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Study of an Advanced Transport Airplane Design Concept Known as FLATBED

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

TABLE NO.		PAGE

LIST OF FIGURES

NO.		PAGE

STUDY OF AN ADVANCED TRANSPORT AIRPLANE KNOWN AS FLATBED

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SUMMARY

FLATBED is a unique aircraft configurational concept (derived by Lockheed-Georgia Company) featuring versatility of payloads which are carried on an open cargo floor - there is no fuselage per se. Flatbed can haul containers, passengers in a removable module, or cargoes and vehicles. Large Army vehicles (tanks and bridge launchers) are literally "carried in the open."

Early assessments of the unusual aspects of the Flatbed concept indicated (a) potential problem areas related to specific technical design details and (b) general concerns related to the overall viability of the concept. Hence, a study was undertaken to assess the feasibility, capability, and economic merit of Flatbed. Such a study has been accomplished through a non-parametric refinement of a point design. Aspects of the study included refinement of the Flatbed configuration and derivation of three reference aircraft (passenger, cargo, and outsize cargo) for purposes of comparison. The study involved smoke flow studies, optimization of a medium sized aircraft for a range of 4815 km (2600 n.mi.), estimation of weights and performance, prediction of acquisition and operating costs, and recommendations for additional areas of technical study.

Refinement of the basic Flatbed concept produced a low-winged vehicle weighing 57209 kg (123,429 lbs.), optimized for cruise speed for the passenger role at M = 0.82 at 10,688m (35,000 ft.). Features include a pressurized cockpit section internally hinged to pivot to starboard for front-loading of cargo. A Vee tail was determined to present the best compromise of drag and weight. Four engines are mounted on pylons above the wing in order to permit the cargo floor to be as low as possible to the ground (2.12m or 83.5 in.). The cargo floor is fitted with roller-rail-track guide systems, powered rollers, and compatible fittings on the passenger and pressurized cargo modules.

Study results indicate the Flatbed concept to be viable from a technical viewpoint. The only unusual structural area relates to provision for adequate stiffness in the fuselage aftbody. In aerodynamic terms, the design process has produced a relatively smaller aircraft to accomplish the specified missions because of a lighter weight fuselage and lesser systems weight.

High altitude cruise speed with either unpressurized or pressurized containers is M = 0.82, which is comparable to conventional passenger type airlines hauling cargo and cargo aircraft such as the C-141 or C-5A. The cruise speeds with outsize military vehicles are above M = 0.5 with ranges compatible with the longest distance required without refueling, 4473m (2415 n.mi.).

It is specifically noted that Flatbed with the passenger module consumes 11 percent more fuel than a conventional passenger airliner and 14 percent more than an outsize military cargo aircraft. Conversely, Flatbed consumes 6 percent less fuel carrying unpressurized cargo in a cocoon and 8 percent less carrying pressurized cargo - - relative to conventionally configured cargo aircraft.

In loadability terms, the 2.12m (83.5 in.) cargo floor height of the Flatbed design is sufficiently low to accommodate loading of containers and roll-on, roll-off of vehicles. The lack of dimensional restrictions permits use of shorter and lesser weight ramps (17 degrees vis-a-vis 11 degrees) in comparison with conventional designs. Cargo loading, tie-down, and guide systems appear to be adequate since they are of conventional design.

In economic terms, the Flatbed backbone acquisition costs are lower than any of the reference aircraft. This results, partially, because the RDT&E costs are about 3 percent lower than a comparable conventional cargo airplane, 18 percent lower than an outsize cargo airplane, and 9 percent lower than a conventional passenger airplane. In the latter case, however, the added RDT&E costs of the passenger module net the Flatbed passenger version about 25 percent higher. Unit production costs of Flatbed, for a comparable production run, are about $1 million lower than a conventional cargo airplane, and $2 million lower than a passenger airliner.

Flatbed DOC's vary between 8 and 26 percent lower than conventional cargo airplanes as a function of production run. (Three cases of varying production runs of Flatbed and the reference airplanes were specified for analysis.) Military life cycle costs are over 30 percent lower than a conventional outsize aircraft. The passenger seat-mile costs are essentially equal to a conventional airplane except for QC operations which are about 8 percent lower for Flatbed.

Recommendations for additional studies include wind-tunnel tests (particularly of vehicular hauls), possible use of a metal matrix aftbody, and both military and commercial cargo airline operations in realistic scenarios.

INTRODUCTION

Historically, transport aircraft have been designed to carry either passengers or cargo, and previous attempts to design dual-purpose transports have not been successful. Although passenger airliners can haul some cargo in belly holds, passenger airliners are inefficient when modified to permit operation as cargo aircraft. Similarly, aircraft designed at the outset as cargo transports make poor conversions to passenger carriers. The "QC" (quick change) approach has also achieved only limited success. Military requirements, particularly the carriage of large items such as tanks and bridge launchers, have produced transports of very large size and weight which require much revision if economic operation as a civil cargo carrier were to be realized.

Traditionally then, manufacturers have designed, and airlines have operated, three separate and distinct airframes, each optimized for the particular carriage of passengers, cargo, or outsized cargo/vehicles. The challenge was whether a practical aircraft concept could be derived to efficiently accomplish all three operations.

As part of continuing studies into advanced transport aircraft, the Lockheed-Georgia Company has derived a new airplane concept known as Flatbed. A unique configuration, Flatbed combines into one airframe the ability to haul cargo, outsize cargo, passengers, or vehicles with the size, shape, and type of cargo virtually unrestrained by cross-sectional dimensions of the fuselage. Preliminary studies showed potential reductions in both acquisition and operating costs plus ready convertibility from one payload to another.

Hence, the significance to both air carrier and shipper lies in efficient and economical operations, versatility and flexibility of payloads, and ready convertibility. Inherent in the Flatbed concept is the promise of effectively achieving the goals of inter- and intra-modality. Flatbed is, in essence, one basic airframe which can haul virtually anything.

The unusual and varied aspects of the design configuration demanded a study to assess the overall viability of the Flatbed concept. Consequently, a study was undertaken (in accordance with the requirements of Reference 1) to explore the feasibility and capability of Flatbed. In scope, the study comprised refinement of the design concept, establishment of design and economic parameters, and analysis of problem areas unique to the concept. The study included derivation of three reference aircraft for comparison of cargo, outsize cargo, and passenger mission/role aspects in terms of weight, performance and cost.

In addition to the authors listed, acknowledgment of their contributions to this study is given to the following:

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FLATBED SYSTEM DESCRIPTION

Configurational Concept

The derivation of the Flatbed configuration (Reference 2) was an extrapolation of the flatbed road truck which features versatility of load. The logical development progressed from the truck to a basic "backbone" which comprises the fuselage of an airplane with the truck cab being replaced with a pressurized cockpit section. On the backbone are carried containers, passengers in a module, or vehicles. In essence, the payload constitutes the shape of the fuselage.

It is emphasized that Flatbed is a configurational concept which may be applied to transport aircraft from small to very large sizes.

System Details

Backbone - The basic "backbone," illustrated in Figure 1, features a fuselage that is slender in depth. The pressurized cockpit section can be swung to the side for front loading and is lightly loaded since the nose gear is aft of the break. A low wing is essential to Flatbed which, combined with a low ground clearance for loading, dictates over-the-wing engines. Some form of laterally displaced vertical tail (such as a twin or Vee tail) is also essential. The landing gear can be kneeled to provide relatively low cargo floor height to facilitate loading of cargo or vehicles.

Intermodal Containers - Intermodal containers can be carried directly on the backbone (Figure 2) with appropriate fairings fore and aft. No provision is made for an environmental control.

As illustrated, the carriage of five containers in this mode results in two longitudinal joints plus six transverse joints which increase drag considerably. Accordingly, an option is suggested whereby the containers are "cocooned" in a lightweight fairing similar in shape to the passenger module (Figure 3). The cocoon is constructed of fiberglass or a composite such as Kevlar, and the reduced number of joints significantly lowers the drag and fuel consumption.

Pressurized Containers - Should pressurization and controlled temperature be required for some cargoes, these may be shipped in containers that match the aft portion of the backbone nose section and culminate in an appropriate fairing at the aft body. A typical pressurized container is shown in Figure 4. Environmental control is achieved by quick-disconnect fixtures into the backbone's engine bleed system.

Outsized Vehicles - Military vehicles too large to fit inside a cocoon may be carried on the backbone in the open as depicted by Figure 5a, which shows an M109A1 self-propelled 155mm howitzer. In this configuration, the aft body fairing carried with

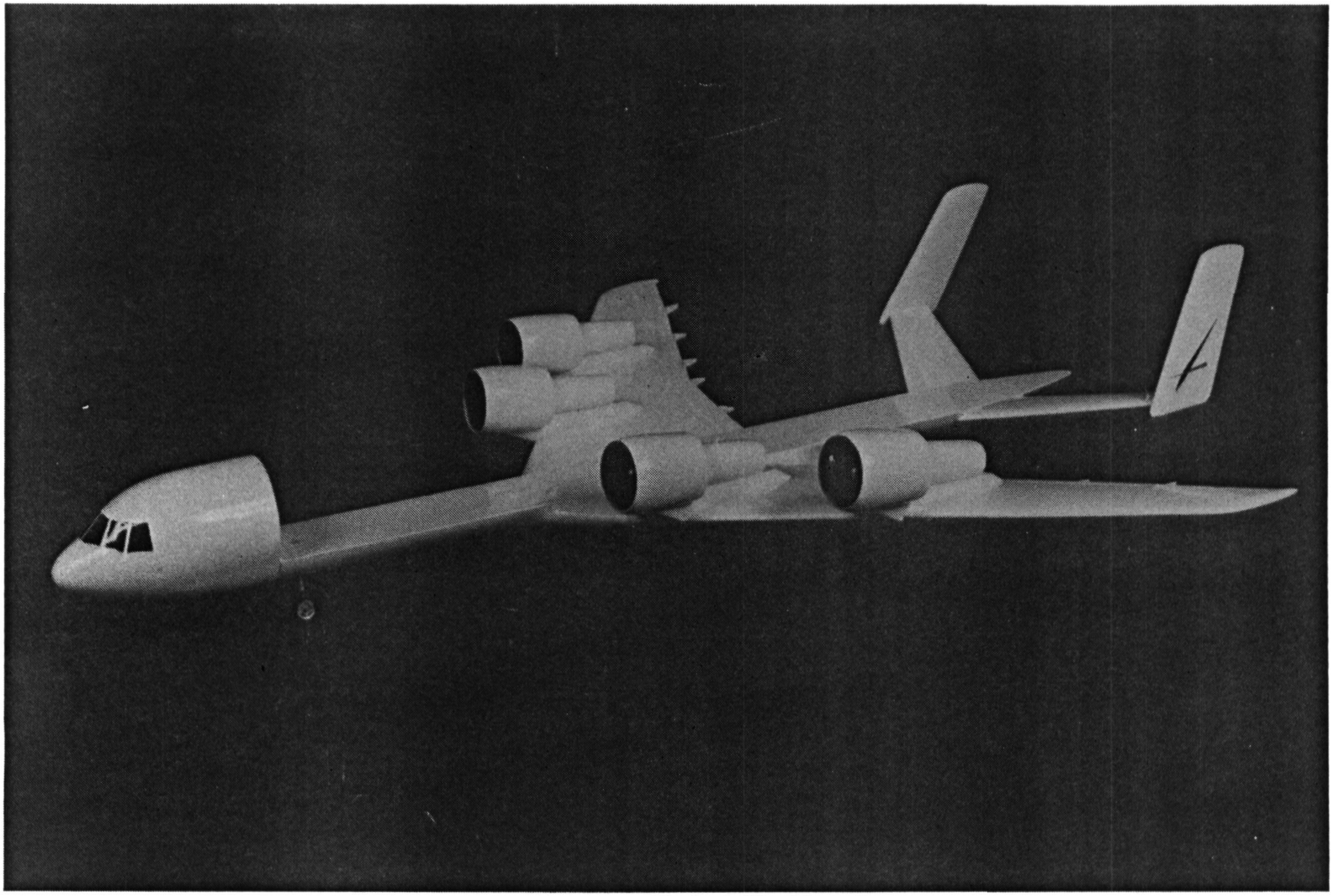


Figure 1 Flatbed "Backbone"

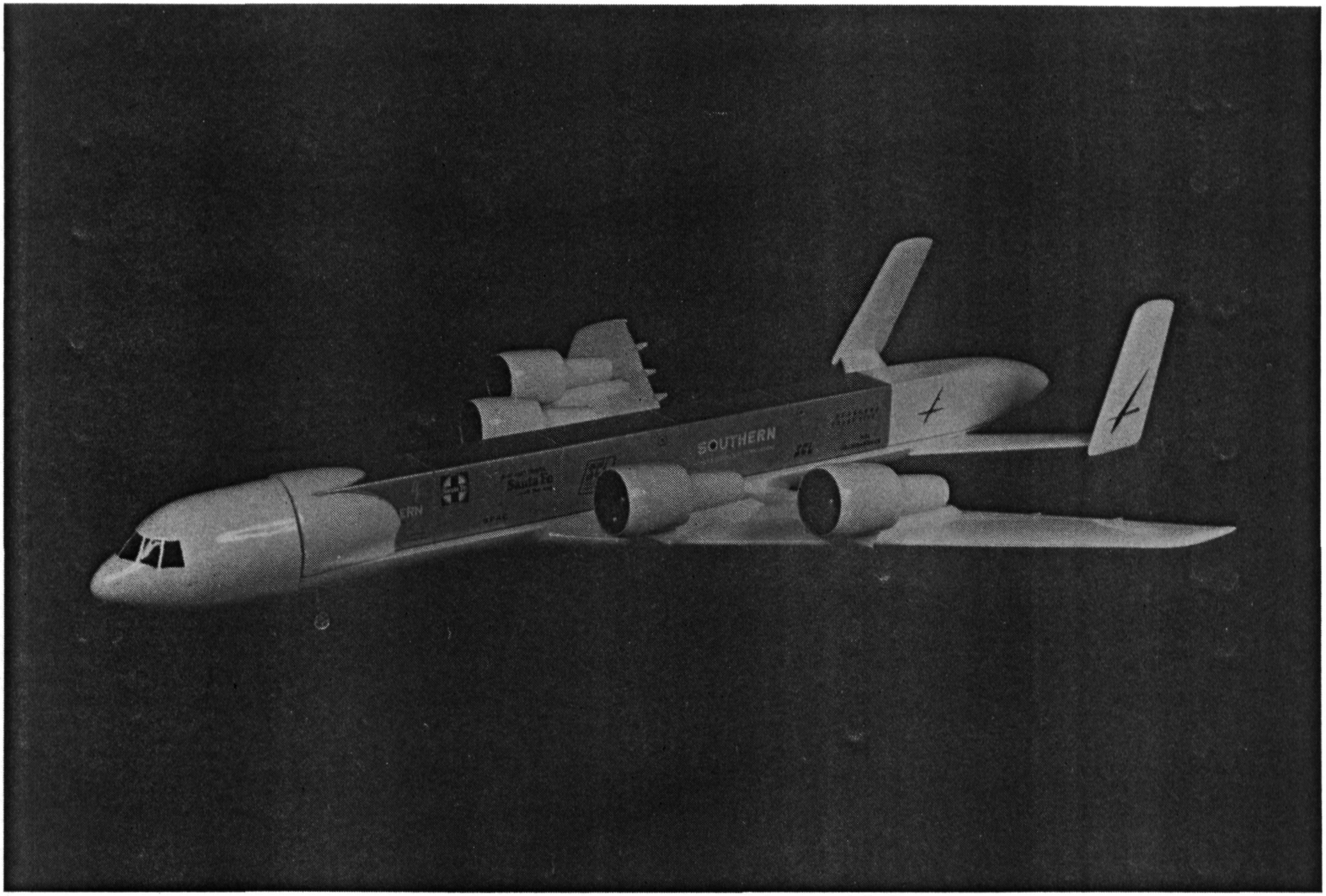


Figure 2 Flatbed with Unpressurized Intermodal Containers

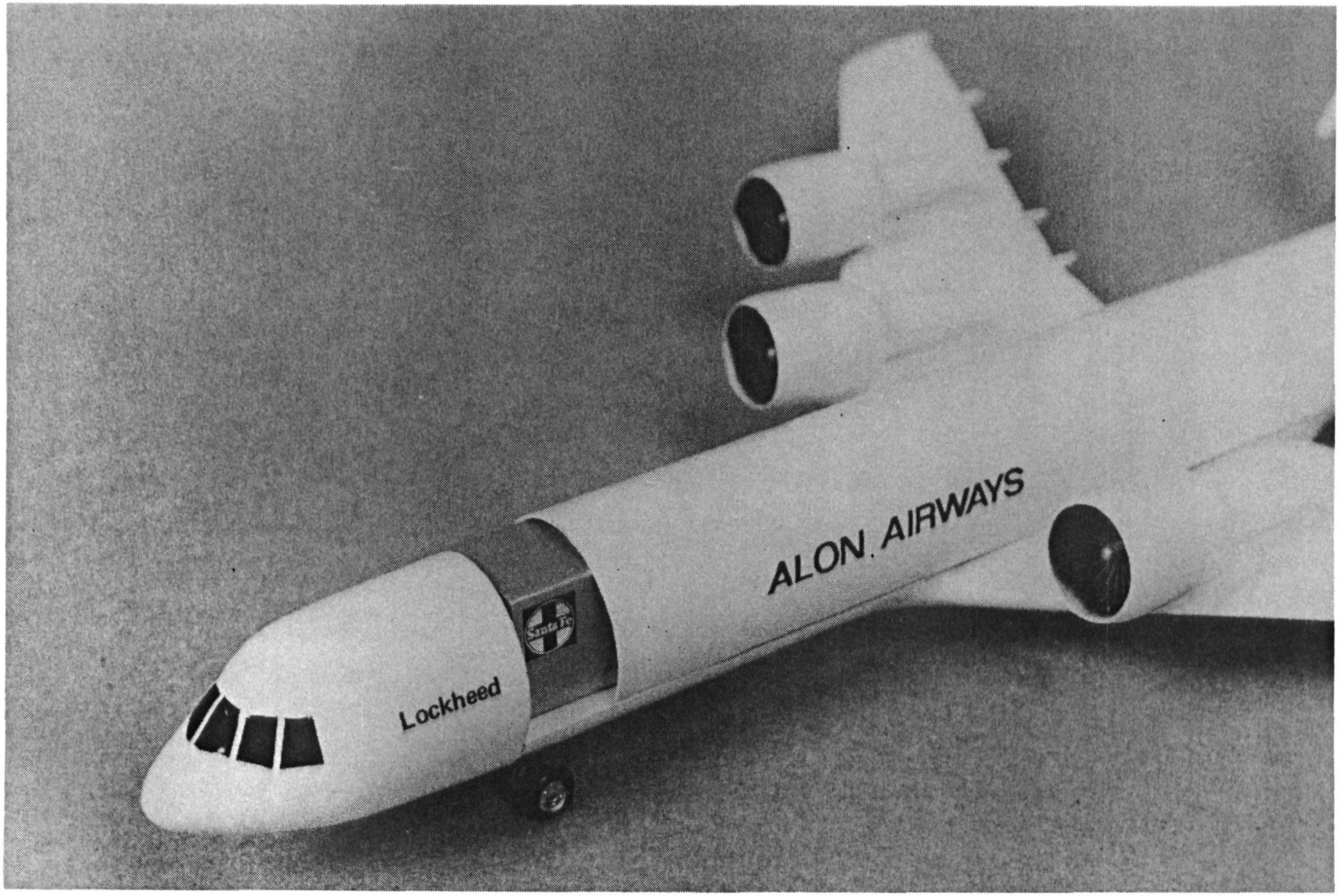


Figure 3 Flatbed with "Cocooned" Intermodal Containers

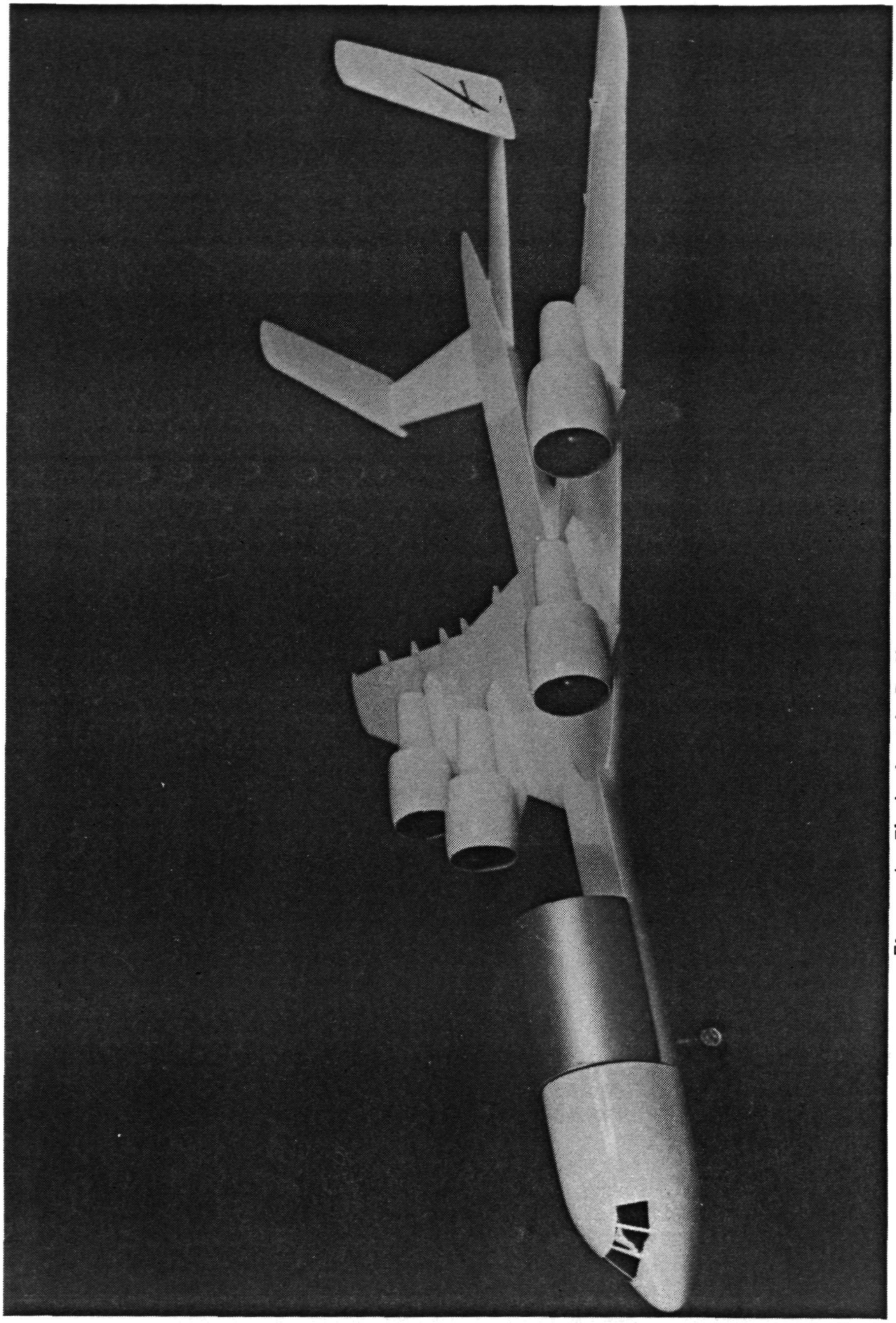


Figure 4 Flatbed with D-Shaped Pressurized Containers

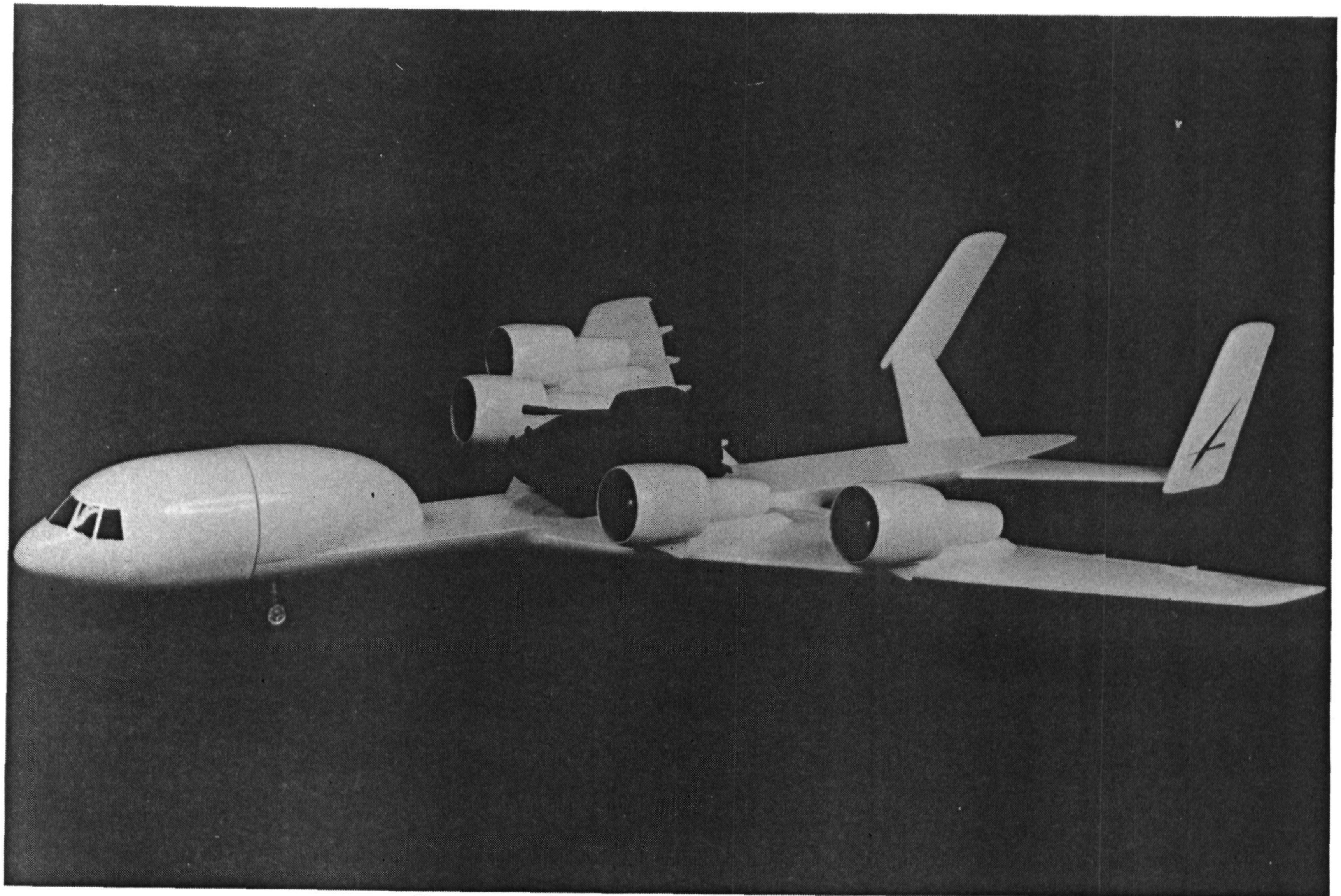


Figure 5a Flatbed with Outsize Military Vehicle

pressurized containers is moved forward to abut the nose. This approach is in keeping with the basic concept which was to eliminate carriage of the heavy fuselage structure necessary to enclose these vehicles--a weight carried throughout the design life of the aircraft only for potential military contingency use.

If military outsize vehicles can be carried, so can civil outsize vehicles such as those representative of the heavy construction equipment industry (Figure 5b). This capability offers a potential new market for the airlines and some definite advantages for the shipper in terms of reduced time and cost of distribution. Reference 3 showed that time for distribution may be reduced from nearly 10 days to a few hours and the cost may be reduced by as much as 40 percent.

Passenger Module - Passengers are carried in a pressurized module (Figure 6). The passenger module contains space for baggage as well as all of the usual amentities offered in conventional passenger airliners. The module slides or rolls onto the backbone by means of conventional rollers and rail systems with appropriate tie-down and locking features. Typical load/unload onto a Flatbed truck is shown in Figure 7.

Terminal Operations - The Flatbed concept, both cargo and passenger versions, is compatible with existing terminal facilities. Operationally, the passenger Flatbed and the cargo Flatbed can be parked at a remote location at the airport, and their respective modules or containers can be unloaded onto flatbed trucks for delivery to the passenger or cargo terminal. Meanwhile, the aircraft may be serviced while freshly loaded passenger modules or cargo containers are brought to the "backbone" for loading. It is estimated that this procedure would decrease turnaround time and add as much as two hours per day to utilization.

The Flatbed concept is compatible with existing cargo and passenger terminal and loading facilities. However, it is considered that exploitation of the Flatbed concept has further potential benefits in terms of advanced terminal systems and operations.

Figure 8 shows that a passenger Flatbed aircraft can utilize existing loading facilities (such as Jetways) at current airport terminals. Both aircraft shown have virtually identical passenger capacities, and the parking space required for aircraft is obvious. Comparably, the Flatbed cargo version can unload at existing cargo terminals by virtue of its swing nose.

Figure 9 shows the advantage offered by Flatbed if only the module is delivered to the terminal building. Parking space is reduced, less than 15 feet wide per aircraft module compared with over 150 feet for a "winged" airliner. Thus, the terminal size may be considerably reduced as was effected in the design of the terminal at the Dulles Internation Airport in Washington, D.C.

Figure 5b Flatbed With Outsize Civil Vehicles

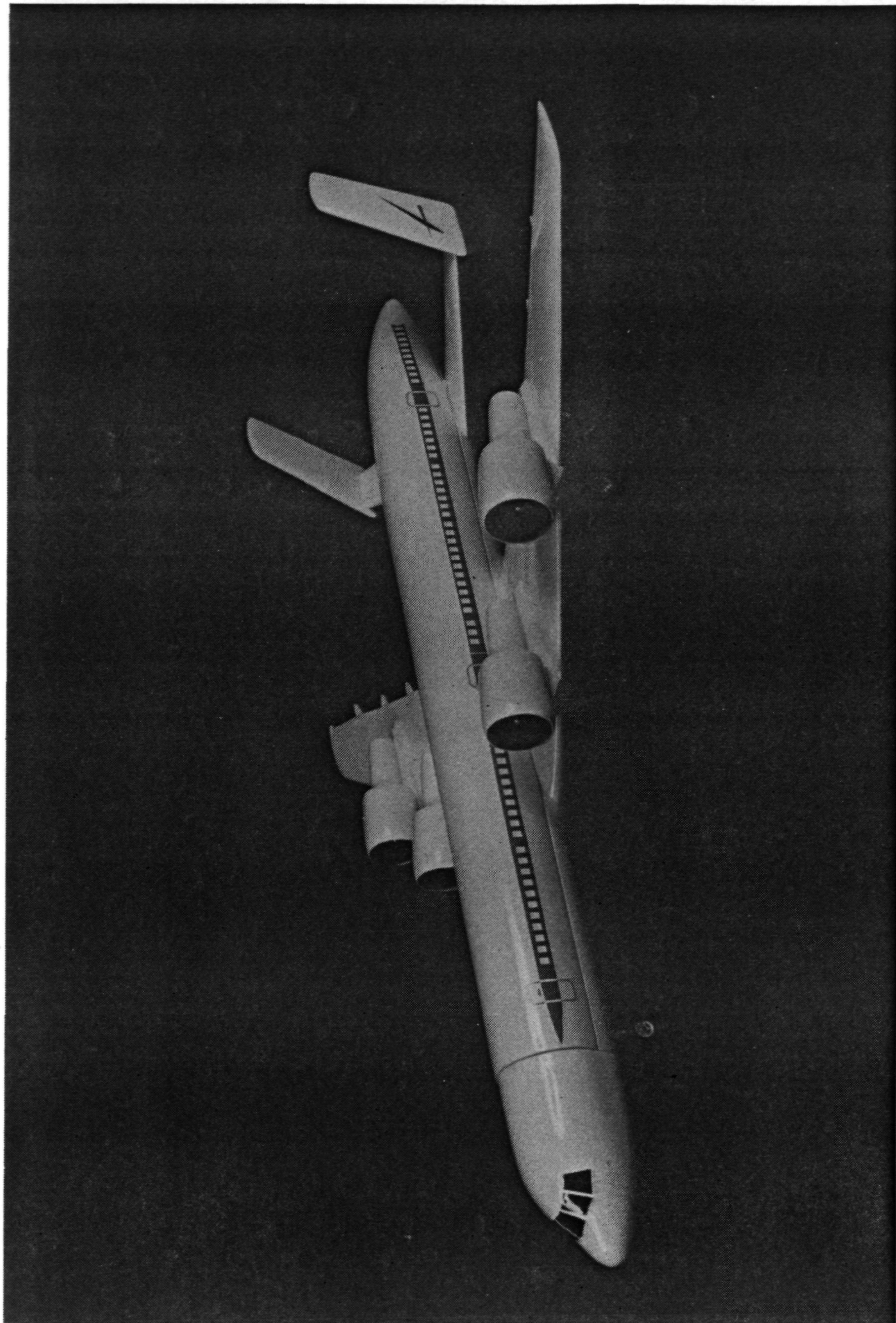


Figure 6 Flatbed with Passenger Module

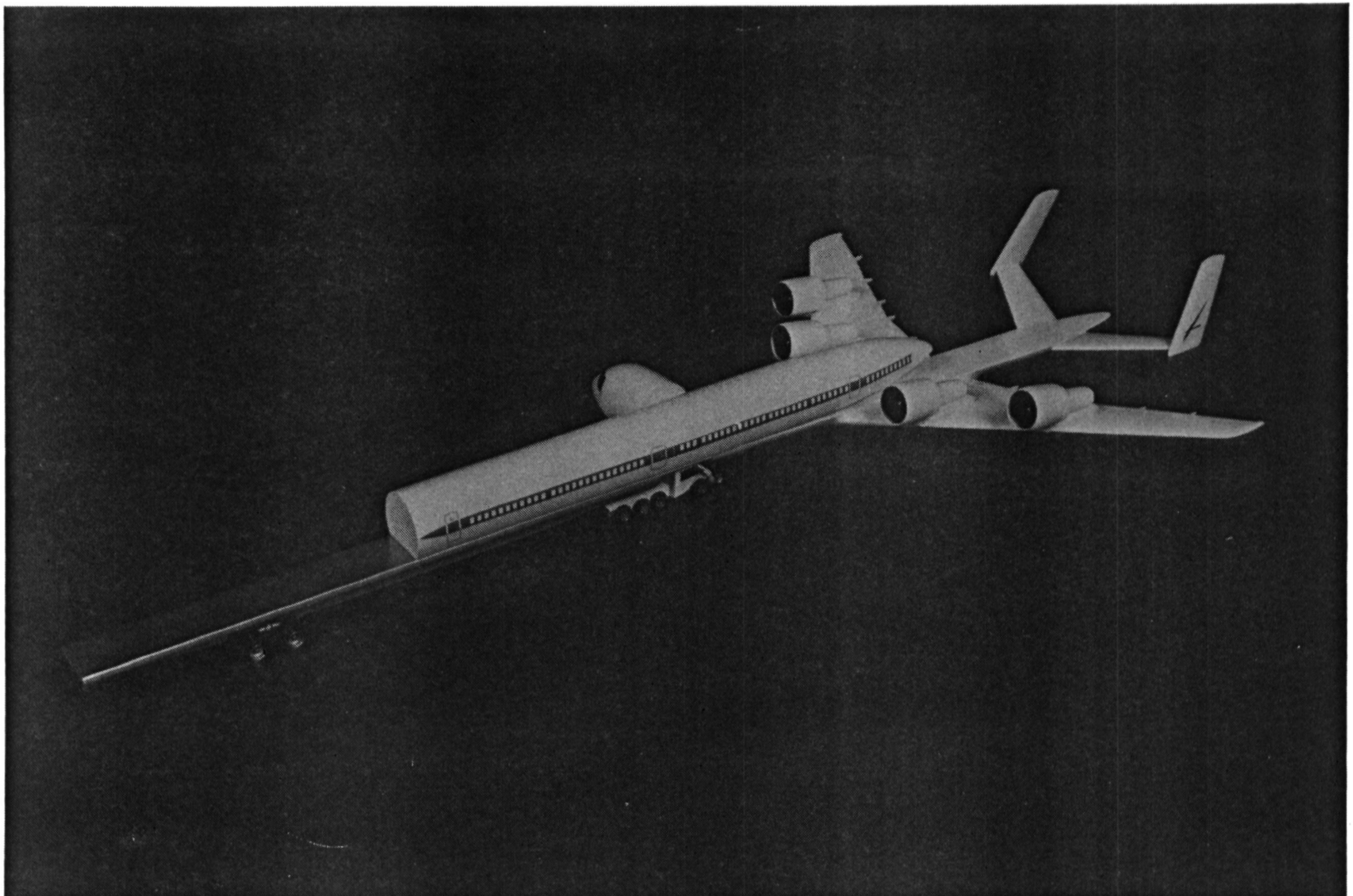


Figure 7 Flatbed PAX Module Load/Unload

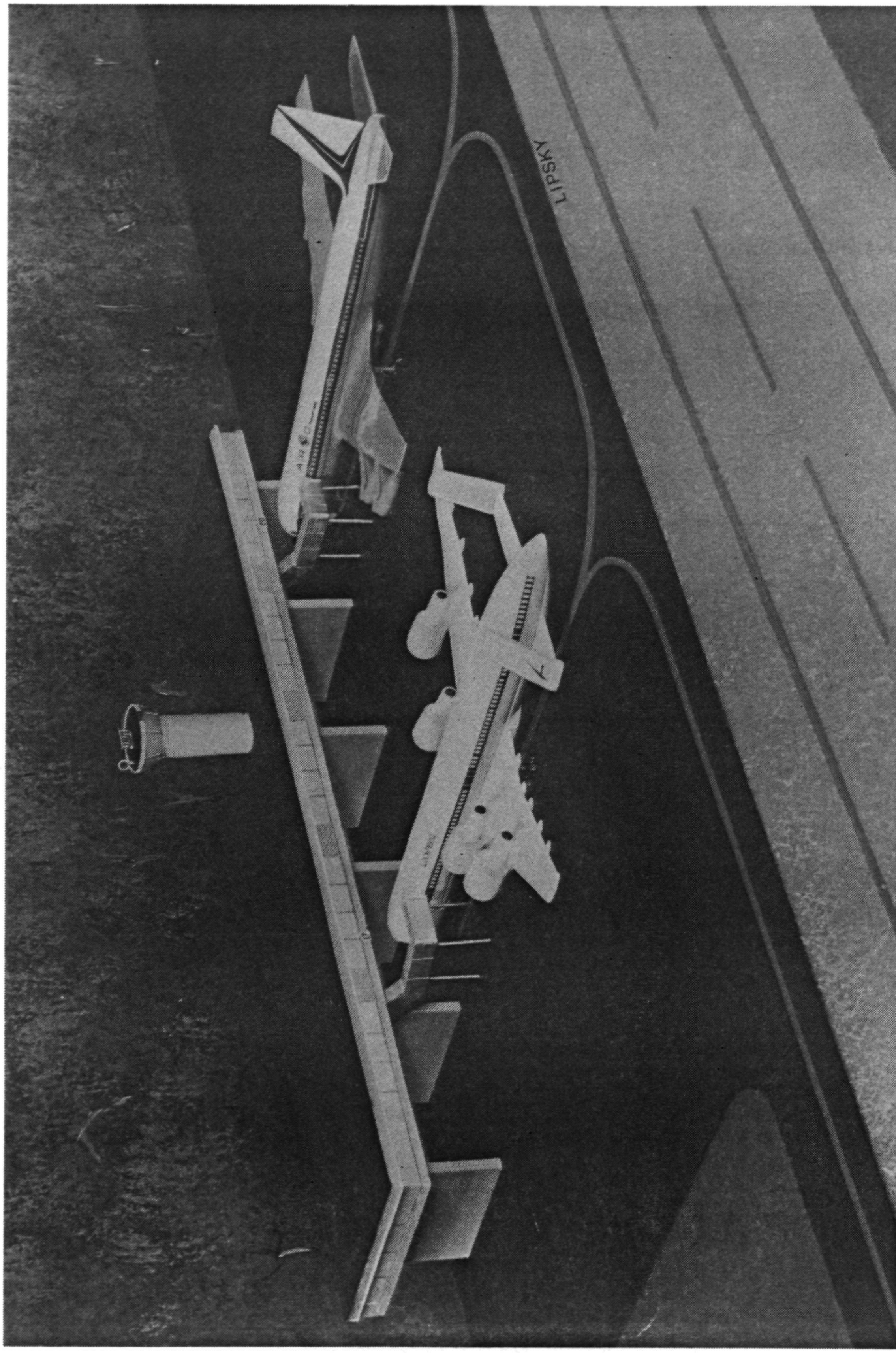


Figure 8 Flatbed Use of Conventional Terminal Facilities

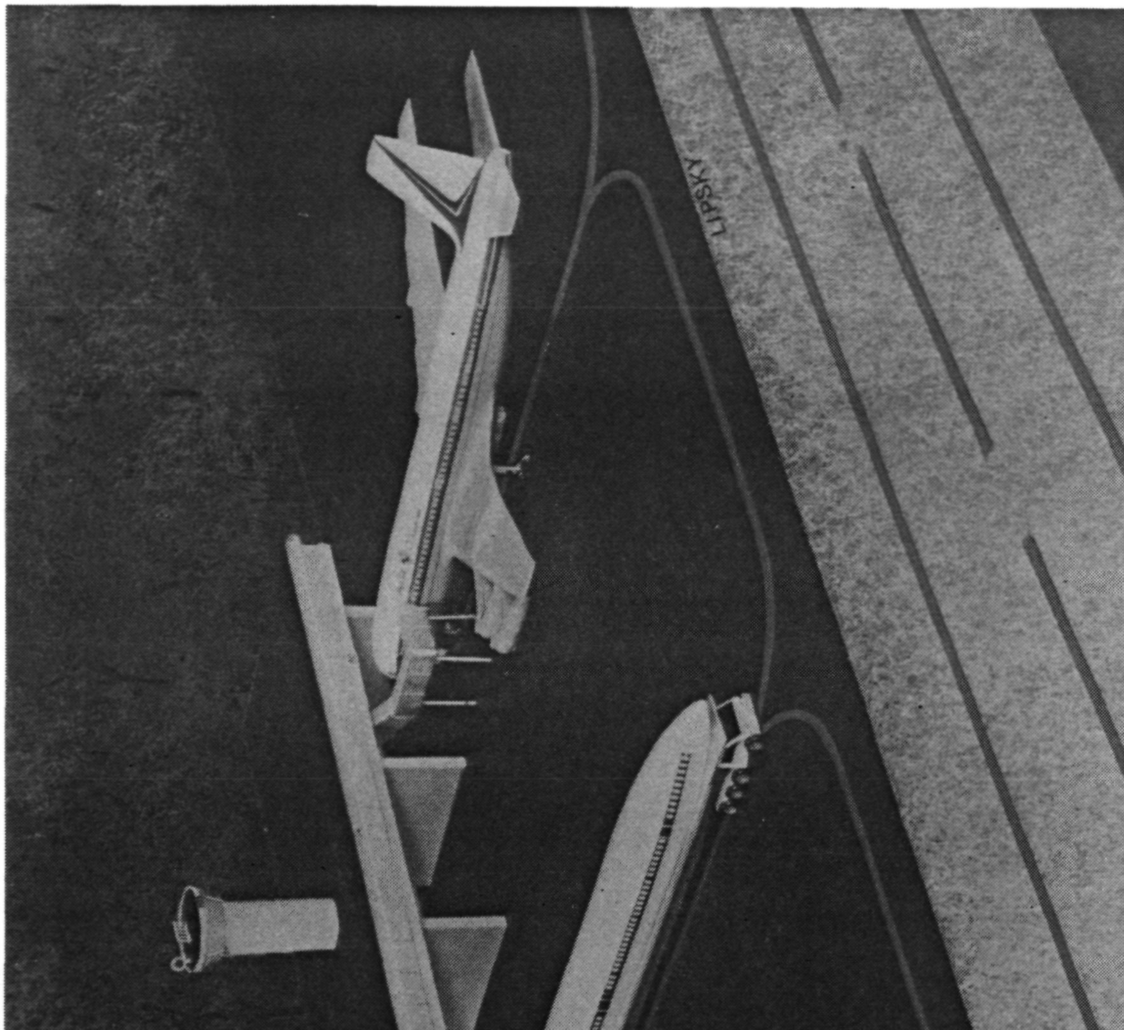


Figure 9 Space Saving Potential with Flatbed PAX Module

The late Eero Saarinen designed Dulles Airport (Reference 4) on the premise of bringing the passengers to the aircraft, not vice versa. Parking the aircraft at a remote spot and moving the passengers or cargo to and from the terminal (as would be done for the Flatbed module) results in the following advantages:

- o Reduced terminal size, passenger walk, and aircraft taxi time.
- o Passenger or cargo area removed from noise, fumes, and jet blast.
- o Flexibility of aircraft servicing and fueling without interference with passenger or cargo loading.

