medium Commuter/General Purpose Aircraft. The Fairchild Metro 23 (see Figure 5.4a) is a medium sized, low-winged 20 seater commuter aircraft powered by 2 Allied Signal TPE331-11U-6 turboprops. It has a retractable undercarriage and is available in a variety of civil and military variants including commuter, freighter, medivac, surveillance and airborne early warning roles. It is therefore suitable for modification as a floatplane or as the basis for a flyingboat to either extend its commercial operations into austere or coastal/lake areas or to increase military flexibility, especially in the surveillance role. Relevant specifications are as follows:

wing span = 17.37m	wing area = 28.71m^2	overall length = 18.09m
empty mass = 4309kg	AUM = 8000kg	
V_{max} = 455km/hr	ROC = 243m/min	range = 2065km
cabin volume = 16.62m^3	door size = 1.755m^2	TO run = unknown
tailplane arm = 8.58m	$V_{TO(flaps\ up)}$ = 191km/hr	fuselage width = 1.76m

Floatplane Design Calculations.

a. Mass Change and Effect on Payload.

i. With pure floats:

from Eqn 2.1: $M_{floats} = (0.1xAUM) + 33 = 781.4kg$

from Reference 24: $M_{undercarriage} = 0.038AUM = 284.4kg$

therefore mass change due to fitting floats is +497kg

ii. With amphibious floats:

from Eqn 2.2: $M_{floats} = (0.13xAUM) + 105 = 1077.9kg$

from Reference 24: $M_{undercarriage} = 0.038AUM = 284.4kg$

therefore mass change due to fitting amphibious floats is +793.5kg

from Eqns 3.14 and 3.15 assuming specified tide and wind speeds are 4.5 kts and 35mph (15.7m/sec) respectively:

$(M_{anchor})_{tide} = 1.05x10^{-5}AUM\ v^3_{tide} = 7.2kg$
$(M_{anchor})_{wind} = 7.4x10^{-4}\ v^2_{wind}\ S = 5.2kg$

therefore anchor mass = 7.2kg

therefore change in payload due to floats and anchor is:

pure float equipped aircraft	= -504.2kg = -16%
amphibious float equipped aircraft	= -800.7kg = -25%

b. Float Dimensions.

From Eqn 2.5: $l_f = (8 + 0.0002AUM) = 9.5m$

From Eqn 2.17: $b_f = l_f /7.5 = 1.27m$

From Eqn 2.8: $h_f = l_f /8.8 = 1.08m$

From Eqn 2.9: $l_{fb} = l_f /2 = 4.75m$

From Eqn 2.10: $z_{min} = 0.9 + (4.4x10^{-5}\ AUM) = 1.23m$

From Eqn 2.11: $h_{max} = \{[170.8b_f (0.9l_f)^3] /AUM\} - \{0.6[AUM/0.454]^{1/3}\} = 2.9m$

From Eqn 2.12: $S_{min} = (\{[0.43(AUM/0.454)^{1/3} + h][(12AUM/1025l_f) - 2b_f^3]\}/6b_f)^{1/2}$
$= (\{[0.43(7484/0.454)^{1/3} + 2.9][(12x7484/1025x9.5) - 2(1.27)^3]\}/6x1.27)^{1/2} = 3.05m$

Note that, from Figure 5.4b, s and h are actually defined by propeller configuration.

c. Purchase Price.

i. With pure floats:

from Eqn 2.13: cost = $2.75AUM^{1.275}$ = \$239251

ii. With amphibious floats:

from Eqn 2.14: cost = (72xAUM) - 73000 = \$465848

d. Performance.

From Eqn 2.15: speed and range ratio = 0.77 therefore:

floatplane max speed = 0.77 x 455 = 350km/hr
floatplane range = 0.77 x 2065 = 1590km

From Eqn 2.16: rate of climb ratio = 0.76 therefore:

floatplane rate of climb = 0.76 x 243m/min = 185m/min

e. Floatplane Configuration. See Figure 5.4b. Note that the float strut synergy is the front spar/rear spar/fuselage frame configuration which equates to the most popular of the twin engine, twin float types from Table 2.14a. Similarly, the float/aircraft relative positions were established using the method of paragraph 2.7 and directional stability ventral fin area from paragraph 2.12.3.

Flyingboat Design Calculations.

a. General Configuration. For use as a commuter or potential military (T(V) or T(M)) aircraft with an AUM of 7484kg (as this is so close to the 8000kg M classification take this as AUM to widen scope of examples). From Eqn 3.1 the configuration is HW.

b. Initial Static Stability Sizing. Using the guidance of para 3.4.1.fixed tip floats of C1 form at 70-79% semi-span is the simplest and most cost-effective lateral stability method. However, to widen scope of examples consider a retractable tip float as the choice of lateral stability method.

Initial estimate of retractable strut and float length = fuselage height = 1.76m therefore hinge is 1.76m from tip. Therefore:

$a = (17.37/2) - 1.76 = 6.9m$

From Eqn 3.2: $(v_{float}\, a)/b^3 = 0.54$ therefore $v_{float} = 0.54b^3/a$

b = fuselage width = 1.76m therefore $v_{float} = 0.54(1.76^3)/6.9 = 0.43m^3$

from C1 proportions: $b_{float} = h_{float} = l_{float}/3$

therefore $v = l_{float}{}^3/9$ and $l_{float} = (9v_{float})^{1/3} = (9x0.43)^{1/3} = 1.57m$

$b_{float} = h_{float} = l_{float}/3 = 1.57/3 = 0.52m$

c. Step Configuration.

From para 3.5.4: V_{max}<250kts therefore step form = lateral

However, V_{max} = 247kts therefore due to closeness of speed and to widen the scope of the examples use a tapered step.

From Eqn 3.5: $l_{ab}/b = 8.01/1.76 = 4.55$

which is outside the parameters of Eqn 3.5. However, continue to use recommendation of 4-8% beam for step depth: specifically 6%.

step depth = 0.06x1.76 = 0.01m

d. Planing Bottom Dimensions.