In terms of true intermodality, cargo containers may be unloaded onto conventional rail flat cars (Figure 10) for railroad distribution or direct delivery dockside to container ships.

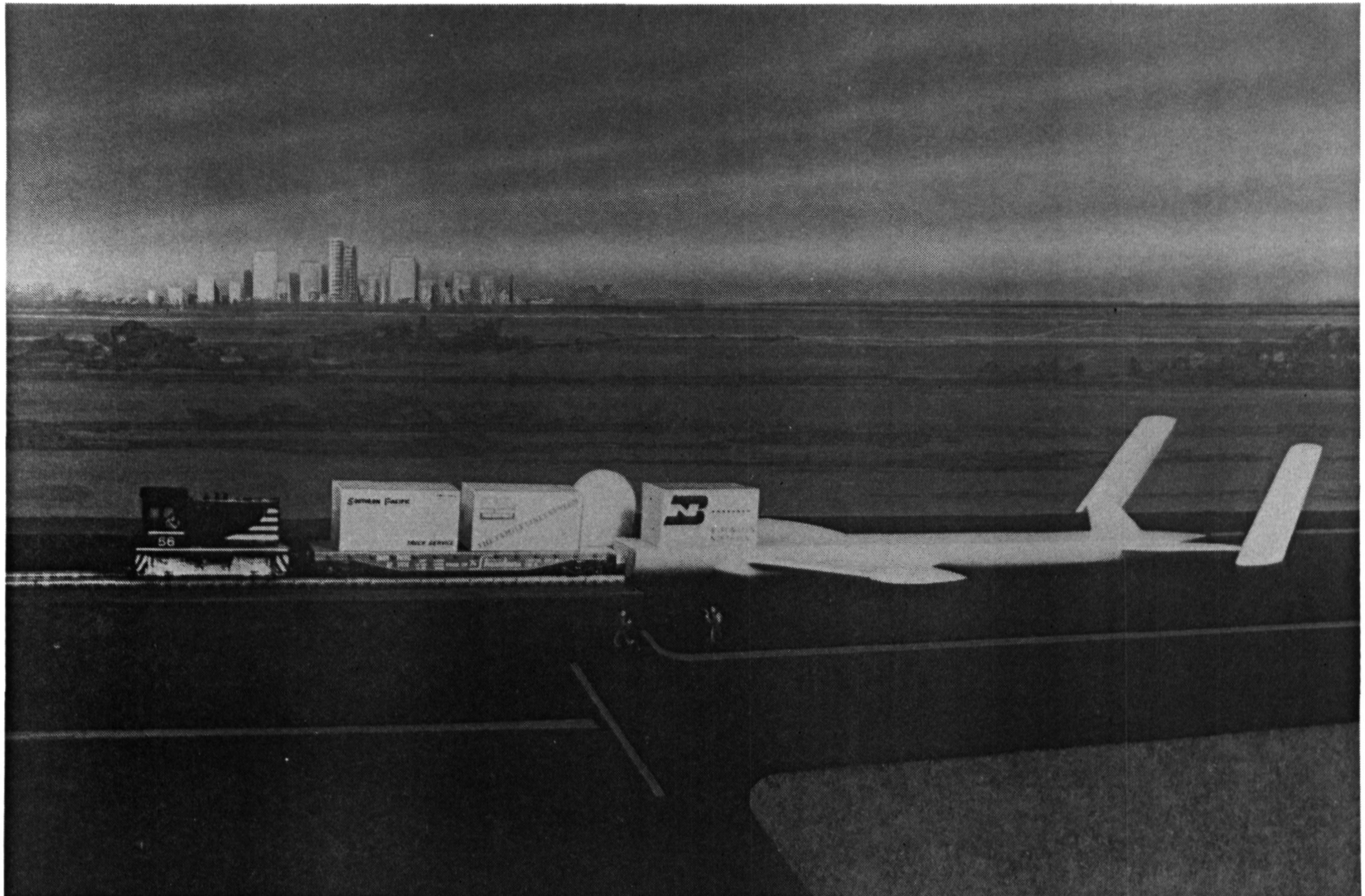


Figure 10 Cargo Containers Load/Unload Onto Rail Car

FLATBED STUDY RESULTS

Study Elements

Study Objectives - The Flatbed configurational concept was originally derived and developed by Lockheed-Georgia Company in 1978 (Reference 2). While initial studies showed the concept to have promise, the problem areas, perceived unknowns, and vagaries inherent in assumptions made it desirable on the part of NASA to pursue additional effort.

Accordingly, the study reported herein was undertaken (per the requirements of Reference 1) comprising refinement of concept, establishment of design parameters, and comparison with conventional transport configurations. The overall objective was an assessment of the feasibility of Flatbed in terms of design elements, performance and economics.

Technical Approach - The study consisted of 11 basic tasks defined as follows:

1. Configurational Analysis - Adaptation of basic Flatbed configuration in terms of general arrangement of major components.

2. Aerodynamic Analysis - Preliminary evaluation of sizes, lift and drag, and initial estimates of performance.

3. Structural Analysis - Initial estimates of loads, stress, and flutter/flexibility (fuselage only) to permit definition of major structural elements and estimates of weight.

4. Stability and Control - Cursory estimation of flying qualities.

5. Selection of Final Configuration/Size.

6. Derivation of Reference Aircraft - Establishment of size and configuration, weights, and performance of aircraft to be compared to Flatbed.

7. Performance Estimates - Aerodynamic performance of Flatbed and Reference Aircraft with various payloads plus structural and energy efficiencies.

8. Economic Analysis - Estimation of DOC and Life Cycle Costs for Flatbed and Reference Aircraft.

9. Comparison with Reference Aircraft.

10. Comparison of Flatbed at Off-Design Operations or Alternative Optimization Conditions.

11. Derivation of Recommended Additional Studies.

Report Data Units - Although all calculations for this study were performed in U. S. Customary Units, data presented herein are in SI units with the U. S. Customary Units following in parentheses.

Design Criteria

Configurations - There are six (6) basic configurations/payloads specified by NASA for the Flatbed study. These are:

1. No payload - backbone only (with appropriate fairing aft of cockpit)
2. PAX (passenger) module.
3. Unpressurized intermodal containers with cocoon.
4. D-shaped pressurized containers.
5. Outsized military vehicle - XM-1 tank.
6. Outsized military vehicle - M60 Bridge Launcher.

Lockheed added two configurations because they were considered pertinent to the Flatbed concept and relevant to the study. These are:

1. Unpressurized intermodal containers without cocoon, and
2. Containers in pressurized cocoon.

The intermodal unpressurized containers are those presumed to be available for the 1990 time period. These have a cross section of 2.6 X 3.05 meters (8.5 X 10 feet) and will be 6.1 meters (20 ft) long. Studies by personnel cognizant of container developments have shown that this will probably be the largest intermodal container available. Such a size can be carried on the highway on truckbeds designed for trailer beds .9 meters (3.0 ft) high with wheel sizes currently used by moving vans.

It is further assumed that the unpressurized, rectangular containers could be enclosed within a cocoon constructed of Kevlar, fiberglass, or a similar material. This cocoon is configured externally to be comparable in shape to the passenger module.

The pressurized containers are not intermodal, but are capable of temperature and pressure control. These containers have the same cross section as the passenger module (more or less igloo or D-shaped) and a length of 6.1 meters (20 ft).

The pressurized cocoon (added payload configuration) is generally similar to the passenger module. Windows are deleted and the floor is strengthened to carry cargo.

There are three (3) reference aircraft as follows:

A. Civil cargo (also for reference military container cargo aircraft).

B. Civil passenger.

C. Military outsize cargo - outsize vehicle capability.

Payloads - The basic or reference payload is that of five unpressurized cargo containers - 49,887 kg (75,000 pounds) including the tare weight of the containers but exclusive of fairings. These five 6.1 meter (20 ft) containers essentially determined the length of the fuselage backbone.

The weight of the passenger module (payload in passenger configuration) is determined as a function of the passenger seating capacity within a module capable of fitting on the backbone dimensions so determined. The weight also includes the module structure, furnishings, and operating equipment (lavatories, galleys, etc) and mail and express. The passenger capacity utilizes an approximate ratio of 10 percent first class and 90 percent tourist. The weight of a passenger plus baggage is 93 kg (205 pounds).

The design payload for the cocooned version of the unpressurized intermodal containers is 34,014 kg (75,000 pounds) plus the weight of the cocoon. The design weight of the payload for the pressurized containers is the weight of the actual cargo in the unpressurized containers plus the tare weight and fairings.

Current weights for XM-1 and M60 Bridge Launcher air transportable weights available from U. S. Army FORSCOM (Computerized Movement Planning and Status System Equipment Characteristics File) are:

XM-1 (105mm gun)	49,887 kg (110,000 pounds)
XM-1 (120mm gun)	50,957 kg (112,360 pounds)
M60 Bridge Launcher	53,808 kg (118,646 pounds)

Since these weights are subject to fluctuations (particularly the XM-1), it was decided to establish design payload weights for analysis as follows:

XM-1 Tank	52,154 kg (115,000 pounds) including ramps
M60 Bridge Launcher	54,422 kg (120,000 pounds) including ramps

With specific regard to military operations with outsized loads (dimensions in excess of 20.6 X 3.0 X 2.7 meters (810 X 117 X 105 inches), including vehicles required to roll-on roll-off, consideration was given to the relative merits of an integral versus detachable ramp. The detachable ramp is construed as a kit (as discussed subsequently).

An additional item considered as a kit is an aerial refueling package to convert Flatbed to a tanker. Provision is made within the backbone for installation of such a kit. Such provision includes the necessary plumbing from top to bottom in the tail cone.

The total design payload for any configuration in general, and of the five pressurized containers in particular, does not exceed that maximum payload available in the backbone structure for a load factor of 2.5 (based upon the structural capability as determined for the 2.0g case which is critical). In no case is the cargo density less than 3.17 kg/cubic meter (7 pounds per cubic foot) nor more than 4.53 kg/cubic meter (10 pounds per cubic foot).

Range - The range for passenger and cargo versions is 4815 km (2600 n.mi.) which permits flight from New York to Los Angeles against headwinds.

The range for outsize military vehicles is 4473 km (2415 n.mi.). This range represents the longest distance throughout the world wherein there is no possible place to land for refueling and is the range from Travis AFB, California, to Hickham AFB, Hawaii. Otherwise stated, this geographical origin and destination pair have no possible location for refueling as do missions, for example, to Europe in support of NATO operations, or missions across the Pacific after departing Hawaii. There are always routings with possible refueling stops. The range (Travis-Hickham) is actually 3913 km (2113 n.mi.); however, Reference 5 indicates that the 90 percentile headwinds are such as to require a design range of 4473 km (2415 n.mi.).

Speed - The cruise speed is Mach = 0.82 for the passenger version. For the cocooned and D-shaped container cargo versions, the speed is a fallout of the design process. In the case of vehicular carriage particularly, the speed is lower because of the necessity to cruise at an altitude compatible with unpressurized flight. It is emphasized, however, that the speed in the cargo versions is generally compatible with conventional air cargo requirements in that overnight delivery would be available.

Altitude - Cruise altitude for the passenger and pressurized cargo versions is 10,668 meters (35,000 ft). For flights with unpressurized cargoes and vehicles the altitude is 5,986 meters (18,000 ft). However, since only vehicular payloads in unpressurized aircraft are limited to 5,986 meters (18,000 ft) by USAF regulations, performance and economic evaluations are also made for unpressurized cargoes at 10,668 meters (35,000 ft). This is considered realistic for container cargo; for, in reality, there is no reason to restrict flight to 5,986 meters (18,000 ft) for cargoes not required to be pressurized or environmentally controlled--there is, in effect, no "break point".

Structure - The load factor for structural design is 2.5 for all payload versions except the versions carrying the XM-1 tank and the M-60 Bridge Launcher which have a load factor of 2.0.

Technology levels are consistent, in general, with Lockheed-Georgia studies of transport aircraft for IOC in the 1990s and specifically with contractual studies currently being performed for NASA by Lockheed-Georgia Company. Structural weight levels, relative to an all aluminum aircraft and including the effects of advanced materials, were as follows:

Wing	0.82
Fuselage	0.88
Empennage	0.73
Nacelles & Propulsion	0.89
Landing Gear	0.97

Note: These factors represent the relative weight of component structure using some degree of advanced materials relative to all aluminum structure.

The required stiffness is designed into the backbone - the containers or modules are not load-carrying. Further, the stiffness is generally comparable to that available in cargo airplanes of similar size designed by Lockheed-Georgia and either currently in service or projected.

Propulsion - The propulsion system technology is based upon the GE-SNECMA/CFM-56 Advanced Technology Engine (Reference 6).

Sizing - The Flatbed aircraft is generally "sized" and optimized for the passenger version. (Sizing in this case refers to the iterative process of determining fuel weight and thus aircraft TOGW required to perform the basic missions, i.e., range at a given speed and altitude.) This criterion is predicated upon the fact that passenger airline operations virtually dictate high cruise speed which, in turn, influences primary geometric parameters such as wing sweep, thickness, etc. Cargo aircraft, conversely, may operate at lower speeds and still efficiently meet user demands.

A tabular summary of configurations, design speeds, altitudes, and ranges, is given in Table 1.

Configurational Analysis

General Arrangement of Components - The basic Flatbed configurational concept was refined and adapted in terms of integration of major components (wings, engines, empennage, cockpit section, and landing gear) into a reasonable general arrangement. To do this, consideration was given to items such as interrelationship of engine exhaust plumes and vertical tail location, empennage arrangement, landing gear length, and aftbody clearance during takeoff/landing, and cargo bed height vis-a-vis engine location/height.

Table 1 Study Configuration Summary

Configuration	Cruise Mach	Altitude	Range
I. Flatbed			
A. Backbone	F	10,668 m (35,000 ft)	F
B. PAX Module	.82	10,668 m (35,000 ft)	4815 km (2600 n.mi.)
*C. Unpressurized Containers	F	5,486 m (18,000 ft)	4815 km (2600 n.mi.)
*D. Unpressurized Containers	F	10,668 m (35,000 ft)	4815 km (2600 n.mi.)
E. Unpressurized Containers w/Cocoon	F	5,486 m (18,000 ft)	4815 km (2600 n.mi.)
*F. Unpressurized Containers w/Cocoon	F	10,668 m (35,000 ft)	4815 km (2600 n.mi.)
G. Pressurized Containers, D-Shaped	F	10,668 m (35,000 ft)	4815 km (2600 n.mi.)
*H. Containers in Pressurized Cocoon	F	10,668 m (35,000 ft)	4815 km (2600 n.mi.)
I. XM-1 Tank	F	5,486 m (18,000 ft)	4473 km (2415 n.mi.)
J. M60 Bridge Launcher	F	5,486 m (18,000 ft)	4473 km (2415 n.mi.)
II. Reference Aircraft			
A. Cargo	.82	10,668 m (35,000 ft)	4815 km (2600 n.mi.)
B. PAX Airliner	.82	10,668 m (35,000 ft)	4815 km (2600 n.mi.)
C. Military Outsize Vehicle	.82	10,668 m (35,000 ft)	4815 km (2600 n.mi.)

* Denotes configurations unspecified by NASA but considered worthy of inclusion at contractor expense

1. F - Fallout - that speed attainable
2. Field length for civil operations not to exceed 2438 meters (8000 ft) balanced field length, standard day
3. Field length for military operations not to exceed 3048 meters (10,000 ft) over a 15.2 meter (50 ft) obstacle, standard day

The goal was minimum weight and drag in order to realize the fewest performance penalties relative to conventional configurations. Also, it is these two aspects which contribute most to economic feasibility since weight directly influences acquisition cost, drag influences fuel cost, and both influence DOC.

Specific aspects studied included: width of the cargo floor, empennage configuration (with trade-offs of stability, control, drag, and weight), engine number and location, landing gear arrangement to achieve lowest height of the cargo bed, aftbody backbone fairing shape, and wing design including high lift system.

Backbone Cross Section Design - The appropriate cross section for Flatbed's backbone was among the initial items addressed in the study. The pertinent influences on size and shape are the requirements to carry 2.59 X 3.05m (8.5 X 10.0 ft) cross section containers, the M60-chassis bridge launcher and the XM-1 tank, as well as the passenger module.

The floor width of the backbone was initially set at 3.63m (143 inches) based on the widest vehicle to be carried, the M-60 bridge launcher, measured at its tread (Figure 11). The upper lobe of the cross-section was at first based on this width and the 2.59 X 3.05m (8.5 X 10.0 ft) containers sitting on rollers 6.98cm (2.75 inches) above the floor, and 22.9cm (9 inches) from the upper corner of the container to the outside of the skin. This resulted in a 2.33m (91.75 inches) upper lobe radius. However, a preliminary check of potential passenger seat arrangement showed this radius to be too small for 6- and 7-abreast, two-aisle configurations, and somewhat large for a 6-abreast, single-aisle configuration. Therefore, the distance from the corner of the container to the outside skin was reduced to 7.62cm (3 inches) and the roller height above the floor to 2.54cm (1 inch). This somewhat arbitrary change results in the 2.25m (88.56 inch) radius shown on Figure 12, and a fairly comfortable passenger cabin.

However, the Flatbed fuselage, because of its relatively small cross sectional area, is inherently more flexible than conventional designs. This fact caused some initial concern that the longitudinal stability and control characteristics and perhaps the empennage flutter and dynamic response characteristics of the design might be unsatisfactory.

Excessive fuselage vertical bending flexibility between the wing and empennage adversely affects longitudinal stability and control effectiveness, and may therefore require an increase in horizontal stabilizer and/or elevator size. It also reduces the fundamental fuselage bending mode frequency, which brings it into closer proximity with the fundamental wing mode frequencies, and undesirably increases its dynamic response to gust, landing, and taxi inputs.

Fuselage torsional flexibility is not considered to be a critical design parameter for wing or empennage flutter stability, but excessive dynamic response will result if the fundamental fuselage torsion mode frequency is too low.

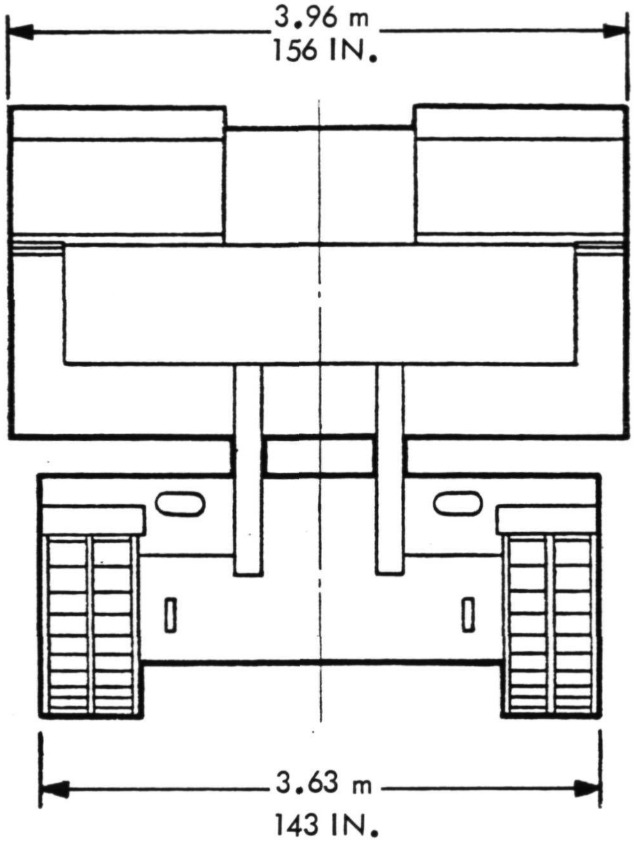


Figure 11 M60 Bridge Launcher, Front View

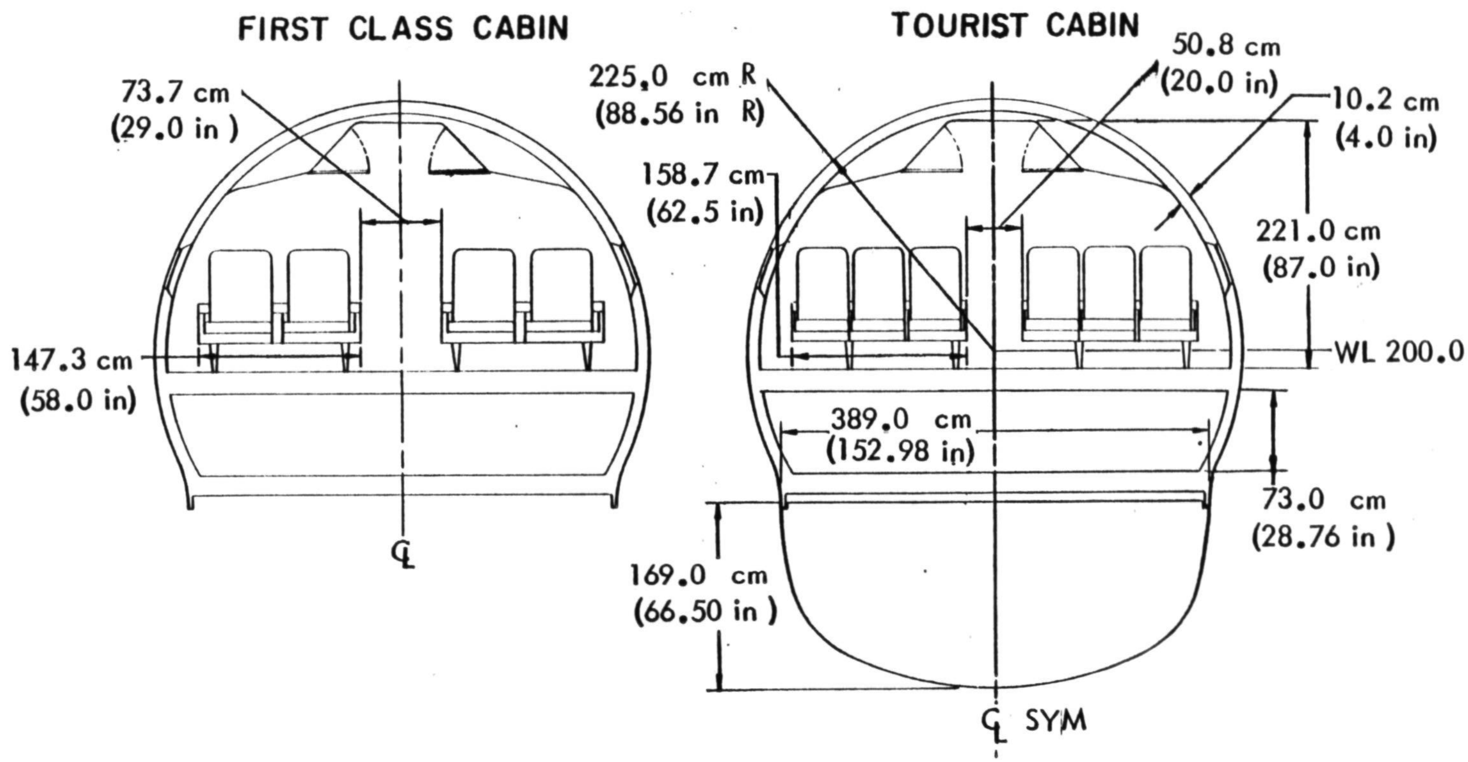


Figure 12 Flatbed Passenger Module Cross Sections

A brief study was therefore conducted to determine if adequate vertical bending and torsional stiffnesses could be achieved without excessive weight penalties.

Stiffness parameters were computed for an initial (or first trial) fuselage design having a semicircular cross-section of 1.78 meters (70 inches) radius, and were compared with those of the C-141A, which has an equivalent (in terms of size) conventional fuselage. Since the bending and torsional flexibilities for the Flatbed design were approximately twice those for the C-141A, this design approach was rejected.

A second design, having a more rectangular cross-section of 1.69 meters (66.5 inches) maximum depth, was found to have overall flexibilities comparable to those of the C-141A and was, therefore, selected as the baseline (Figure 13). The maximum stiffnesses, which occur in the vicinity of the wing, are somewhat lower for Flatbed in relation to the C-141A. However, the Flatbed torsional and vertical bending stiffnesses are higher in the aft portion of the fuselage because it does not have a large cargo door and associated cut-out in the structure. In addition, Flatbed Backbone's distance between the wing and empennage is shorter than the C-141A. Hence, the integration of torsional and bending stiffnesses of the Flatbed aftbody produces a flexibility of structure somewhat less than that of the C-141A. As a result, the Flatbed fuselage vertical bending and torsion mode frequencies should be somewhat higher than those of the C-141A, and the flexibility effect on the longitudinal stability and control effectiveness should be somewhat less.

On the basis of the stiffness-dynamic analysis, a quasi-elliptical shape (shown in Figure 12) was selected. This is considered optimum since the fuselage is not pressurized and it permits the cargo floor to be as low as possible to the ground to facilitate loading. Resultant floor height is 2.1 meters (82.5 inches) in the kneeled attitude as more fully discussed in the paragraphs describing the landing gear.

The floor width was established at 3.88m (153 inches). In addition to providing torsional rigidity, the additional width relative to the widest vehicular tread (143 inches) allows a margin for error during drive-on, drive-off operations. The intersection with the upper lobe radius is faired with a 96cm (38 inch) fillet radius.

Empennage Configurational Trade Studies - The potential empennage configurations for the Flatbed were the twin tail, twin tail with engines at the intersection of the horizontal and vertical, the butterfly or V-tail, and a twin vertical, high horizontal arrangement known as the Pi (π) tail. These four empennage configurations were evaluated on the basis of drag, weight, and systems and structural complexity. Figure 14 shows preliminary drag and weights data derived to assist the evaluation.

The criteria for selecting one of these configurations included the ability to load over the aft fuselage, locating the empennage geometry at the maximum distance away from the wake of the forward fuselage and payload, interference with the engine exhaust plume, and avoidance of a configuration that would preclude a fair comparison with conventional reference aircraft. For instance, a canard equipped

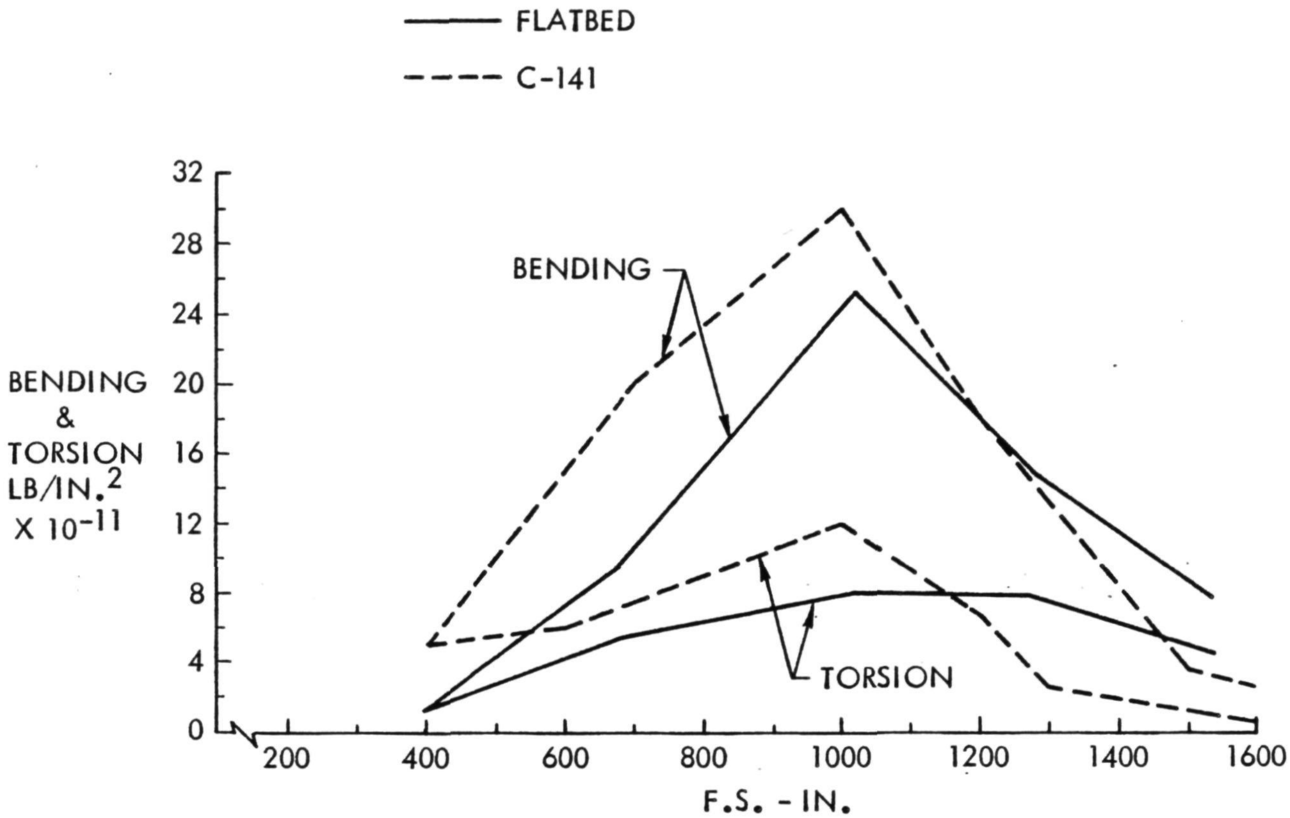


Figure 13 Comparative Fuselage Stiffness

(PRELIMINARY DATA USED FOR TRADE STUDY ONLY)

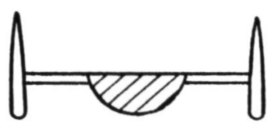
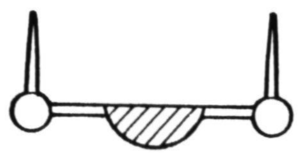
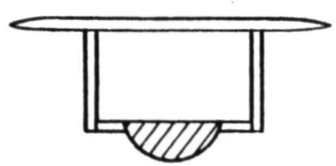
CONFIGURATION	Δ DRAG	Δ WT. - LB.	STABILITY & CONTROL
	.0042	8,051	TWO RUDDER SYSTEMS
	.0047	10,378	TWO RUDDER SYSTEMS
	.0037	6836	COMPLEX-CROSS COUPLED
	.0056	6712	TWO RUDDER SYSTEMS

Figure 14 Some Empennage Configurational Aspects

Flatbed would be a very interesting configuration. However, it could not be fairly compared to a C-141 (or conventional) cargo aircraft; as that might confuse the benefits of a canard with the benefits of the Flatbed itself.

On the basis of the aerodynamic penalties of the Pi tail and the weight penalties of the nacelle/twin vertical tail arrangement (see Figure 14), these two configurations were eliminated from further consideration. The two remaining configurations were subjected to a more complete stability and control evaluation as the fuselage size was iterated.

The butterfly or Vee-tail was finally selected for the baseline Flatbed.

Empennage Sizing, Stability and Control - The stability and controllability levels designed into the Flatbed are commensurate with technology of the 1990 period. The empennage was sized in anticipation of full-time automatic stability augmentation systems using active controls which permits a small amount of negative static stability.

The basic parameters considered in sizing the "effective" horizontal tail are shown by Figure 15. These data relate the tail volume coefficient to nose wheel lift-off, trim on landing approach, stability and center-of-gravity limits. The requirements considered a negative static margin of 8% at the most aft center-of-gravity position. The required forward center-of-gravity limit was checked for the trim required on landing approach and for most forward position permissible to achieve nose wheel lift-off. The most critical condition related to the requirement for nose wheel lift-off and this requirement was used to help set the horizontal tail volume coefficient.

Sizing of the vertical part of the empennage was determined by providing a level of directional stability equivalent to a C_{n_β} of 0.0015/degree. This has been found to provide a desirable level for good handling qualities based on experience with large cargo vehicles. The rudder was sized to assure adequate control with failure of the most adverse engine on takeoff.

With selection of a Vee-tail, the size of the surfaces and the dihedral angle reflected the loss of end plate effect, the change in downwash, and the change in effective aspect ratio of the vertical and horizontal stabilizers. Control chords were higher for the Vee-tail to achieve the combined critical longitudinal and lateral directional requirements.

The critical condition for sizing of the control surface on the Vee-tail was that which demanded the maximum longitudinal control and directional control at the same time. This condition results if an engine failure occurs at the speed of nose wheel lift-off.

Flow Analysis - The multitude of combinations of possible payload variations which makes the Flatbed concept so attractive could cause drastic air flow changes around the cargo bed. Exposed odd shaped cargo loads can disrupt the flow causing buffet,

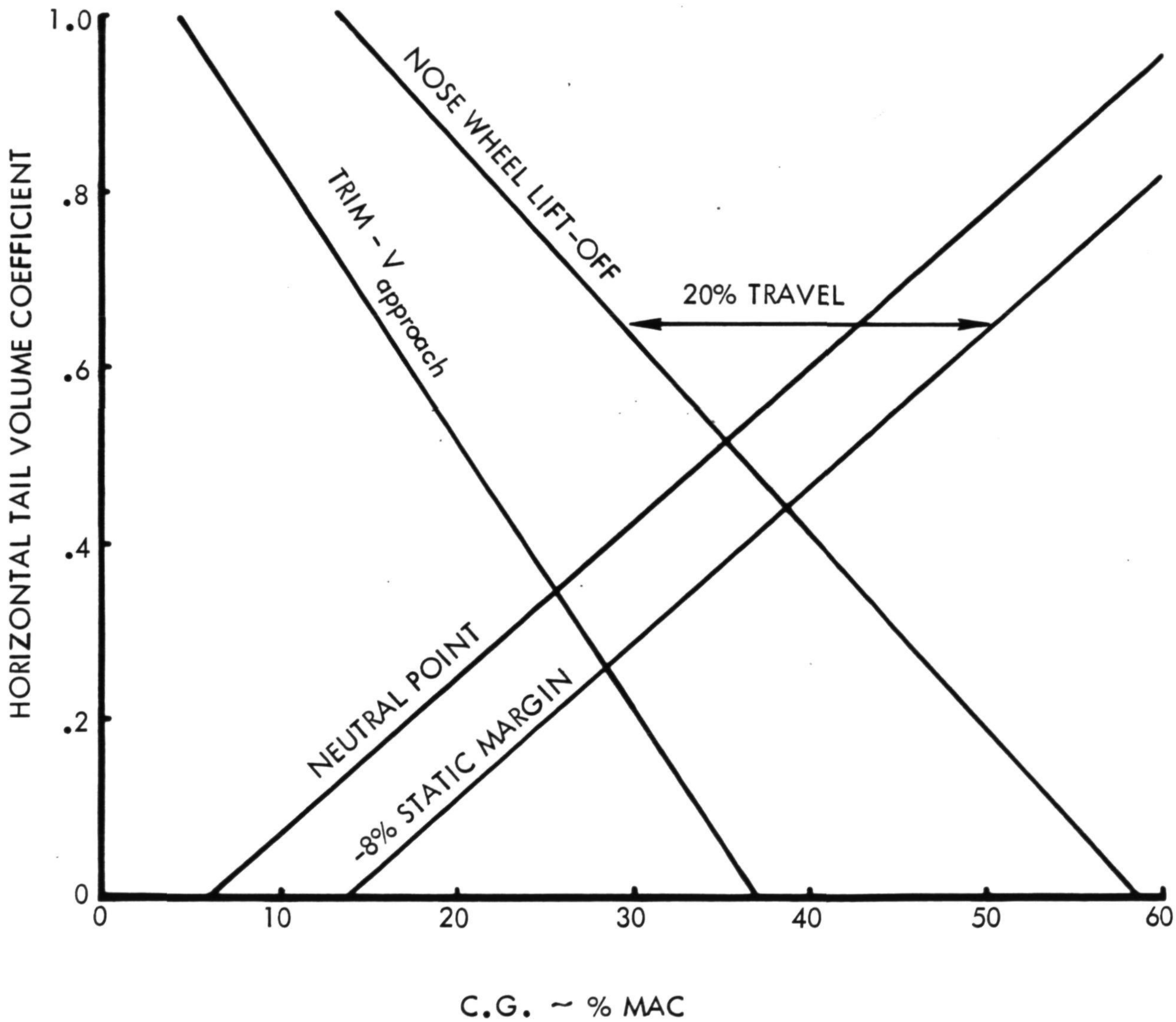


Figure 15 Flatbed Horizontal Tail Sizing Factors

drag increases, and loss of tail effectiveness. A flow visualization study was therefore made to investigate possible problems.

A 1/87.5 scale model was fabricated and installed in the flow visualization smoke tunnel of the Lockheed-Georgia Research Facility. A quarter view of the model testbed is shown by Figure 16. Since flow at the fuselage centerline was the major concern for this study, the total wing was not included.

The tail configuration at the time of this test consisted of a dihedraled horizontal stabilizer with twin tip-mounted vertical fins. Figure 17 presents a side view of the model and the strong vortex shedding evident is typical of a circular cross section with a bluff afterbody. A canopy fairing using the aft portion of the cylindrical passenger module with an appropriate fillet smooths the flow as shown in Figure 18. The characteristic doughnut vortex shedding is thus eliminated. A random multiple load behind the bluff section is shown in Figure 19. A comparison of Figure 19 with Figure 17 shows that filling the void immediately aft of the body probably helps the flow pattern. Since the initial vortex shedding appears reduced, its influence on the downstream cargo should be diminished.

Figures 20 and 21 show smoke tunnel results of a tank behind a fairing, in both 1/4 view and side view.

Figure 22 shows that the PAX module or cocoon shape offers less problems and reduces vortex shedding. The string of intermodal containers is shown in Figure 23 with a pseudo faired aft body. Flow appears smooth except in the region of the corners.

Figure 24 shows a configuration of a locked vortex afterbody. As shown, the presence of the cargo floor evidently prevents the formation of the steady-state ring vortex achieved on axi-symmetric bodies. Further work could possibly improve this technique.

Another concept which shows promise can be seen in Figures 25 and 26. These photographs were made during an independent Lockheed-Georgia research project on afterbody vortex control. They show the concept of locking the vortex by introducing suction (from engine bleed) behind the blunt cockpit section. Vortex shedding frequency and the resulting buffet can be directly related to the suction level. Downstream flow is thus smoothed by proper suction of the vortex core. Such a concept has application at the blunt afterbody and possibly all along the cargo floor. A tremendous amount of flexibility would then be available to tailor the flow according to the external load.

An estimate of the required power for this type of vortex control was made at a start-of-cruise condition of M = 0.6 at an altitude of 5986 meters (18,000 feet). Approximately 2670 N (600 pounds) of thrust is required. This is equivalent to approximately 18% of the excess thrust available at that cruise condition. A trade is obviously indicated. The power required to control the vortex consumes about 1043 kg (2300

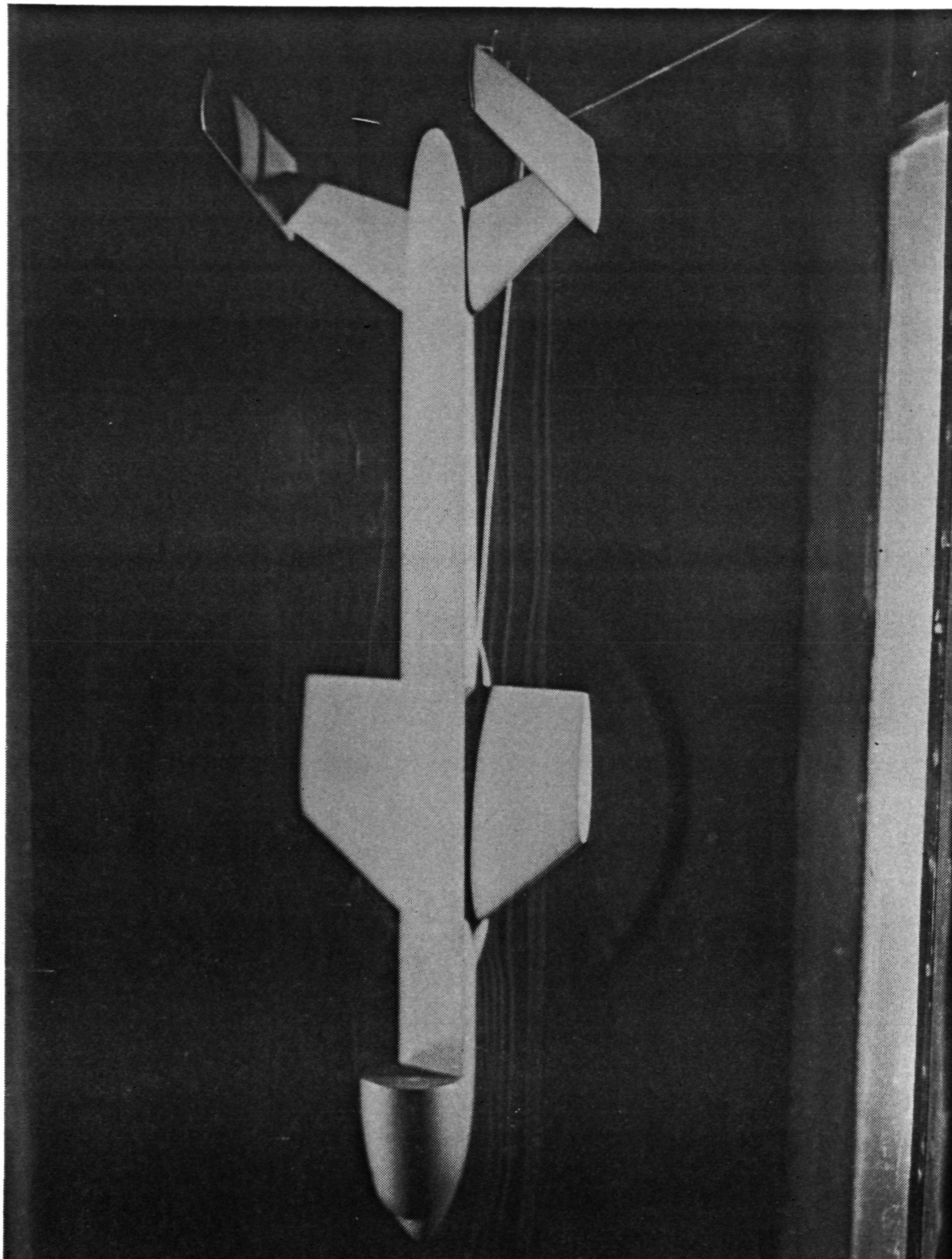


Figure 16 Smoke Tunnel Results - Backbone Only (1/4 View)

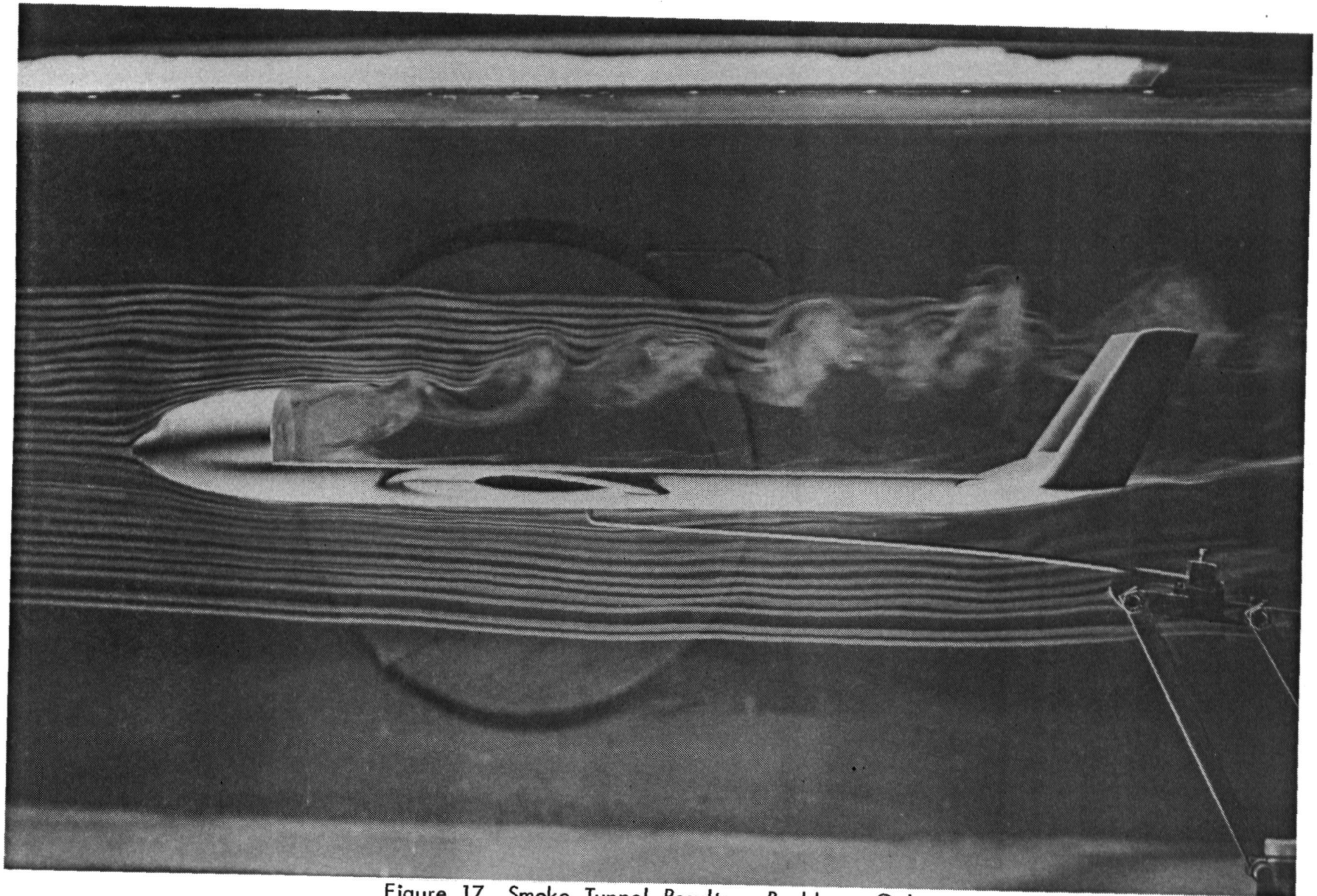


Figure 17 Smoke Tunnel Results - Backbone Only

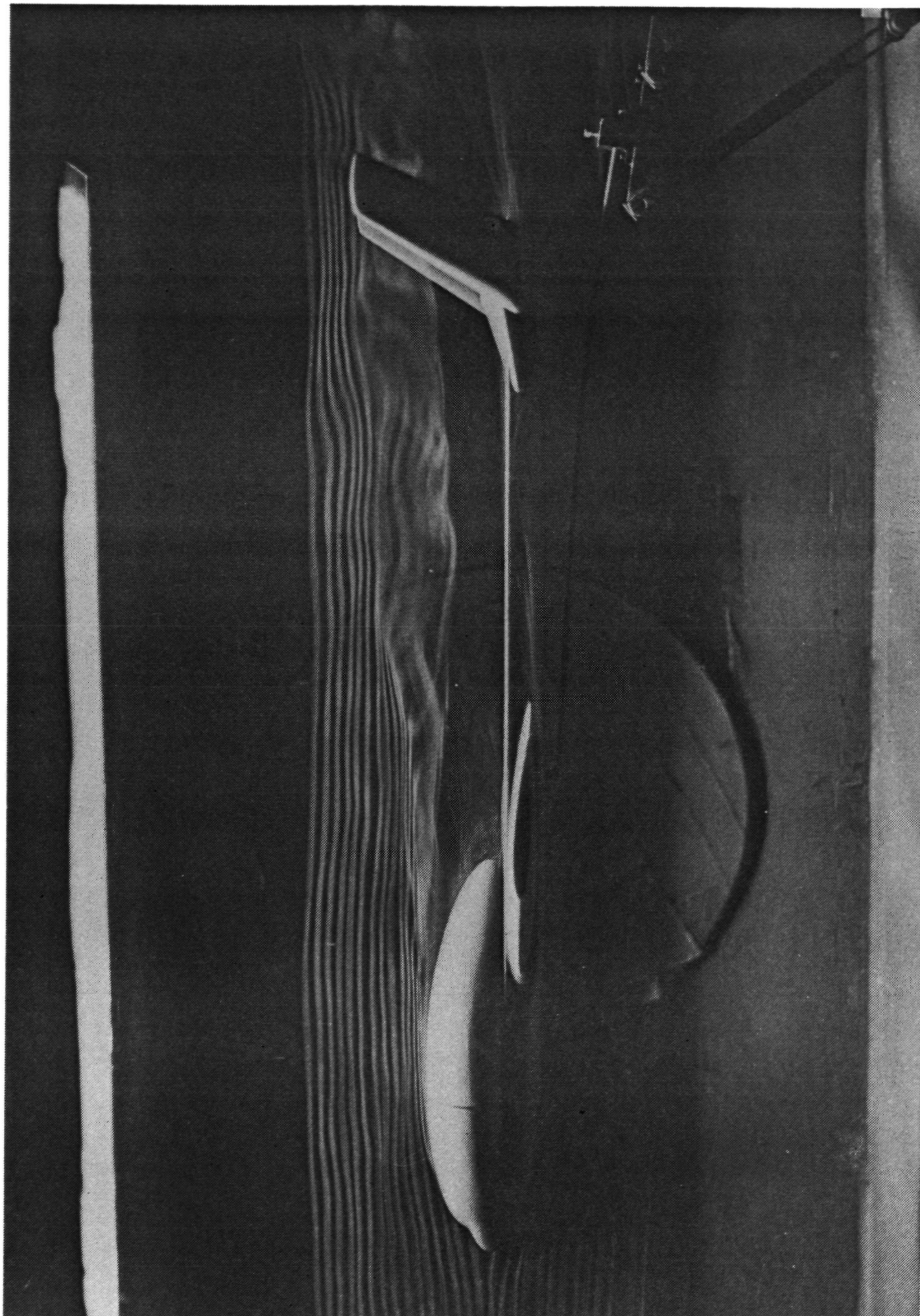


Figure 18 Smoke Tunnel Results - Backbone Plus Fairing

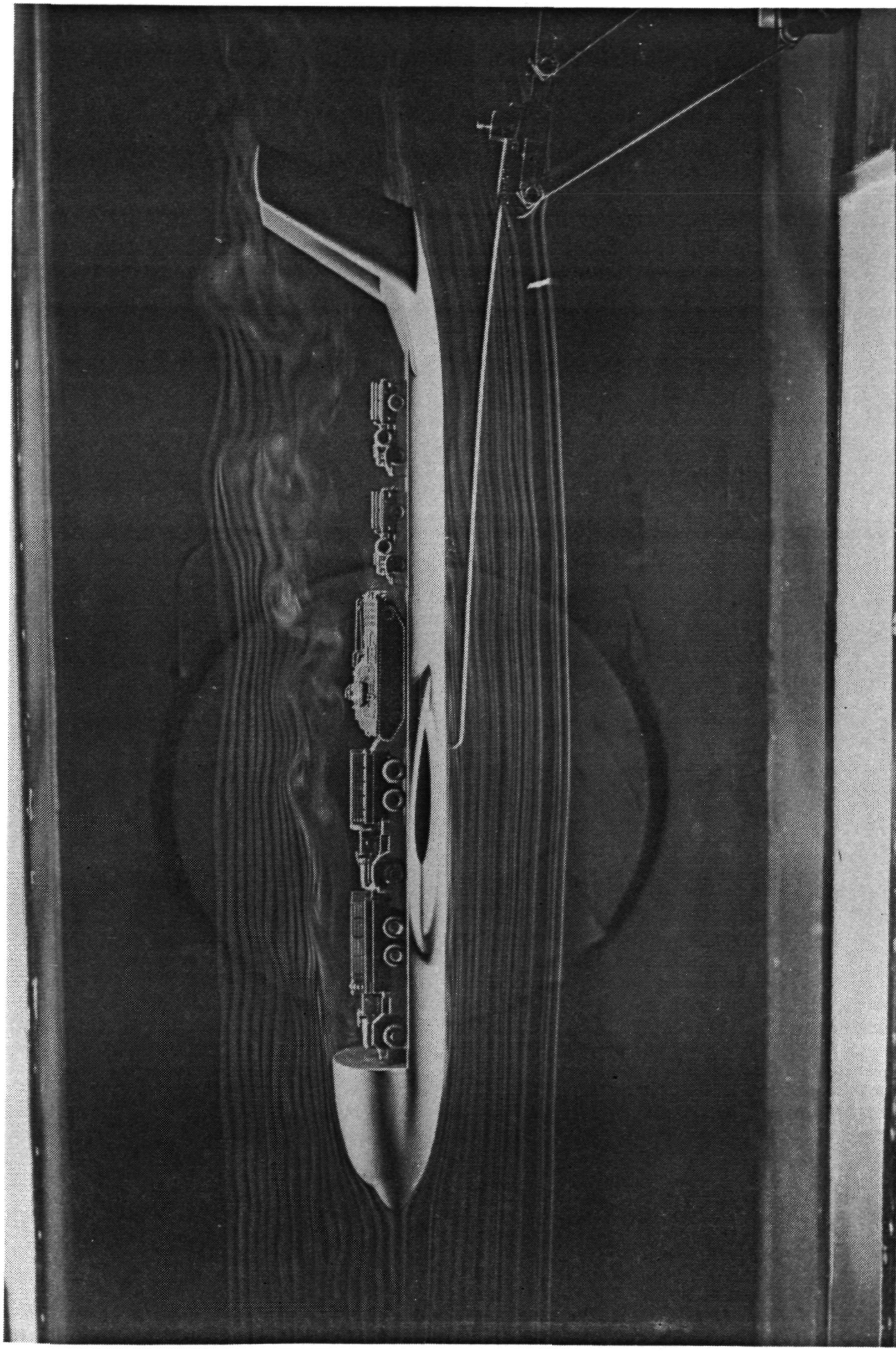


Figure 19 Smoke Tunnel Results - Line of Vehicles

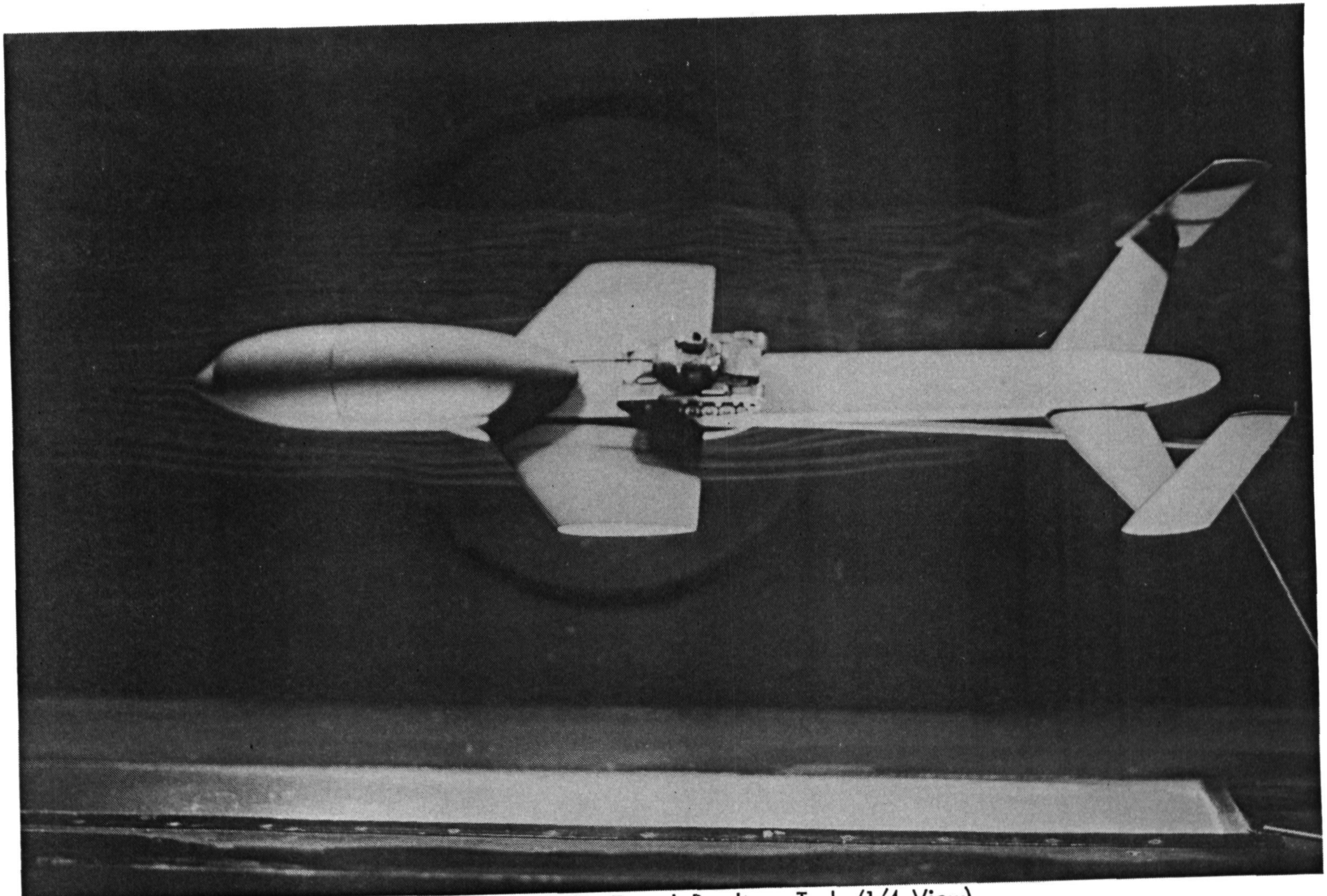


Figure 20 Smoke Tunnel Results - Tank (1/4 View)

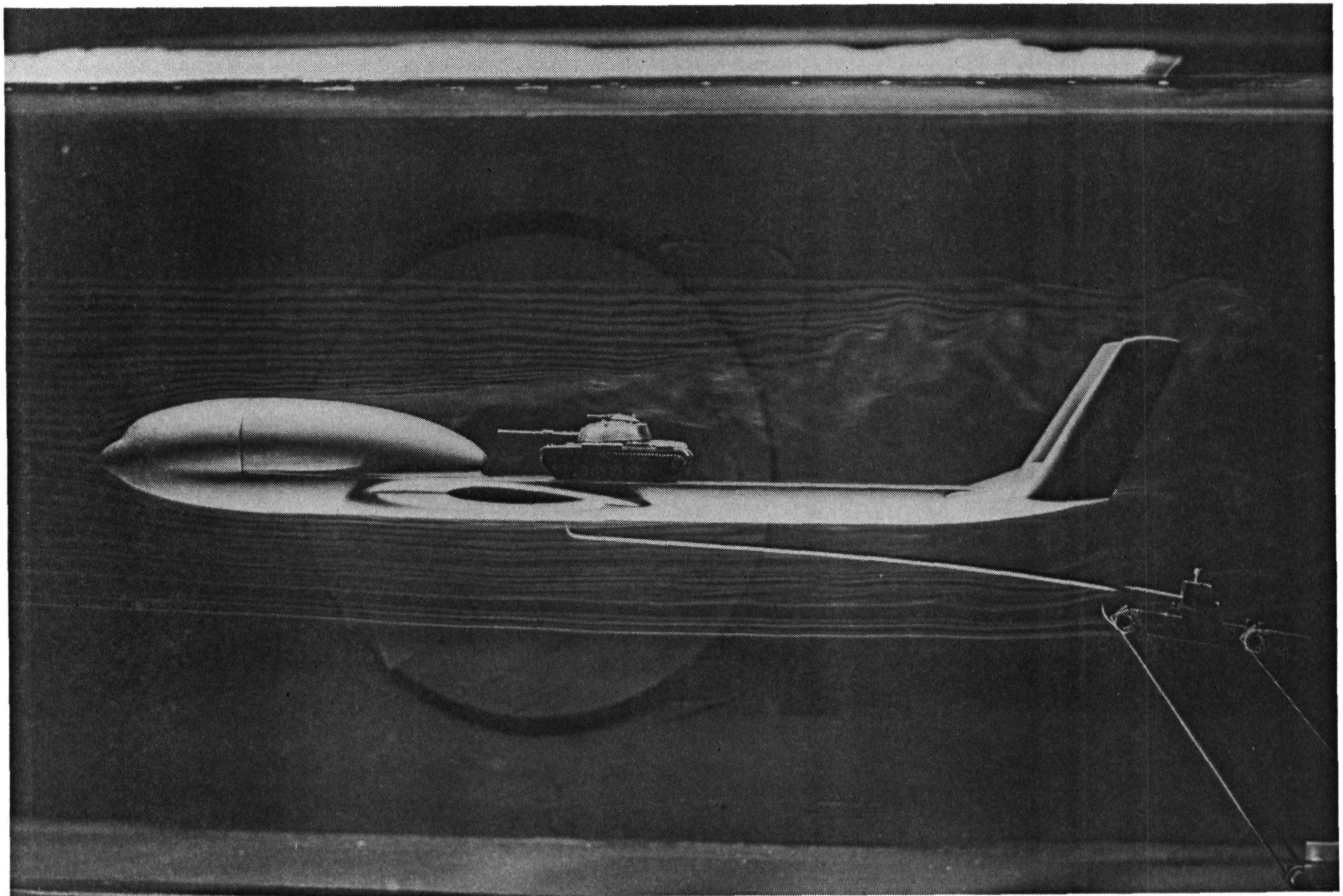


Figure 21 Smoke Tunnel Results - Tank with Fairing

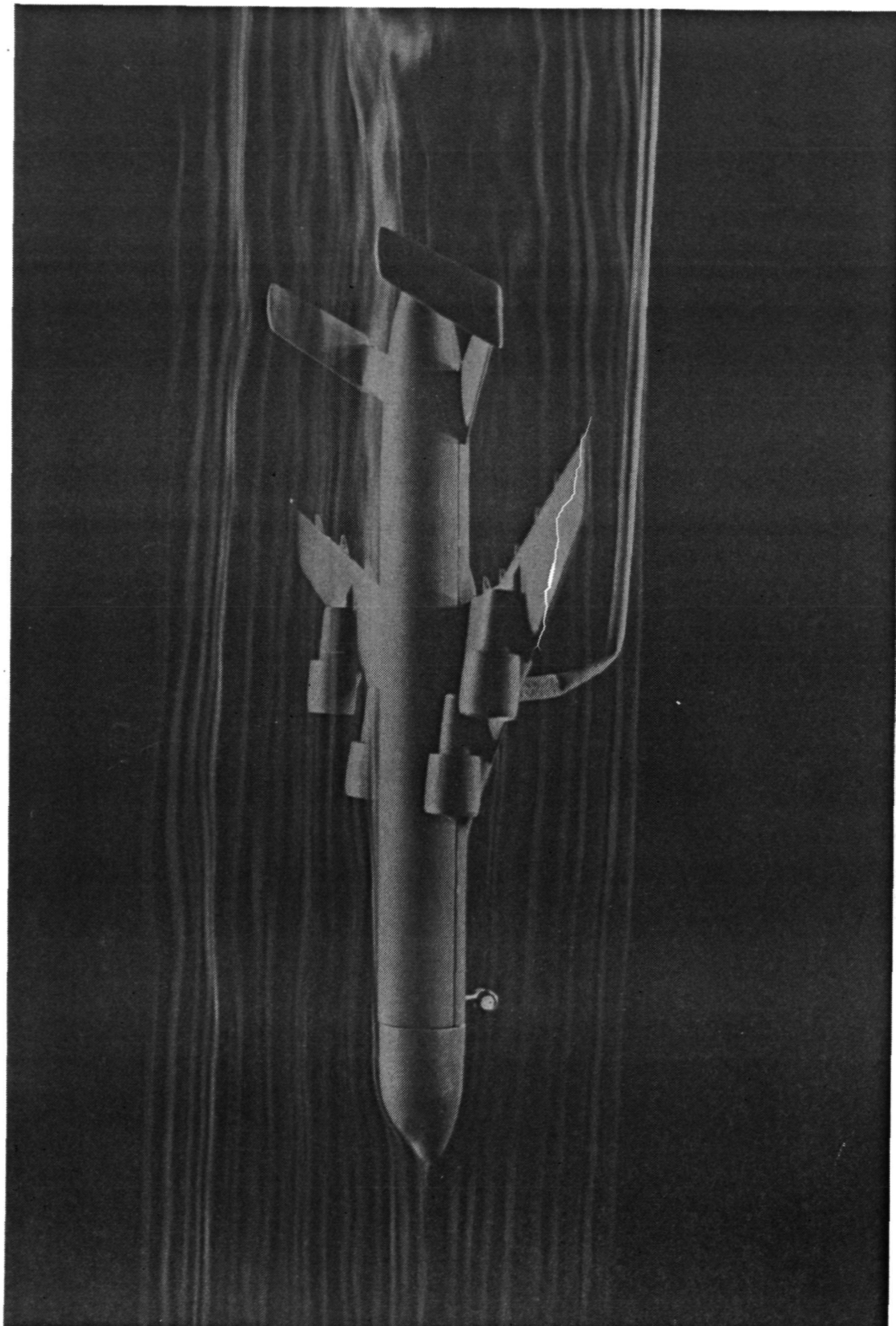


Figure 22 Smoke Tunnel Results - PAX Module

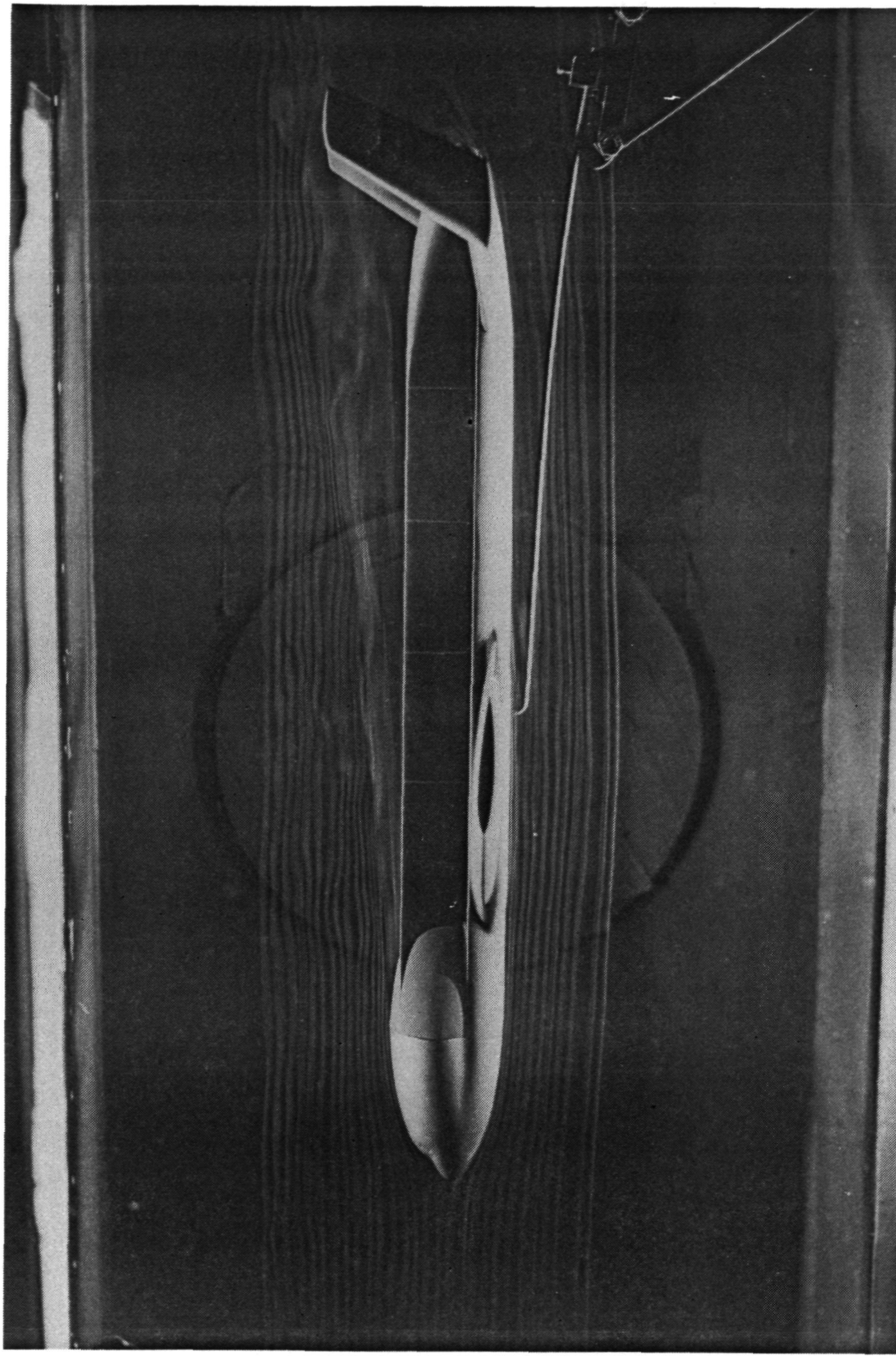


Figure 23 Smoke Tunnel Results - Containers

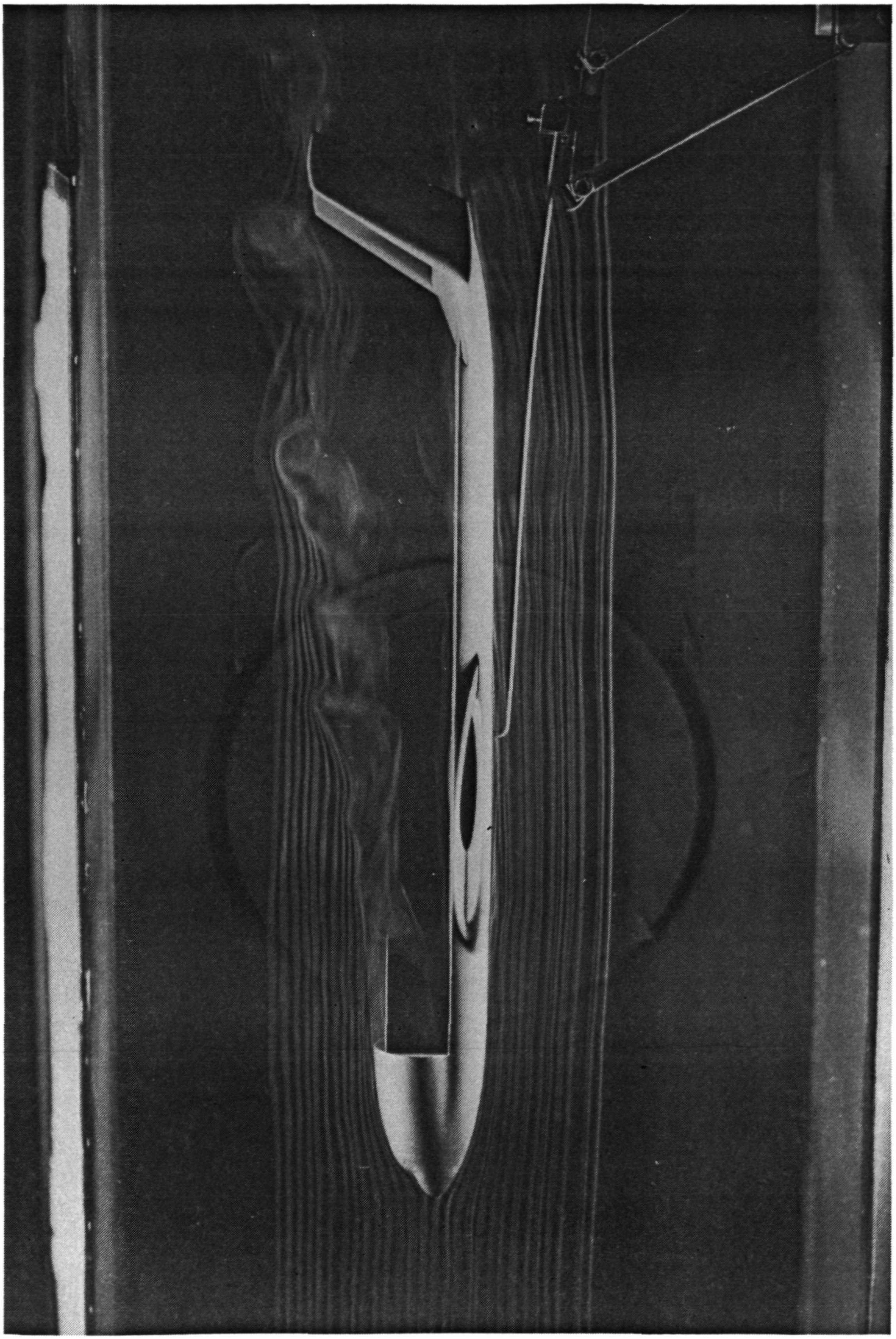


Figure 24 Smoke Tunnel Results - Backbone with Splitter Plate (Locked Vortex)

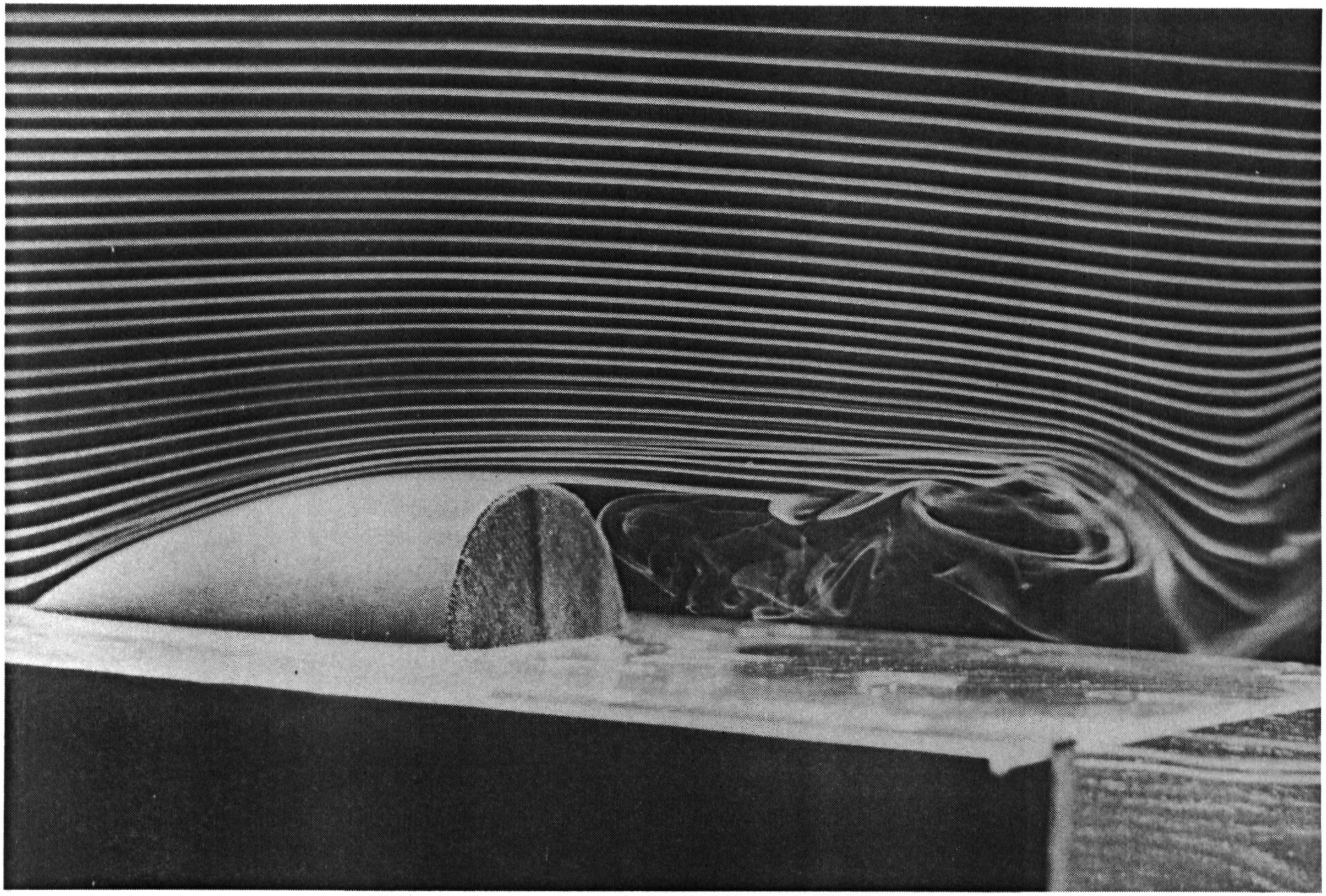


Figure 25 Smoke Tunnel Results – Flow Aft of Blunt Body

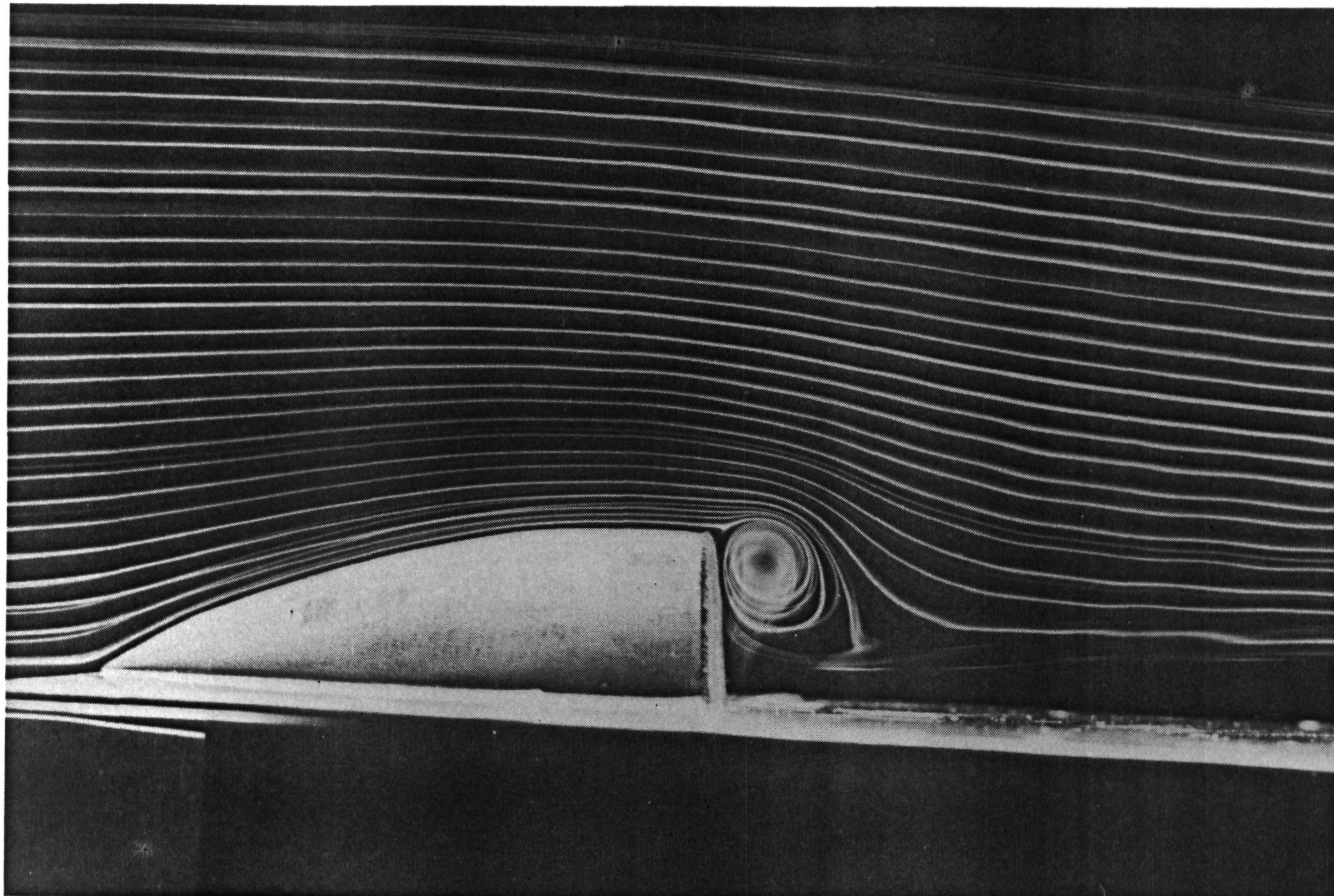


Figure 26 Smoke Tunnel Results - Locked Vortex Created by Suction

pounds) of fuel over the 4473 km (2415 n.mi.) range flown with vehicles aboard. This relates to the fairing weight which is 363 kg (800 pounds); however, there are important logistical advantages.

Engine Location and Number - A brief consideration was given to the number of engines for the Flatbed. The number of engines could, in reality, only be a multiple of two. For example, a third engine would compromise the basic concept of Flatbed in that it would, perforce, be located on the centerline thus hampering loadability. Two engines would require engines of relatively large thrust (approximately 100,863N or 50,000 pounds) which, in turn, create engine-out problems in terms of stability, control and climb (second segment). Consequently, a four-engined configuration was determined as the best compromise.

Several possible locations for the four engines were explored. These included (1) over-the-wing pylon-mounted engines, (2) conventional underwing pylon-mounted engines, and (3) two engines mounted near the cockpit below the cargo floor waterline plus two engines mounted in the horizontal tail as the only feasible arrangement from a balance standpoint.

Only the arrangement with four over-the-wing engines appears to offer an acceptable overall location and compromise after appropriate considerations were given to drag, weight, balance, cargo loading, and cargo floor height above the ground. For example, nacelle placement in the conventional position, under the wing, causes the cargo floor height to be equal to or greater than 3.05 meters (10 feet), and engines in the horizontal tail caused unacceptable weight penalties.

The data base for over-the-wing nacelle placement is sparse, making aerodynamic merit of this placement difficult to evaluate. Reference 7 summarizes some of the data sources that are available and evaluates the design problem. Lockheed IRAD studies and the results of Reference 8 were used to establish a preliminary location for the Flatbed nacelles, i.e., spanwise locations of 0.374 and 0.622 of the semi-span, vertical placement above the wing of one nozzle diameter ($Z/D = 1.0$), and a longitudinal placement of the exit plane at 10 percent of the local wing chord. Optimization of nacelle and pylon detail designs was considered to be beyond the scope of this study.

Landing Gear - The design and configuration of the landing gear was of particular importance in the Flatbed design because of the need to achieve a cargo floor as close to the ground as possible.

The location of the nose landing gear aft of the hinged cockpit section break had been previously established. The kneeling nose gear design itself is a conventional, steerable, two-wheel design. Thus, particular attention was given to the main landing gear and its retraction scheme

The backbone depth, probable size and normal stroke of a conventional main landing gear, and relationship of the rotation angle during takeoff or landing approach would result in a cargo floor height of 3.76 meters (148 inches). This is far in excess of a desirable height for reasonable cargo loading and roll-on, roll-off capability for vehicles.

Accordingly, various retraction and kneeling schemes were tried to achieve a lower height for cargo loading. Although the fuselage depth itself may have been adequate for retracting the landing gear, the required cut-out in structure would have resulted in excessive weight penalty to achieve required backbone aftbody strength. The location of the rear spar of the wing complicated the problem by dictating the location of the gear attachment.

A solution, given by Figures 27 and 28, features a gear which retracts aft into an extension of the wing root fairing. (The size of the fairing required then provided adequate space for location of an APU). Figure 27 also shows the gear in its kneeled position which results in a cargo bed/floor height of 2.1 meters (83.5 inches).

Kneeling is achieved by initiating the retraction sequence, but movement of a hydraulically actuated "stop" into position holds the sequence and provides structural support during loading operations. The main landing gear itself is a conventional four-wheel bogie design. Retraction is achieved by means of a ball screw actuator either electrically or hydraulically driven.

Front versus Rear Loading - The relative merits of both front and rear loading of cargo and passenger modules were evaluated and consideration was also given to the desirability of providing for aerial delivery/air drop. These evaluations also were a part of the selection process for the empennage configuration.

Nose loading was selected for the following reasons:

- Loading over the aftbody would require heavy structure (and a strut) to accommodate the largest military vehicles (up to 54,422 kg or 120,000 pounds).
- The fitting of ramps would require a "squared off" aftbody or, at least, a removable fairing.
- The loads on the forebody can be taken by major structure and braced by the nose gear which is aft of the break.
- It is easier for a pilot to nose an airplane into a loading dock than it is to back in. This is also true for purposes of compatibility with "Jetway" loading systems in passenger operations.
- Loading from the front permits use of conventional roller/rail systems because of the broad width available at the break vis-a-vis a necessary curved (in planform) aftbody. Thus, vertical and lateral alignment of the loading and loaded beds is facilitated.

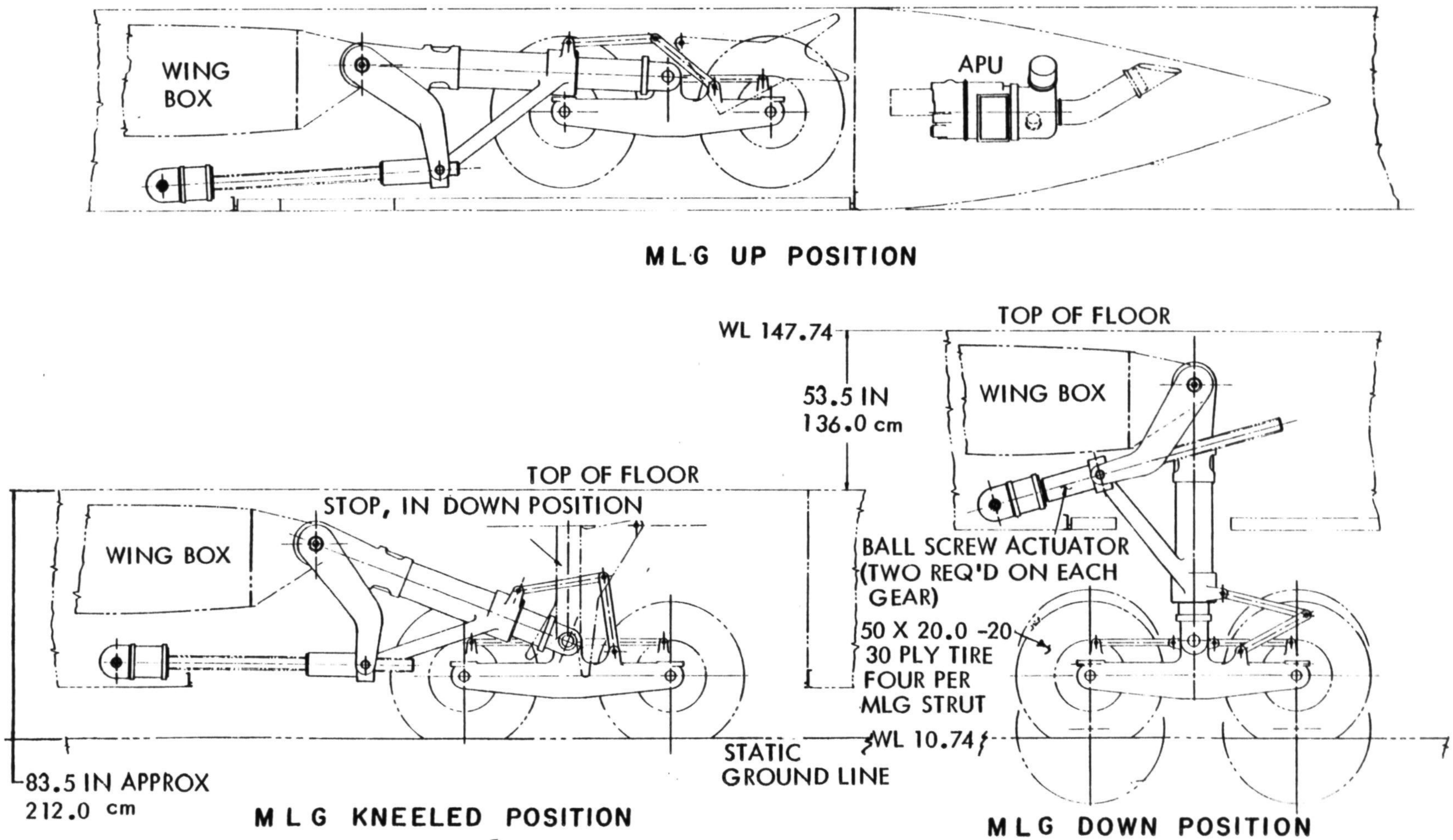


Figure 27 Retraction Scheme - Main Landing Gear

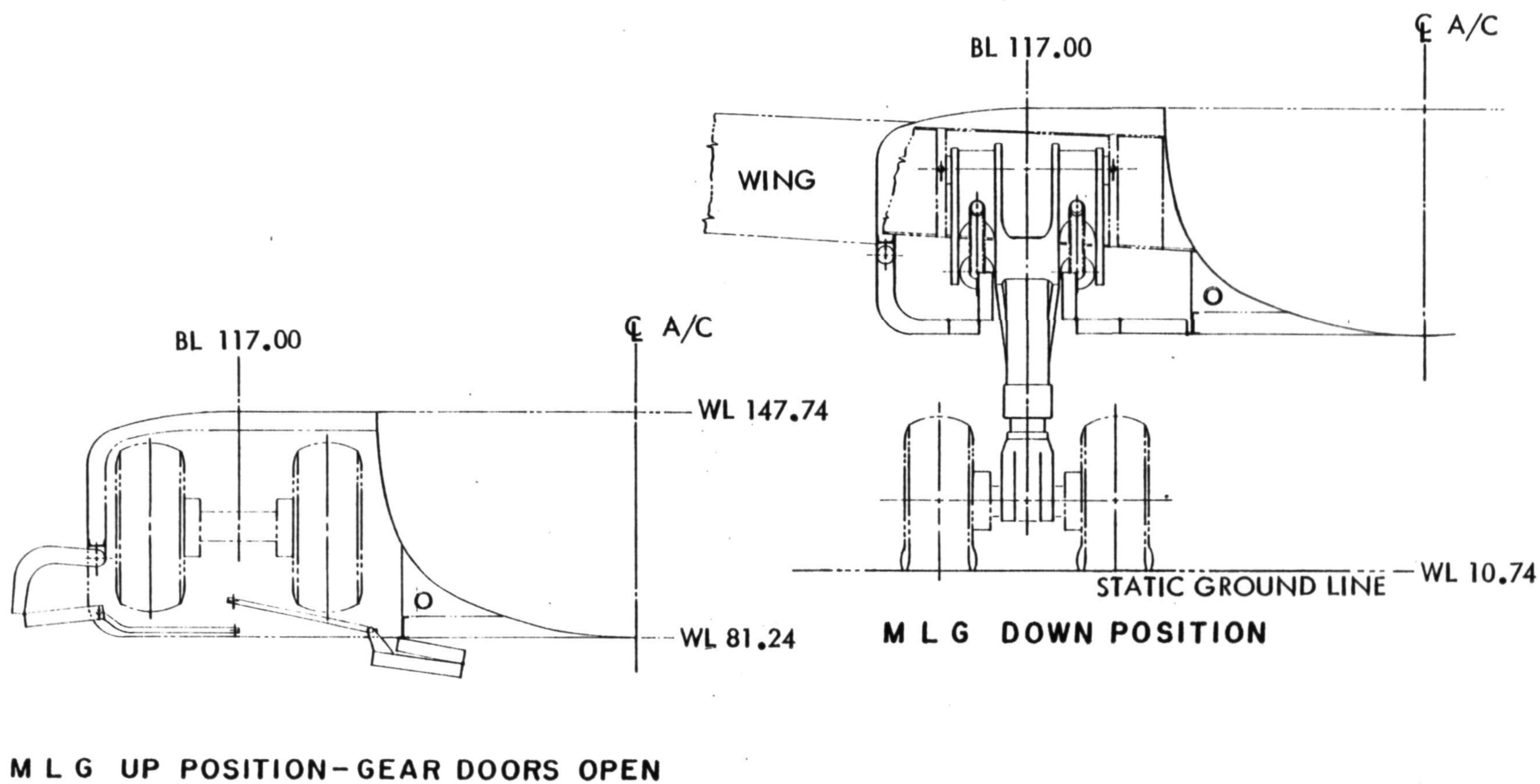


Figure 28 Main Landing Gear and Pod

A hinged nose, capable of being swung to starboard, was selected for the configuration because of its simplicity. The hinging/pivoting is facilitated by advanced technology control systems such as fly-by-wire or the very new fibre optics.