From Eqn 3.6: $l/b = 5.29$ b = 1.76 therefore l = 1.76 x 5.29 = 9.3m

AUM>8000kg therefore from Eqn 3.6:

$(\text{forebody area})_{min} = 10 + 5.8x10^{-4}AUM = 10 + 5.8x10^{-4}(8000) = 14.64m^2$

From Eqn 3.8: $l_{fb}/b = 3.5$ therefore $l_{fb} = 3.5 \times 1.76 = 6.16m$

Therefore $l_{ab} = l - l_{fb} = 14.64 - 6.16 = 8.48m$

Check that linear dimensions match AUM-based forebody area method using simple "flattened" model (see Appendix 8):

forebody area = l_{fb}^{*} x b where $l_{fb}^{*} = l_{fb} - l_{bow} = l_{fb}$ - b for low speed flyingboats

forebody area = $(l_{fb} - b)b = (6.16 - 1.76)1.76 = 7.74m^2 < 14.64$ indicating too small a forebody. Therefore increase l_{fb}^{*} to 8.32m to generate $14.64m^2$ forebody area. Recalculating afterbody length gives:

$l_{ab} = l - l_{fb} = 9.3 - 10.08 = -0.78m$

which is clearly incorrect. Comparing the total length of the fuselage (18.09m) with the estimated length of the planing bottom (9.3m) illustrates the additional length available for a sensible afterbody. The length of the afterbody is therefore extended to:

$l_{ab} = 18.09 - 10.08 = 8.01m$

$C_{\Delta max} = AUM /(\rho_{H2O}\, x b^3) = 8000/(1025x1.76^3) = 1.43$

From Eqn 3.9: $C_{\Delta max} < 4.36$ therefore design is acceptable

From Eqn 3.10: deadrise angle = 16°   From Eqn 3.11: afterbody angle = 7°

e. Tail Configuration and Sizing. The overall configuration is HW therefore based on the guidance of para 3.7.1 the fin could be single or twin to keep the rudder/s in line with the propeller centre-lines. Similarly, the horizontal tailplane should be mounted high, again in-line with the propeller centre-line.

From Section 3.7: $FVC_{flyingboat} = FVC_{landplane}$ and $HVC_{flyingboat} = HVC_{landplane}$

f. Mass Estimation.

From Eqn 3.13: $M_{planing\ bottom}$ (%AUM) = $17.8AUM^{-0.25} = 17.8x8000^{-0.25}$ = 1.88%

AUM = 8000kg therefore $M_{planing\ bottom}$ = 8000 x 0.0188 = 150.4kg

From Appendix 8: assuming planing bottom approximately = 0.25 surface area

mass of equivalent area of landplane fuselage $M_{fuselage} = 0.25x0.0542(S_F^{1.07}V_D^{0.743}k_1)$

where $S_F = k_2 2.56\, L[(b + h)/2] = 1.1x2.56x18.09[(1.76+1.76)/2] = 89.7m^2$
$k_1 = 0.22 + 0.36[L_T/(b + h)] = 0.22 + 0.36[8.58/(1.76+1.76)] = 1.10$
V_D = 358mph = 159.3m/sec (0.445)

$M_{fuselage} = 0.25x0.0542(89.7^{1.07}x159^{0.743}\ x1.1) = 79.3kg$

Therefore additional mass = 150.4 - 79.3 = 71.1kg

anchor mass = 7.2kg (see floatplane example)

From Eqn 3.16: $M_{tip\ float}$ (%AUM) = $2.4AUM^{-0.1} = 2.4x8000^{-0.1}$ = 1.0%

(note caveat in para 3.8.3 to use this method with care)

AUM = 8000kg therefore $M_{tip\ float} = 0.01 \times 8000 = 80kg$

Therefore $(M_{empty})_{flyingboat} = (M_{empty})_{landplane} + 71.1 + 7.2 + 80 = 4467kg$

Therefore payload = 8000 - 4467 = 3533kg

g. <u>Draft.</u>

From the method of para 3.9.1

$$draft = 1.2\left(h_1 + \left\{\frac{(M/\rho) - h_1 b\,[\,l_b/4 + l_{fb}^*/2 + l_{ab}/4\,] + h_2 b\,[\,l_{ab}/4\,]}{b\,[\,l_b/2 + l_{fb}^* + l_{ab}/2\,]}\right\}\right)$$

consider cross-section of lower hull: tan(deadrise angle) = $(h_1)/(b/2)$
deadrise portion of hull = $h_1 = (1.76/2)\tan 16° = 0.25$

assume step depth is negligible therefore:

$$draft = 1.2\left(0.25 + \left\{\frac{(8000/1025) - 0.25 \times 1.76[1.76/4 + 8.32/2 + 8.01/4]}{1.76[1.76/2 + 8.32 + 8.01/2]}\right\}\right) = 0.54m$$

From the simplified method of para 3.9.2:

$$\begin{aligned} draft &= 1.55AUM/(\rho_{H2O}\,b)(\,l_{fb}^* + 0.5[l_{bow} + l_{ab}]) \\ &= 1.55 \times 8000/(1025 \times 1.76)(\,8.32 + 0.5[1.76 + 8.01]) = 0.52m \end{aligned}$$

use most conservative figure: draft = 0.54m

check using guidance of para 3.9.3: $draft/h_1 < 2.56$

$draft/h_1 = 0.54/0.27 = 2.0 < 2.56$ therefore design is OK

h. <u>Spray.</u>

As $l_{fb}/b = 10.08/1.76 = 5.7 > 5$ therefore use Eqn 3.20 with care. However, from 3.11.3a the high l/b ratio will decrease spray height and therefore the result will be conservative:

$$\begin{aligned} z = 2.1b(C_\Delta)^{2/3}/(l_{fb}/b) = (2.1 \times 1.76 \times 1.43^{2/3})/(10.08/1.76) &= 0.84m \text{ from waterline} \\ &= 0.84 + 0.54 = 1.2m \text{ from keel} \end{aligned}$$

height of fuselage = 1.76m therefore spray height will not exceed wing root meaning wings, engine and propeller positions can be as required by HW configuration.

Some spray/waves are likely to hit the windscreen at low speed therefore include dams.

i. Power Loading.

From Eqn 3.24: power loading < 6.68

power of 2x1000hp engines = 2000hp therefore power loading = 8000/2000 = 4kg/hp
Therefore design is likely to be overpowered from the point of view of take-off.

j. Take-off Distance and Time.

From Eqn 3.26: $d_{TO} = 4.7$(wing loading) - 15

where wing loading = 8000/28.71 = 279kg/m^2

Therefore $d_{TO} = 4.7(279) - 15 = 1296$m

From Eqn 3.28: $t_{TO} = d_{TO}/0.6V_{TO} = 1296/(0.6x53) = 41$sec

From Eqn 3.29: $d_{landing} = 1.52\ d_{TO} = 1.52x1296 = 1970$m

All are acceptable for this role and will allow the flyingboat to operate on medium sized lakes, inland waterways and harbours.

k. Drag.

From Eqn 3.29: $C_{D0} = 0.005S^{-0.1}RT$ where R = 4.5 (Eqn 3.30) and T = 2.6 (Eqn 3.31)

Therefore $C_{D0} = 0.005(28.71)^{-0.1}(4.5x2.6) = 0.0418$

l. Undercarriage. From Section 3.8 the advantages of a nosewheel undercarriage exceed those for a tailwheel.

m. Performance Indicator Calculation. Examined for M mass classification and T(V) role therefore from Table 4.3 the reference aircraft is the Albatross (G111 civilian version).

For reference aircraft: $M_{empty} = 9125$kg

Payload = 3147kg therefore PI = (payload/M_{empty})rating = (3147/9125)7 = 2.41
Range = 4320km therefore PI = (range/M_{empty})rating = (4320/9125)5 = 2.37
Speed = 553km/hr therefore PI = (speed/M_{empty})rating = (553/9125)1 = 0.061
TO distance = 1349m therefore PI = (TO^{-1}/M_{empty})rating = ($7.41x10^{-4}$/9125)9 = $7.31x10^{-7}$
Cabin volume = 25.3m^3 therefore PI = (vol/M_{empty})rating = (25.3/9125)8 = $2.22x10^{-2}$

Door area = 1.06m^2
Loading: direct path = 1.5 factor
no lifting operation required = no factor
therefore modified door area = 1.5 x 1.06 = 1.59m^3

Loading = 1.59m^2 therefore PI = loading/M_{empty})rating = (1.59/9125) 4 = $0.70x10^{-3}$

Maintainability Values

A	A = 2	D = 2
	E = 2	E = 0
B	A = 2	F = 2
	E = 2	G = 3
C	A = 2	
	E = 2	Total = 19

Maintainability = 19 therefore PI = maint/M_{empty})rating = (19/9125)3 = $6.25x10^{-3}$

For the Metro-based flyingboat: M_{empty} = 4467kg (assume range and speed remain same as landplane)

Payload = 3533kg therefore PI = (payload/M_{empty})rating = (3533/4467)7 = 5.54
Range = 2065km therefore PI = (range/M_{empty})rating = (2065/4467)5 = 2.31
Speed = 455km/hr therefore PI = (speed/M_{empty})rating = (455/4467)1 = 0.10
TO distance = 1296m therefore PI = (TO^{-1}/M_{empty})rating = ($7.72x10^{-4}$/4467)9 = $15.5x10^{-7}$
Cabin volume = $16.62m^3$ therefore PI = (vol/M_{empty})rating = (16.62/4467)8 = $2.89x10^{-2}$

Door area = $1.755m^2$
Loading: direct path = 1.5 factor
no lifting operation required = no factor
therefore modified door area = 1.5x1.755 = $2.63m^3$

Loading = $2.63m^2$ therefore PI = loading/M_{empty})rating = (2.63/4467)4 = $2.35x10^{-3}$

Maintainability Values

A	A = 2	D = 2
	E = 2	E = 1
B	A = 2	F = 2
	E = 2	G = 3
C	A = 0	
	E = 0	Total = 16

Maintainability = 16 therefore PI = maint/M_{empty})rating = (16/4467)3 = $10.7x10^{-3}$

Comparing with reference aircraft gives:

	Albatross	Metro	ratio
payload	2.41	5.54	2.30
range	2.37	2.31	0.97
speed	0.061	0.10	1.63
TO dist	$7.3x10^{-7}$	$15.5x10^{-7}$	2.12
volume	$2.22x10^{-2}$	$2.98x10^{-2}$	1.34
loading	$0.7x10^{-3}$	$2.35x10^{-3}$	3.36
maint	$6.25x10^{-3}$	$10.7x10^{-3}$	1.71

This illustrates the superiority of the Metro-based flyingboat design compared to the Albatross. This should not be a surprise considering the relative ages of the aircraft.

The final configuration is shown at Figure 5.4c.

5. Twin Turboprop Large Commuter/Light Freighter/MPA. The Airtech (IPTN/ CASA) CN-235 (see Figure 5.5a) is a medium sized military and civil freighter which is also used as a maritime patrol aircraft. The CN-235 is powered by 2 General Electric CT7-9C turboprop engines, can seat up to 44 passengers, a variety of freight containers or can be equipped with a 360° surveillance radar and weapons in the patrol role. It has a high wing and a rear loading ramp. It is therefore suitable for a floatplane modification or as the basis for a flyingboat to either extend its commercial operations into austere or coastal/lake areas or to increase military flexibility, especially in the surveillance role. In common with similar types of freighter it can also use palletised firebombing equipment. Relevant specifications (military version) are as follows:

wing span = 25.81m	wing area = 59.1m^2	overall length = 21.40m
empty mass = 8800kg	AUM = 16000kg	TO run (Srs 200) = 1051m
V_{max} = 445km/hr	ROC = 465m/min	range (with max payload) = 1528km
cabin volume = 43.24m^3		door size (aperture) = 4.465m^2
tailplane arm = 11.25m	$V_{TO(flaps\ up)}$ = 186km/hr	fuselage width = 2.7m

Floatplane Design Calculations.