Figure 29 schematically depicts the hinge mechanism. Several schemes were tried in order to achieve an internal hinge so that there would not be a drag penalty. The final arrangement requires the nose to move forward 2.49 meters (98 inches) before the cockpit section swings to the side. The forward movement is accomplished with a threaded shaft operated by a hydraulic motor; the sideward movement by conventional hydraulic piston.

Sizing/Optimization - The Flatbed aircraft is sized and the configuration optimized for the passenger version, i.e., cruise at Mach 0.82 at an altitude of 10,668 meters (35,000 feet). The basic tool for this process, as well as all performance estimations, is the Lockheed Generalized Aircraft Sizing and Performance Program (GASP). GASP is a computer model capable of calculating aircraft size, performance, and direct operating costs (if desired) as an integral part of its operation. All elements of a flight profile are estimated with output being pertinent geometric values, weights, fuel requirements, and performance aspects including takeoff and landing distances.

Basic Flatbed Drag - A fundamental input to the GASP is the drag for a generalized configuration. The basic drag definition for the selected Flatbed airplane (Table 2) is a component buildup accounting for friction, form, interference, compressibility, roughness, induced and profile drag due to lift, and trim drag and is incorporated as part of the GASP sizing program. Table 2 presents, in tabular form, the drag build up for the sized Flatbed aircraft at the design condition, $M = 0.82$, $h = 10668$m (35,000 ft.), $C_L = 0.425$. Based on previous Lockheed experience a wing span efficiency of $e \doteq 0.92$ was utilized in this study. Figure 30 presents the drag polars for several Mach numbers.

Figure 31 compares the drag characteristics and cruise efficiency of the Flatbed and three reference aircraft used in this study with existing, jet-powered Lockheed aircraft. It is observed that the estimated drag levels used in this study compare well with the state-of-the-art for conventionally designed cargo aircraft. The effects of drag on some of the unique features of the various Flatbed aircraft configurations and backbone are discussed in the following paragraphs of this section.

The GASP model sized and optimized Flatbed with the general output summary given by Appendix A. In the context of this study, the airplane was sized or balanced so that fuel available equals the fuel required to perform the specified mission profile of Figure 32.

A complete parametric sizing of the Flatbed airplane was not within the scope of the study. Therefore, parameters such as aspect ratio, sweep angle, taper ratio and wing loading were not evolved but were predetermined based on previous Lockheed studies. The selected geometric values in Figure 33 are representative of aircraft designed

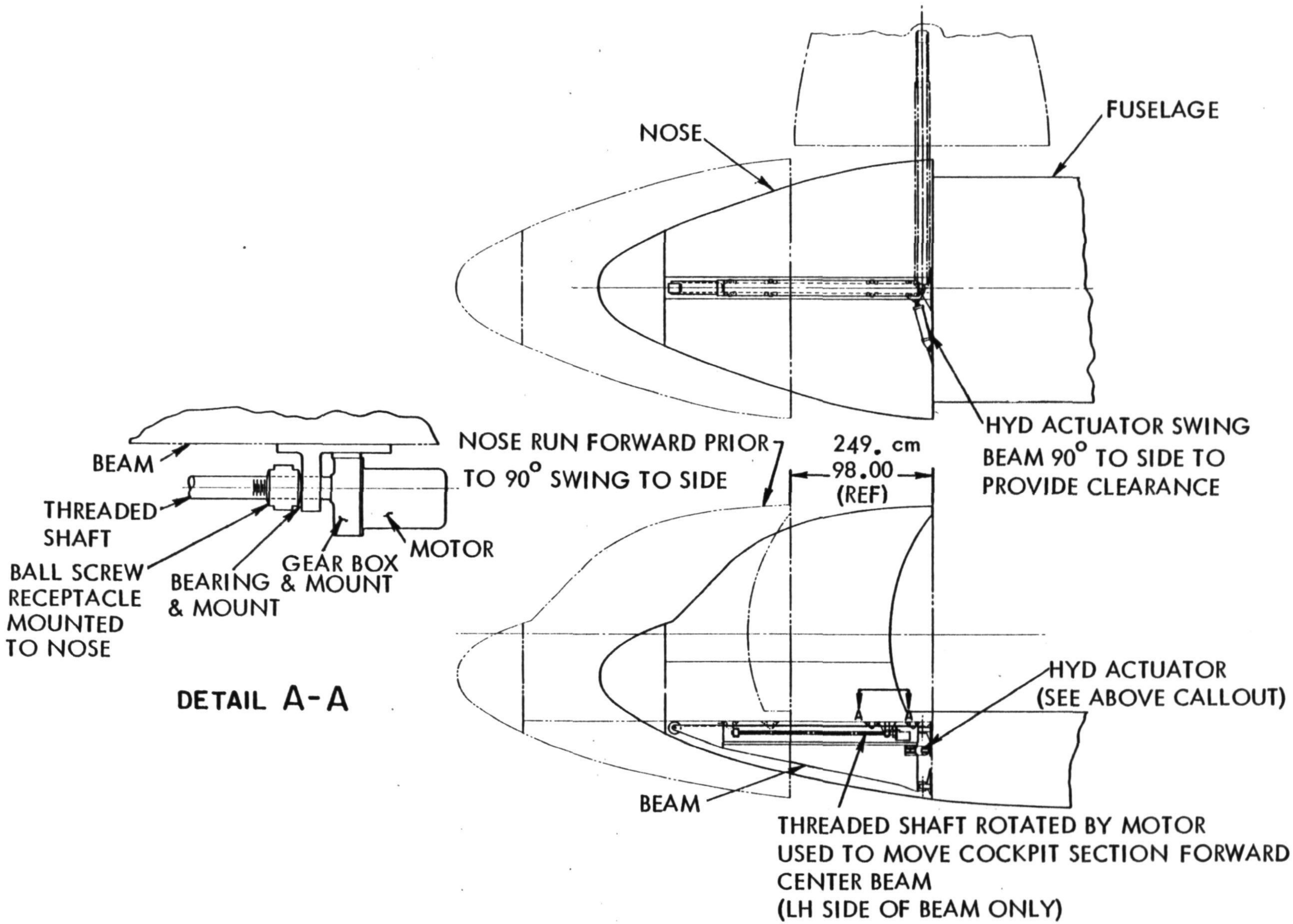


Figure 29 Schematic - Cockpit Section Hinge Mechanism

Table 2 Flatbed Point Design Drag Build-Up

PASSENGER MODULE

$M_{DES} = 0.82$

$ALT_{CRUISE} = 35{,}000$ FT.

$S = 2717$ FT.^{2}

SUBSONIC FORM AND FRICTION DRAG		.01316
INTERFERENCE		.0006
AERODYNAMIC ROUGHNESS		.00072
TRIM EFFECTS		.0012
COMPRESSIBILITY		.0010
PROFILE DRAG		.01668
PROFILE DRAG DUE TO LIFT		.00012
INDUCED DRAG, $C_L = .425$		.00781
DESIGN POINT DRAG, C_D	=	.02461

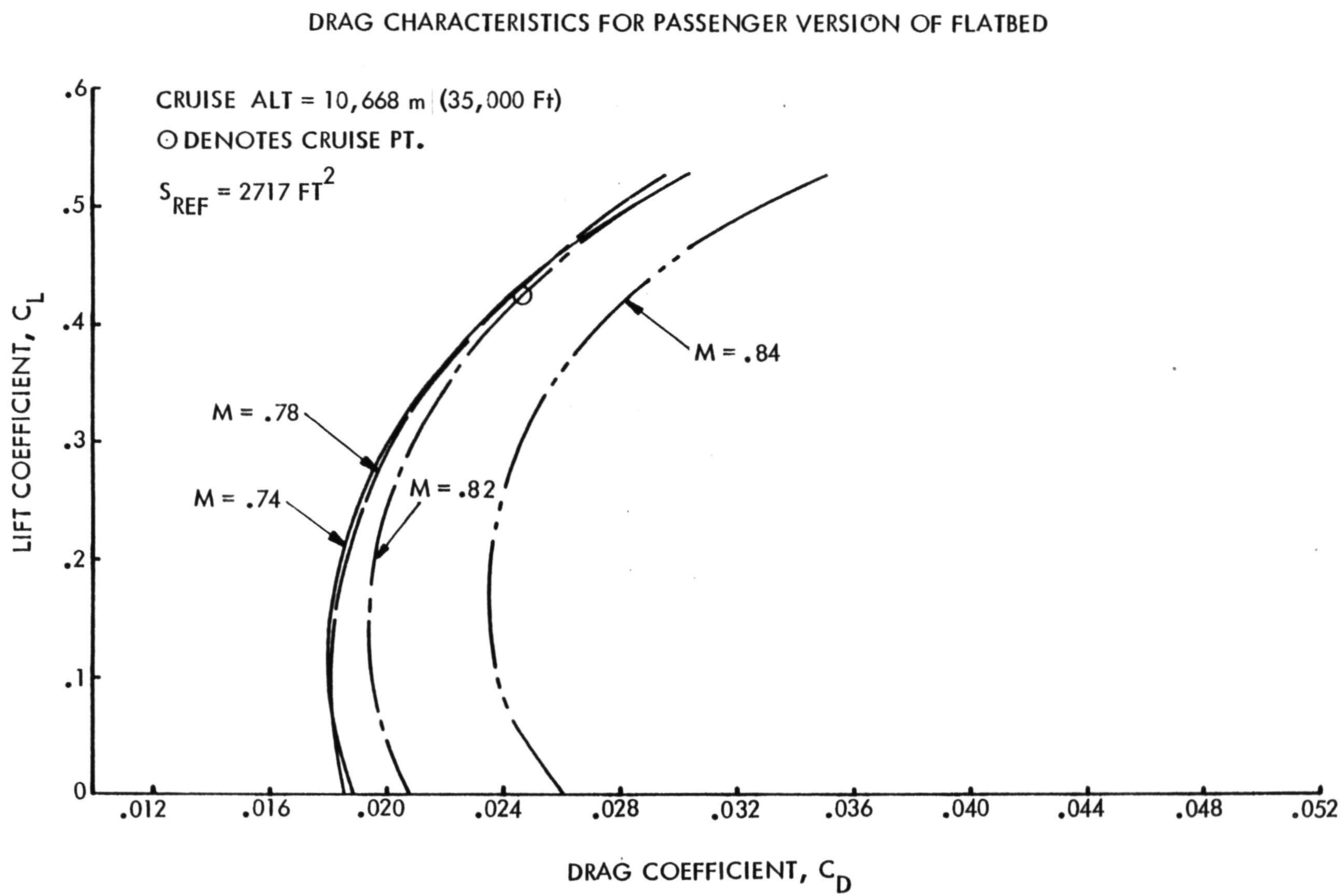


Figure 30 Drag Polars for PAX Flatbed

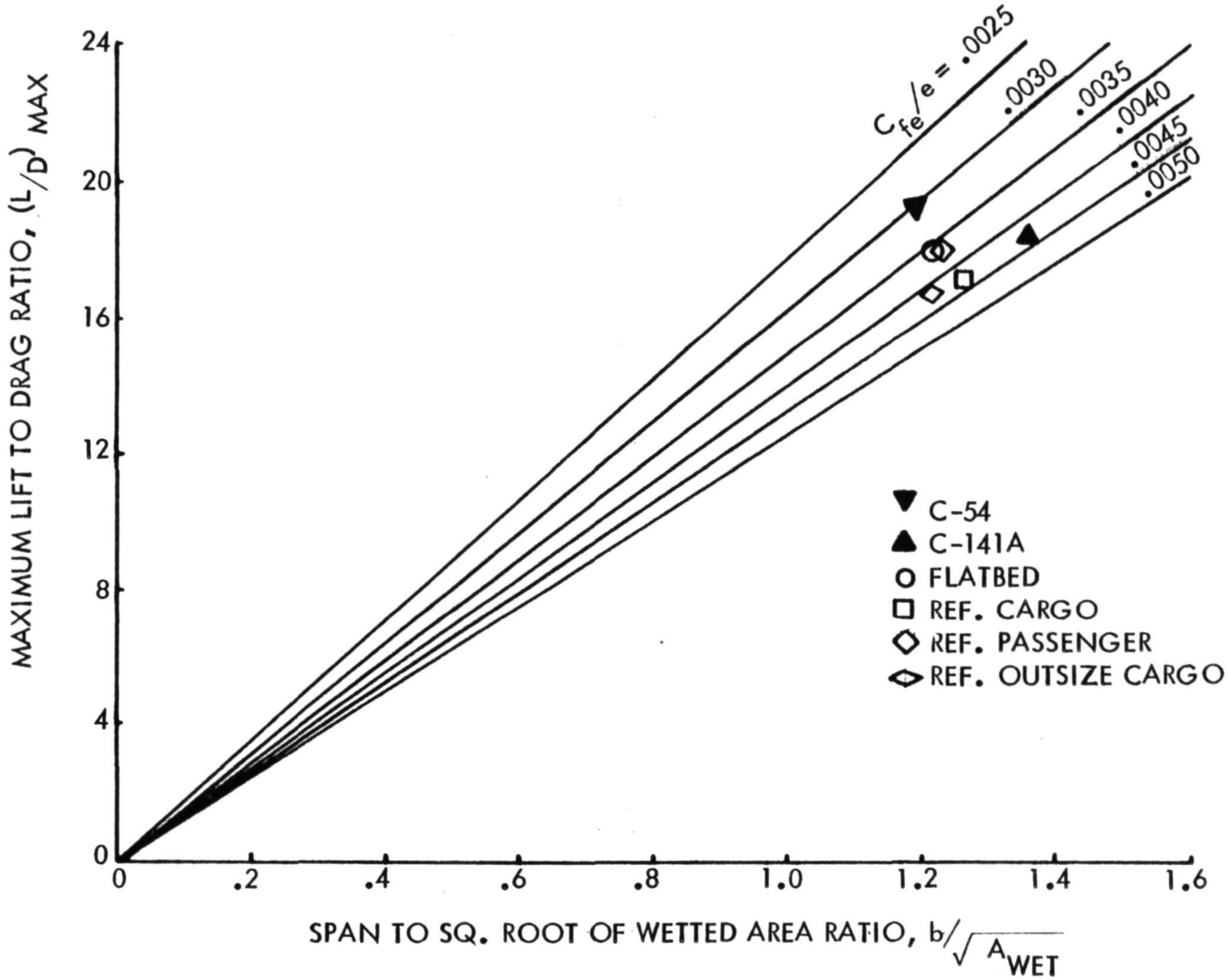


Figure 31 Cruise Efficiency - Comparison with State-of-the Art Aircraft

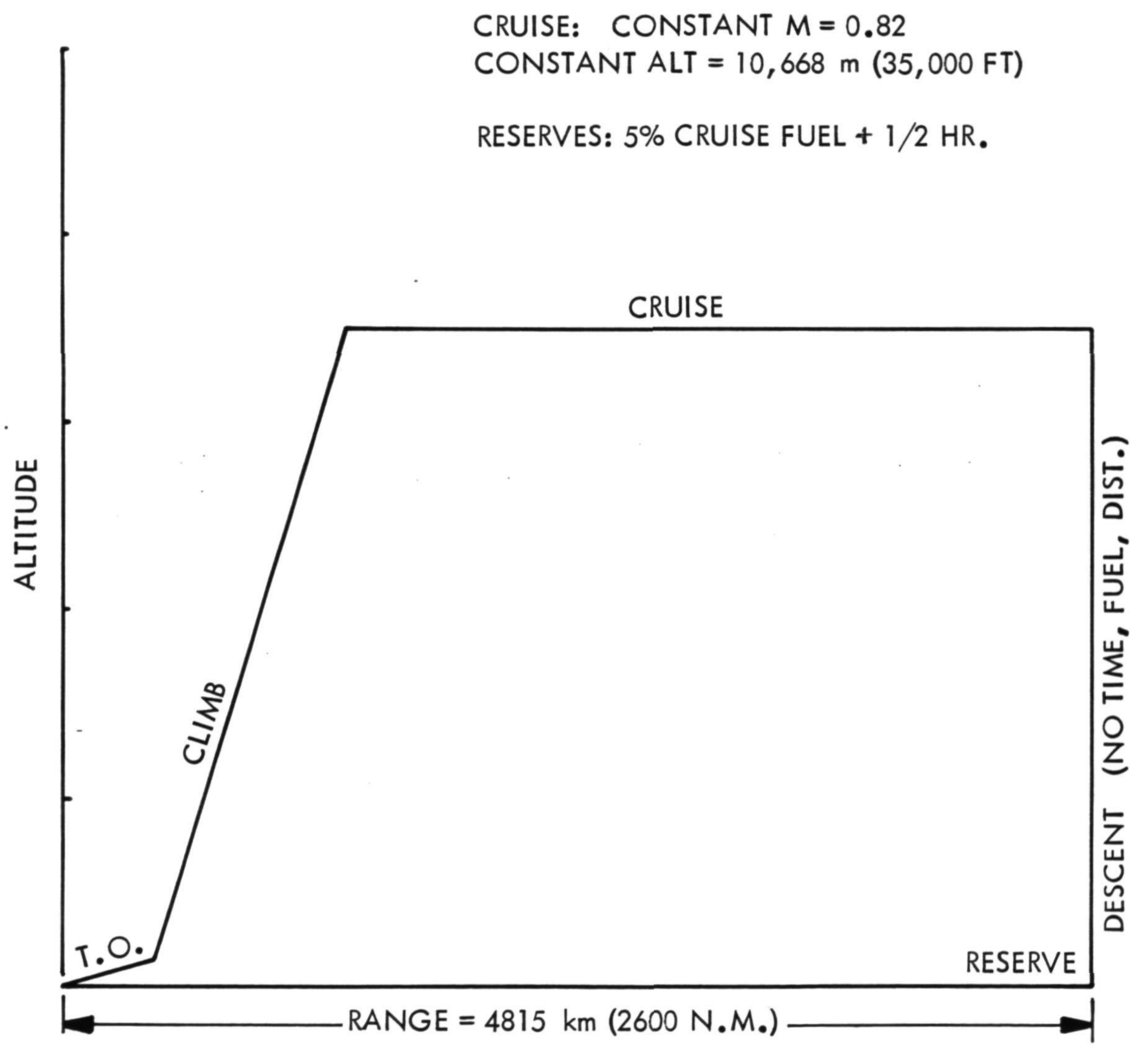


Figure 32 Mission Profile

WING CHARACTERISTICS

S_{REF} = 252 Sq m (2717 Sq Ft) (BASIC)

$S_{PLANFORM}$ = 270 Sq m (2911 Sq Ft) (TOTAL)

$\Lambda\ c/4 = 25^{\circ}$

$\lambda = .402$

$AR = 8.0$

$t/c_{MEAN} = .1057$

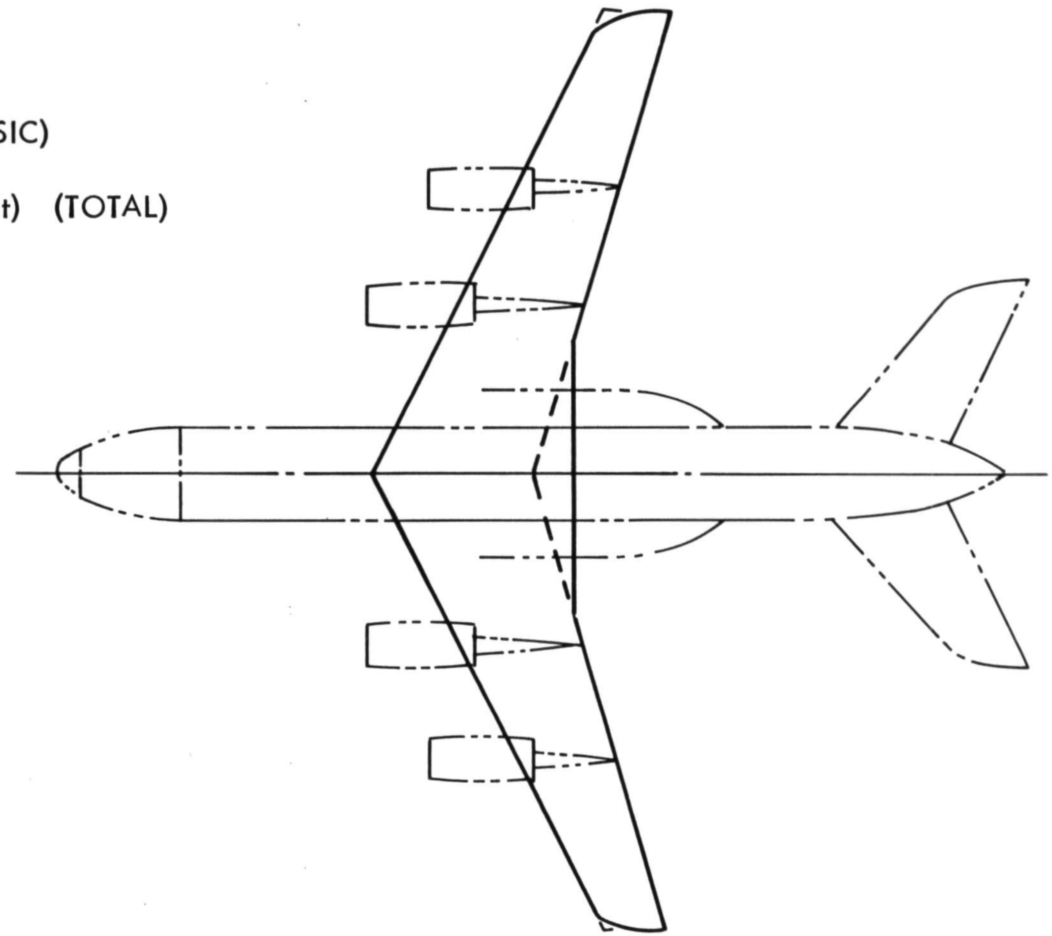


Figure 33 Flatbed Basic Wing Characteristics

for the 1990 time period. These same parameters apply to the reference passenger and cargo airplanes used for the comparative purposes of this study.

For these studies, the wing airfoil is a representative supercritical section designed. to the Flatbed mission requirements in terms of Mach number and lift coefficient. The maximum lift coefficient is 3.0. The empennage airfoil is a representative symmetrical section designed for low trim drag at cruise conditions.

The CFM-56 engine was selected as the powerplant for this study. It was scaled from the basic uninstalled rating of 97,900N (22,000 lb), (sea level, static) to the required rating in the sizing process. For the Flatbed airplane, the rating is 91,344N (20,535 lb).

Final General Arrangement, Backbone - As a result of GASP analyses, the Flatbed backbone was sized and a final general arrangement made. This included correct wing and empennage geometry. The result is given by Figure 34.

The study of the final arrangement included a check of the engine's exhaust velocity and temperature profiles to assure that these had no adverse impact on the empennage. Figure 35, displaying a plot of the exhaust velocity and temperature profiles as related to the Flatbed geometry, shows no high temperature or velocity effects on the Vee tail. It is thus concluded that the final geometric arrangement of engines is adequate in relation to the tail. These data are specifically applicable to the CFM 56 engine and are taken from Reference 6.

Component Design Details

Component Structural Arrangement - Typical structural arrangement layouts were made of the wing, empennage, fuselage, and cockpit section. Although the structural members were not sized, the arrangement of structure is pertinent to the study and representative of the state-of-the-art.

Wing - As shown by Figure 36, the wing is of two-spar construction with the ribs running perpendicular to the sweep angle. The exposed portion of the wing is one piece and connects to a center wing structural box of multi-spar and rib design. Leading and trailing edge flaps are attached to the front and rear beams respectively in conventional manner. Engine pylons are attached to special wing ribs running streamwise to reduce the "kick" loads otherwise associated with ribs perpendicular to the spars at pylon attach points.

Empennage - Details of the empennage structural arrangement are given by Figure 37. Of two-spar construction with perpendicular ribs, the exposed empennage portions are connected to the center box. The two-piece double hinged ruddervator is attached to the rear spar by conventional means.

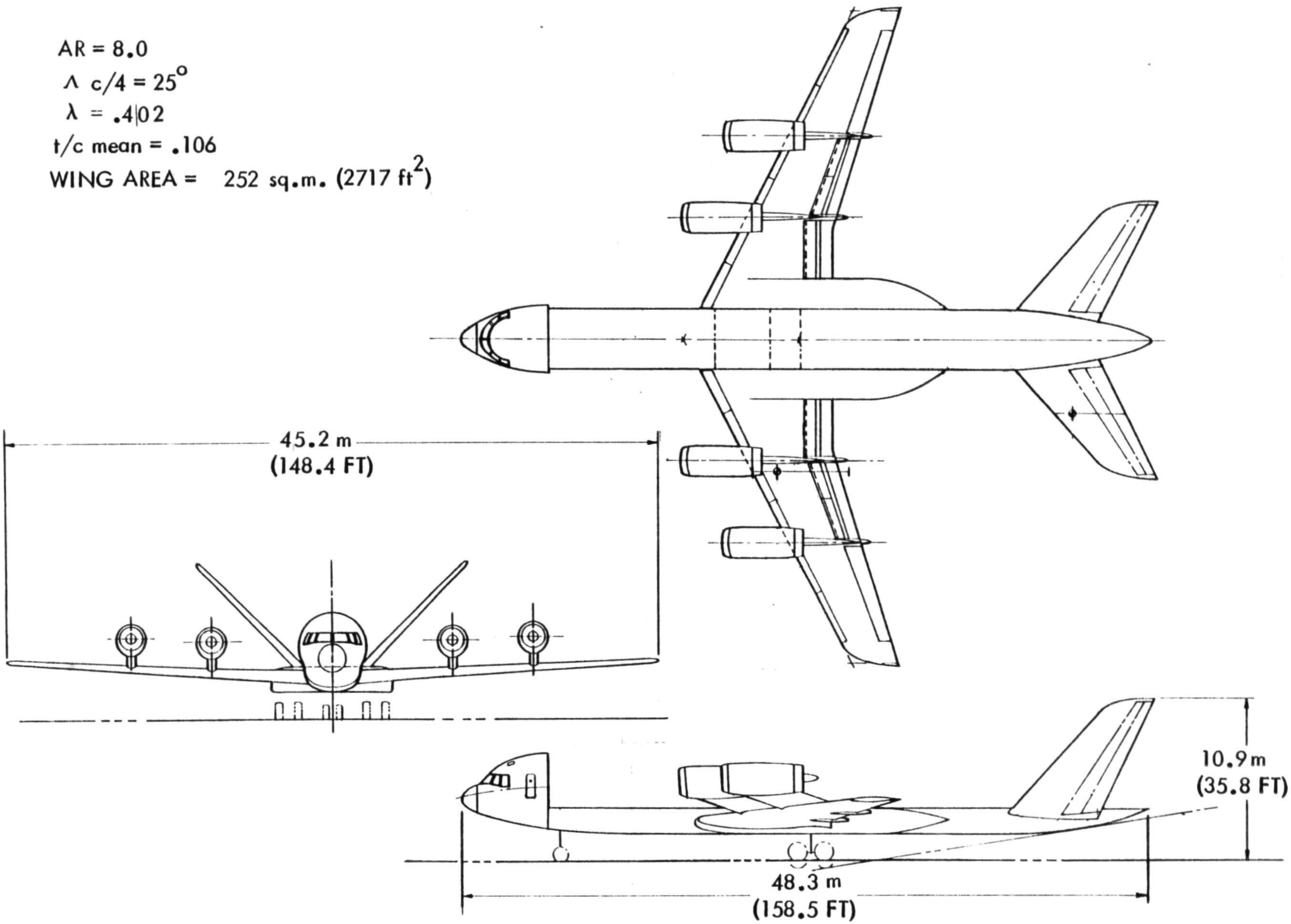


Figure 34 Flatbed Backbone - General Arrangement

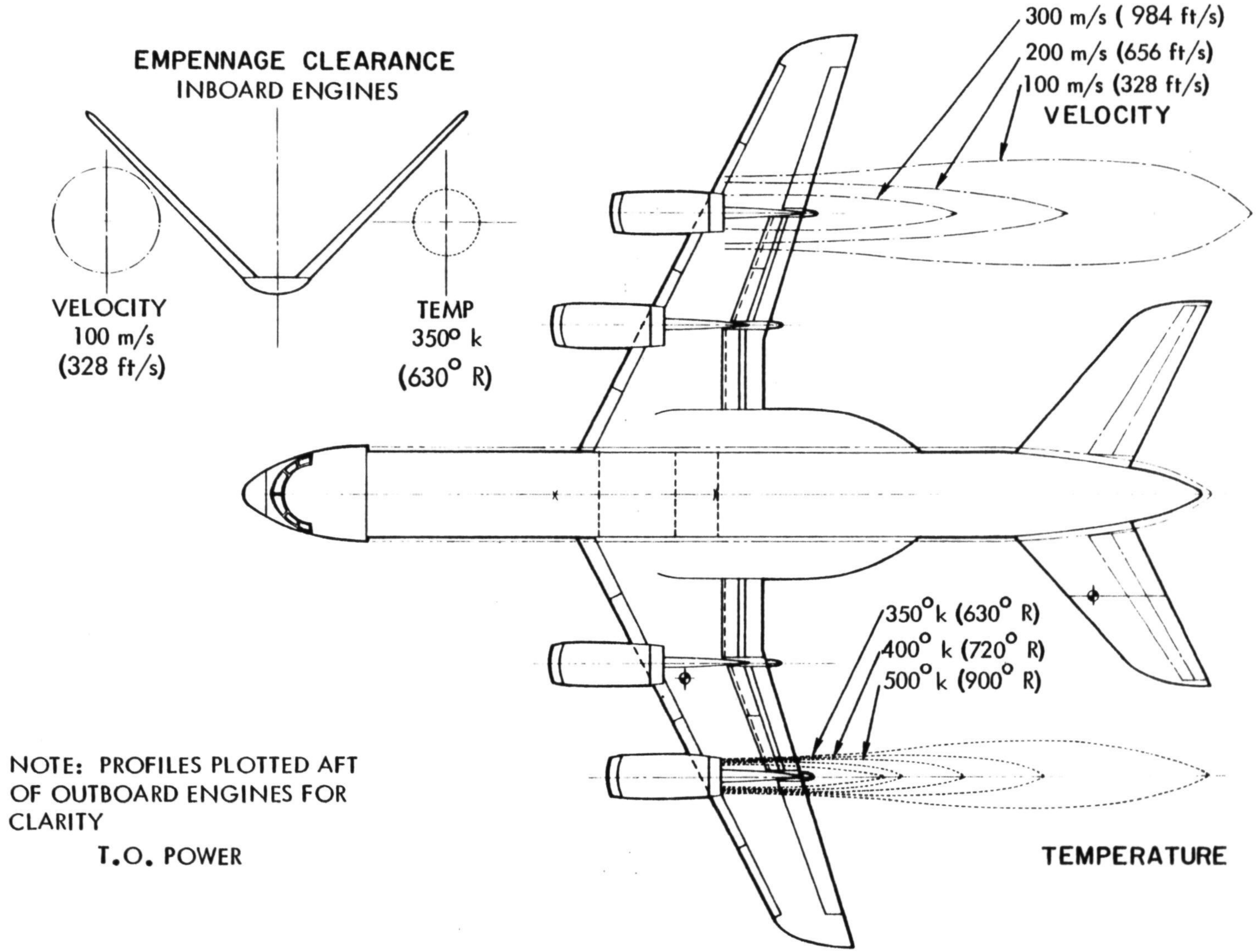


Figure 35 Engine Exhaust Temperature and Velocity Profiles

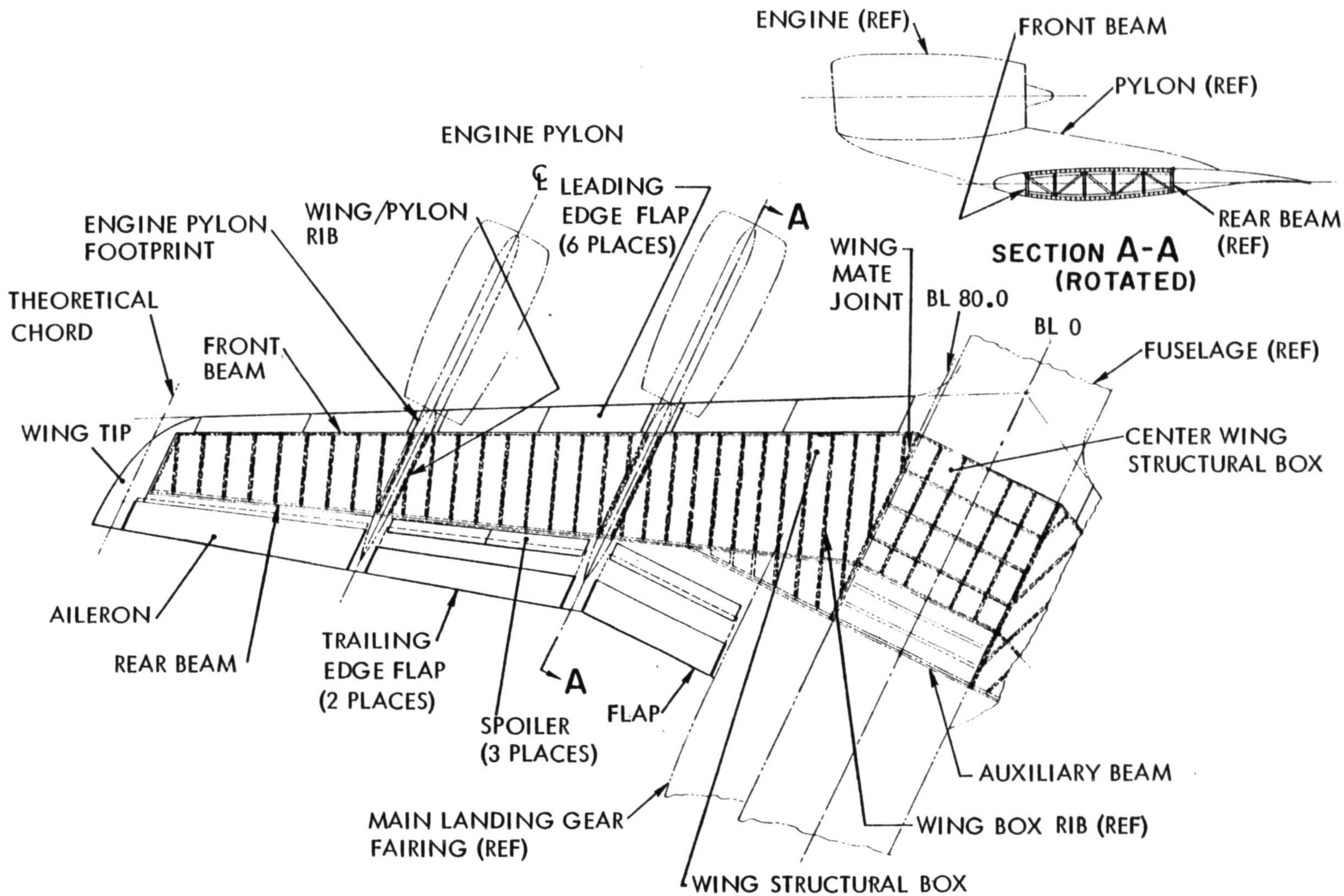


Figure 36 Wing Structural Details

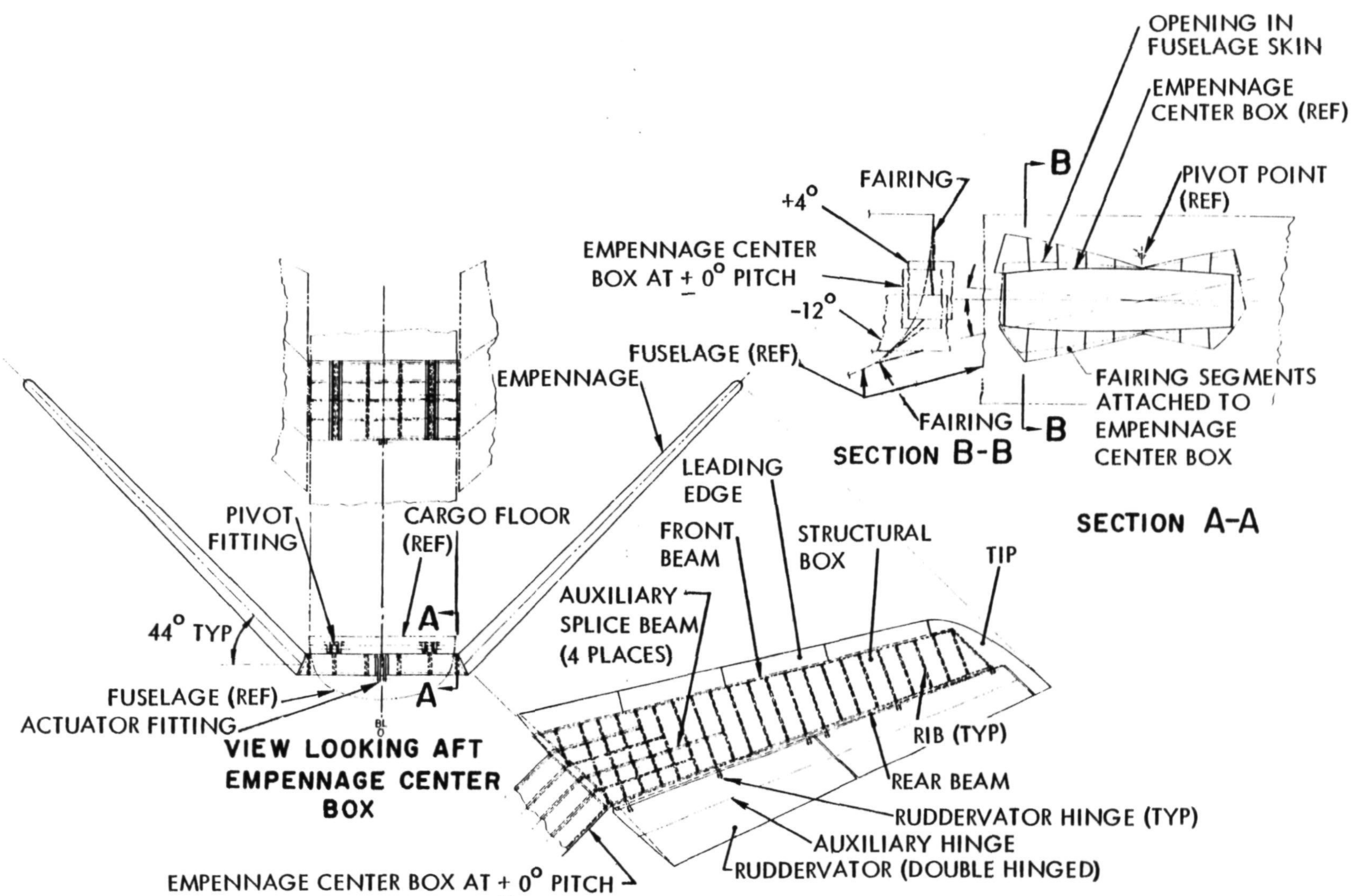


Figure 37 Empennage Structural Details

The incidence of the entire Vee tail may be adjusted in flight to provide trim in the longitudinal mode. Accordingly, the center box is connected to a pair of pivot fittings with the box itself moved by an actuator. Appropriate fairing segments on both port and starboard sides close the open fuselage section.

Fuselage – Primary backbone structural details are given by Figure 38. This figure also provides details of the wing root fairing which houses the retracted main landing gear as well as the horizontal stabilizer pivot and the forward bulkhead which contains the nose to fuselage latches. The structural arrangement is comprised of a left and right keel beam at BL 26 and a centerline keel beam aft of the stabilizer pivot box. Bulkhead spacing is .51 meters (20 inches).

The hinged cockpit/nose section is secured to the bulkhead at FS 320 which contains the environmental duct for pressurizing the nose section. This bulkhead is fitted with 19 latches and a bulb-type seal as well as a control plug receptacle.

Cockpit (Nose) Section – The pressurized cockpit section structural arrangement is given by Figure 39. The pressure bulkhead is convex (forward) with appropriate support members added to efficiently distribute the load. The cockpit underfloor section is unpressurized and is comprised of conventional web and truss design.

Load/Unload Systems – Containers and the passenger module are loaded and unloaded onto the backbone by conventional roller/rail systems. Vehicles are driven aboard using left and right ramps each 76 cm (30 in.) wide. The airplane can load directly from existing passenger or cargo terminal facilities or, alternatively, from flatbed trucks carrying the payload.

Ramps – The use of ramps for loading vehicles is an important consideration. Ramps have been designed for a slope of 17 degrees in accordance with the design requirements of U.S. Army vehicles (Reference 9) to negotiate such a "tip over" angle (Figure 40 and 41). In contrast, conventional aircraft ramps require considerably lesser angles so that large vehicles crossing the threshold do not contact the ceiling of the cargo compartment.

Two laterally disposed and adjustable ramps may be attached to the backbone. Two and three segment ramps were designed, the former from a 17 degree slope and the latter for a slope of about 11 degrees. Ramp details of design and attachment are given by Figure 42a. The total weight of the two-segment ramp is about 648 kb (1430 pounds). On-board storage could be,typically, achieved using "pockets" (Figure 42b) for a weight penalty of about 272 kg (600 pounds).

Logical design questions include the relative merit of carrying integral ramps. The advantages of integral ramps are their availability and a reduction in logistics. However, the disadvantages (which seemingly outweight the advantages) are: complexity, weight penalty, effect on performance, and the fact that they are not needed for passenger or container missions.