a. Mass Change and Effect on Payload.

i. With pure floats:

from Eqn 2.1: $M_{floats} = (0.1xAUM) + 33 = 1633kg$

from Reference 24: $M_{undercarriage} = 0.038AUM = 608kg$

therefore mass change due to fitting floats is +1025kg

ii. With amphibious floats:

from Eqn 2.2: $M_{floats} = (0.13xAUM) + 105 = 2185kg$

from Reference 24: $M_{undercarriage} = 0.038AUM = 608kg$

therefore mass change due to fitting amphibious floats is +1577kg

from Eqns 3.14 and 3.15 assuming specified tide and wind speeds are 4.5 kts and 35mph (15.7m/sec) respectively:

$$(M_{anchor})_{tide} = 1.05x10^{-5}AUM\ v^3_{tide} = 15.3kg$$
$$(M_{anchor})_{wind} = 7.4x10^{-4}\ v^2_{wind}\ S = 10.8kg$$

therefore anchor mass = 15.3kg

therefore change in payload due to floats and anchor is:

pure float equipped aircraft = -1040.3kg = -14%
amphibious float equipped aircraft = -1592.3kg = -22%

b. Float Dimensions.

From Eqn 2.5: $l_f = (8 + 0.0002AUM) = 11.2m$

From Eqn 2.7: $b_f = l_f /7.5 = 1.5m$

From Eqn 2.8: $h_f = l_f /8.8 = 1.27m$

From Eqn 2.9: $l_{fb} = l_f /2 = 5.6m$

From Eqn 2.10: $z_{min} = 0.9 + (4.4x10^{-5} AUM) = 1.6m$

From Eqn 2.11: $h_{max} = \{[170.8b_f (0.9l_f)^3] /AUM\} - \{0.6[AUM/0.454]^{1/3}\} = -3.2m$

This negative result illustrates the limits of this method as described in Appendix 2.

c. Purchase Price.

i. With pure floats:

from Eqn 2.13: cost = $2.75AUM^{1.275}$ = \$630355

ii. With amphibious floats:

from Eqn 2.14: cost = (72xAUM) - 73000 = \$1079000

d. Performance.

From Eqn 2.15: speed and range ratio = 0.78 therefore:

floatplane max speed = 0.78 x 445 = 347km/hr
floatplane range = 0.78 x 1528 = 1192km

From Eqn 2.16: rate of climb ratio = 0.76 therefore:

floatplane rate of climb = 0.76 x 465m/min = 353m/min

e. Floatplane Configuration. See Figure 5.5b. Note that the float strut synergy is the front bulkhead/rear spar frame configuration which maximises the use of the wide fuselage structure but, due to the lack of similar aircraft in the database, is not popular (see Table 2.14a). Similarly, the float/aircraft relative positions were established using the method of paragraph 2.7 and directional stability ventral fin area from paragraph 2.12.3.

Flyingboat Design Calculations.

Assume rear door is replaced by fixed afterbody and freight door and 2xlarge paratroop doors are fitted over the stubs.

a. General Configuration. For use as a freighter(T(V)) aircraft or an MPA/firebomber (T(M)) and an AUM of 16000kg (mass classification H) then from Eqn 3.1 the configuration is HW.

b. Initial Static Stability Sizing. Using the guidance of para 3.3.1.fixed tip floats of C1 form at 70-79% semi-span is the simplest and most cost-effective lateral stability method. However, as the design already has undercarriage sponsons, to ease side hatch loading and to increase the spread of the examples, stubs are used instead.

From Eqn 3.3: stub volume = 8.74×10^{-4}AUM = 13.98m^3
$b_{stub}/b = 0.95$ therefore $b_{stub} = 0.95 \times 2.7 = 2.54$m
$l_1/b_{stub} = 2.14$ therefore $l_1 = 2.14 \times 2.56 = 5.48$m
$l_1/l_2 = 1.45$ therefore l2 = 5.48/1.45 = 3.78m
$t_{stub}/b_{stub} = 0.29$ therefore $t_{stub} = 0.29 \times 2.54 = 0.74$m

c. Step Configuration.

From para 3.5.4: V_{max}<250kts therefore step form = lateral

From Eqn 3.5: $l_{ab}/b = 9.44/2.7 = 3.49$

which is inside the parameters of Eqn 3.5. Therefore use recommendation of 4-8% beam for step depth: specifically 6%.

step depth = 0.06x2.7 = 0.162m

d. Planing Bottom Dimensions.

From Eqn 3.6: $l/b = 5.7$ b = 2.7 therefore l = 3.7 x 2.7 = 15.39m

AUM>8000kg therefore from Eqn 3.7:

$(\text{forebody area})_{min} = 10 + 5.8 \times 10^{-4}\text{AUM} = 10 + 5.8 \times 10^{-4}(16000) = 19.28\text{m}^2$

From Eqn 3.8: $l_{fb}/b = 3.5$ therefore $l_{fb} = 3.5 \times 2.7 = 9.45$m

Therefore $l_{ab} = l - l_{fb} = 19.28 - 9.45 = 9.83$m

Check that linear dimensions match AUM-based forebody area method using simple "flattened" model (see Appendix 8):

forebody area = $l_{fb}^* \times b$ where $l_{fb}^* = l_{fb} - l_{bow} = l_{fb} - b$ for low speed flyingboats

forebody area = $(l_{fb} - b)b = (9.45 - 2.7)2.7 = 18.22\text{m}^2 < 19.28$ indicating too small a forebody. Therefore increase forebody length to 9.84m to generate 19.28m^2 forebody area.

Recalculating afterbody length gives:

$l_{ab} = l - l_{fb} = 19.28 - 9.84 = 9.44$m

$C_{\Delta max} = AUM / (\rho_{H2O} x b^3) = 16000/(1025x2.7^3) = 0.8$

From Eqn 3.9: $C_{\Delta max} < 4.36$ therefore design is acceptable

From Eqn 3.10: deadrise angle = 18° From Eqn 64: afterbody angle = 7°

e. Tail Configuration and Sizing. The overall configuration is HW therefore based on the guidance of para 3.7.1 the fin could be single or twin to keep the rudder/s in line with the propeller centre-lines. Similarly, the horizontal tailplane should be mounted high, again in-line with the propeller centre-line.

From Section 3.7: $FVC_{flyingboat} = FVC_{landplane}$ and $HVC_{flyingboat} = HVC_{landplane}$

f. Mass Estimation.

For an amphibious freighter flyingboat:

From Eqn 3.13: $M_{planing\ bottom}$ (%AUM) = $17.8AUM^{-0.25} = 17.8x16000^{-0.25} = 1.58\%$

AUM = 16000kg therefore $M_{planing\ bottom}$ = 0.0158 x 16000 = 252.8kg

For a pure MPA/firebomber flyingboat:

From Eqn 3.13: $M_{planing\ bottom}$ (%AUM) = $38.9AUM^{-0.33} = 38.9x16000^{-0.33} = 1.59\%$

which is approximately the same as the amphibious flyingboat.

From Appendix 8: assuming planing bottom approximately = 0.25 surface area

mass of equivalent area of landplane fuselage $M_{fuselage} = 0.25x0.0542(S_F^{1.07} V_D^{0.743} k_1)$

where $S_F = k_2 2.56\ L[(b + h)/2] = 1.1x2.56x21.4[(2.7+2.7)/2] = 161.4m^2$
$k_1 = 0.22 + 0.36[L_T/(b + h)] = 0.22 + 0.36[11.25/(2.7+2.7)] = 0.97$
V_D = 240mph = 107m/sec

$M_{fuselage} = 0.25x0.0542(161.4^{1.07}x107^{0.743}\ x0.97) = 97.5$kg

Therefore additional mass = 252.8 - 97.5 = 155.3kg

anchor mass = 15.3kg (see floatplane example)

From Eqn 3.17: M_{stub} (%AUM) = $4AUM^{-0.1} = 4x16000^{-0.1} = 1.52\%$

AUM = 16000kg therefore M_{stub} = 0.0152 x 16000 = 243.2kg

$(M_{empty})_{amphib\ flyingboat} = (M_{empty})_{landplane} + 155.3 + 15.3 + 243.2 = 9214$kg

Therefore payload$_{\text{amphib flyingboat}}$ = 16000 - 9214 = 6786kg

$(M_{empty})_{\text{pure flyingboat}} = (M_{empty})_{\text{amphib flyingboat}} - M_{undercarriage}$ = 9214 - 608 = 8606kg

Therefore payload$_{\text{pure flyingboat}}$ = 16000 - 8606 = 7394kg

g. Draft.

From the method of para 3.9.1

$$\text{draft} = 1.2\left(h_l + \left\{\frac{(M/\rho) - h_l b\,[\,l_b/4 + l_{fb}^*/2 + l_{ab}/4\,] + h_s b\,[\,l_{ab}/4\,]}{b\,[\,l_b/2 + l_{fb}^* + l_{ab}/2\,]}\right\}\right)$$

consider cross-section of lower hull: tan(deadrise angle) = $(h_l)/(b/2)$
deadrise portion of hull = h_l = (2.7/2)tan18° = 0.44

assume step depth is negligible therefore:

$$\text{draft} = 1.2\left(0.44 + \left\{\frac{(16000/1025) - 0.44\text{x}2.7[2.7/4 + 7.14/2 + 9.44/4]}{2.7[\,2.7/2 + 7.14 + 9.44/2\,]}\right\}\right) = 1.28\text{m}$$

From the simplified method of para 3.9.2:

$$\begin{aligned}\text{draft} &= 1.55AUM/(\rho_{H2O}\,b)(\,l_{fb}^* + 0.5[l_{bow} + l_{ab}]) \\ &= 1.55\text{x}16000/(1025\text{x}2.7)(7.14 + 0.5[2.7 + 9.44]) = 0.68\text{m}\end{aligned}$$

use most conservative figure: draft = 1.28m

check using assumptions of para 3.9.3: draft/h_l < 2.56

draft/h_l = 1.28/0.41 = 3.21 > 2.56

therefore to gain a ratio of 2.56 h_l = 0.5 which produces a deadrise of:

$\beta = \tan^{-1}[0.5/(2.7/2)] = 20°$

this can now be iterated around the draft equations for as many times as is necessary, but for this example remain at one iteration with an addition to the keel depth of 0.5-0.44 = 0.06m due to the increased deadrise.

h. Spray.

As l_{fb}/b = 9.84/2.7 = 3.64 < 5 use Eqn 3.20:

$$\begin{aligned}z = 2.1b(C_\Delta)^{2/3}/(l_{fb}/b) &= (2.1\text{x}2.7\text{x}0.8^{2/3})/(9.84/2.7) = 1.34\text{m from waterline} \\ &= 1.34 + 1.28 = 2.9\text{m from keel}\end{aligned}$$

height of fuselage = 2.7 + 0.06 = 2.76m therefore spray height will exceed the wing root meaning the wing, engine and propeller positions as required by the HW configuration are too low. Therefore increase the fuselage keel to wing root distance to the spray height of 2.9m.

Some spray/waves are likely to hit the windscreen at low speed therefore include dams.

i. Power Loading.

From Eqn 3.24: power loading < 5.35

power of 2x1750hp engines = 3500hp therefore power loading = 16000/3500 = 4.6kg/hp

Therefore design is acceptable.

j. Take-off Distance and Time.

From Eqn 3.26: $d_{TO} = 4.7(\text{wing loading}) - 15$

where wing loading = 16000/59.1 = 270.7kg/m^2

Therefore $d_{TO} = 4.7(270.7) - 15 = 1257$m

From Eqn 3.28: $t_{TO} = d_{TO}/0.6V_{TO} = 1257/(0.6x51.7) = 40.5$sec

From Eqn 3.29: $d_{landing} = 1.52\, d_{TO} = 1.52x1257 = 1911$m

All are acceptable for this role and will allow the flyingboat to operate on large lakes, inland waterways and harbours.

k. Drag.