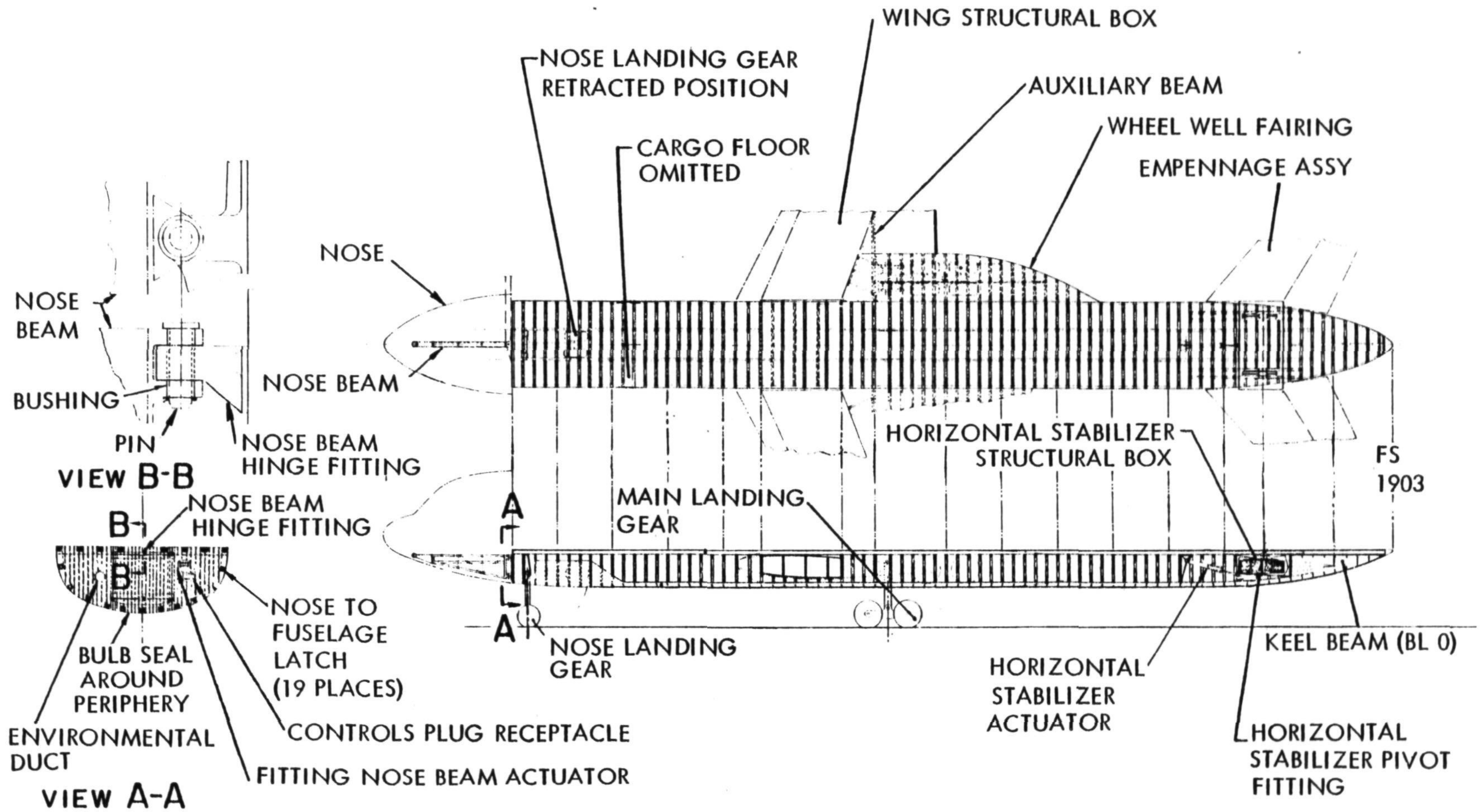


Figure 38 Backbone Structural Details

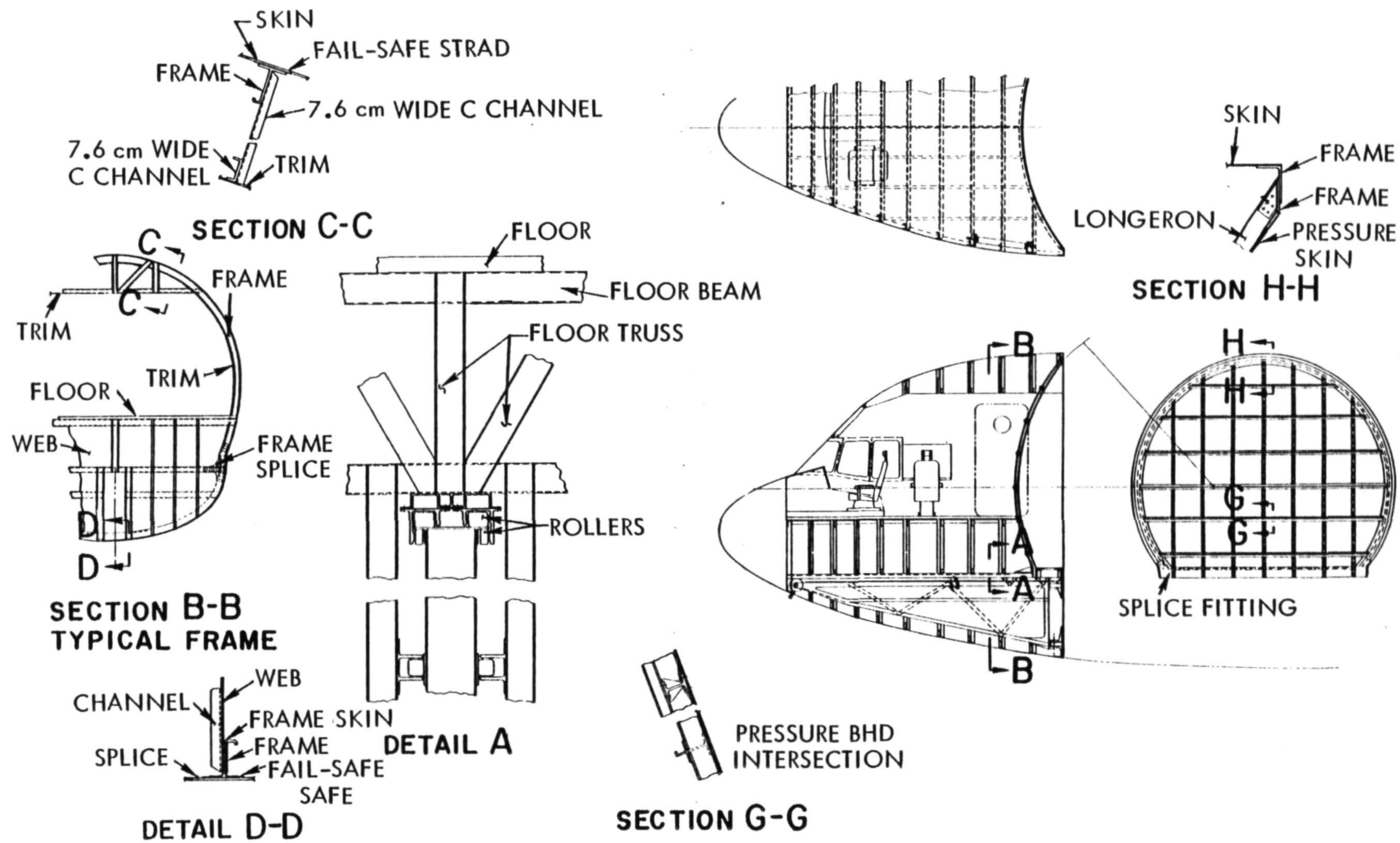


Figure 39 Cockpit Section Details

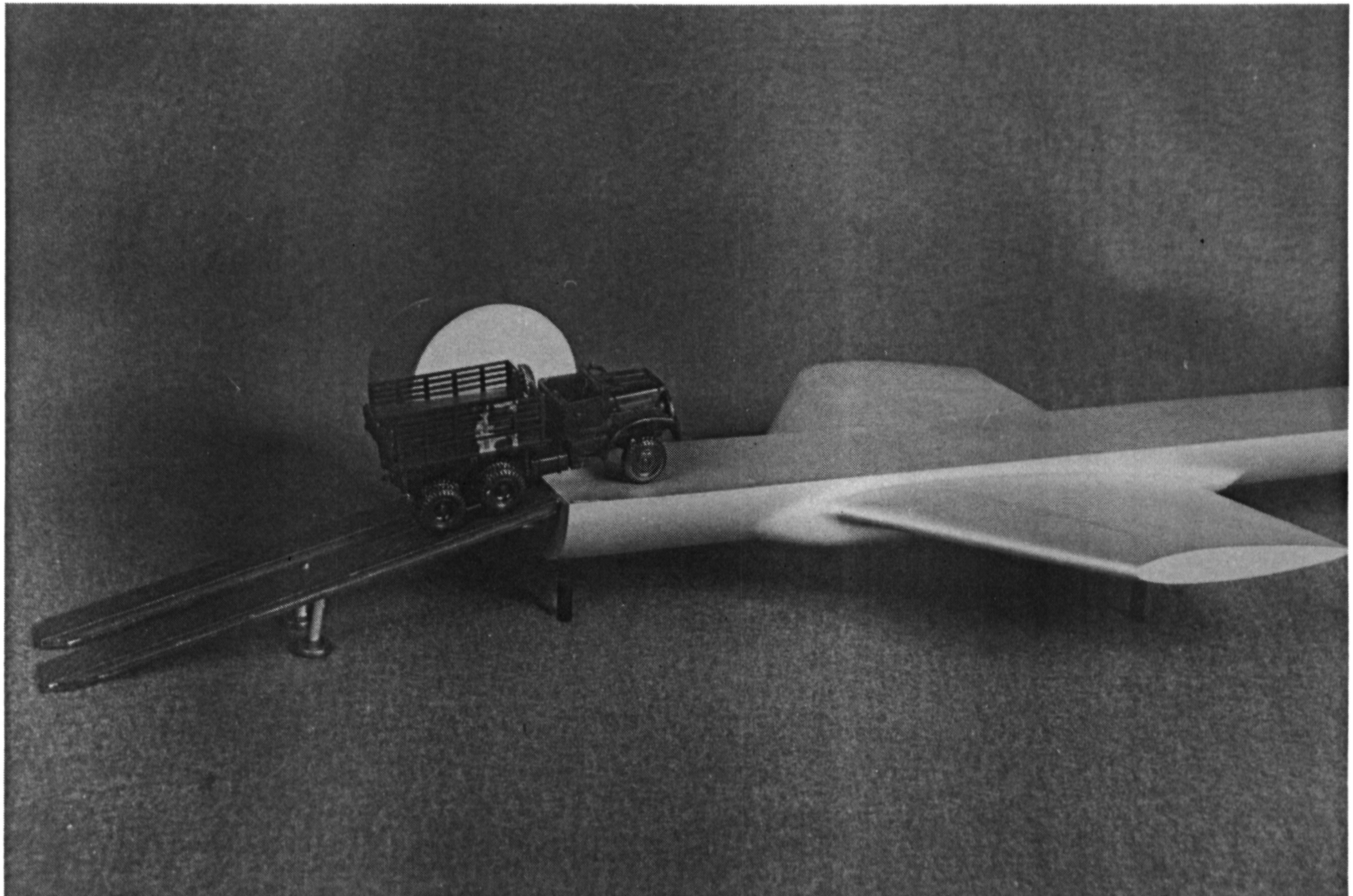


Figure 40 Army Truck Negotiating Ramp to Cargo Bed "Tip Over" Angle

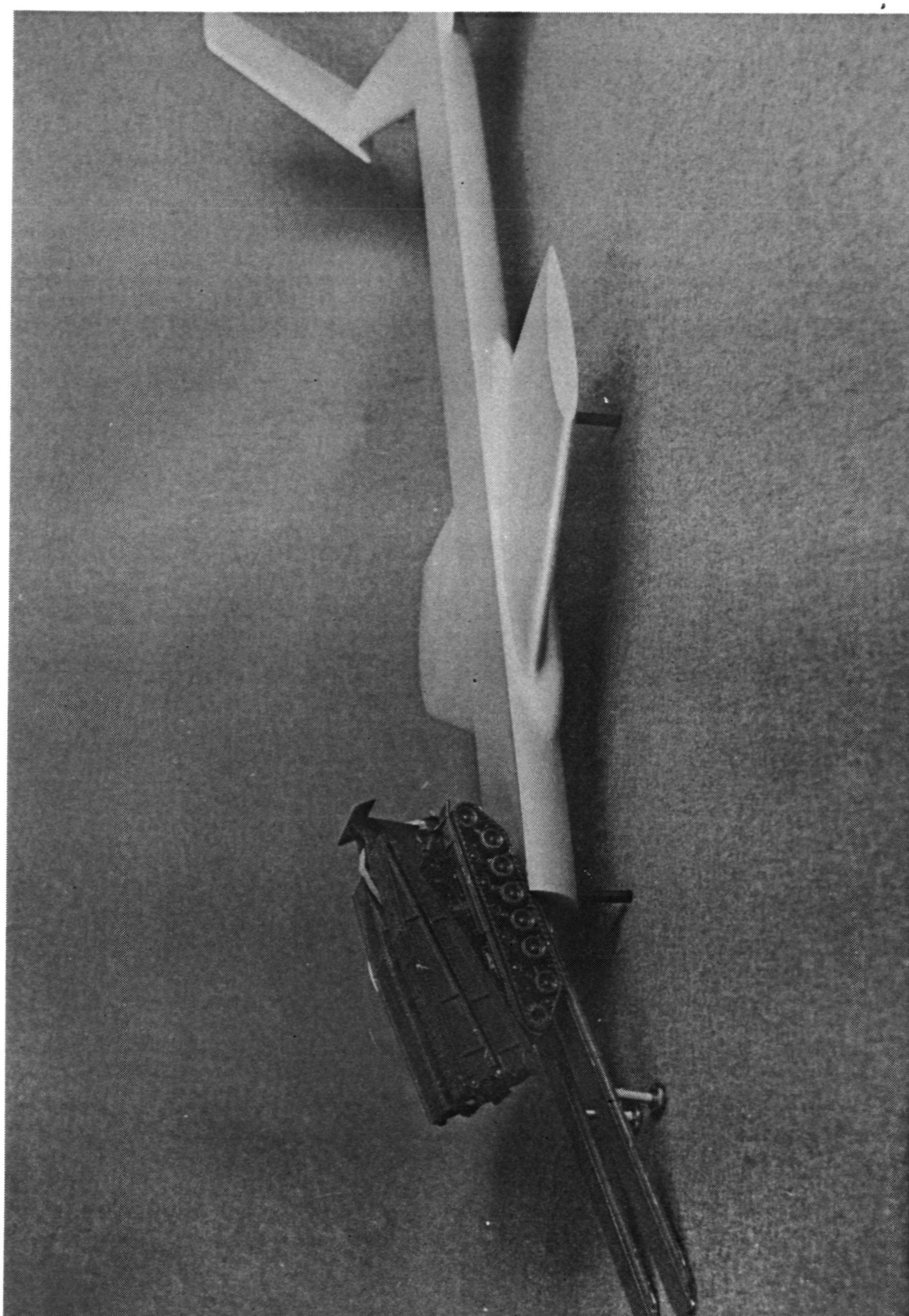


Figure 41 Dimensional Freedom - Roll-On, Roll-Off

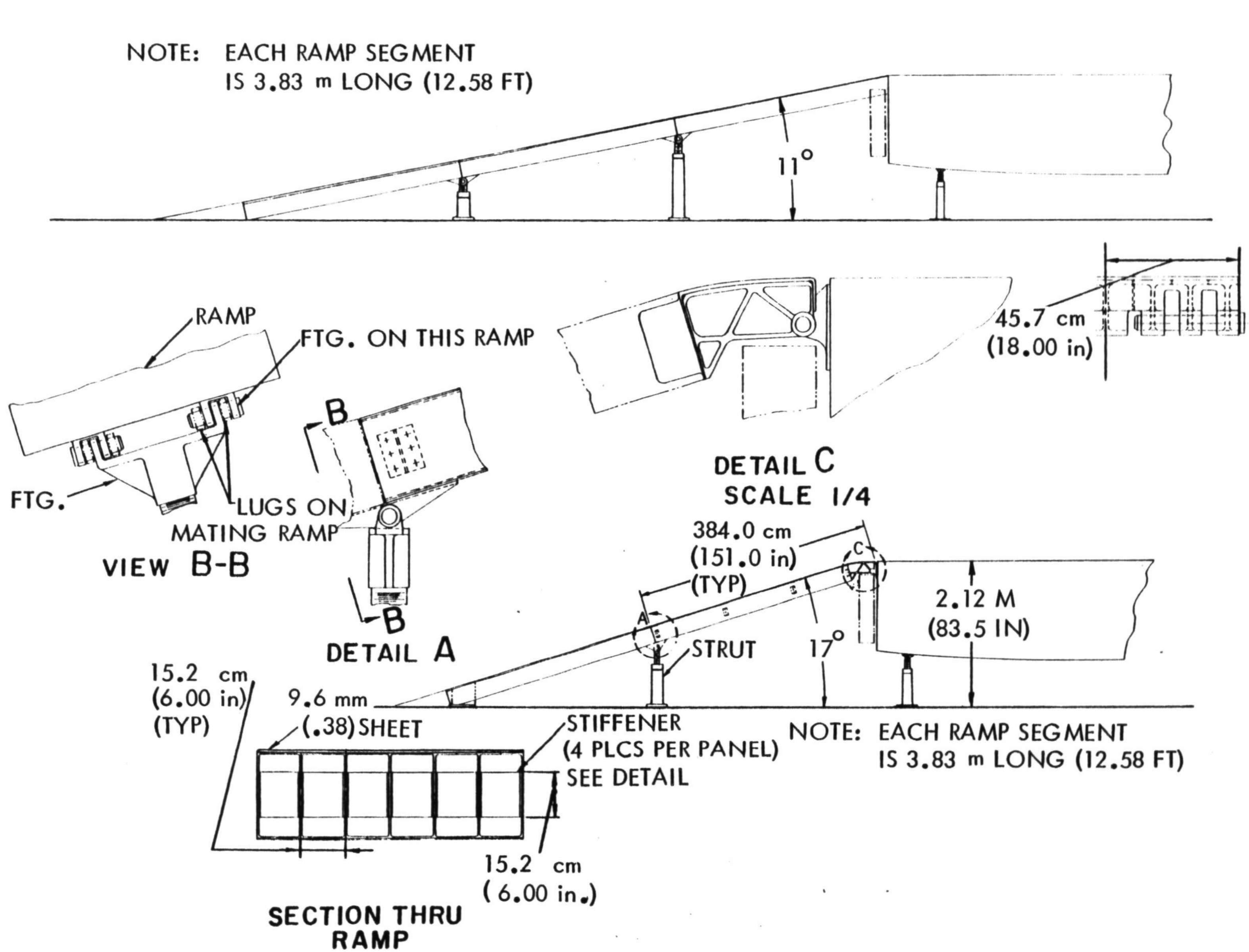


Figure 42a Vehicle Loading Ramp Design

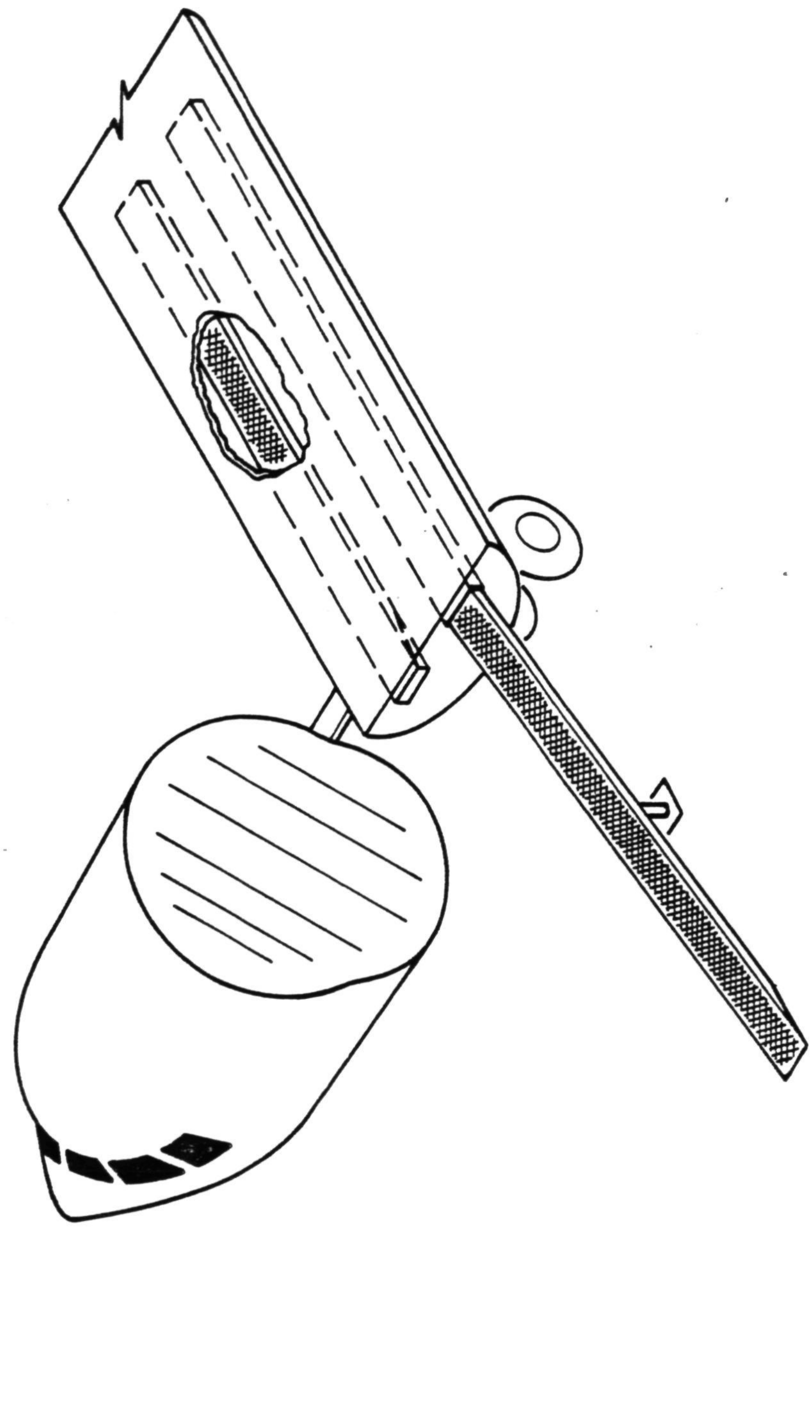


Figure 42b. Backbone "POCKETS" For Ramp Storage

It is recommended that a kit be provided and, accordingly, no weight penalty was assessed the basic backbone.

Cargo Floor Systems - Loading of cargo or the passenger module is facilitated by use of rollers (both powered and unpowered), rails, tracks or guides, and restraint systems. Necessary features for alignment have been conceptually formulated.

Details of the systems are given by Figures 43 and 44. Containers or a passenger module may be slid onto the cargo floor on conventional rollers, 5.08 cm (2 inches) in diameter located on 25.4 cm (10 inches) centers and mounted in channels. These rollers are invertible for flush stowage when carrying vehicular payloads. Rollers are disposed laterally to accommodate the varying widths of containers and the passenger module. Teeter rollers are incorporated into the end of all roller channels.

Cargo (container) restraint rails are located at BL 48.12 (left and right), Figure 43.

The restraint rails and tie down rings are designed to fold into a well in the floor structure (Figure 45) so as to provide a flush floor surface (when required).

The restraint rail is hinged on the lower side within the floor and rotated into loading position manually, and will lock into position automatically. The restraint rail contains restraint pins mounted at intervals so as to engage lock holes within the lower edge of the container and restrain the container against fore and aft and upward loads. The restraint pins are extended and retracted into the container by means of a mechanism mounted on the back side of the restraint rail.

Folding the restraint rail for a flat floor is accomplished by first retracting the restraint pins and then applying a downward force on the operating handle which will release the lock sears allowing the rail to be folded flat.

The passenger module has a guide (Figure 44) attached beneath its floor which rides in a track fitting in the floor of the Flatbed backbone to assure proper lateral positioning of the module during landing and to distribute module pressurization loads into the backbone. The afterbody portion of the backbone has a center guide rail (Figure 43) which is used to secure the module or aft container fairing. Conventional ring-type tie-down fittings are utilized as described by Figure 45. These are located on 101.6 cm (40 inch) centers. Lying flush with the floor, these fittings are capable of handling 11,338 kg (25,000 pounds) loads.

Power rollers have been mounted on the fuselage centerline to facilitate movement of containers and passenger module onto the cargo floor without external force (i.e., manual, winching, etc.). Similar power rollers are assumed to be on the floor of flatbed trucks or loading docks from which cargo is loaded onto Flatbed. The powered rollers are 5.1 cm (2 inches) in diameter, electrically driven, and of 373 watts (1/2 HP) power. With these rollers, the operator of the flatbed truck or loading dock simply

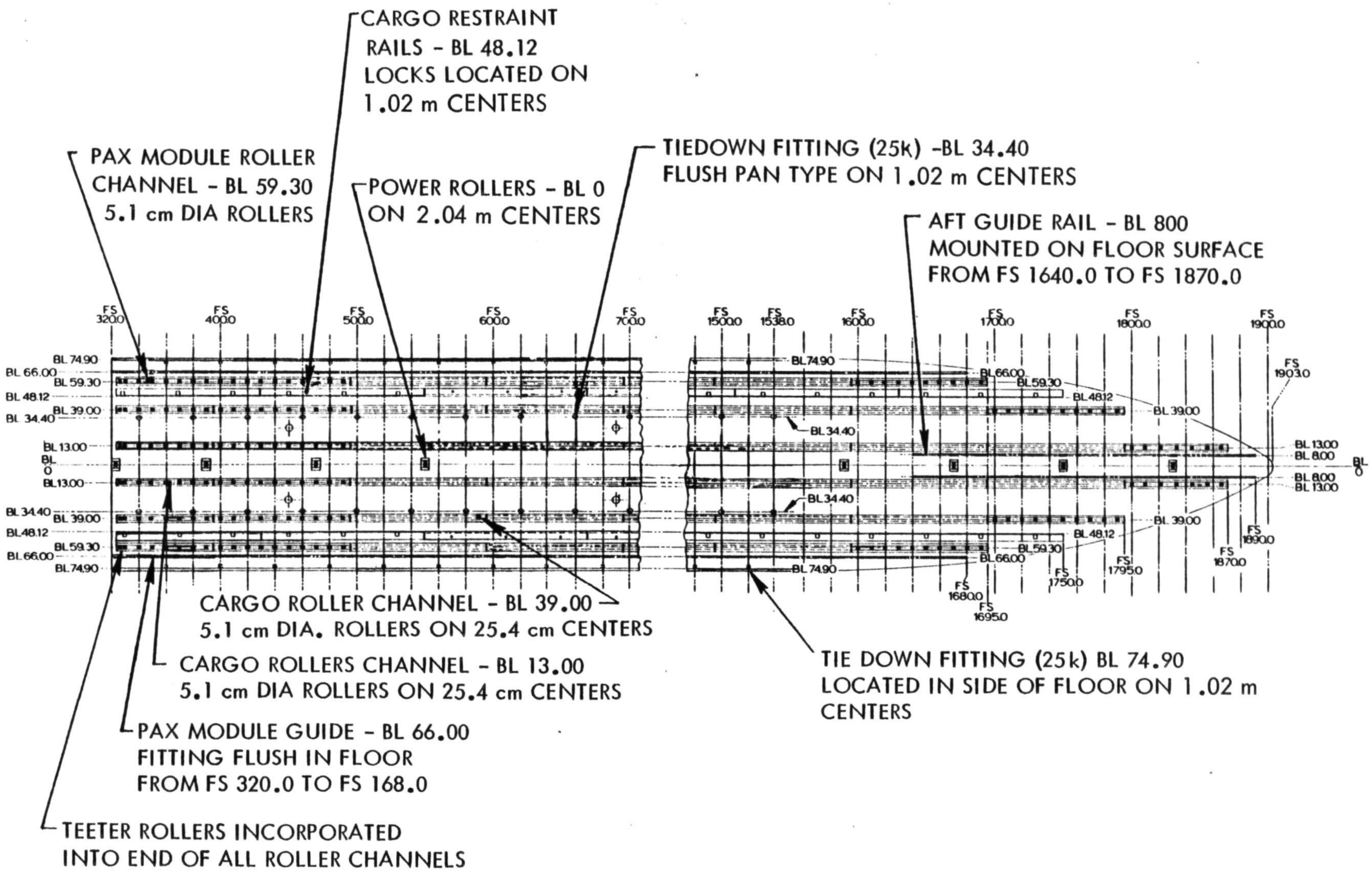


Figure 43 Backbone Cargo Floor Details

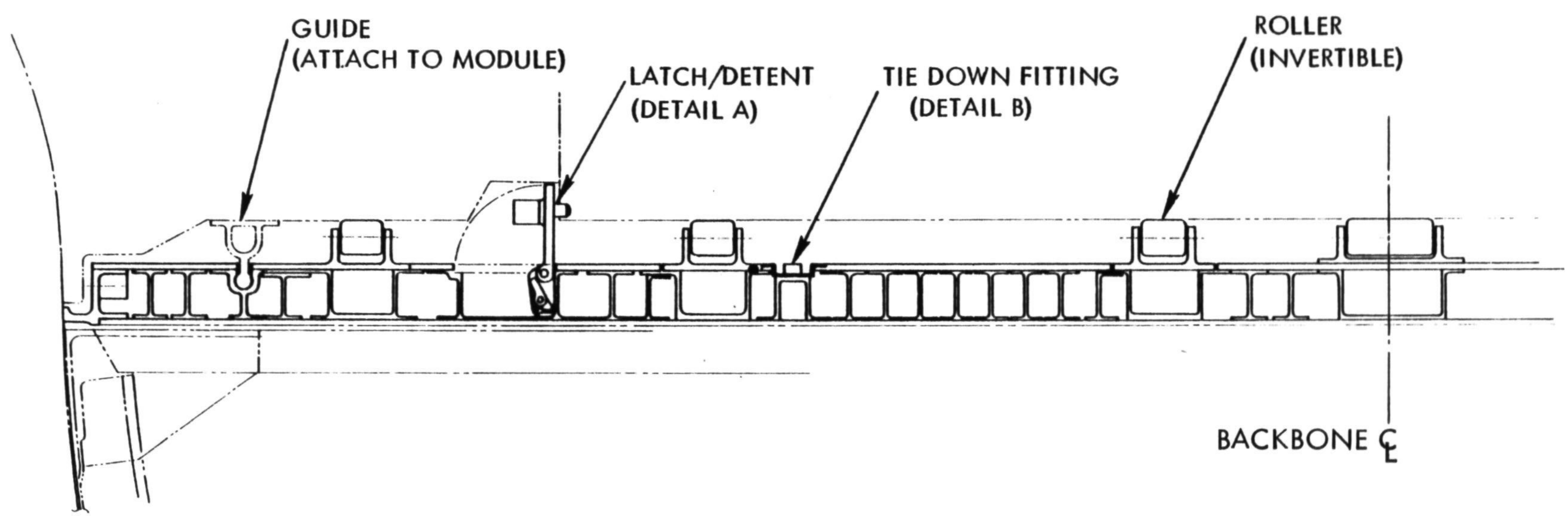


Figure 44 Passenger Module Track/Rail/Latch System

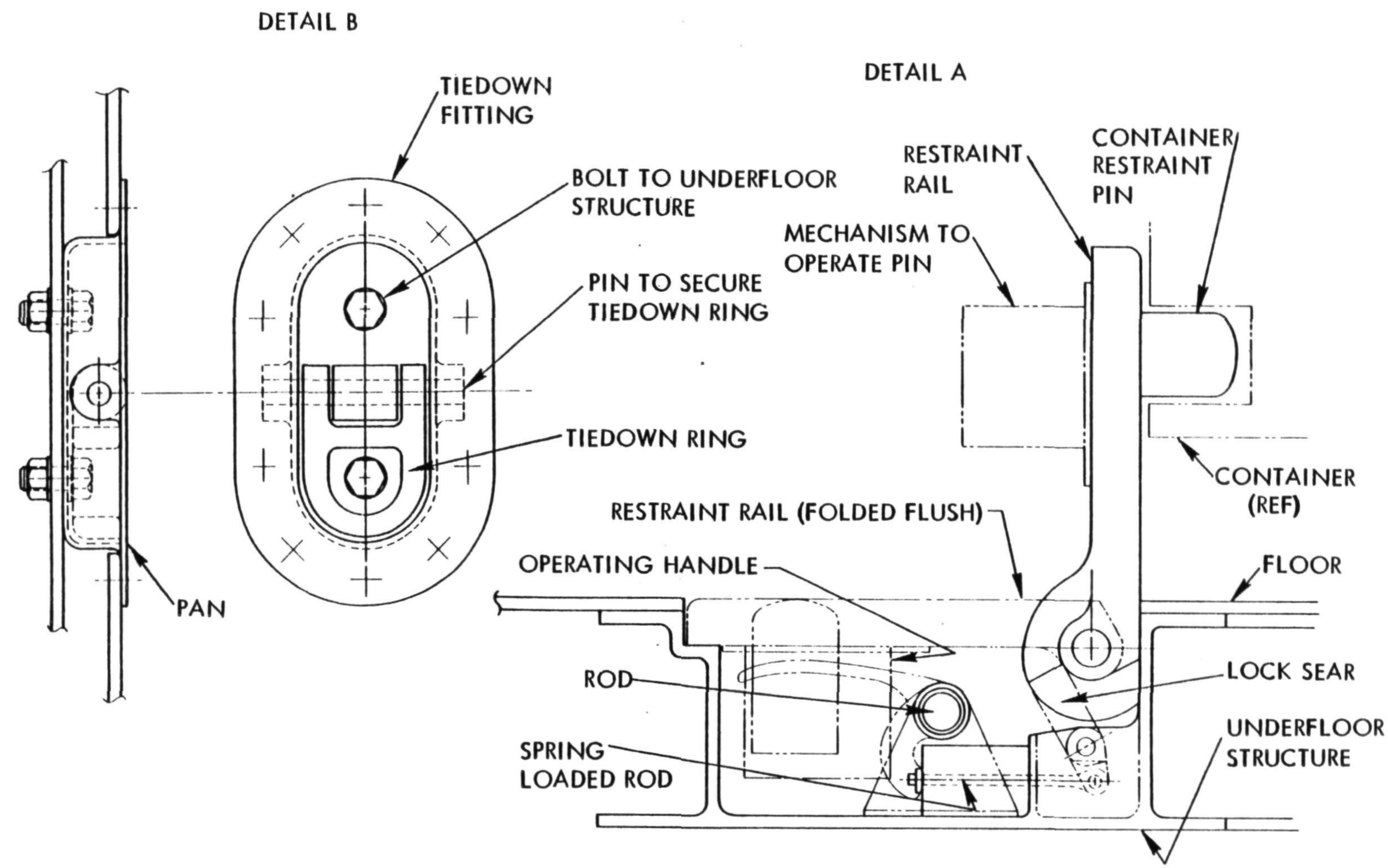


Figure 45 Guide Rail and Tie-Down Ring Details

energizes the system and containers or module begin to move onto Flatbed and continue until fully aboard. Flatbed powered rollers are supplied power either through external power connections or the onboad APU.

Alignment - When the flatbed truck brings a passenger module or cargo containers to the Flatbed backbone for loading (or during unloading) careful vertical and lateral alignment is necessary to avoid binding. In addition, it is necessary for the bed of the truck and the backbone cargo floor to be continually co-equal in height. A solution is suggested which features a sliding bed on the truck mounted atop ball rollers (Figure 46). The bed is hydraulically actuated at both front and rear ends so that the entire bed may be moved laterally at either end. In addition, the front and rear ends of the bed feature vertical positioning, which permits the relative height of truck and backbone to be adjusted to compensate for changes in load.

Alignment is achieved by a laser system on the truck aiming on a reflector on the backbone.

Environmental Systems - Several systems to provide proper environment (i.e., pressurization and temperature) were considered. These included carriage of such equipment in each passenger module or each pressurized cargo container. However, the complexity, weight penalty, mechanics and electronics of connections, and logistics militated against this approach.

Accordingly, a system was devised which utilized existing air sources in each backbone. The system utilizes either engine bleed for flight conditions or APU output for ground conditions. Basically, two ducts running fore and aft are connected to the air sources (Figure 47). These ducts are laterally disposed at BL 26 and are 12.7 cm (5 inches) in diameter, longitudinally placed at FS 450, 690, 930, 1170, and 1410.

System connections are made automatically upon actuation of a control aboard the module or container. As described by Figure 47, the module is fitted with a housing in the lower floor containing a pneumatically actuated duct sleeve. Upon actuation, the duct is lowered to the cargo floor of the backbone to mate with the outlet. Close alignment is achieved by means of a rubber seal. The flapper valve permitting flow between the backbone and module is opened by a pin located in the module's duct sleeve.

Maintenance - The Flatbed concept itself should not create any significant maintenance problems in the usual sense. However, there is one unusual problem on the large exposed cargo floor generated by weather. Specifically, a means is needed on the ground to protect the exposed cargo floor from snow, sleet, and freezing rain, as well as normal rain. The severe elements would obviously clog roller and rail systems and inhibit loading. Normal rain might freeze upon ascent to cruising altitude and jam loading/unloading mechanisms. Should the ground temperature be sufficiently low and the time for descent short these systems would then not function properly.

Although the onboard environmental system could supply heat, an alternative system is described by Figure 48. Essentially, a rolled tarpaulin of 0.25 mm nylon material is

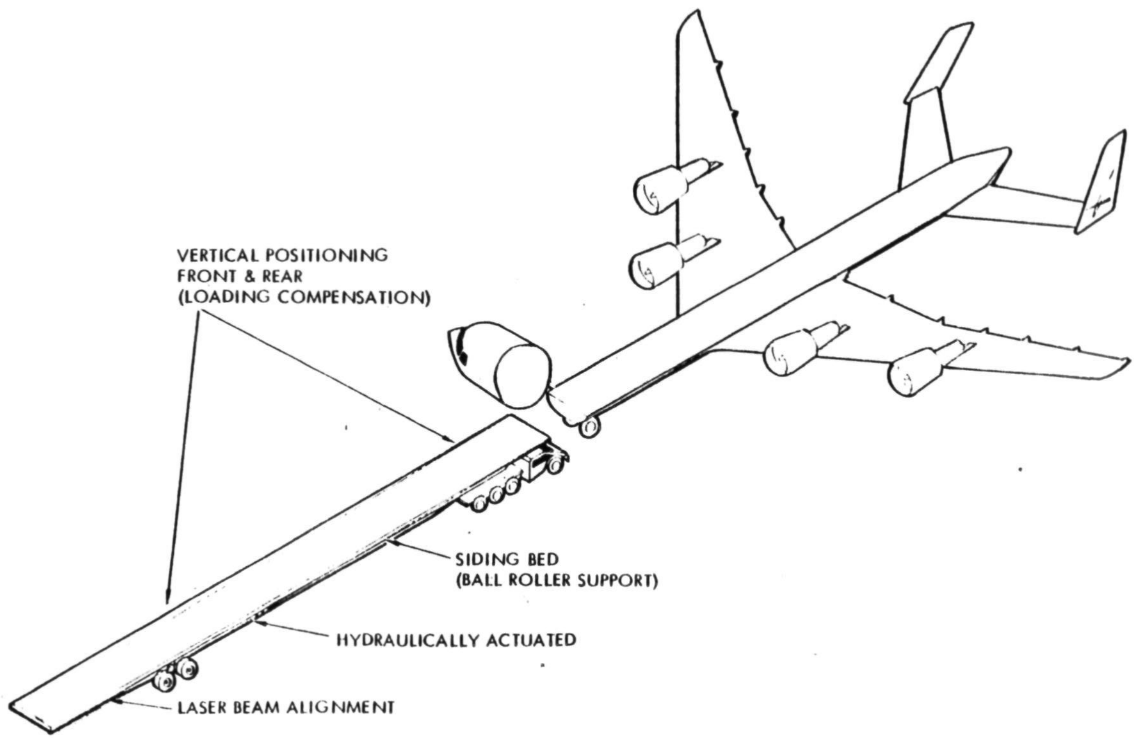


Figure 46 Alignment - Loading Vehicle/Platform with Backbone

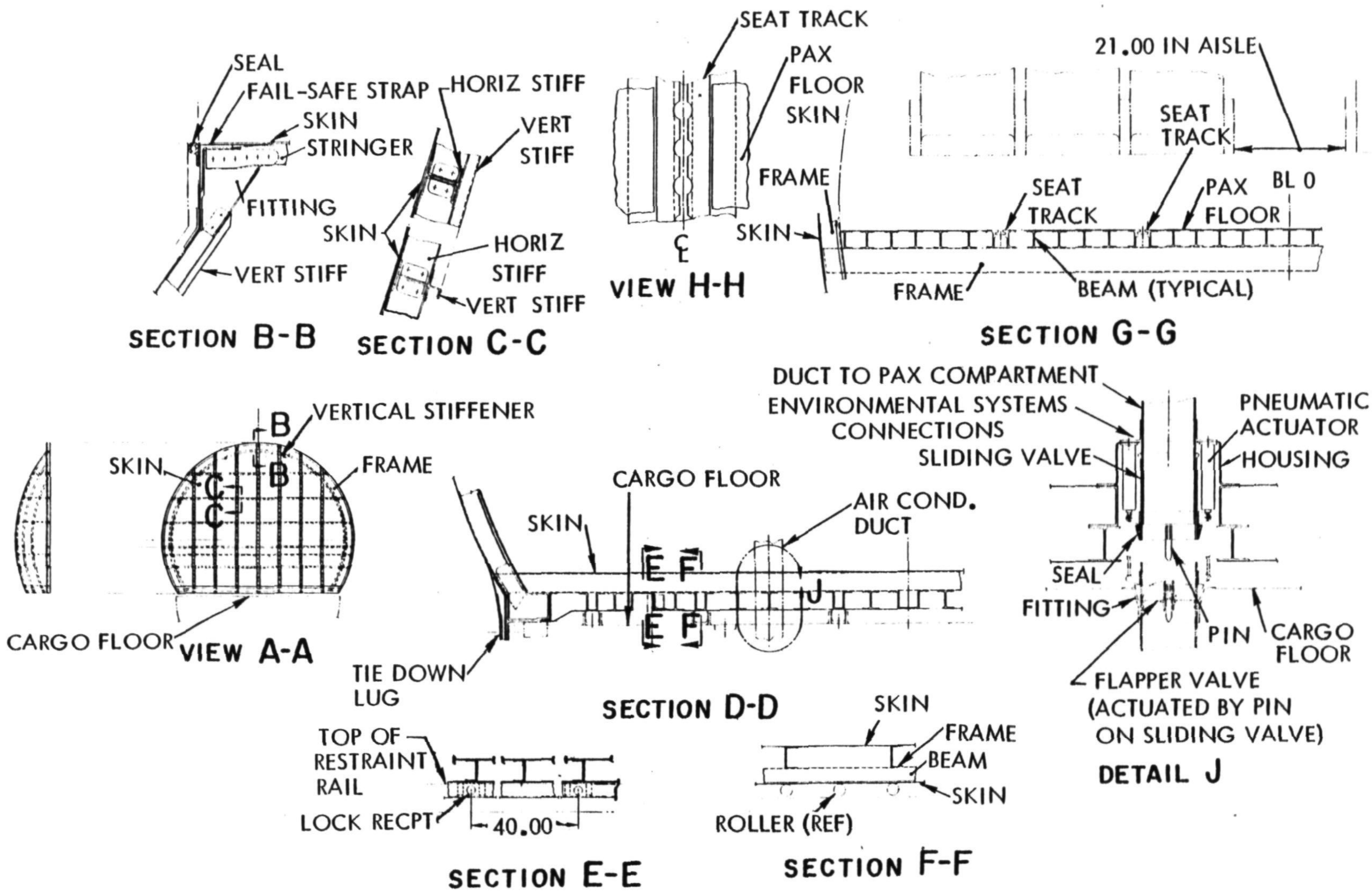


Figure 47 Passenger Module Details

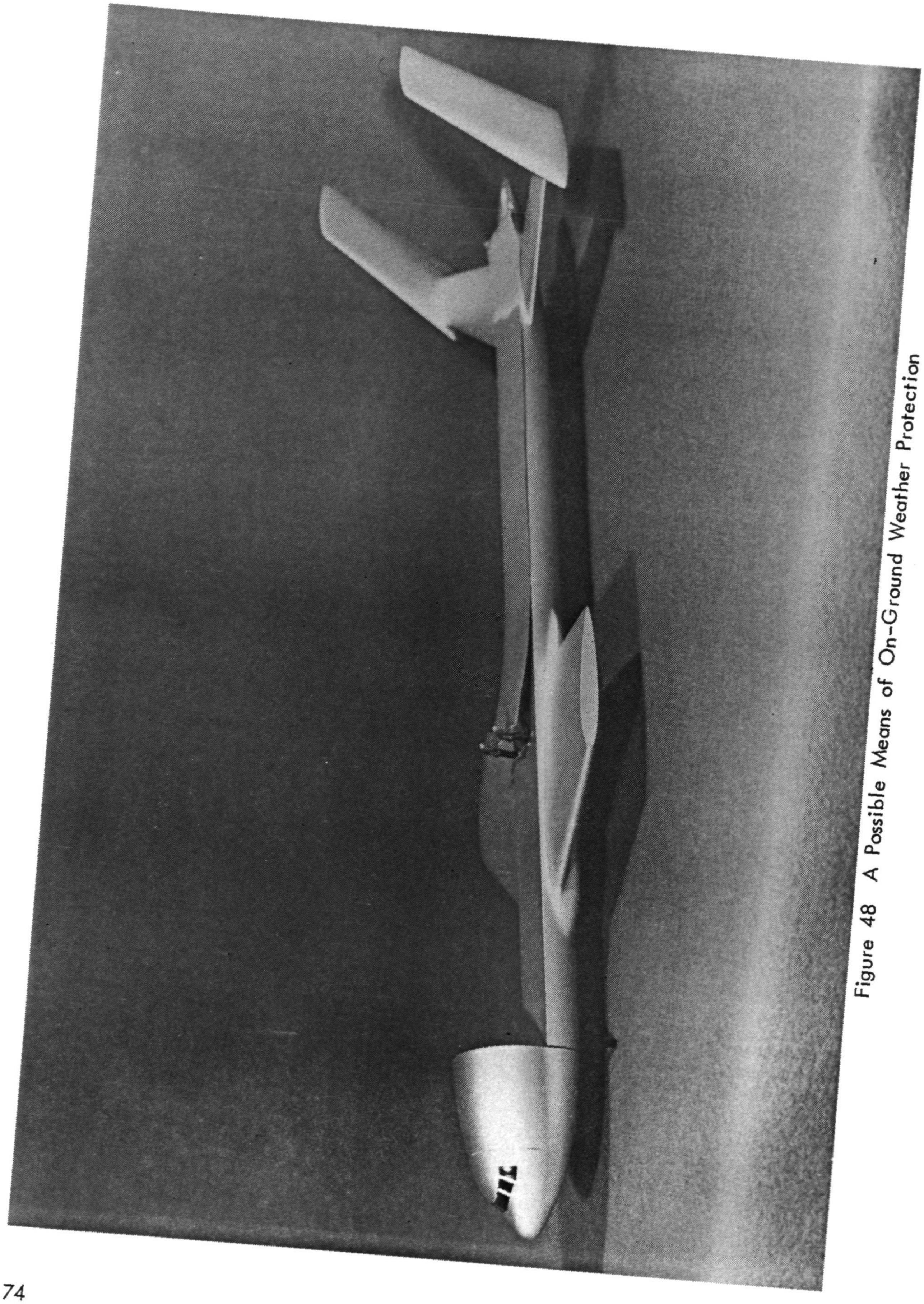


Figure 48 A Possible Means of On-Ground Weather Protection

stored in a fore-and-aft orientation in a heated compartment in the tail cone. To be deployed, the rolled 54.4 kg (120 pounds) "tarp" is elevated above the floor line, rotated 90 degrees, and unrolled by two men. When stretched the full length of the cargo floor, the tarp extends 15.2 cm (6 inches) on either side, where it may be tied to small hook fittings along the fuselage. Re-rolling is facilitated by a small electric motor following removal of snow which is achieved by the manual means as currently employed at airport terminals.