From Eqn 3.29: $C_{D0} = 0.005S^{-0.1}RT$ where R = 4.9 (Eqn 3.30) and T = 2.4 (Eqn 3.31)

Therefore $C_{D0} = 0.005(59.1)^{-0.1}(4.9x2.4) = 0.03910$

l. Undercarriage. From Section 3.6 the advantages of a nosewheel undercarriage exceed those for a tailwheel for the amphibious flyingboat.

m. Performance Indicator Calculation. Examined for H mass classification and T(V) role and therefore from Table 4.3 the reference aircraft is the Sunderland. However, the relative age and relevance of this aircraft makes comparison valueless (note low points for the Sunderland as a reference aircraft) and therefore consider a T(M) amphibious flyingboat where the CL415 is the reference aircraft.

For reference aircraft: M_{empty} = 12333kg

Payload = 7398kg therefore PI = (payload/M_{empty})rating = (7398/12333)8 = 4.80
Range = 2427km therefore PI = (range/M_{empty})rating = (2427/12333)7 = 1.38
Speed = 203km/hr therefore PI = (speed/M_{empty})rating = (203/12333)2 = $3.30x10^{-2}$
TO distance = 814m therefore PI = (TO^{-1}/M_{empty})rating = ($1.228x10^{-3}$/12333)9 = $8.96x10^{-7}$
Cabin volume = 35.03m^3 therefore PI = (vol/M_{empty})rating = (35.03/12333)3 = $8.52x10^{-3}$

Door area = $2.34m^2$
Loading: direct path = 1.5 factor
no lifting operation required = no factor
therefore modified door area = 1.5 x 2.34 = $3.51m^3$

Loading = $3.51m^2$ therefore PI = loading/M_{empty})rating = (3.51/12333)1 = $2.84x10^{-4}$

Maintainability Values

A	A = 2	D = 2
	E = 2	E = 1
B	A = 3	F = 1
	E = 2	G = 3
C	A = 0	
	E = 2	Total = 18

Maintainability = 18 therefore PI = maint/M_{empty})rating = (18/12333)5 = $7.30x10^{-3}$

For CN235-based amphibious flyingboat: M_{empty} = 9214kg (assume range and speed remain same as landplane)

Payload = 6786kg therefore PI = (payload/M_{empty})rating = (6786/9214)8 = 5.89
Range = 1528km therefore PI = (range/M_{empty})rating = (1528/9214)7 = 1.16
Speed = 445km/hr therefore PI = (speed/M_{empty})rating = (445/9214)2 = $9.66x10^{-2}$
TO distance = 1257m therefore PI = (TO^{-1}/M_{empty})rating = ($7.95x10^{-4}$/9214)9 = $7.76x10^{-7}$
Cabin volume = $42.24m^3$ therefore PI = (vol/M_{empty})rating = (42.24/9214)3 = $1.37x10^{-2}$

Door area = $3.325m^2$
Loading: direct path = 1.5 factor
no lifting operation required = no factor
therefore modified door area = 1.5x3.325 = $4.99m^3$

Loading = $4.99m^2$ therefore PI = loading/M_{empty})rating = (4.99/9214)1 = $5.41x10^{-4}$

Maintainability Values

A	A = 2	D = 2
	E = 2	E = 0
B	A = 3	F = 1
	E = 3	G = 3
C	A = 2	
	E = 0	Total = 18

Maintainability = 18 therefore PI = maint/M_{empty})rating = (18/9214)5 = $9.77x10^{-3}$

Comparing with reference aircraft gives:

	CL415	CN235	ratio
Payload	4.80	5.89	1.23
Range	1.38	1.16	0.84
Speed	3.30×10^{-2}	9.66×10^{-2}	2.93
TO dist	8.9×10^{-7}	7.76×10^{-7}	0.87
Volume	0.85×10^{-2}	1.37×10^{-2}	1.61
Loading	2.84×10^{-4}	5.41×10^{-4}	1.90
Maint	7.30×10^{-3}	9.77×10^{-3}	1.34

This illustrates the key areas the CN235-based flyingboat design would have to develop to challenge the CL415, ie range and TO distance at the expense of speed.

The final configuration is shown at Figure 5.5c.

6. Long Range Jet-engined MPA Flyingboat. The BAe Nimrod MR2 (see Figure 5.6a) is a large, jet-powered, long range maritime patrol aircraft. The Nimrod is powered by 4 Rolls Royce Spey low by-pass ration turbojets each of 54KN thrust. Relevant specifications are as follows:

wing span = 35.0m   wing area = $197m^2$ overall length = 39m
empty mass = 39000kg   AUM = 87090kg   TO run = 1463m
V_{max} = 817km/hr   range = 9200km   fuselage width = 2.95m
cabin volume = $73.1m^3$ tailplane arm = 19.5m $V_{TO(flaps\ up)}$ = 150km/hr

a. General Configuration. For use as a maritime patrol aircraft (T(M)) aircraft and an AUM of 87090kg (mass classification SH) then from Eqn 3.1 the configuration is HW.

b. Initial Static Stability Sizing. Using the guidance of para 3.4.1.fixed tip floats of C1 form at 70-79% semi-span is the simplest and most cost-effective lateral stability method. However, for minimum drag use retractable floats retracting into sensor pods at 70% semi-span.

From Eqn 3.2: $(v_{float}\,a)/b^3 = 1.31$ therefore $v_{float} = 1.31b^3/a$

b = fuselage width = 2.95m   a = 70%(span/2) = 0.7(35/2) = 12.25m

therefore $v_{float} = 1.31(2.95^3)/12.25 = 2.74m^3$

from C1 proportions: $b_{float} = h_{float} = l_{float}/3$

therefore $v = l_{float}^3/9$ and $l_{float} = (9v_{float})^{1/3} = (9\times2.74)^{1/3} = 2.91m$

$b_{float} = h_{float} = l_{float}/3 = 2.91/3 = 0.97m$

c. Step Configuration.

From para 3.5.4: V_{max}>250kts therefore step form = elliptical and faired

From Eqn 3.5: $l_{ab}/b = 15.55/2.95 = 5.27$

which is outside the parameters of Eqn 3.5. Therefore use recommendation of 4-8% beam for step depth with care:

step depth = 0.06x2.95 = 0.18m

d. Planing Bottom Dimensions.

From Eqn 3.6: $l/b = 9.23$ $b = 2.95$ therefore $l = 9.23 \times 2.95 = 27.23$m

AUM>8000kg therefore from Eqn 3.7:

$(\text{forebody area})_{min} = 10 + 5.8\times10^{-4}AUM = 10 + 5.8\times10^{-4}(87090) = 60.5m^2$

From Eqn 3.8: $l_{fb}/b = 3.5$ therefore $l_{fb} = 3.5 \times 2.95 = 10.32$m

Therefore $l_{ab} = l - l_{fb} = 27.23 - 10.32 = 16.91$m

Check that linear dimensions match AUM-based forebody area method using simple "flattened" model (see Appendix 8):

forebody area = $l_{fb}^* \times b$ where $l_{fb}^* = l_{fb} - l_{bow} = l_{fb} - b$ for low speed flyingboats

forebody area = $(l_{fb} - b)b = (10.32 - 2.95)2.95 = 21.76m^2 < 60.5$ indicating too small a forebody. Therefore increase l_{fb}^* to 20.5m to generate $60.5m^2$ forebody area. Recalculating afterbody length gives:

If $l_{fb}^* = 20.5$m then $l_{fb} = 20.5+2.95 = 23.45$m

$l_{ab} = l - l_{fb} = 27.23 - 23.45 = 3.78$m

which is, by examination, far too low. Comparing the total length of the fuselage (39m) with the estimated length of the planing bottom (27.23m) illustrates the additional length available for a sensible afterbody. The length of the afterbody is therefore extended to:

$l_{ab} = (39 - 23.45) = 15.55$m

$C_{\Delta max} = AUM/(\rho_{H2O} \times b^3) = 87090/(1025\times2.95^3) = 3.31$

From Eqn 3.9: $C_{\Delta max} < 4.36$ therefore design is acceptable

From Eqn 3.10: deadrise angle = 20° From Eqn 3.11: afterbody angle = 7°

e. Tail Configuration and Sizing. The overall configuration is HW therefore based on the guidance of para 3.7.1 the fin could be single or twin to keep the rudder/s in line with the engine centre-lines. However, as a jet this is inadvisable so the centre mounting of the Nimrod fin is retained. Similarly, the horizontal tailplane should be mounted high, requiring a considerably larger fin than the Nimrod. No additional mass estimation is completed for this addition although in reality one would be required.

From Section 3.7: $FVC_{flyingboat} = FVC_{landplane}$ and $HVC_{flyingboat} = HVC_{landplane}$

f. Mass Estimation.

From Eqn 3.13: $M_{planing\ bottom}$ (%AUM) = $17.8AUM^{-0.25} = 17.8x87090^{-0.25} = 1.04\%$

AUM = 87090kg therefore $M_{planing\ bottom}$ = 0.0104 x 87090 = 906kg

From Appendix 8: assuming planing bottom approximately = 0.25 surface area

mass of equivalent area of landplane fuselage $M_{fuselage} = 0.25x0.0542(S_F^{1.07}V_D^{0.743}k_l)$

where $S_F = k_2 2.56\ L[(b + h)/2] = 1.1x2.56x39[(2.95+2.95)/2] = 324m^2$
$k_l = 0.22 + 0.36[L_T/(b + h)] = 0.22 + 0.36[19.5/(2.95 + 2.95)] = 1.41$
V_D = 500mph = 227m/sec

$M_{fuselage} = 0.25x0.0542(324^{1.07}x227^{0.743}\ x1.41) = 522kg$

Therefore additional mass = 906 - 522 = 383kg

Assume anchor mass is negligible as a % of AUM.

From Eqn 3.16: $M_{tip\ float}$ (%AUM) = $2.4AUM^{-0.1} = 2.4x87090^{-0.1} = 0.77\%$

(note caveat in para 3.8.3 to use this method with care)

AUM = 87090kg therefore $M_{tip\ float}$ = 0.0077x87090 = 670kg

From Eqn 3.19: $M_{retraction\ mechanism} = 0.37M_{retracted\ item}$ = 0.37x670 = 248kg

Therefore $(M_{empty})_{flyingboat} = (M_{empty})_{landplane}$ + 383 + 670 + 248 = 40301kg

Therefore payload = 87090 - 40301 = 46789kg

g. Draft.

From the method of para 3.9.1

$$draft = 1.2\left(h_l + \left\{\frac{(M/\rho) - h_l b\,[\,l_b/4 + l_{fb}^*/2 + l_{ab}/4\,] + h_t b\,[\,l_{ab}/4\,]}{b\,[\,l_b/2 + l_{fb}^* + l_{ab}/2\,]}\right\}\right)$$

consider cross-section of lower hull: tan(deadrise angle) = $(h_l)/(b/2)$

deadrise portion of hull = h_l = (2.95/2)tan20° = 0.54m

assume step depth is negligible therefore:

$$draft = 1.2\left(0.54 + \left\{\frac{(87090/1025) - 0.54x2.95[2.95/4 + 20.5/2 + 15.55/4]}{2.95[\,2.95/2 + 20.5 + 15.55/2\,]}\right\}\right) = 1.49m$$

From the simplified method of para 3.9.2:

$$draft = 1.55AUM/(\rho_{H2O}b)(l_{fb}^* + 0.5[l_{bow} + l_{ab}])$$
$$= 1.55x87090/(1025x2.95)(20.5 + 0.5[2.95 + 15.55]) = 1.5m$$

use most conservative figure: draft = 1.5m

check using assumptions of para 3.9.3: $draft/h_l < 2.56$

$draft/h_l = 1.5/0.54 = 2.78$

Therefore to gain ratio of 2.56: $h_l = 0.59m$

which produces a deadrise of: $\beta = \tan^{-1}(0.59/[2.95/2]) = 22°$

This can now be iterated around the draft equation as many times as necessary but for this example remain at one iteration with an addition to the keel of 0.59-0.56 = 0.03 due to increase in deadrise.

h. Spray.