It is considered that special attention must be given to prevention of corrosion. Both the cargo floor and the backbone underfloor area will be exposed to an environment conducive to corrosion. The rollers, latches, channels, and electrical and environmental connectors cannot be totally protected from moisture and airborne contaminants during flight. Even with a cover on the ground, moisture/condensation will collect on these components.

Corrosion in the underfloor area may result because it is not pressurized (as a conventional modern transport is) and experience with unpressurized aircraft indicates that moisture will be "breathed" into this area upon each descent. The moisture might condense on the cool structure and could deposit contaminants. The resultant potential for corrosion either requires more frequent inspection and/or additional treatment. Additional treatment might include the relatively new polydisulphide coatings used on carrier-based aircraft. Alternatively, the underfloor area could be pressurized at a low differential by air bled from the environmental ducts.

Payload Element Design

The basic premise of Flatbed includes carriage of a passenger module, unpressurized intermodal containers, unpressurized containers in a cocoon, and pressurized containers as well as vehicles sitting in the "open." In addition, it appears that a possible configuration is the carriage of cargo inside a pressurized cocoon. Accordingly, the study necessitated design of these unique payload elements.

Design of Passenger Module - The requirements for the Flatbed passenger module are to carry passengers (and baggage) with an approximate 10 percent first class - 90 percent coach split in the passenger load. The length of the passenger module is determined by the requirement for the backbone to carry five 6.1 m (20 foot) long containers, with 7.62 cm (3 inches) clearance between each one, and a suitable aftbody length. An iterative design process led to the configuration and internal arrangement shown on Figure 49.

Accommodations are provided for 180 passengers with 20 first class and 160 coach class. First class seat pitch is 94 cm (38 inches) and coach class seat pitch is 86 cm (34 inches). These values of seat pitch are compatible with those extant on current commercial passenger airliners, including the L-1011. Provisions by way of folding jump seats are also made for 4 flight attendants per FAR 121.391. Type I and III exit and emergency doors are provided in accordance with the requirements of FAR 25,

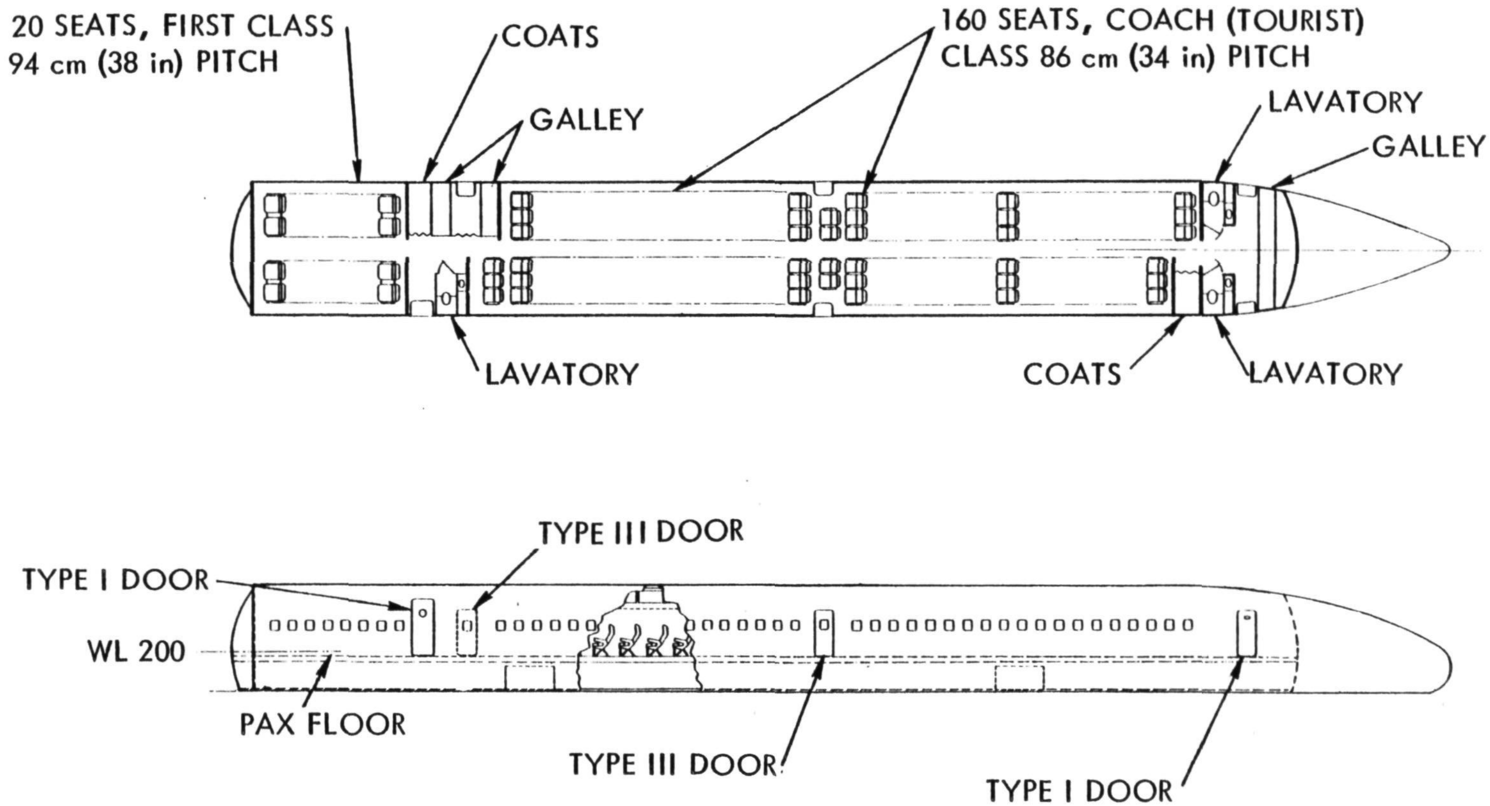


Figure 49 Interior Arrangement - Flatbed PAX Module

Para. 25.807. Both first class and coach class galleys are provided along with three lavatories. (The number of lavatories is not specified by FAR 25 but was determined from consultation with Delta Air Lines who provide three lavatories on B-727-200 and from Reference 10 which indicates that the B-767 will provide three for 197 passengers.) Provisions for hanging coats is provided in accordance with current practice on L-1011 aircraft.

Design of Containers - Both unpressurized intermodal and pressurized containers were designed in cursory fashion and in preliminary terms. The former is rectangular in shape and the latter shaped to fit the aft portion of the cockpit section (D-shaped).

The unpressurized container is a rectangular parallelepiped measuring 2.59 X 3.05 X 6.1 meters (8.5 X 10 X 20 feet). It is similar in its design to current containers in terms of hoisting points, nesting or stackability, and general aluminum construction. Weights were estimated by extrapolation from existing intermodal containers.

A pressurized container is designed to be an airborne standard container, 6.1 m (20 feet) long. As shown on Figure 50, a pressure door is provided at one end for loading. It is not intermodal because of its height and width, and its shape prevents stacking.

Design of Cocoons - Two items peculiar to the Flatbed concept were subjected to a cursory design analysis: an unpressurized cocoon and a pressurized cocoon. The unpressurized cocoon is designed to be a simple aerodynamic fairing which could be installed on the backbone to eliminate the six transverse and two longitudinal joints that are exposed to the airstream when carrying standard intermodal containers. This unpressurized cocoon, shown in Figure 51, attaches to the backbone only along the sides, has no bottom, and would be constructed possibly out of fiberglass skins bonded to a honeycomb core (for light weight to react only airloads).

A pressurized cocoon, capable of housing intermodal containers or palletized cargo, was designed so the advantages of flying at the design cruise altitude could be weighed against this much heavier cocoon structure. As shown in Figure 52, it requires both a floor and pressure bulkheads at the front and rear, the front one being hinged and latched so that it can open for loading cargo. Another rail/roller system is required inside this cocoon for attachment of containers.

Reference Aircraft Design

Three aircraft of conventional configuration were designed to provide a basis for comparison. These are a reference passenger airplane, cargo airplane, and outsize cargo airplane. These aircraft were designed to the same technology levels as Flatbed and the same general criteria. The general configurations are comparable to those projected for the 1990's by companies engaged in design of passenger and cargo airplanes. Sizing was established through use of the GASP.

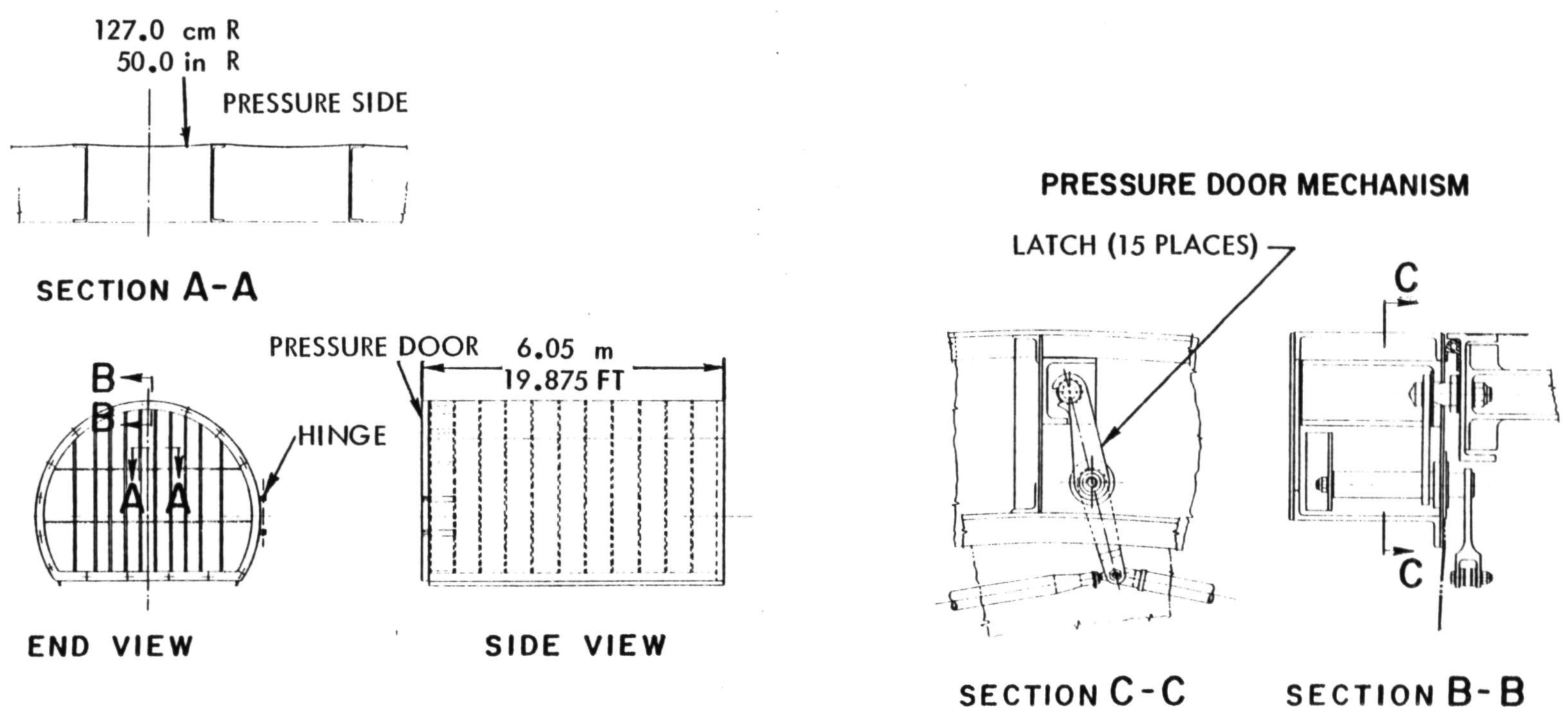


Figure 50 Pressurized D-Shaped Container Design Details

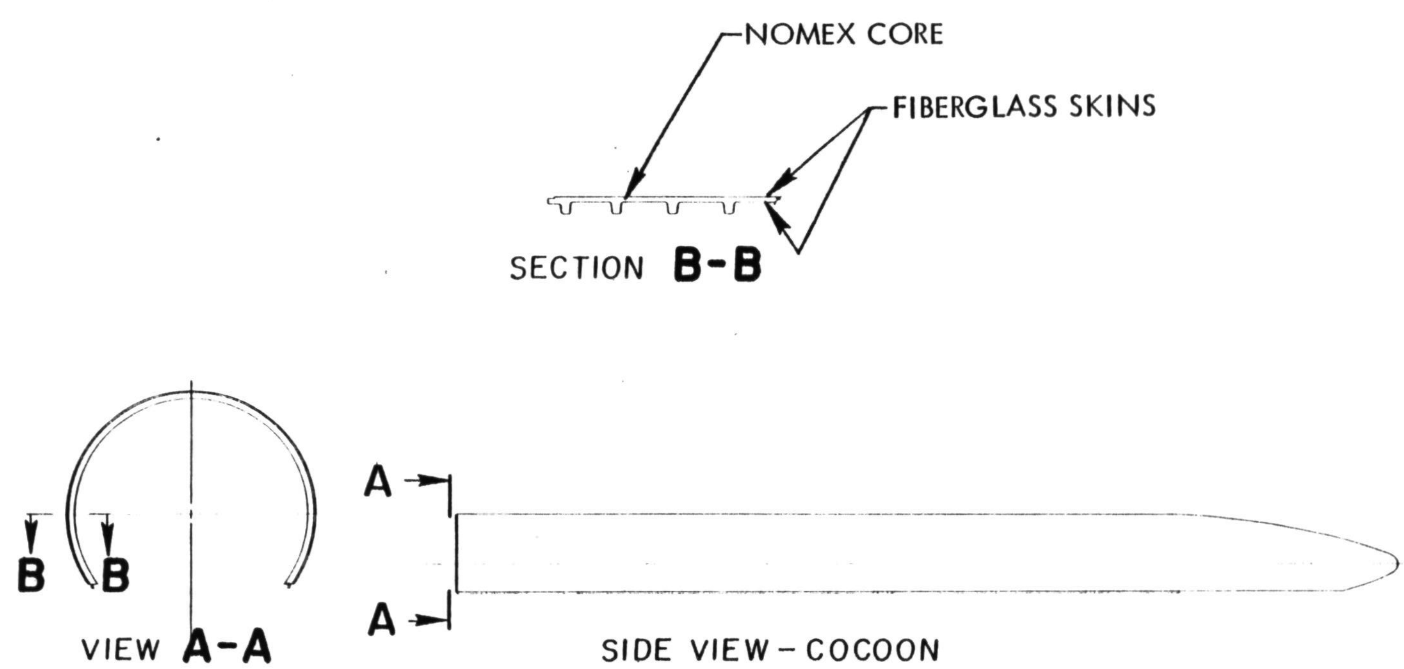


Figure 51 Unpressurized Cocoon Configuration

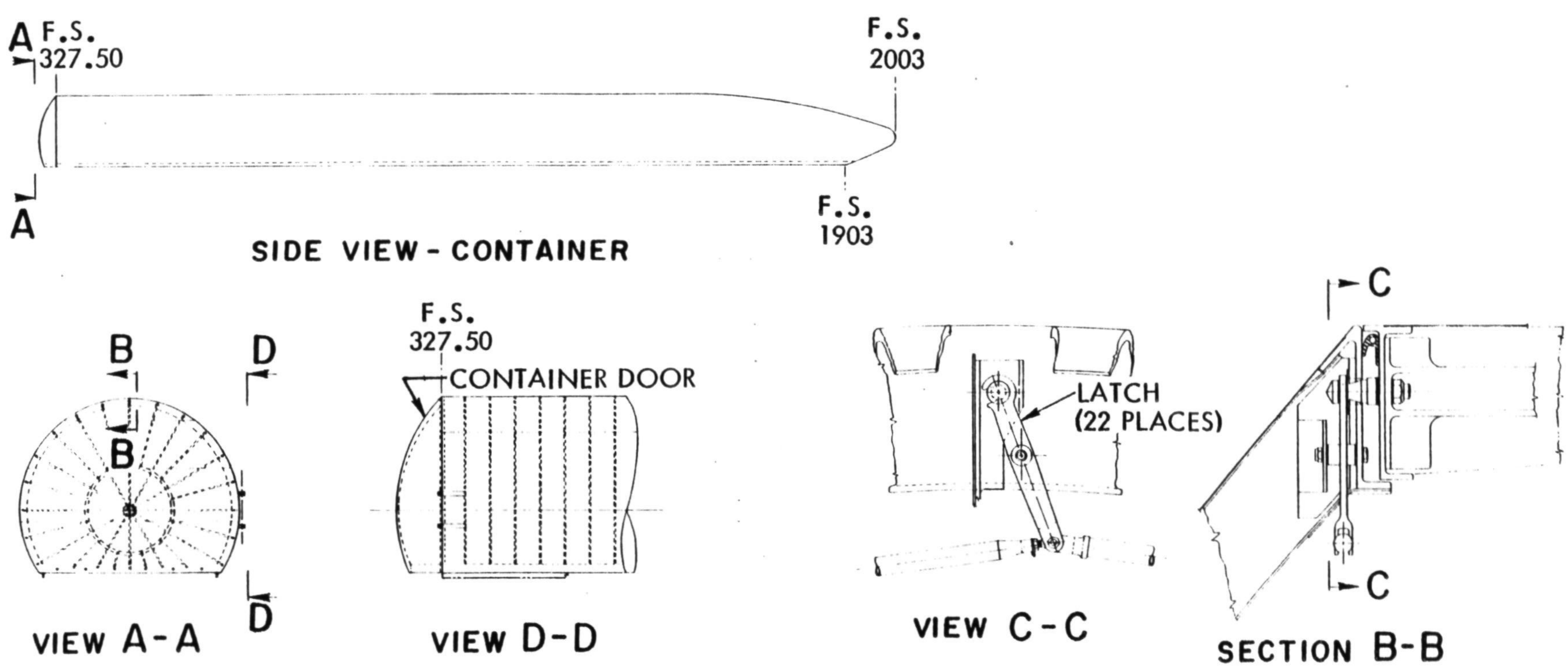


Figure 52 Pressurized Cocoon Design Details

Passenger Airplane - The reference passenger airplane, Figure 53, is a low-wing, four engine, T-tail design. The number of engines was selected as four in order to put comparisons with Flatbed on an equal basis. The T-tail is representative of current practice.

Since the reference passenger aircraft is required to have the same interior accommodations as the Flatbed passenger module, the 2.25 m (88.56 inches) upper lobe radius necessary for 6-abreast seating was simply continued to form a circular-shaped fuselage. As on most other conventional passenger aircraft, this configuration has considerable space in the belly for cargo and baggage, as shown on Figure 54.

The reference passenger aircraft interior arrangement, shown in Figure 55, is essentially the same as the Flatbed arrangement, with only minor shifting of seat locations to a conventional forward cabin entrance location.

Although the reference passenger aircraft has the same passenger accommodations (180) as the Flatbed passenger module, the similarity ends there. A conventional fuselage passenger aircraft normally has considerable space under the passenger floor for locating such items as the nose gear wheel well, main gear wheel wells (low-wing aircraft), baggage/cargo holds, and various servicing points. Adopting this configuration led to the question of whether the 34,013 kg (75,000 pounds) design payload originally specified could properly be used for the reference passenger aircraft.

To establish the correct value, CAB ER586 Service Segment data were acquired through I. P. Sharp Associate's time-shared computer system. Flight by airliners for one year for all airlines between Atlanta-Dallas, Atlanta-Chicago, Atlanta-Washington, and Atlanta-NYC were studied. These city pairs were considered representative of airline service and would also account for seasonal variations and geographic differences. A computer printout for each flight by airline number for each city pair by month was received and studied to establish a likely (or design) belly-hold cargo weight. Figure 56 presents a typical printout for Atlanta-Dallas for Delta Flights 1162, 1175, and 1185 featuring L-1011 and B-727 service for the period of July 1978 to July 1979.

From these data, a value of 31.8 kg (70 pounds) per seat was established as the design mail/cargo load for the reference passenger aircraft. Since the seating capacity is 180, the design mail/cargo load is 5715 kg (12,600 pounds) for a total design payload of 23,024 kg (50,760 pounds).

The aircraft was sized to perform the M = 0.82, 4815 km (2600 n.mi.) range mission, resulting in the configuration depicted on Figure 55.

Cargo Airplane - The reference cargo airplane is adapted from previous and current Lockheed-Georgia studies into a "medium" sized cargo airplane. It features a high wing with four pylon-mounted engines and a T-tail. Loading of the cargo is through aft fuselage doors. In general, the configuration is typical of the genre of C-141 and C-5A designs.

CRUISE MACH NO.	0.82
DESIGN PAYLOAD - kg (lbs)	34,010 (75,000)
DESIGN RANGE - km (n mi)	4815 (2600)
OPERATING WT. - kg (lbs)	62,330 (137,400)
MAX. GROSS WT. - kg (lbs)	131,600 (290,100)
BLOCK FUEL - kg (lbs)	31,300 (69,000)
THRUST PER ENGINE - N (lbs)	100,200 (22,500)

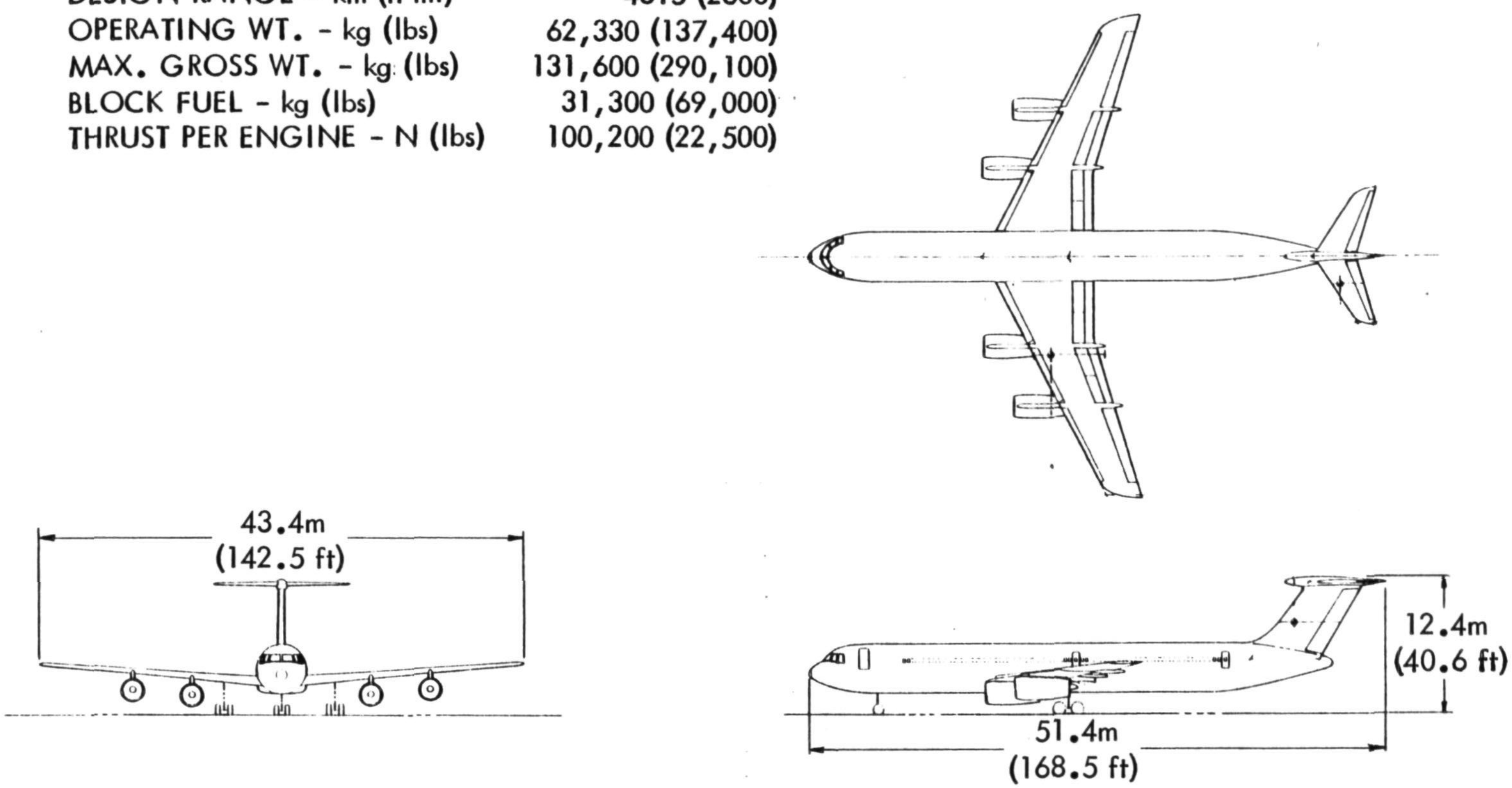


Figure 53 General Arrangement - Reference Passenger Airplane

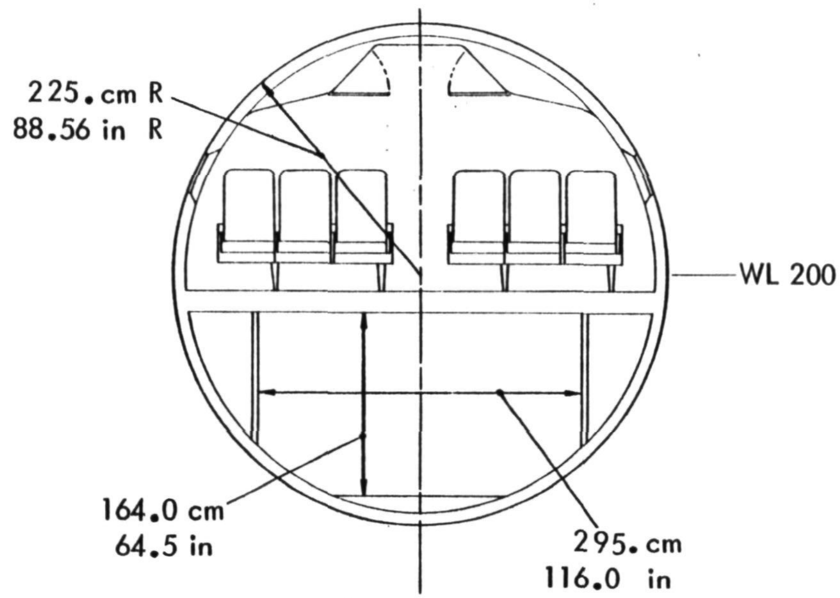


Figure 54 Reference Passenger Airplane - Fuselage Cross Section

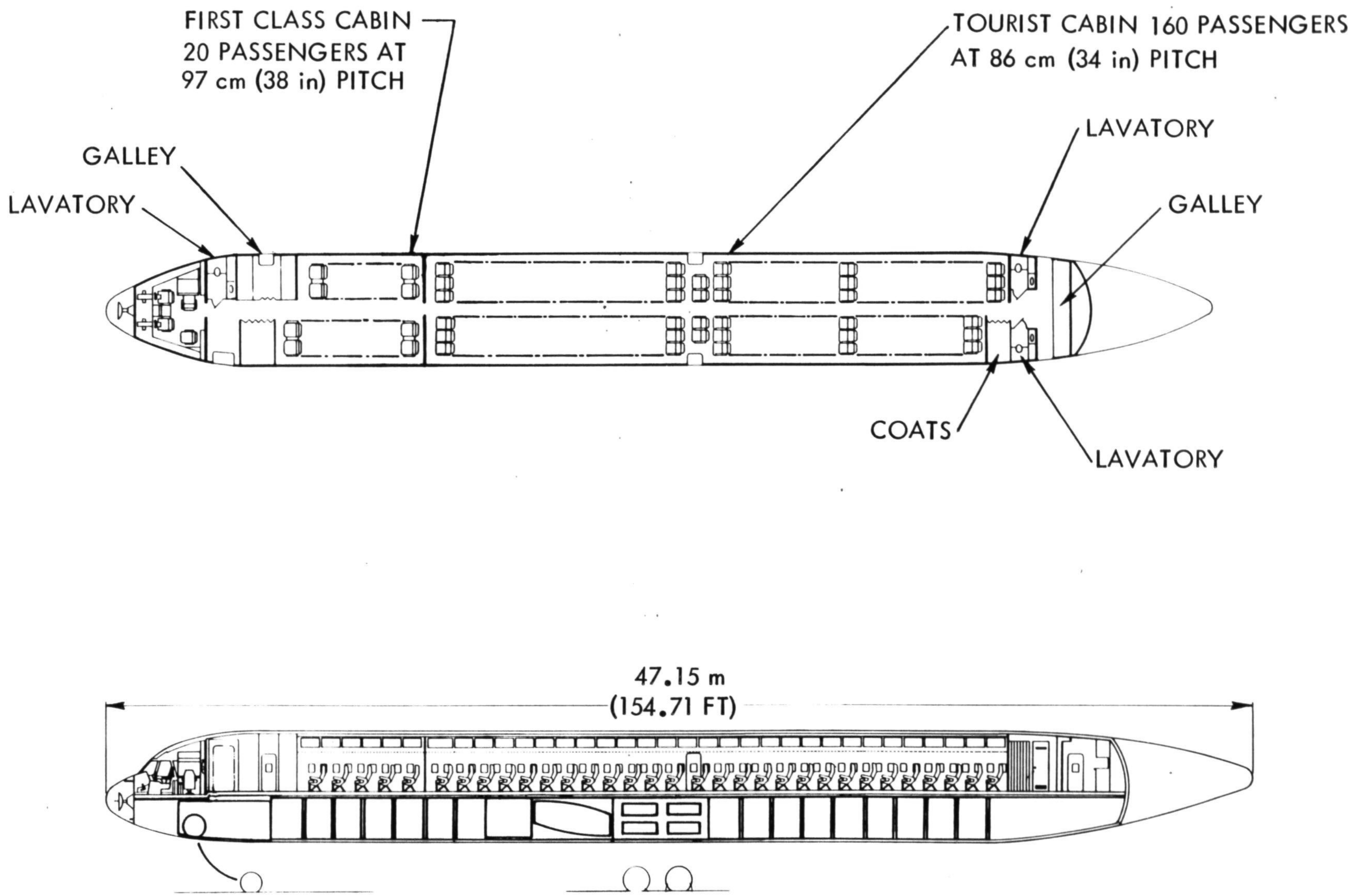


Figure 55 Reference Passenger Airplane - Interior Arrangement

CARGO/MAIL DATA FOR NASA FLATBED STUDY
CITY-PAIR: ATL+DFW

CARRIER: DL
FLIGHT NUMBER: 1162
EQUIPMENT TYPE: L-1011

	JUL/78	AUG/78	SEP/78	OCT/78	NOV/78	DEC/78	JAN/79	FEB/79	MAR/79	APR/79	MAY/79	JUN/79
REVENUE:												
PASSENGERS									1,637	2,790	2,988	1,438
MAIL-TONS									3.91	5.53	6.27	2.75
MAIL-LBS/PAX									4.77	3.97	4.20	3.83
FRT+EXP - TONS									70.15	141.40	117.11	55.74
FRT+EXP - LBS/PAX									85.71	101.36	78.38	77.52
AVAILABLE:												
NUMBER OF SEATS									6,153	8,497	8,204	4,102
TOTAL TONS									828	1,144	1,105	552
CARGO TONS									213.15	294.35	284.20	142.10
CARGO LBS/SEAT									69.28	69.28	69.28	69.28

CARRIER: DL
FLIGHT NUMBER: 1175
EQUIPMENT TYPE: B-727-200 L-1011

	JUL/78	AUG/78	SEP/78	OCT/78	NOV/78	DEC/78	JAN/79	FEB/79	MAR/79	APR/79	MAY/79	JUN/79
REVENUE:												
PASSENGERS	2,940	3,568	2,162	1,949	2,337	887						
MAIL-TONS	31.92	42.94	36.00	34.01	42.27	26.10						
MAIL-LBS/PAX	21.71	24.07	33.30	34.89	36.17	58.86						
FRT+EXP - TONS	39.97	48.78	38.93	31.16	58.07	50.29						
FRT+EXP - LBS/PAX	27.19	27.34	36.01	31.97	49.69	113.39						
AVAILABLE:												
NUMBER OF SEATS	8,149	8,793	7,845	7,943	8,196	4,044						
TOTAL TONS	1,117	1,200	1,067	1,084	1,111	548						
CARGO TONS	302.15	321.15	282.85	290.05	291.30	143.40						
CARGO LBS/SEAT	74.16	73.05	72.11	73.03	71.08	70.92						

CARRIER: DL
FLIGHT NUMBER: 1185
EQUIPMENT TYPE: L-1011

	JUL/78	AUG/78	SEP/78	OCT/78	NOV/78	DEC/78	JAN/79	FEB/79	MAR/79	APR/79	MAY/79	JUN/79
REVENUE:												
PASSENGERS	4,716	5,339	3,810	3,703	3,987	5,238	3,869	2,498	3,981	4,619	4,079	5,628
MAIL-TONS	26.26	24.44	26.09	25.95	36.94	47.52	30.88	25.22	36.44	36.38	39.44	31.77
MAIL-LBS/PAX	11.14	9.16	13.70	14.02	18.53	18.14	15.96	20.19	18.31	15.75	19.34	11.29
FRT+EXP - TONS	87.03	74.97	94.88	110.19	129.51	106.67	148.53	120.54	125.43	120.95	109.06	87.99
FRT+EXP - LBS/PAX	36.91	28.08	49.81	59.51	64.97	40.73	76.78	96.51	63.01	52.37	53.48	31.27
AVAILABLE:												
NUMBER OF SEATS	8,764	8,648	8,529	8,909	8,059	9,083	9,025	7,618	9,083	8,790	8,497	8,790
TOTAL TONS	1,198	1,189	1,163	1,209	1,093	1,223	1,218	1,026	1,223	1,184	1,144	1,184
CARGO TONS	321.80	324.40	310.35	318.55	287.45	314.65	315.95	263.90	314.65	304.50	294.35	304.50
CARGO LBS/SEAT	73.44	75.02	72.78	71.51	71.34	69.28	70.02	69.28	69.28	69.28	69.28	69.28

Figure 56 Sample Printout City Pair Airline Statistics

The reference cargo aircraft utilizes a cross-section shape based on previous Lockheed research and development studies. The cargo compartment is 3.57m wide by 3.44m high (11.7 ft by 11.3 ft) resulting in a cargo envelope of 11.97 m^2 (129 ft^2), the same as that required for the AMST aircraft, YC-14 and YC-15. These dimensions are realistic for the payload tonnage to be carried. The length of the cargo compartment permits carriage of the five containers. The vehicle was then resized to the Mach 0.82, 4815 km (2600 n.mi.) mission resulting in the configuration shown on Figure 57.

Outsize Cargo Airplane - The outsize cargo airplane was also adapted from previous and current designs capable of hauling large vehicles such as the XM-1 tank. Again, the general configuration is that of a four-engined high wing aircraft with a T-tail. The reference outsized cargo aircraft is sized around the largest military vehicle to be carried, the M60 Bridge Launcher. The widest part of this vehicle is at the bridge, which is carried on top. Assuming 15.2 cm (6 inch) clearances at the sides and 7.62 cm (3 inches) on the top, the minimum fuselage cross-section to carry the bridge launcher has a 6.1 m (20 foot) diameter.

Given the cross-section for this aircraft, the other primary design requirement is to determine the length of the cargo compartment. This was set at the same dimension as the reference cargo aircraft, based on five containers. The design payload was also left at 34,013 kg (75,000 pounds), with the outsized vehicle mission being one at a reduced load factor to carry the 54,422 kg (120,000 pounds) payload. This configuration is shown on Figure 58.

Cross-Sectional Comparison - For ready reference, the cross-sections of Flatbed and each of the three reference airplanes are given by Figure 59.

Structural Analysis

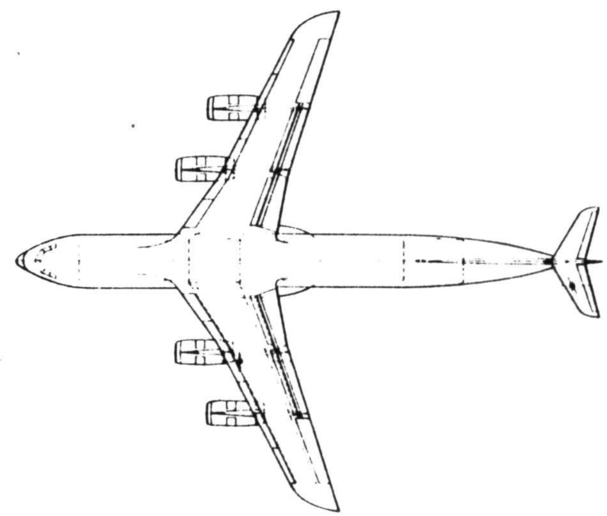
Structural analysis of the Flatbed concept consisted primarily of flutter and dynamic considerations, loads/stress analysis, and estimation of weights.

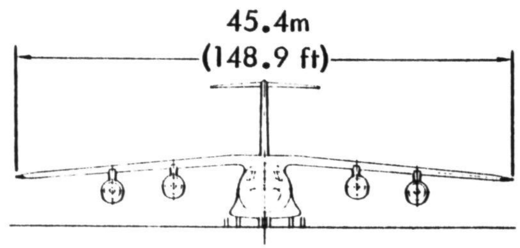
Flatbed Flutter and Dynamic Considerations - The Flatbed configuration poses no unusual flutter problems. The overwing engine arrangement has essentially the same flutter characteristics as an equivalent underslung design. The torsional stiffness distribution required for flutter prevention and the corresponding wing weights are therefore consistent with those for conventional designs.

The Vee-tail configuration is somewhat unusual but does not possess any particularly undesirable flutter characteristics. Since the tail surfaces are rather highly loaded in both bending and torsion during maneuvers, little, if any, additional material is likely to be required for flutter prevention.

The influences of flexibility on backbone fuselage depth vis-a-vis empennage size were previously discussed in the section entitled Component Design.

CRUISE MACH NO.	0.82
DESIGN PAYLOAD - kg (lbs)	23,020 (50,760)
DESIGN RANGE - km (n mi)	4815 (2600)
OPERATING WT. - kg (lbs)	62,770 (138,400)
MAX. GROSS WT. - kg (lbs)	117,500 (259,000)
BLOCK FUEL - kg (lbs)	25,900 (57,200)
THRUST PER ENGINE - N (lbs)	85,900 (19,300)





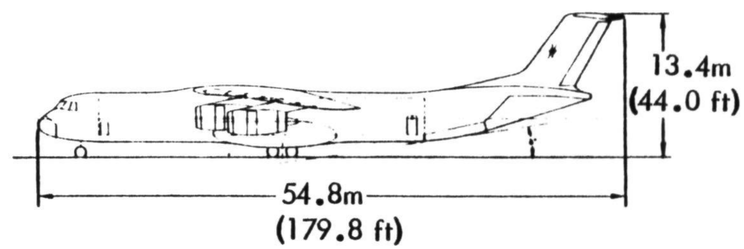


Figure 57 General Arrangement - Reference Cargo Airplane

CRUISE MACH NO.	0.82
DESIGN PAYLOAD - kg (lbs)	34,010 (75,000)
DESIGN RANGE - km (n mi)	4815 (2600)
OPERATING WT. - kg (lbs)	71,600 (157,800)
MAX. GROSS WT. - kg (lbs)	145,500 (320,900)
BLOCK FUEL - kg (lbs)	35,500 (78,300)
THRUST PER ENGINE - N (lbs)	114,300 (25,700)

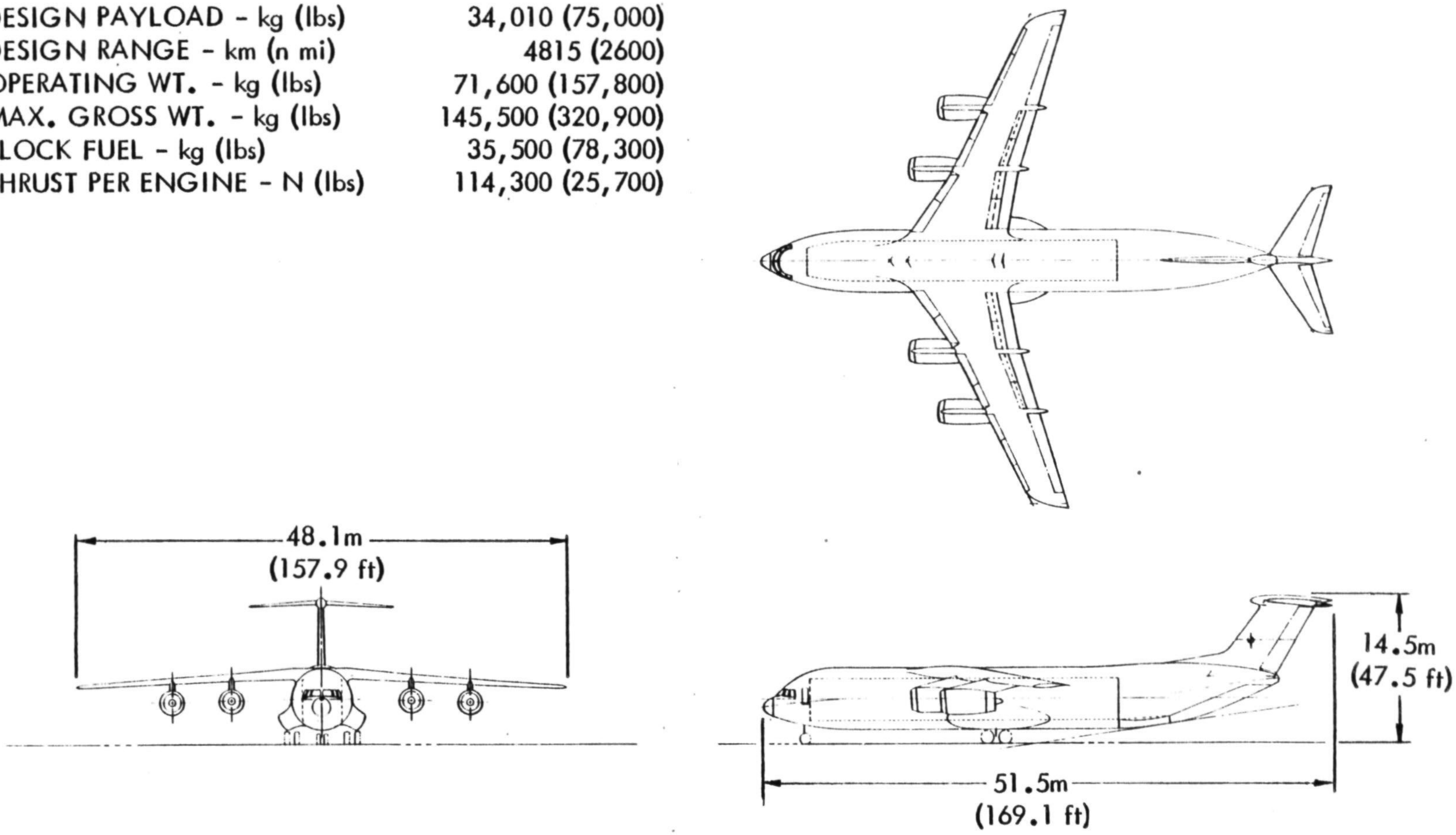


Figure 58 General Arrangement - Reference Outsize Cargo Airplane

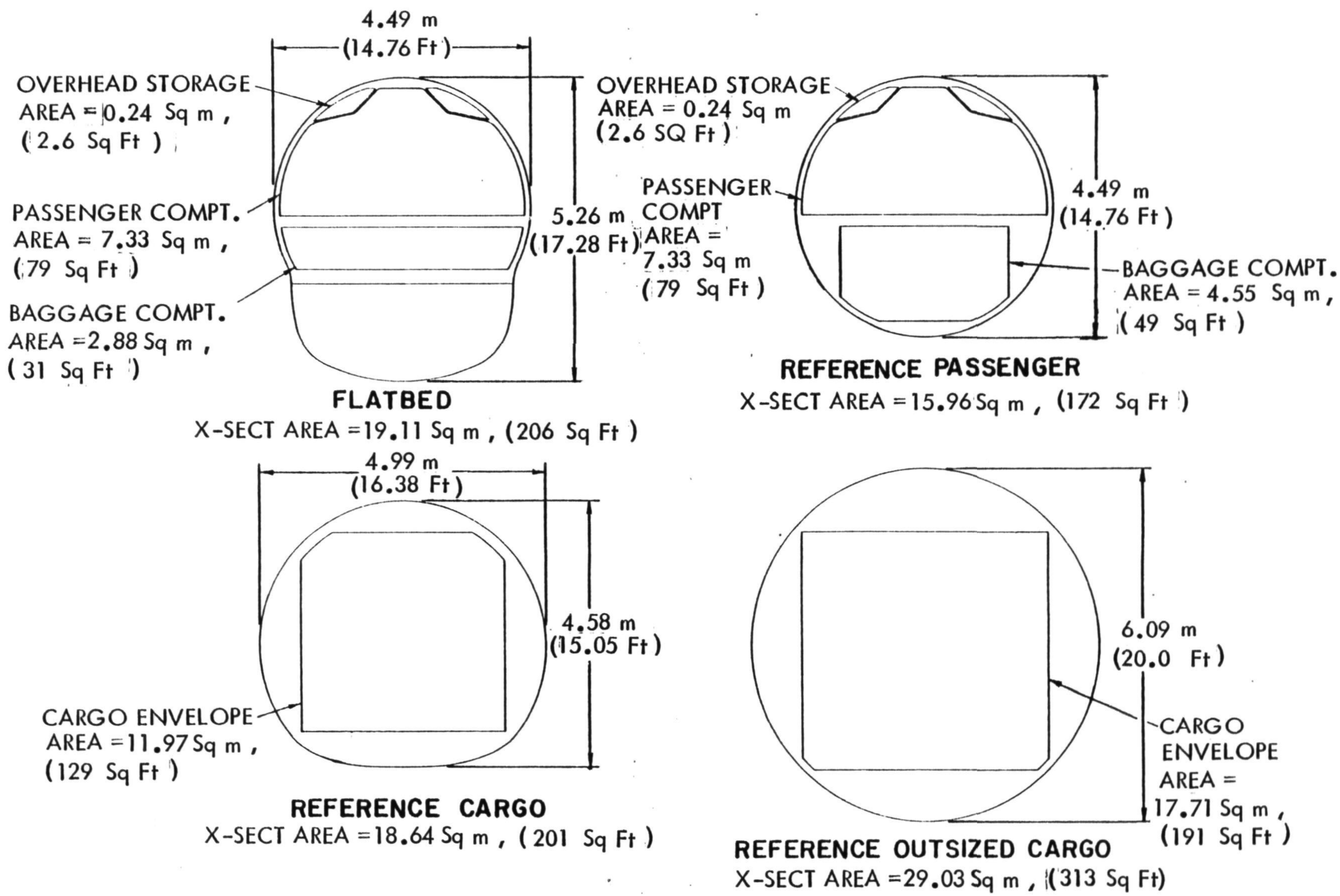


Figure 59 Cross-Sectional Comparison - Reference Airplanes & Flatbed

Flatbed Stress Analysis - An analysis of the Flatbed fuselage backbone was made to determine the structural element sizes. Two different cross-sections were investigated to determine if a flattened underfloor is more efficient than a half-circle shape.

Structural design of the Flatbed fuselage is based upon static strength and flutter requirements. The forward fuselage is "strength" critical while the aft fuselage is designed for both strength and torsional stiffness. Figure 60 shows the fuselage skin thickness variation along the fuselage. Some adjustments to this distribution are possible in order to avoid tapered skins. Axial element requirements are presented in Figure 61.

A study of two different cross-sections resulted in the selection of a flattened underfloor as the most efficient shape structurally. The primary advantage of the flattened shape over the half-circle shape is the improved torsional stiffness.

Considerations for fatigue are not based upon mission profiles and intended aircraft usage, but are reflected in the selection of a tensile cut-off ultimate stress of 275.8 MPa (40,000 psi). This approach is used very successfully in the preliminary design phase of most new aircraft where available time and mission definition are limited.

Weight Estimation - The weight data for particular structural items and subsystems were derived by utilizing a series of equations based primarily on statistical data recognizing the state-of-the-art for the Flatbed time period of 1990, and reflecting experience with recent cargo and passenger airplanes built by Lockheed. Structural weights were based on existing aluminum technology for the primary structure and advanced composite material, where appropriate in the secondary structure. A weight estimation subroutine composed of this series of statistical equations is included in the General Airplane Sizing Program (GASP) used to arrive at the optimum airplane configuration. These equations were used, with only minor modifications, for all the group weights on the three reference aircraft since they presented no unique features not included in the statistical equations.

All individual weight groups of the Flatbed were estimated by these equations with the exception of the fuselage backbone, butterfly tail and over-the-wing pylons. These items do not fall within the statistical data samples and thus were not candidates for this type of weight estimation. These components were estimated by use of analytical methods including flutter and stress analysis. Since the backbone cross-sectional area is small relative to a fuselage cross-section the entire structure between the wing and empennage is stiffness critical. The "D" shape bending and torsional material was designed to the C-141A stiffness criteria and the Vee-tail was sized to the fuselage stiffness.

Weights for the Flatbed fuselage and its secondary structural items are based upon sufficient stress analysis to establish preliminary sizing. Items, other than the basic fuselage structure, for which a stress analysis was accomplished are as follows:

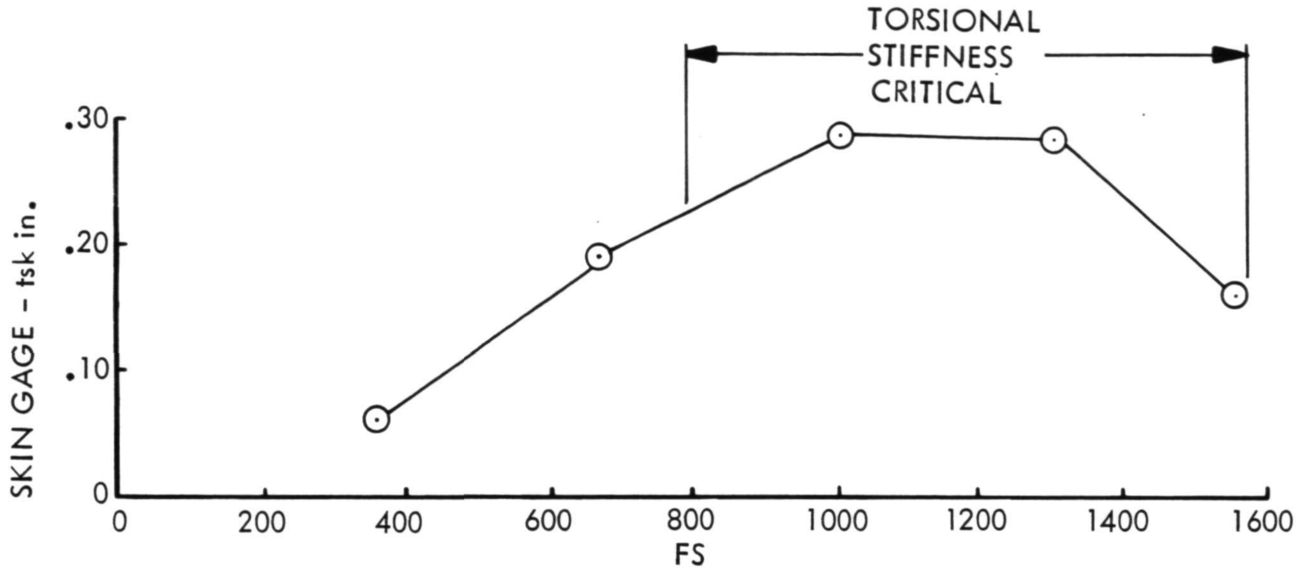


Figure 60 Flatbed Fuselage Skin Thickness

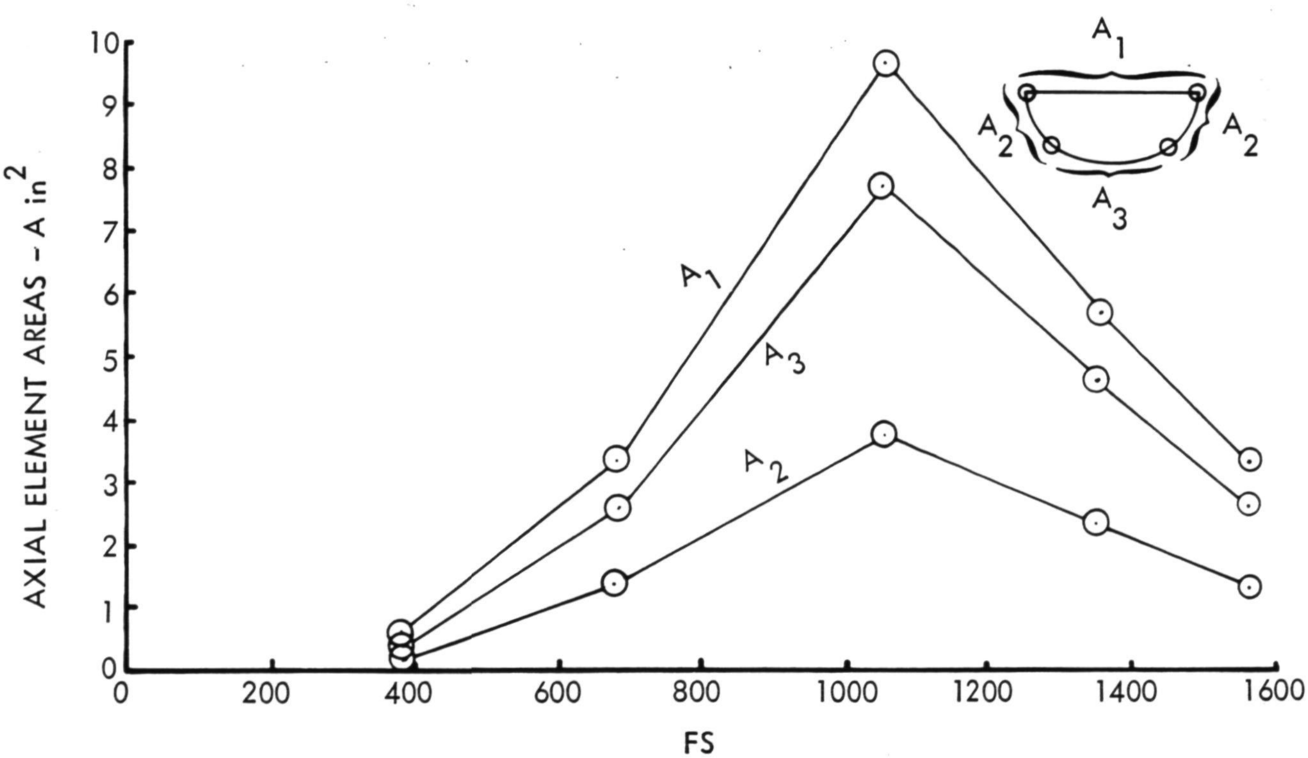


Figure 61 Flatbed Fuselage Bending Material

- Passenger module
- Loading ramps
- Cargo cocoon

The weight of the fuselage backbone was estimated by using cross-section area required at various stations along the longitudinal axis from Fuselage Station 396 to Fuselage Station 1536. The required cross-sectional area was integrated between stations and the material required was calculated. The weights for secondary structure and individual functional items were estimated individually by comparison with similar items on existing airplanes.

Weight of the cargo loading system, rails and rollers and tie-down devices was estimated from the similar system used in the C-5A airplane. An additional penalty was added for the vehicle loading treadways and under-floor support structure for the 16,326 kg (36,000 pound) single axle load requirement. The teeter and slam loads of a tracked vehicle coming off the ramp onto the fuselage floor were investigated and proved to be no special problem, since the flight loads for the single axle vehicles were more critical. Table 3 presents a summary of the fuselage weights.

The butterfly tail was estimated analytically since practically no statistical data exists on this type configuration. In order to allow for the sizing function of the GASP program to work, an initial configuration was calculated and equated to a Tee-tail configuration. Once the optimum configuration for the Flatbed airplane was completed the Tee-tail derived in this program was converted to the butterfly configuration and the weights recalculated. The final weights for the empennage are approximately two percent different from those estimated by the GASP weight subroutine.

The pylons were estimated in a similar manner to the tail except that the analytical estimate was used to develop a factor which was applied to the equation for estimation of under-the-wing pylon weights. This allowed the engine sizing routine to be used "as is" and have the nacelle group weight reflect the over-the-wing pylon penalty.

For systems and equipment weights, there were some modifications necessary to the basic equations due to the Flatbed configuration. These included the electrical group (where there was no requirement for conventional fuselage lighting), the furnishings group (where all fuselage furnishings were deleted) and the air conditioning group (where no fuselage air conditioning existed). These items were estimated individually and factors derived to be used in the basic weight subroutine. All of these items were included in the individual replacement for the fuselage when used on the Flatbed. As an example, of the 7847 kg (17,300 pounds) estimated for the pressurized cargo module, almost 1406 kg (3100 pounds) is functional-mechanical systems. The passenger module has almost 7257 kg (16,000 pounds) of passenger furnishings, 6127 kg (13,508 pounds) of additional electrical, 223 kg (500 pounds) of avionics, and 816 kg (1,800 pounds) of air conditioning. These items are estimated by comparison to similar items on the Lockheed L-1011 airplane.

Table 3 Flatbed Fuselage Weight Summary

	WEIGHT KGS	WEIGHT LBS
FOREBODY BASIC STRUCTURE	668	1,470
FLATBED BASIC STRUCTURE	9,080	20,018
WINDSHIELD	281	620
MAIN LANDING GEAR FAIRING	430	947
FLOORING AND SUPPORTS - CREW STATION	148	326
STAIRWAY AND LADDER	8	17
NOSE LANDING GEAR DOOR AND MECHANISM	87	191
MAIN LANDING GEAR DOORS AND MECHANISM	382	843
FOREBODY ACTUATING MECHANISM	116	257
ESCAPE HATCH AND MECHANISM	15	32
ENTRANCE DOOR AND MECHANISM	49	108
DRAINAGE INSTALLATION	8	17
STABILIZING JACK INSTALLATION	25	55
EXTERIOR PROTECTIVE FINISH	20	44
ANTI-SKID PROTECTION	19	42
LOADING SYSTEM - RAILS AND ROLLERS	3,271	7,212
INFLIGHT REFUELING	69	153
TOTAL FUSELAGE WEIGHT	14,676	32,352

Table 4 presents a weight summary of the passenger module.

Table 5 presents a Group Weight Summary for the Flatbed baseline airplane. A summary of the various missions is included in Table 6.

The Reference Passenger Airplane Group Weight Summary is presented in Table 7. A mission summary for this airplane is presented in Table 8.

Tables 9 and 10 are Group Weight Summaries for the Reference Cargo Airplane and the Reference Outsized Cargo Airplane, respectively. The corresponding mission summaries are shown in Tables 11 and 12.

In order to facilitate a weight comparison, a Group Weight Summary for the Flatbed backbone and the three reference airplanes is presented (in U.S. units only) in Appendix B.

Structural efficiencies for Flatbed configurations and the reference aircraft are given by Table 13. For this measure, total and not net payload is used since the structural efficiency should be based on the sum of the gross load being carried by the airplane's structure.

Performance Analysis

Each of the Flatbed payload configurations (Figures 62 through 68) and the three reference airplanes were analyzed in terms of aerodynamic performance. The basic tool used for estimation of performance was the GASP. In general, the end values were those considered to be "fallouts" (that which is available) since the optimizing/sizing configurations were Flatbed with the passenger module. Such calculations not only included speed but also block and mission fuel, TOGW and takeoff distance. These final weight and performance parameters were evaluated to determine various structural and aerodynamic efficiencies.

Drag Estimation - The incremental drag coefficients associated with each of the various payload configurations were estimated from data contained in References 11 through 13. Tables 14 and 15 summarize these drag coefficients. Table 14 summarizes the drag coefficients in terms of design conditions, wetted and reference areas, and incremental effects. Table 15 specifically relates incremental drag of the various payloads to the drag of the fuselage with the passenger module.

Unpressurized Containers and Cocoon - Flight with unpressurized cargo is examined in two modes of carriage. First, an unpressurized cocoon identical in shape and size to the passenger module is used to house the intermodal cargo containers. This mode of carriage is therefore identical in drag characteristics to the passenger module. The second mode of cargo carriage is the mounting of intermodal cargo containers to the backbone in the open air.

Table 4 Passenger Module Weight Summary

PASSENGER MODULE ITEM	WEIGHT	
	kgs	LBS.
POD STRUCTURE	8,938	19,706
FURNISHINGS	7,242	15,966
ELECTRICAL SYSTEM	611	1,348
AVIONICS	218	480
AIR CONDITIONING	832	1,835
EMPTY WEIGHT	17,841	39,335
OPERATING EQUIPMENT	2,297	5,065
PASSENGERS (180)	13,472	29,700
BAGGAGE	3,266	7,200
OPERATING WEIGHT (MAXIMUM)	36,876	81,300

Table 5 Flatbed Backbone Weight Summary

ITEM	WEIGHT kgs	WEIGHT LBS
WING	13,168	29,031
EMPENNAGE	2,490	5,490
FUSELAGE	14,674	32,352
LANDING GEAR - NOSE	731	1,612
MAIN	4,893	10,787
NACELLES	2,800	6,172
PROPULSION GROUP	10,242	22,581
AUXILIARY POWER PLANT	255	562
SURFACE CONTROLS	1,579	3,481
INSTRUMENTS	546	1,205
HYDRAULICS	736	1,622
ELECTRICAL	1,219	2,687
AVIONICS	1,089	2,400
FURNISHINGS	777	1,713
AIR CONDITIONING & ANTI-ICING	763	1,682
AUXILIARY GEAR	24	52
WEIGHT EMPTY	55,986	123,429
OPERATING EQUIPMENT	1,473	3,247
OPERATING WEIGHT	57,459	126,676

Table 6 Flatbed Mission Weight Summary

MISSION 2.5G LIMIT LOAD FACTOR	WEIGHT	
	kgs	LBS.
OPERATING WEIGHT - BACKBONE	57,461	126,676
PASSENGER MODULE - MAXIMUM	36,876	81,300
MISSION FUEL (2600 N.M.)	32,462	71,567
GROSS WEIGHT - PASSENGER MISSION	126,799	279,543
OPERATING WEIGHT - BACKBONE	57,461	126,676
FAIRING BEHIND COCKPIT	363	800
MISSION FUEL (2600 N.M.)	25,207	55,576
GROSS WEIGHT - FERRY MISSION	83,031	183,052
OPERATING WEIGHT - BACKBONE	57,461	126,676
PRESSURIZED COCOON	7,847	17,300
CARGO	29,370	64,750
MISSION FUEL (2600 N.M.)	32,530	71,720
GROSS WEIGHT - PRESSURIZED CARGO	127,208	280,445

Table 6 cont.

MISSION 2.5G LIMIT LOAD FACTOR	WEIGHT	
	kgs	LBS.
OPERATING WEIGHT - BACKBONE	57,461	126,676
CONTAINER - PRESSURIZED	8,051	17,750
FAIRING	363	800
CARGO	29,370	64,750
MISSION FUEL (2600 N.M.)	32,787	72,285
GROSS WEIGHT - PRESSURIZED CONTAINERS	128,032	282,261
OPERATING WEIGHT - BACKBONE	57,461	126,676
COCOON - UNPRESSURIZED	2,063	4,550
CARGO	34,019	75,000
MISSION FUEL - (2600 N.M.)	44,648	98,432
GROSS WEIGHT - UNPRESSURIZED COCOON	138,191	304,658
OPERATING WEIGHT - BACKBONE	57,461	126,676
CONTAINERS - UNPRESSURIZED	4,649	10,250
AFT FAIRING	363	800
FORWARD FAIRINGS	136	300
CARGO	29,370	64,750
MISSION FUEL (2600 N.M.)	45,870	101,127
GROSS WEIGHT - UNPRESSURIZED CONTAINERS	137,849	303,903

Table 6 cont.

MISSION 2.0G LIMIT LOAD FACTOR	WEIGHT	
	kgs	LBS.
OPERATING WEIGHT - BACKBONE	57,461	126,676
M-60 TANK	52,163	115,000
MISSION FUEL (2415 n.mi.)	48,047	105,926
GROSS WEIGHT - M-60 TANK MISSION	157,671	347,602
OPERATING WEIGHT - BACKBONE	57,461	126,676
BRIDGE LAUNCHER	54,431	120,000
MISSION FUEL (2415 n.mi.)	49,847	109,895
GROSS WEIGHT - BRIDGE LAUNCHER	161,739	356,571

Table 7 Reference Passenger Airplane Weight Summary

ITEM	WEIGHT kgs	WEIGHT LBS.
WING	13,023	28,711
EMPENNAGE	1,909	4,209
FUSELAGE	11,163	24,610
LANDING GEAR - NOSE	665	1,467
MAIN	4,453	9,818
NACELLES	1,914	4,220
PROPULSION GROUP	9.399	20,722
AUXILIARY POWER PLANT	245	540
SURFACE CONTROLS	1,476	3,254
INSTRUMENTS	537	1,184
HYDRAULICS	688	1,516
ELECTRICAL	1,985	4,377
AVIONICS	1,306	2,880
FURNISHINGS	7,326	16,152
AIR CONDITIONING & ANTI-ICING	1,799	3,967
AUXILIARY GEAR	23	47
WEIGHT EMPTY	57,911	127,674
OPERATING EQUIPMENT	4,273	9,419
OPERATING WEIGHT	62,184	137,093

Table 8 Reference Passenger Airplane Weight Summary

ITEMS	WEIGHT	
	kgs	LBS.
OPERATING WEIGHT	62,184	137,093
PASSENGERS (180)	13,472	29,700
BAGGAGE	3,266	7,200
CARGO	6,287	13,860
ZERO FUEL WEIGHT	85,209	187,853
MISSION FUEL	30,847	68,007
GROSS WEIGHT	116,056	255,860

Table 9 Reference Cargo Airplane Group Weight Summary

ITEM	WEIGHT	
	kgs	LBS.
WING	13,540	29,851
EMPENNAGE	1,590	3,505
FUSELAGE	17,299	38,138
LANDING GEAR - NOSE	734	1,618
MAIN	4,911	10,827
NACELLES	2,268	5,000
PROPULSION GROUP	11,241	24,783
AUXILIARY POWER PLANT	259	571
SURFACE CONTROLS	1,578	3,478
INSTRUMENTS	558	1,231
HYDRAULICS	735	1,621
ELECTRICAL	1,296	2,857
AVIONICS	1,089	2,400
FURNISHINGS	2,366	5,216
AIR CONDITIONING & ANTI-ICING	1,350	2,976
AUXILIARY GEAR	24	54
WEIGHT EMPTY	60,838	134,124
OPERATING EQUIPMENT	1,506	3,321
OPERATING WEIGHT	62,344	137,445

Table 10 Reference Cargo Airplane Weight Summary

ITEM	WEIGHT	
	kgs	LBS.
WING	15,159	33,419
EMPENNAGE	2,072	4,569
FUSELAGE	21,290	46,937
LANDING GEAR - NOSE	808	1,782
MAIN	5,411	11,929
NACELLES	2,562	5,648
PROPULSION GROUP	12,810	28,241
AUXILIARY POWER PLANT	272	599
SURFACE CONTROLS	1,733	3,822
INSTRUMENTS	565	1,245
HYDRAULICS	808	1,781
ELECTRICAL	1,315	2,900
AVIONICS	1,089	2,400
FURNISHINGS	2,505	5,523
AIR CONDITIONING & ANTI-ICING	1,557	3,433
AUXILIARY GEAR	27	59
WEIGHT EMPTY	69,983	154,287
OPERATING EQUIPMENT	1,588	3,500
OPERATING WEIGHT	71,571	157,787

Table 11 Reference Outsize Cargo Airplane Group Weight Summary

ITEM	WEIGHT	
	kgs	LBS.
OPERATING WEIGHT	62,344	137,445
CARGO	34,019	75,000
ZERO FUEL WEIGHT	96,363	212,445
MISSION FUEL	35,220	77,647
GROSS WEIGHT	131,583	290,092

Table 12 Reference Outsize Cargo Airplane Weight Summary

ITEM	WEIGHT	
	kgs	LBS.
OPERATING WEIGHT	71,571	157,787
CARGO	34,019	75,000
ZERO FUEL WEIGHT	105,590	232,787
MISSION FUEL	39,959	88,094
GROSS WEIGHT	145,549	320,881

Table 13 Structural Efficiencies

CONFIGURATION	TOGW LBS	STRUCTURE WT LBS	PAYLOAD WT LBS	STRUCTURE WT / TOGW	PAYLOAD WT / TOGW
BASELINE AIRPLANE - FLATBED		85,444			
PASSENGER MISSION	279,543		81,300	0.31	0.29
PRESSURIZED CARGO MISSION	280,445		82,050	0.30	0.29
PRESSURIZED CONTAINERS	282,262		83,300	0.30	0.30
UNPRESSURIZED CONTAINERS	303,903		76,100	0.28	0.25
UNPRESSURIZED PALLETS	304,648		79,550	0.28	0.26
M-60 TANK - OVERLOAD	347,602		115,000	0.25	0.33
REFERENCE PASSENGER A/P	255,860	73,034	50,760	0.29	0.20
REFERENCE CARGO A/P	290,092	88,938	75,000	0.31	0.26
REFERENCE OUTSIZED CARGO A/P	320,881	104,284	75,000	0.32	0.23

NOTE: THIS TABLE GIVEN IN U.S. UNITS SINCE THERE IS NO EFFECT ON EFFICIENCIES

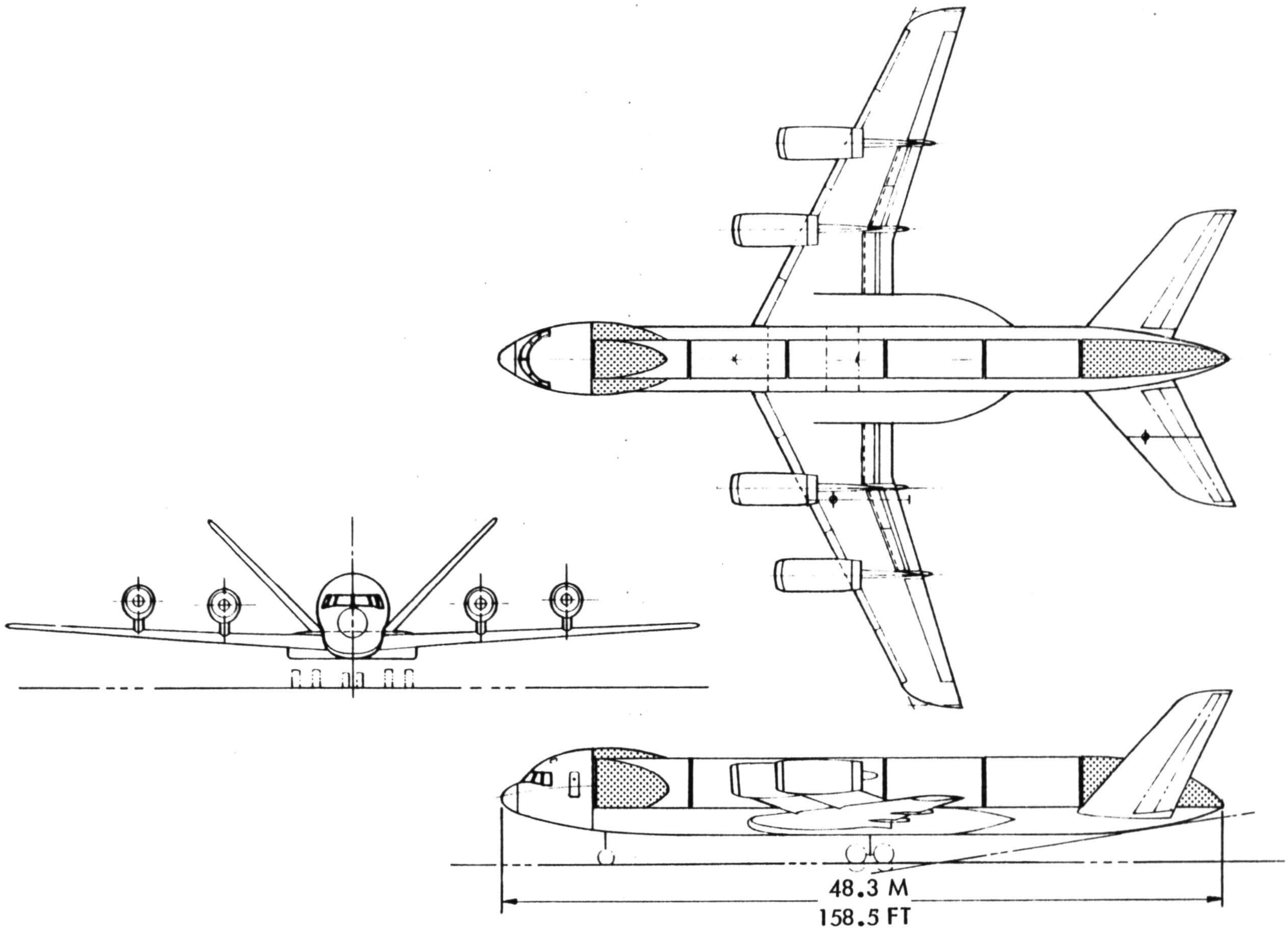


Figure 62 General Arrangement - Flatbed with Intermodal Unpressurized Containers

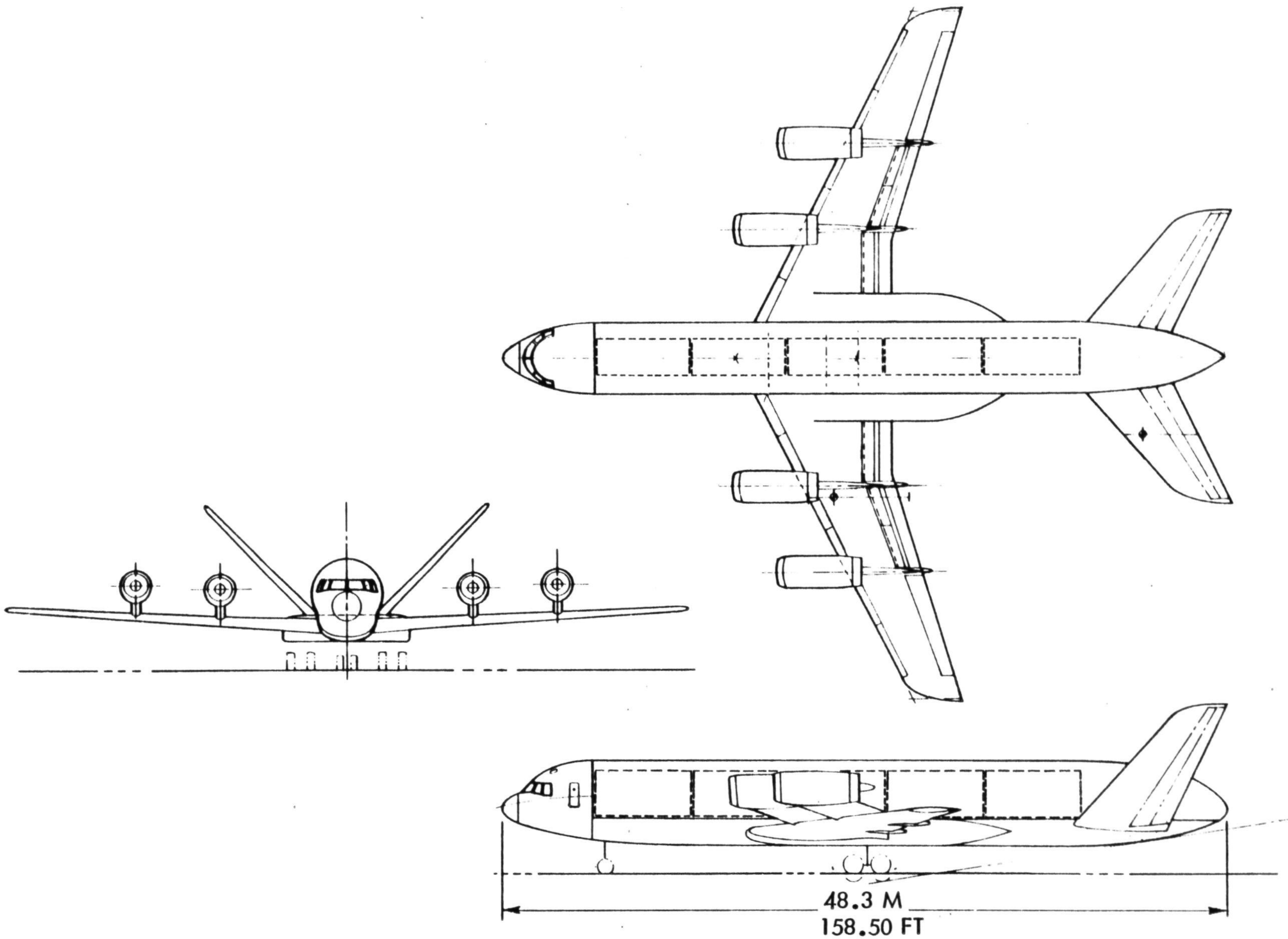


Figure 63 General Arrangement - Flatbed with Unpressurized Cargo Cocoon

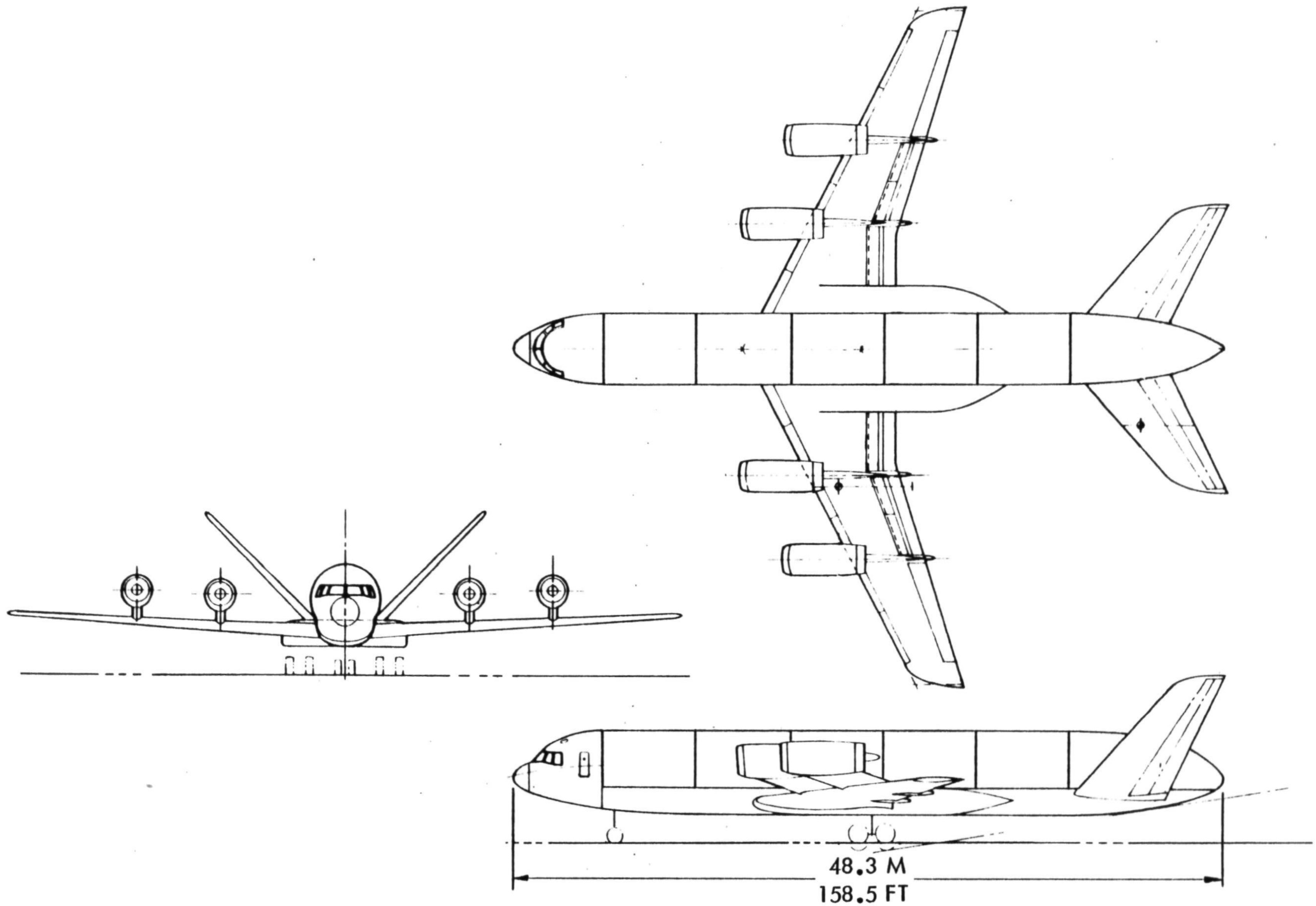


Figure 64 General Arrangement - Flatbed with D-Shaped Pressurized Cargo Containers

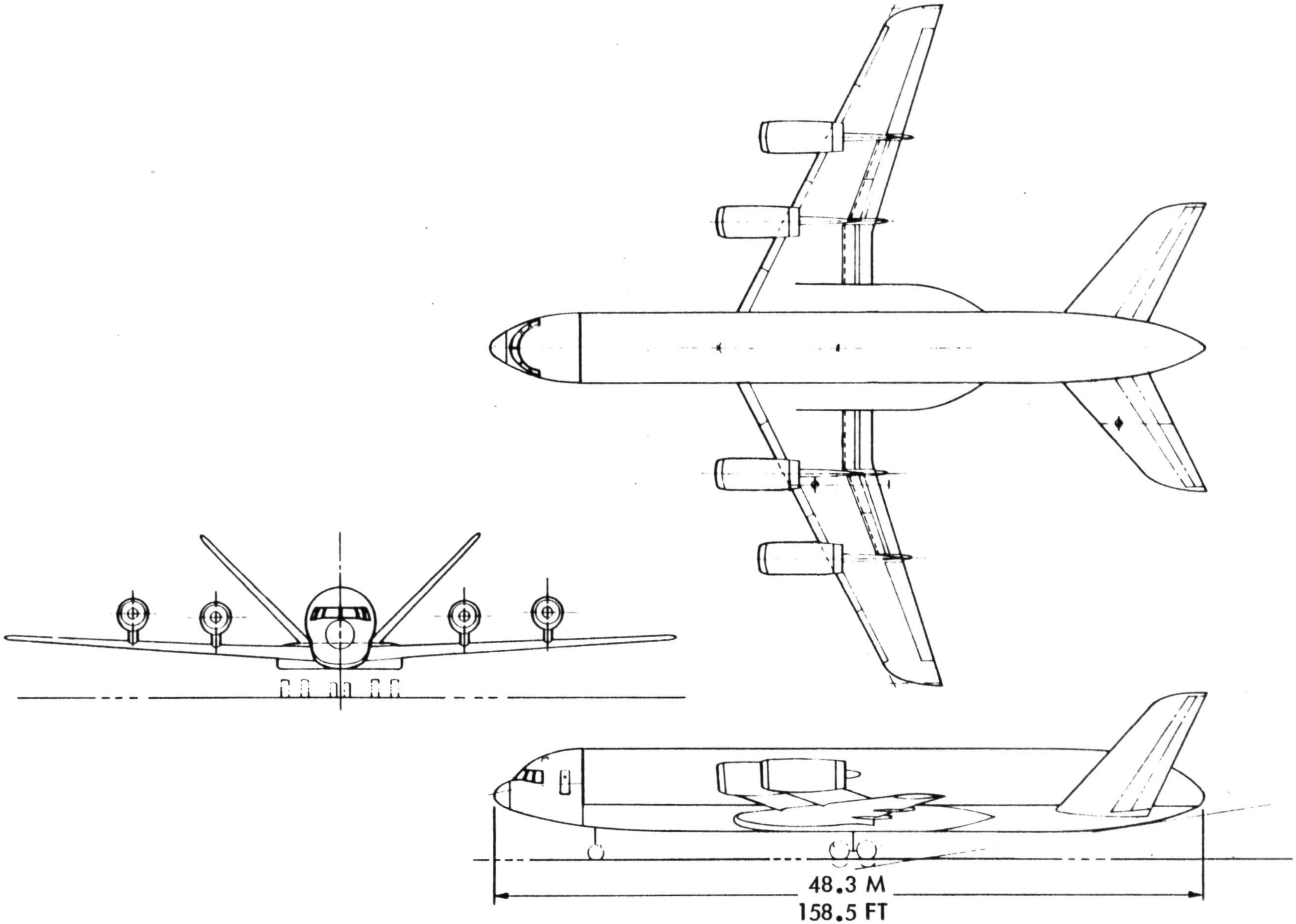


Figure 65 General Arrangement - Flatbed with Pressurized Cocoon

CRUISE MACH NO.	0.82
DESIGN PAYLOAD - kg (lbs)	36,870 (81,300)
DESIGN RANGE - km (n mi)	4815 (2600)
OPERATING WT. - kg (lbs)	54,450 (126,700)
MAX. GROSS WT. - kg (lbs)	126,800 (279,500)
BLOCK FUEL - kg (lbs)	28,800 (63,600)
THRUST PER ENGINE - N (lbs)	91,300 (20,500)