As $l_{fb}/b = 23.45/2.95 = 7.87 > 5$ therefore use Eqn 3.20 with care. However, from para 3.11.3a the high l/b ratio will decrease spray height and therefore the result will be conservative.

$$z = 2.1b(C_\Delta)^{2/3}/(l_{fb}/b) = (2.1x2.95x3.31^{2/3})/(23.4/2.95) = 1.75m \text{ from waterline}$$
$$= 1.5 + 1.75 = 3.25m \text{ from keel}$$

height of fuselage = 2.95 + 0.03 = 2.98m therefore spray height will exceed wing root meaning wings and engine positions cannot be as required by the HW configuration. However, the guidance of para 3.10.6 indicates that, as a jet powered aircraft, this was likely to occur and positioning the intakes in a similar manner to the Be42 (see Plates 1.1 and 1.6) is likely to solve the problem.

i. Power Loading.

From Eqn 3.25: power loading < 365 kg/KN

power of 4x54KN engines = 216KN therefore power loading = 87090/216 = 403kg/KN

This is high compared to the other jet flyingboats (see para 13.13.2) and suggests that more powerful engines are required.

j. Take-off Distance and Time.

wing loading = 87090/197 = 442kg/m^2

Therefore from Eqn 3.27: $d_{TO} = (0.755/\rho\, C_{LUS}\, g)(Mg/S)(Mg/T_o)^2 = 2182m$

From Eqn 3.28: $t_{TO} = d_{TO}/0.6V_{TO} = 2182/(0.6x83) = 44sec$

From Eqn 3.29: $d_{landing} = 1.52\ d_{TO} = 1.52x2182 = 3323m$

This is almost twice that of the Be42 and is therefore unacceptable.

k. Drag.

From Eqn 3.29: $C_{D0} = 0.005S^{-0.1}RT$ where R = 4.5 (Eqn 3.30) and T = 1.6 (Eqn 3.31)

Therefore $C_{D0} = 0.005(197)^{-0.1}(4.5x1.6) = 0.02122$

l. Undercarriage. From Section 3.6 the advantages of a nosewheel undercarriage exceed those for a tailwheel.

m. Performance Indicator Calculation. Examined for SH mass classification and T(M) role therefore from Table 4.3 the reference aircraft is the Shin Meiwa US1.

For reference aircraft: M_{empty} = 25500kg

Payload = 19500kg therefore PI = (payload/M_{empty})rating = (19300/25500)8 = 6.12
Range = 4207km therefore PI = (range/M_{empty})rating = (4207/25500)7= 1.15
Speed = 268km/hr therefore PI = (speed/M_{empty})rating = (268/25500)2 = $2.1x10^{-2}$
TO distance = 735m therefore PI = (TO^{-1}/M_{empty})rating = ($1.36x10^{-3}$/25500)9 = $4.8x10^{-7}$
Cabin volume = $68m^3$ therefore PI = (vol/M_{empty})rating = (68/25500)3 = $8x10^{-3}$

Door area = $2m^2$
Loading: direct path = 1.5 factor
lifting operation not required = no factor
therefore modified door area = 2x1.5 = $3m^2$

Loading = $3m^2$ therefore PI = loading/M_{empty})rating = (3/25500)1 = $1.18x10^{-4}$

Maintainability Values

A	A = 2	D = 0
	E = 2	E = 0
B	A = 2	F = -1
	E = 2	G = 0
C	A = 2	
	E = 0	Total = 9

Maintainability = 9 therefore PI = maint/M_{empty})rating = (9/25500)5 = $1.76x10^{-3}$

For Nimrod-based flyingboat: M_{empty} = 40300kg (assume range and speed remain same as landplane)

Payload = 46790kg therefore PI = (payload/M_{empty})rating = (46790/40300)8 = 9.29
Range = 9200km therefore PI = (range/M_{empty})rating = (9200/40300)7= 1.60
Speed = 920km/hr therefore PI = (speed/M_{empty})rating = (920/40300)2 = $4.56x10^{-2}$
TO distance = 2062m therefore PI = (TO^{-1}/M_{empty})rating = ($4.85x10^{-4}$/40300)9 = $1.08x10^{-7}$
Cabin volume = $73.1m^3$ therefore PI = (vol/M_{empty})rating = (73.1/40300)3 = $5.44x10^{-3}$

Door area = $2m^2$
Loading: direct path = 1.5 factor
no lifting operation required = no factor
therefore modified door area = 2x1.5 = $3m^2$

Loading = $3m^2$ therefore PI = (loading/M_{empty})rating = (3/40300)1 = 7.44×10^{-5}

Maintainability Values

A	A = 2	D = 2
	E = 2	E = 1
B	A = 2	F = 1
	E = 3	G = 1
C	A = 0	
	E = 0	Total = 14

Maintainability = 14 therefore PI = (maint/M_{empty})rating = (14/40300)5 = 1.74×10^{-3}

Comparing with reference aircraft gives:

	ShinMeiwa	Nimrod	ratio
payload	6.12	9.29	1.52
range	1.15	1.60	1.39
speed	2.1×10^{-2}	4.56×10^{-2}	2.17
TO dist	4.8×10^{-7}	1.08×10^{-7}	0.23
volume	8.0×10^{-3}	5.44×10^{-3}	0.68
loading	1.18×10^{-4}	0.74×10^{-4}	0.63
maint	1.76×10^{-3}	1.74×10^{-3}	0.99

Note that the considerable differences between the Shin Meiwa reference aircraft and the Nimrod-based flyingboat make it of limited value as a reference aircraft, yet the most valid flyingboat, the Be42 did not have sufficient information available to fill that role.

The final configuration is shown at Figure 5.6b.

APPENDIX 19

BIBLIOGRAPHY

This bibliography details the books, journals and papers which are not quoted as references, but formed an essential part of the background of this study. The bibliography may also be used as the basis of deeper study into any particular element of this study. To aid in this process the bibliography is separated into subject headings.

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