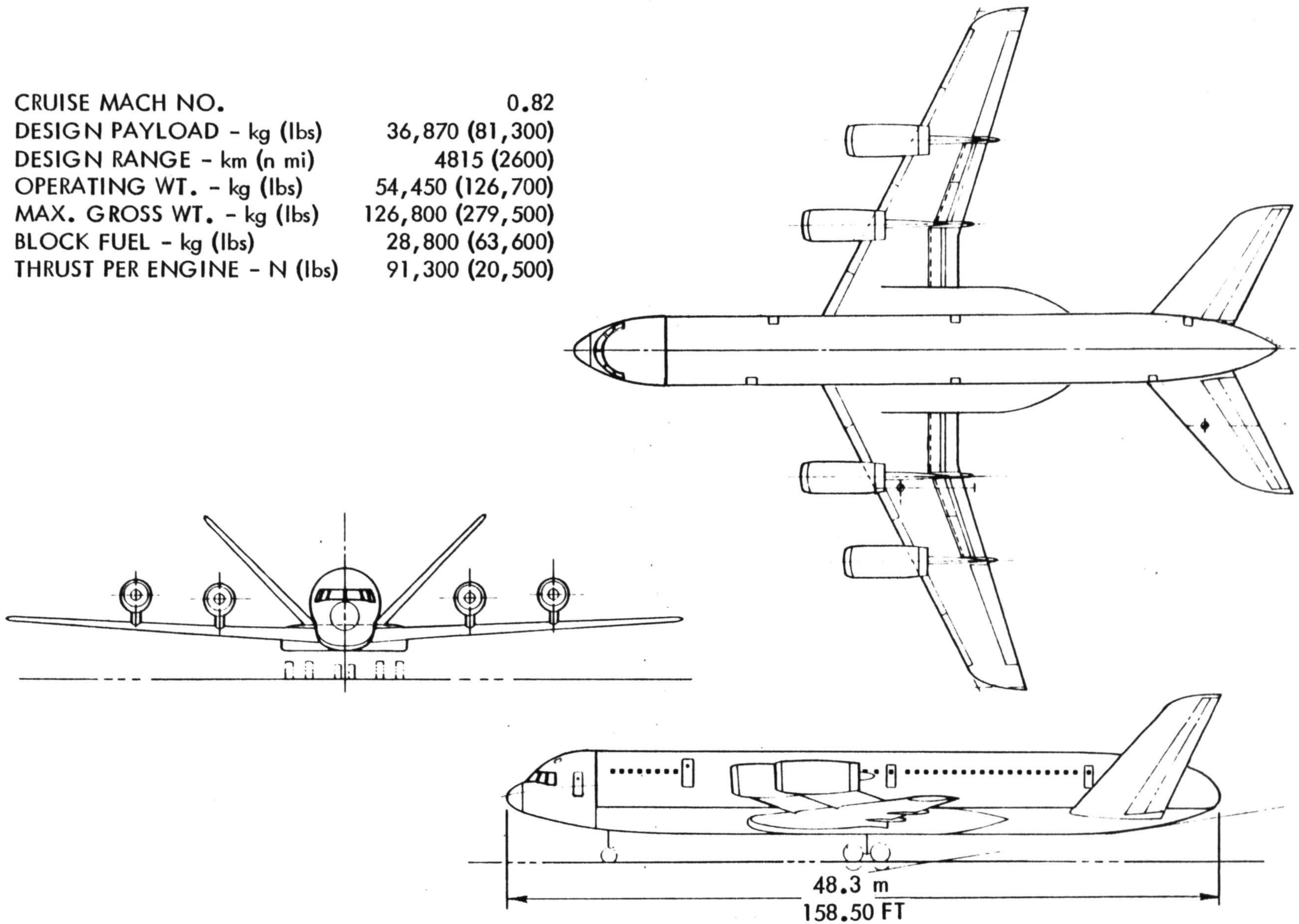


Figure 66 General Arrangement - Flatbed with Passenger Module

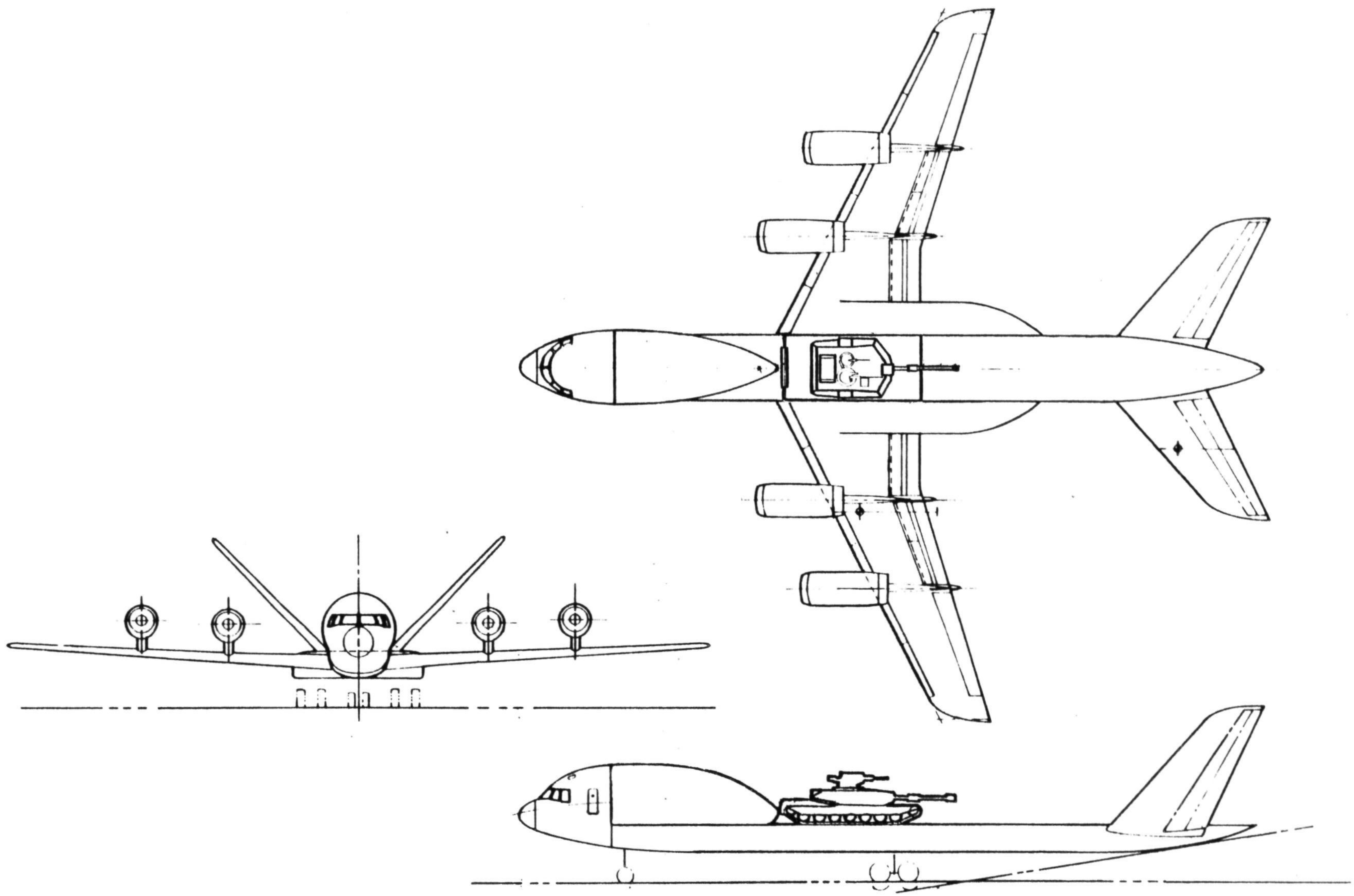


Figure 67 General Arrangement - Flatbed with XM-1 Tank

BRIDGE LAUNCHER EXTENDED

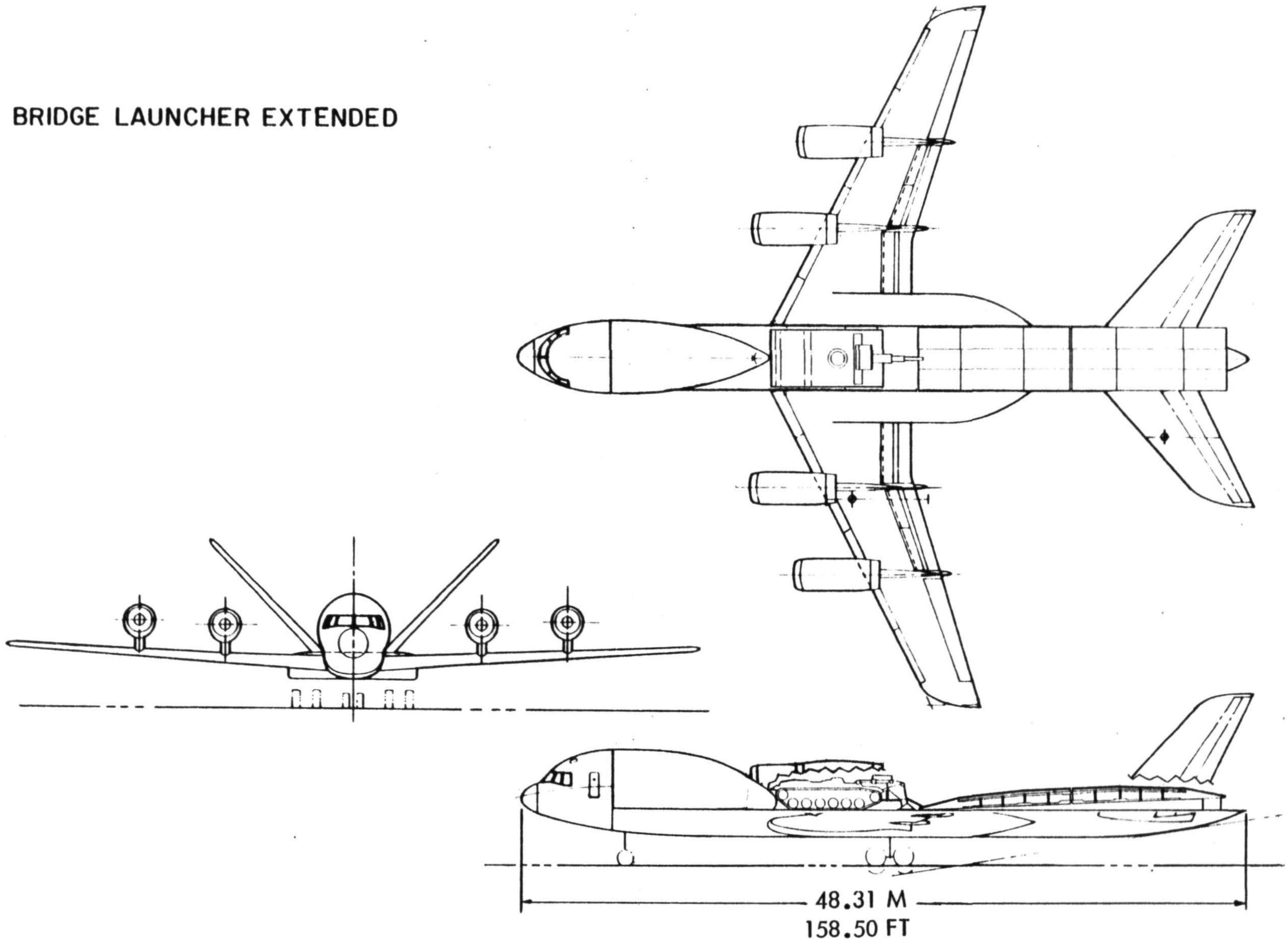
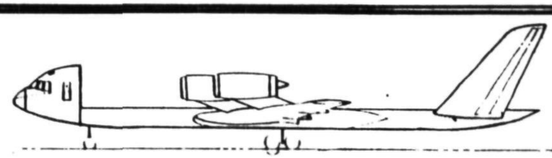
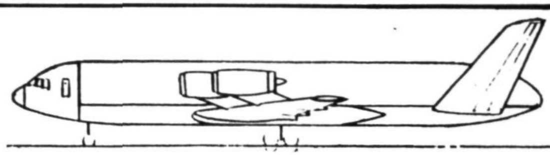
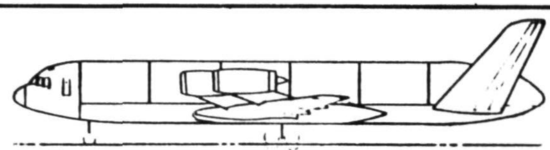
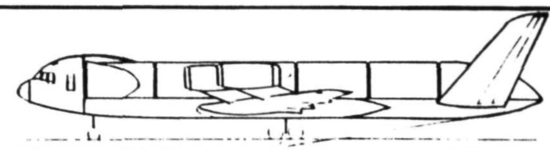
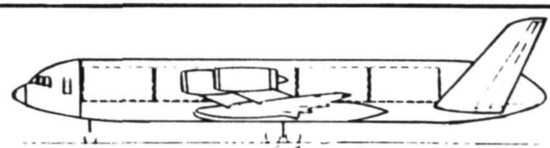
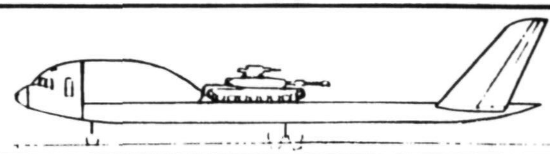
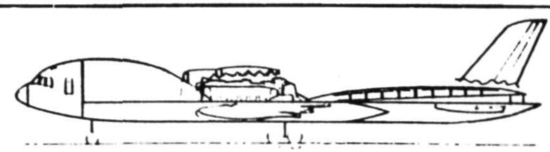


Figure 68 General Arrangement - Flatbed with Bridge Launcher

Table 14 Drag Summary - Flatbed with Varying Payloads

	CONFIGURATION	DESIGN CONDITIONS (M/h/R)	A_{WET} (ft.^{2})	A_{π} (ft.^{2})	$C_{D_{\pi}}$	$C_{D_{FUS}}$	$\Delta C_{D_{CARGO}}$	$\Delta C_{D_{NET}}$
1.	PASSENGER MODULE	.82/35K/2600	7192	199.5	-	.0049	-	0
2.	BACKBONE WITH FAIRING	↓	5439	↓	-	.0040	-	-.0009
3.	PRESSURIZED COCOON	↓	7192	↓	-	.0049	-	0
4.	PRESSURIZED CONTAINERS	↓	7192	↓	-	.0049	.00025	.00025
5.	UNPRESSURIZED COCOON	.74/18K/2600	7192	199.5	-	.0049	-	0
6.	UNPRESSURIZED CONTAINERS	.73/18K/2600	-	-	-	.0049	.0011	.0011
7.	XM-1 TANK	.60/18K/2415	-	73.81	.233	.0040	.0064	.0055
8.	M-60 BRIDGE LAUNCHER	.54/18K/2415	-	61.66	.291	.0040	.0074	.0065

Table 15 Incremental Drag - Various Flatbed Payloads

PAYLOAD CONFIGURATION	ADDITIONAL DRAG ITEM	$\Delta C_{D_{NET}}$ (REL. TO PAX MODULE)
	NO MODULE	.0082
	0	0
	LONGITUDINAL GAPS (2) TRANSVERSE GAPS (6)	.00025
	FORWARD FAIRING (3) LONGITUDINAL GAPS (2) TRANSVERSE GAPS (6)	.0011
	0	0
	FAIRING ASSY $\Delta C_D = -.0009$ TANK $\Delta C_D = +.0064$	.0055
	FAIRING ASSY $\Delta C_D = -.0009$ M60 BR. L. $\Delta C_D + .0074$	.0065

In order to improve the drag characteristics of the "open" configuration, a fairing to smooth the airflow is used at the first container/forward fuselage juncture. A sketch of an approximated fairing is shown in the upper portion of Table 15 in addition to a tail cone fairing for the last container. The drag characteristics of the forward fairing as shown is based on afterbody characteristics presented in References 11 and 12. The afterbody characteristics of the tail cone are estimated to be the same as those of the basic passenger module such that no additional drag is incurred. Additional drag due to longitudinal and transverse gaps similar to the pressurized cargo containers is also assumed. The gap size has been assumed to be 5.1 cm (2 inches) and the drag increment predicted from Reference 11. Table 15 summarizes the additional drag increments associated with the unpressurized containers.

Pressurized Containers - The pressurized cocoon, used to carry the standard cargo containers, has the same basic aerodynamic shape as the passenger version. For this reason, no additional drag is associated with the pressurized cocoon. The pressurized cargo containers especially designed for Flatbed operation simulate the passenger module in aerodynamic shape; hence, the drag characteristics are similar. However, additional longitudinal and transverse gaps are anticipated due to the stacking of the containers and mating to the Flatbed backbone. An assumption as to the possible size of these gaps (5.1 cm or 2 inches) was made and an estimated drag value obtained. Based on the information found in Reference 11, the estimated incremental drag is $\Delta C_D = +.00025$.

Military Vehicles - In each of the previous modes of cargo carriage, the payload was adjoined to the Flatbed such that a fuselage shape was simulated aft of the forward fuselage compartment. A carriage of military (or civil) vehicles exposes the blunt base of the forward fuselage. Figure 68 shows the desired backbone configuration for open air cargo; i.e., the forward fuselage fitted with an aerodynamically shaped afterbody (overall fineness ratio is approximately three).

Data presented in Reference 11 are used to define the profile drag of the fuselage configuration with the aftbody fairing. In addition, wetted surface of the lower Flatbed fuselage and the upper Flatbed surface aft of the fuselage housing is incorporated in the drag estimate which is summarized in Table 15. For comparison, backbone drag is presented sans the afterbody fairing. Clearly, utilization of the afterbody is necessary when flying open air cargo.

Two representative military vehicles are considered in this study - an XM-1 tank and a M-60 bridge launcher. Drag evaluation of vehicles such as these is difficult due to the lack of pertinent data. However, Reference 13 reports on the testing of similar tracked vehicles at low speeds and these data have been applied to the vehicles of this study. The basic drag coefficient, based on frontal area, C_{D_π} is 0.50. It has been suggested that since cruise Mach numbers are approximately 0.60, the presence of a bow wave may exist. This conjecture may be valid and the possibility of its existence is acknowledged. For the purposes of this study, however, no attempt is made to account for a drag contribution due to bow wave presence.

Table 15 summarizes the drag build-up for the vehicles. Approximate frontal areas of the XM-1 tank and M-60 bridge launcher are shown. A reduction in the free air drag of the tank is available because the mode of carriage is seen to be in a trail position, behind the fuselage afterbody. Again, using Reference 11 as a basis, an interference factor for tandem bodies of 0.50 is assumed and the resulting incremental drag for the tank is $\Delta C_D = 0.00635$ based on the reference wing area.

The bridge launcher drag increment is estimated in a similar manner with an additional effect included. The frontal area of the bridge launcher in the folded position is prohibitively high from a drag standpoint. Therefore, the bridge is assumed to be in an extended position along the length of the backbone reducing the frontal area by fifty percent (see Figure 69). An additional interference factor of 1.30 derived from Reference 11 for the extended bridge launcher is applied to the trail position interference factor. The resulting drag of the bridge launcher is $\Delta C_D = 0.00738$. It should be noted that only with Flatbed can the bridge launcher be carried in its extended position - a position achieved after driving aboard.

Geometric Comparison of Aircraft - A comparison of geometric properties, propulsion system parameters, and selected weights is given by Table 16 for Flatbed and the three reference aircraft.

Table 16 presents the summary of the sized Flatbed airplane, and a comparison with the three reference airplanes. The basic sized Flatbed airplane includes the passenger module having a gross payload of 36,871 kg (81,300 pounds). The payload includes passengers, furnishings, support systems, baggage and extra cargo as well as the structural weight of the module. Compared to the reference passenger airplane, the Flatbed version is heavier. Thus, the Flatbed airplane is not an efficient design for passenger operations only. However, the merit of this concept is that it is not restricted to one type of operation only but rather it offers payload flexibility.

Performance Comparison of Aircraft - A comparison of the relative performance of Flatbed and the three reference aircraft is presented by Table 17. Several aspects are worthy of note:

1. The cruise Mach Number of the Flatbed, low altitude cargo version is respectably higher than had been indicated by the original Lockheed analysis (Reference 2). This, it is believed, is due to the availability of more representative drag data.

   The cruise Mach Number of Flatbed carrying the XM-1 tank at 5486 meters (18,000 ft) altitude is 0.60 which translates to a speed of 519 km/hr (280 kts) EAS or a dynamic pressure of 12.7×10^3 pascals (1.85 psi). For the M60 bridge launcher, the cruise speed would be 463 km/hr (250 kts) EAS or a dynamic pressure of 10.1×10^3 pascals (1.47 psi). Based upon discussions with various Army personnel (Reference 14 typical) it is believed that Army vehicles can withstand these airloads.

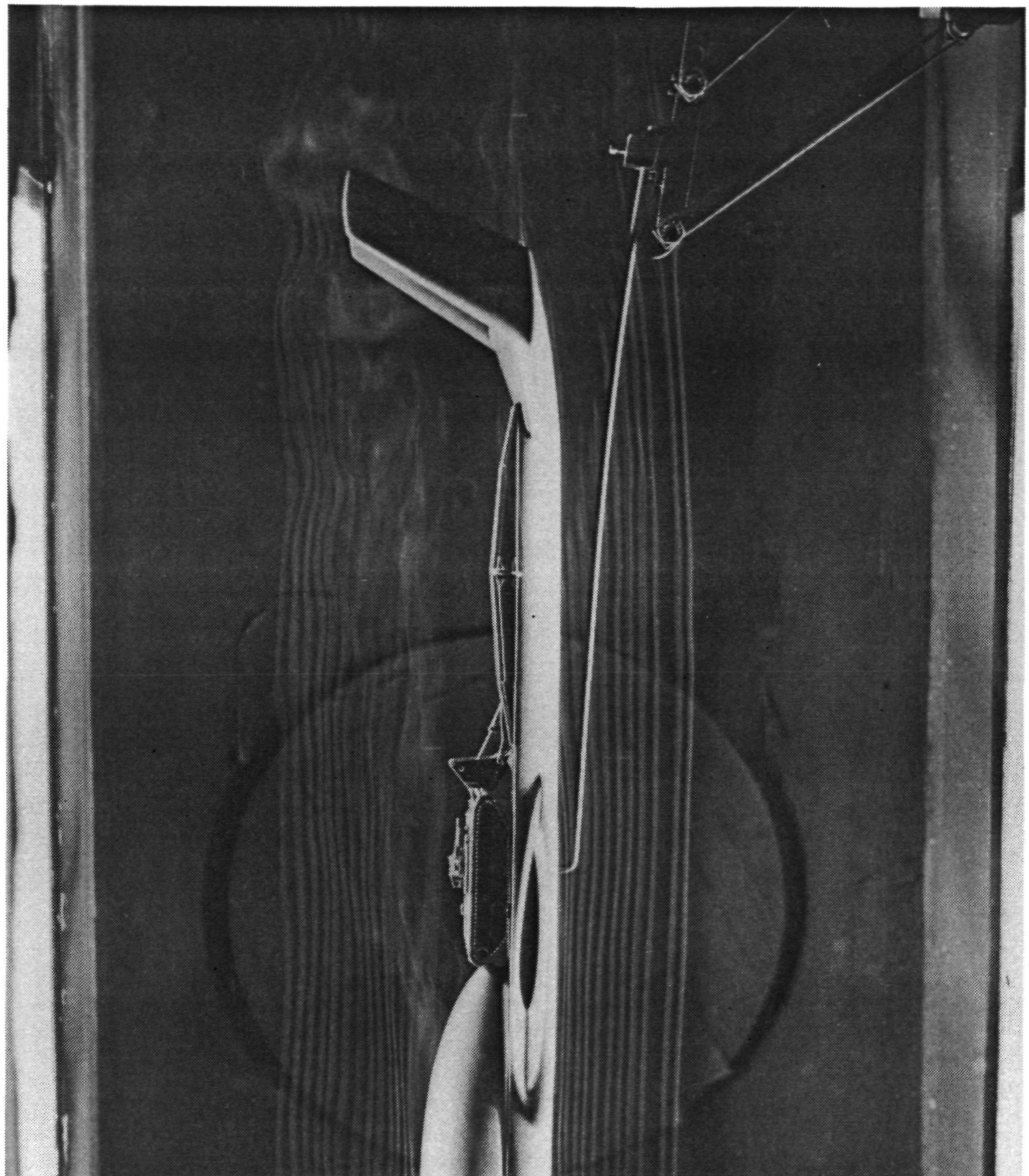


Figure 69 Flatbed With Bridge Launcher Extended Position

Table 16 a Comparison of Geometric and Propulsion Parameters - Flatbed vs. Reference Airplanes (Metric)

		FLATBED A/P PASSENGER MOD.	REFERENCE PASSENGER	REFERENCE CARGO A/P	REFERENCE OUTSIZE CARGO
WING:					
$AR, \Lambda_{C/4}, \lambda$		8.0/25°/.402	8.0/25°/.402	8.0/25°/.402	8.0/25°/.402
S_w	sq m	252.40	234.10	261.79	289.56
FUSELAGE:					
l	m	48.48	47.15	51.63	51.52
h	m	5.39	4.49	4.58	6.09
w	m	4.49	4.49	3.27	2.57
Fineness Ratio		9.84	10.48	10.79	8.45
Wetted Area	sq m	668.13	597.99	683.92	851.93
EMPENNAGE:					
H.T. Area	sq m	} 101.7	38.68	31.89	45.45
V.T. Area	sq m		50.64	32.16	44.68
PROPULSION:					
Engine Rated Thrust	N	91,340.0	85,899.0	100,164.0	114,251.0
Engine Weight (each)	kg	1740.5	1623.5	1932.3	2243.8
Engine SFC - Cruise	kg/hr/N	.0769	.0734	.0768	.0768
TOGW	kg	126,772.7	117,454.2	131,556.7	145,519.5
W/S (T.O.)	kg/sq m	502.3	501.7	502.5	502.5
T/W (T.O.)		.2938	.298	.3105	.3202
W/S (Cruise)	kg/sq m	486.7	486.7	486.7	486.7

Table 16b Comparison of Geometric and Propulsion Parameters – Flatbed vs. Reference Airplanes (U.S. Units)

		FLATBED A/P PASSENGER MOD.	REFERENCE PASSENGER	REFERENCE CARGO A/P	REFERENCE OUTSIZE CARGO
WING:					
$AR, \Lambda_{C/4}, \lambda$		$8.0/25^{\circ}/.402$	$8.0/25^{\circ}/.402$	$8.0/25^{\circ}/.402$	$8.0/25^{\circ}/.402$
S_w	ft^2	2717.	2520	2818.	3117
FUSELAGE:					
l	ft	159.06	154.71	169.42	169.05
h	ft	17.69	14.76	15.05	20.00
w	ft	14.76	14.76	16.38	20.00
Fineness Ratio		9.84	10.48	10.79	8.45
Wetted Area	ft^2	7192	6437	7362	9171
EMPENNAGE:					
H.T. Area	ft^2	} 1095	416.4	343.25	489.3
V.T. Area	ft^2		545.2	346.20	480.95
PROPULSION:					
Engine Rated Thrust	lbs	20535	19312	22519	25686
Engine Weight (each)	lbs	3838	3580	4261	4948
Engine SFC - Cruise	lb/hr/lb	.754	.720	.753	.753
TOGW	lbs	279,543	258,995	290,092	320,881
W/S (T.O.)	psf	102.9	102.8	102.9	102.9
T/W (T.O.)	-	.2938	.298	.3105	.3202
W/S (Cruise)	psf	99.7	99.7	99.7	99.7

Table 17a Airplane Performance Summary and Comparison (Metric)

Configuration	Cruise Mach	Cruise Alt. (m)	Cruise Range (km)	S_{REF} (sq.m)	OWE (kg)	Payload (kg)	Mission Fuel (kg)	Block Fuel (kg)	TOGW (kg)	Fuel Eff. (kg/kg/km)	T.O.Dist. (m)	Landing Distance (m)
Flatbed:												
Passenger Module	.82	10,668	4,815	252.4	57447	36869.5	32455.6	28820.3	126772.7	16.7×10^{-4}	1642.2	1134.1
Backbone With Fairing	.82	↓	4,815	↓	↓	362.8	25203.7	22410.1	83014.0	-	-	865.0
Backbone With Fairing	.82	↓	6,504	↓	↓	362.8	32455.1	29528.2	90265.5	-	942.7	889.7
Pressurized Cocoon	.82	↓	4,815	↓	↓	37209.5	32525.0	28882.9	127181.8	5.5×10^{-4}	1653.2	1136.5
Pressurized Containers	.80	↓	4,815	↓	↓	37776.5	32781.2	29144.6	128005.8	5.5×10^{-4}	1661.4	1140.8
Unpressurized Cocoon	.74	5,486	4,815	252.4	57447	36075.9	44221.6	39319.3	137745.1	7.7×10^{-4}	2299.7	1167.9
Unpressurized Containers	.73	↓	4,815	↓	↓	34511.3	45456.5	40488.9	137415.4	8.2×10^{-4}	2283.2	1162.2
Unpressurized Cocoon	.82	10668	4,815	↓	↓	34511.3	33235.6	125194.5	125194.5	6.3×10^{-4}	1711.1	1127.4
Unpressurized Containers	.82	10668	4,815	↓	↓	36075.9	32068.3	125596.3	125596.3	6.8×10^{-4}	1720.9	1120.7
Tank	.60	↓	4,473	↓	↓	52152.5	47900.9	43059.8	157501.0	6.3×10^{-4}	2994.0	1285.6
Bridge/Launcher	.54	↓	4,473	↓	↓	54420.0	49426.0	44676.0	161293.6	6.2×10^{-4}	3001.6	1304.8
Reference Aircraft:												
Passenger	.82	10,668	4,815	234.1	62769	23019.6	31664.7	25942.0	117454.2	8.0×10^{-4}	1724.2	1127.7
Passenger (CRAF)	↓	↓	↓	239.5	64866	23019.6	32286.9	26449.4	120172.9	8.2×10^{-4}	1728.8	1128.0
Cargo	↓	↓	↓	261.7	62331	34012.5	35212.9	31286.0	131556.7	6.5×10^{-4}	1676.4	1154.2
Outsize Cargo	↓	↓	↓	289.5	71556	34012.5	39950.6	35507.2	145519.5	7.4×10^{-4}	1606.6	1151.5
Outsize Cargo	.78	5,486	4,473	289.5	71556	54420.0	42044.8	37210.5	168021.7	5.2×10^{-4}	2221.9	1279.5

Table 17b Airplane Performance Summary and Comparison (U.S. Units)

Configuration	Cruise Mach	Cruise Alt. (ft)	Cruise Range (nm)	S_{REF} (ft^2)	OWE (lbs)	Payload (lbs)	Mission Fuel (lbs)	Block Fuel (lbs)	TOGW (lbs)	Fuel Eff. (lbs/lbsxnm)	T.O.Dist. (ft)	Landing Distance (ft)
Flatbed:												
Passenger Module	.82	35,000	2600	2717	126,676	81,300	71,567	63,551	279,543	3.01×10^{-4}	5388	3721
Backbone With Fairing	.82	↓	2600	↓	↓	800	55,576	49,416	183,052	-	-	2838
Backbone With Fairing	.82	↓	3512	↓	↓	800	71,566	65,112	199,042	-	3093	2919
Pressurized Cocoon	.82	↓	2600	↓	↓	82,050	71,720	63,687	280,445	2.99×10^{-4}	5424	3729
Pressurized Containers	.80	↓	2600	↓	↓	83,300	72,285	64,266	282,262	2.97×10^{-4}	5451	3743
Unpressurized Cocoon	.74	18,000	2600	2717	126,676	79,550	97,512	86,702	303,738	4.19×10^{-4}	7545	3832
Unpressurized Containers	.73	18,000	2600	↓	↓	76,100	100,235	89,281	303,011	4.51×10^{-4}	7491	3813
Unpressurized Cocoon	.82	35,000	2600	↓	↓	79,550	70,723	62,782	276,949	3.42×10^{-4}	5646	3677
Unpressurized Containers	.82	35,000	2600	↓	↓	76,100	73,287	64,811	276,063	3.70×10^{-4}	5614	3699
Tank	.60	18,000	2415	↓	↓	115,000	105,625	94,950	347,301	3.42×10^{-4}	9823	4218
Bridge/Launcher	.54	18,000	2415	2717	126,676	120,000	108,988	98,514	355,664	3.40×10^{-4}	9848	4281
Reference Aircraft:												
Passenger	.82	35,000	2600	2520	138,412	50,760	69,823	57,204	258,995	4.33×10^{-4}	5657	3700
Passenger (CRAF)	↓	↓	↓	2579	143,036	50,760	71,195	58,323	264,990	4.45×10^{-4}	5672	3701
Cargo	↓	↓	↓	2818	137,445	75,000	77,647	68,988	290,092	3.54×10^{-4}	5500	3787
Outsize Cargo	↓	↓	↓	3117	157,788	75,000	88,094	78,296	320,881	4.02×10^{-4}	5271	3778
Outsize Cargo	.78	33,000	2415	3117	157,788	120,000	92,712	82,052	370,500	2.83×10^{-4}	7290	4198

Based upon the cruise speed of Flatbed carrying the bridge launcher, the flight time from Travis to Hickham is approximately 8 hours -- not too long in terms of pilot/crew fatigue.

2. The takeoff and landing distances for all versions except the outsize vehicle version indicate that Flatbed can use most commercial airfields. The takeoff and landing distances for the XM-1 and M60 Bridge Launcher meet the requirements to use military airfields and are compatible with study criteria.

3. Two lines on Table 17 show the performance of the backbone alone (plus fairing). The first predicts performance for a range of 4815 km (2600 n.mi.) and the second the maximum range achievable, 6504 km (3512 n.mi.).

4. Flight with the especially designed pressurized cargo containers requires more fuel than the passenger version to fly the specified range. This is due to an increase in payload and the drag penalty associated with the multiple junctures between containers.

5. The pressurized cocoon configuration of the Flatbed in Table 17 also provides a valid comparison with the reference cargo airplane. The Flatbed cargo airplane has a zero fuel weight 1687 kg (3720 pounds) lighter and requires 2404 kg (5300 pounds) less fuel for the same range. However, the usable volume of the pressurized cocoon is probably less than that of the reference cargo airplane.

6. The Flatbed airplane with the M-60 bridge launcher, a 54,422 kg (120,000 pounds) outsize payload, can be compared to the reference outsize cargo airplane with the same payload for the same range, 4473 km (2415 n.mi.), in Table 17. The reference airplane can cruise at a higher altitude and Mach Number with less fuel than the Flatbed airplane. For the Flatbed airplane, the greater fuel load is a result of the lower cruise altitude and higher drag associated with the open air cargo. The cruise speed was selected to provide the minimum fuel required for the range and to also permit a takeoff distance less than 3048 meters (10,000 feet).

7. The tabulation of fuel efficiencies as presented in Table 17 shows Flatbed to be generally fuel efficient in comparison with reference airplanes except for carriage of outsize cargo. For example, Flatbed with the passenger module is about 30 percent more efficient than the reference passenger aircraft (3.01×10^{-4} vs. 4.33×10^{-4}) for the measure of efficiency used (pounds of fuel divided by the product of pounds payload and range in nautical miles). Flatbed with unpressurized containers cruising at high altitude is about 4 percent more efficient. However, Flatbed with the XM-1 tank is about 20 percent less efficient than the reference outsize cargo airplane.

These examples are based upon the total payload carried by the backbone. If net payload were used (29,365 kg or 64,750 pounds) the fuel efficiency value for the unpressurized containers at high altitude cruise would be 4.20 instead of 3.42 which would mean that Flatbed was nearly 19 percent less efficient than the reference aircraft. However, if the purpose of fuel efficiency is to measure the relative ability to carry weight a given distance, then total payload and not net payload should be used and Flatbed is more fuel efficient. When the total or gross load carried by Flatbed is used as the measure, the resultant higher efficiency reflects the influence of a conventional fuselage. A conventional fuselage has more wetted area contributing to drag and the conventionally configured airplane is slightly larger.

Furthermore, it is opined that the fuel efficiency measure, as defined in Reference 1, is not truly applicable in the passenger version. It is suggested that the measure might be how much fuel is required to haul a given number of passengers a specified distance. Since the passenger loads for both Flatbed and the reference airplanes are identical (180 plus baggage and mail) then Flatbed utilizes about 11 percent more fuel to accomplish the mission.

8. Comparison of fuel required for Flatbed with unpressurized cargo (either containers alone or in cocoon) shows that well over 10,000 kg (22,000 pounds) of fuel can be saved by flight at cruise altitudes above 5486 meters (18,000 ft). The higher cruise altitude also permits a higher cruise speed, Mach 0.82 vis-a-vis 0.74. Fuel efficiency is also improved about 20 percent relative to flight at lower altitudes.

Payload/range data for all the Flatbed configurations and the reference aircraft are presented in Figures 70 and 71.

<u>Penalty to Reference PAX Aircraft for CRAF</u> - Flatbed has inherent capability for use as a CRAF vehicle because of its interchangeability of payloads. To permit the reference passenger airplane to haul cargo in the event of a military contingency requires the conventionally configured aircraft to have a larger entrance door and a heavier floor. The weight penalty is 1224 kg (2700 pounds) which causes additional fuel to be carried to the extent that the TOGW is increased 2494 kg (5500 pounds) on a medium-sized transport.

<u>Effect of Alternative Sizing/Optimization Criteria</u> - The basic criteria required Flatbed to be optimized for the passenger module version at a cruise Mach Number of 0.82 at an altitude of 10,668 meters (35,000 ft.). Performance with all other payloads was then a "fallout."

As required, an assessment was made of the effect of sizing Flatbed for carriage of cargo containers in an unpressurized cocoon at low altitude. For this case, the cruise Mach Number would be 0.74 at an altitude of 5486 meters (18,000 ft.) which is the "fallout" performance of this configuration when Flatbed was sized for passenger

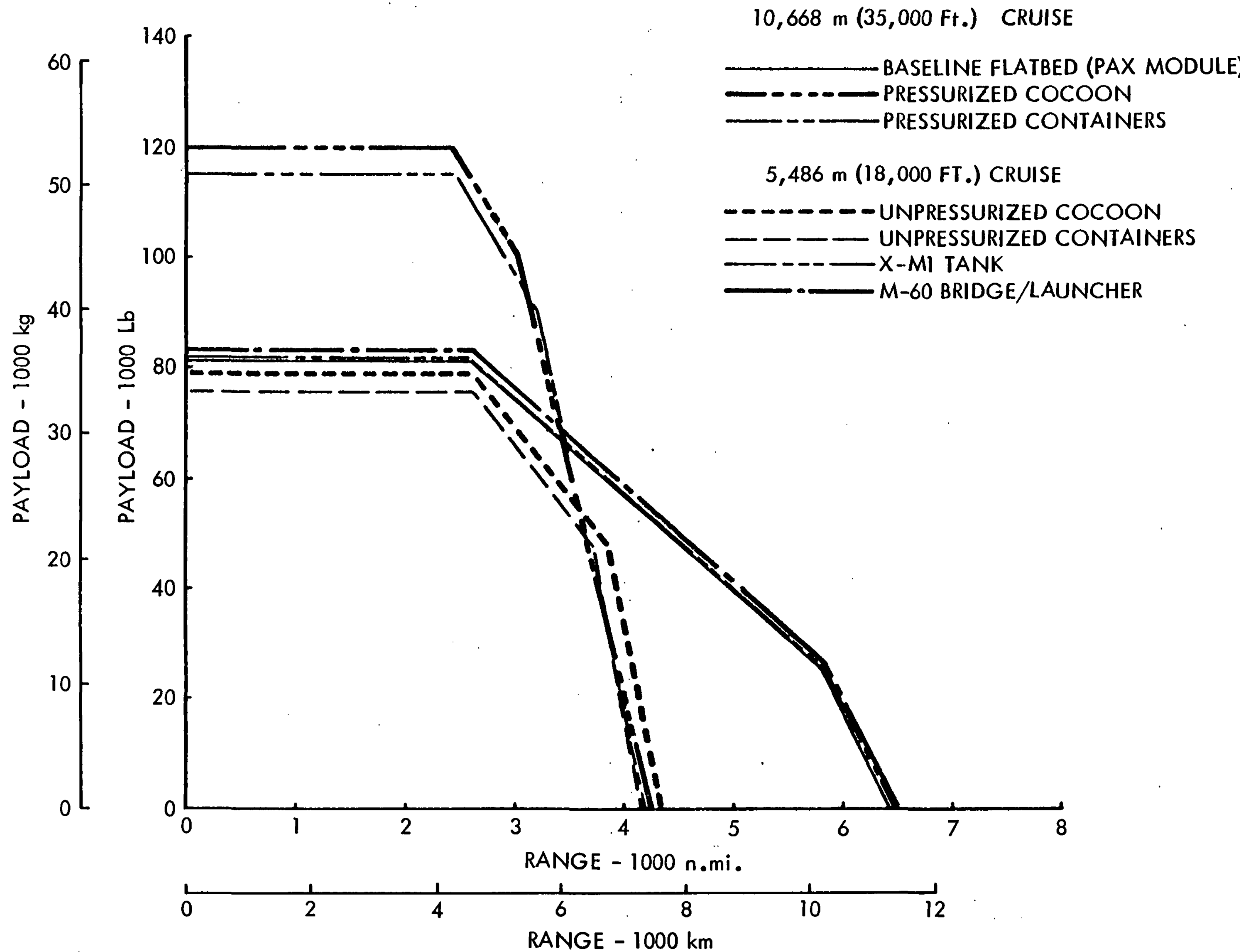


Figure 70 Payload - Range - Flatbed Configurations

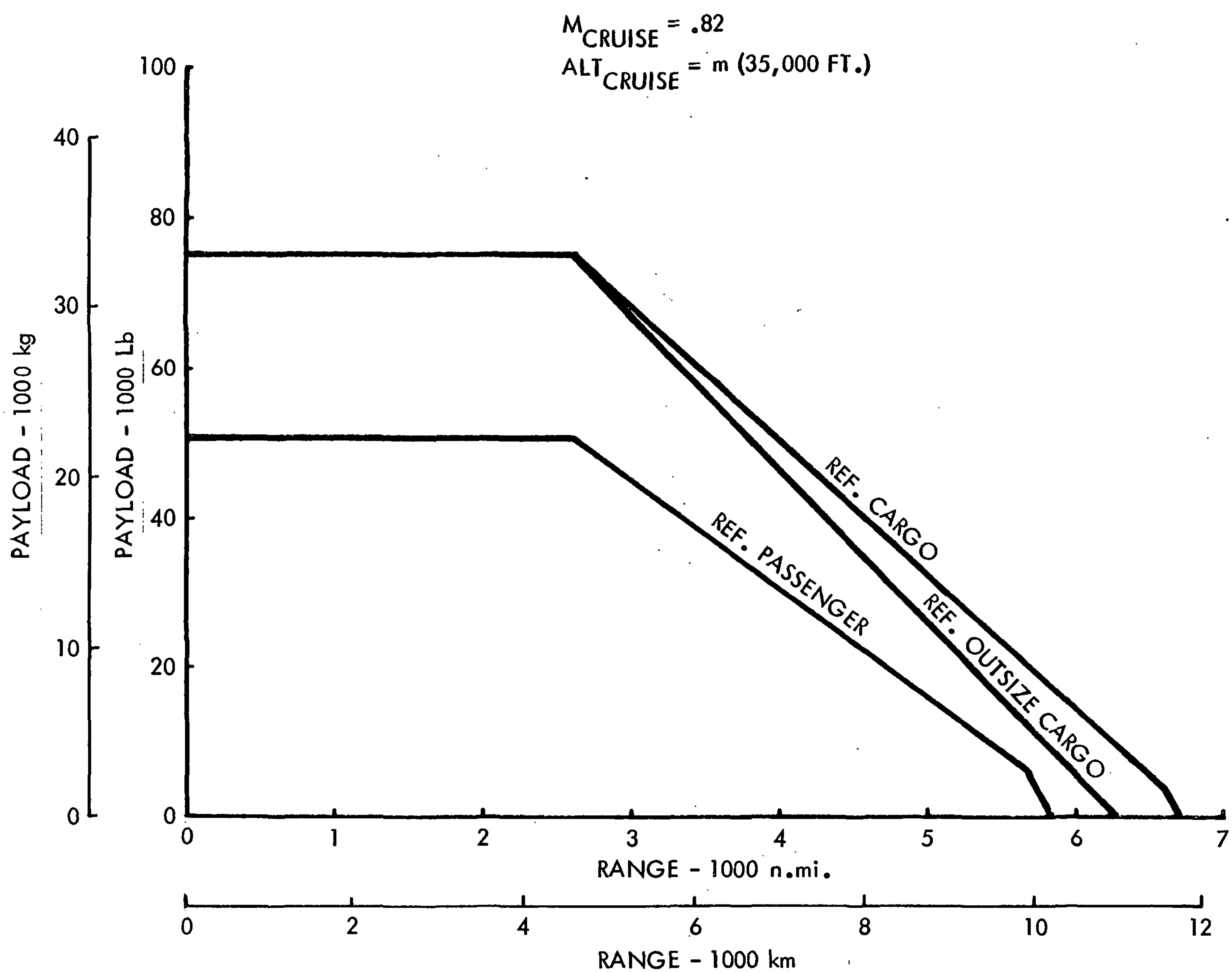


Figure 71 Payload-Range - Reference Airplanes

operations. For this sizing/optimization, the performance of the passenger version is a "fallout."

The effect of these alternative design/sizing criteria is given by Table 18. The original sizing is given by the first two columns and the effect of alternative sizing (optimizing on the cargo airplane) is given by the third, fourth and fifth columns. (The fifth column presents an analysis of the effect of sizing/optimization as a cargo airplane with an unpressurized cocoon at an altitude of 10,668 meters and Mach Number of 0.82 vis-a-vis a low altitude of 5486 meters and Mach = 0.74. Results tabulated in Column 5 indicate that the basic backbone size would not significantly change from the original sizing as a passenger airplane as presented in Column 1.)

The basic Flatbed sized with the passenger module payload and cruise conditions in Column 1 is compared to the alternative criteria design in Column 3. The two payloads are identical in drag coefficient and differ only slightly in weight. Both airplanes are sized using identical start-of-cruise wing loading.

The following changes are reflected by the lower altitude design: a larger wing area, a larger engine size, a larger wing thickness ratio and reduced cruise Mach Number. The increased wing thickness and reduced design Mach Number contributes largely to the 1683 kg (3711 pounds) reduction in primary structure weight. With the weight increase in other areas (propulsion, aircraft systems and equipment) due to larger wing area and engine size, the operating weight empty (OWE) exhibits a net 227 kg (500 pound) weight reduction for the lower altitude airplane. However, this configuration requires more fuel to fly the design range ($\Delta \; W_{fuel}$ = 16,194 kg (35,708 pounds)); the final result is a 15,174 kg (33,458 pounds) increase in TOGW for the Flatbed to fly the design mission at lower altitude and lower Mach Number.

A comparison of Flatbed with identical payloads (passenger modules) but with two different sizing criteria, Columns 1 and 4, shows that the Flatbed sized as a cargo airplane but operated as a passenger airplane requires more fuel for the same range because it is operated at a lower altitude. The penalty is 1437 kg (3167 pounds) of fuel as a result of the larger, thicker wing and slightly larger engine required for low altitude operation. Further, the operation as a passenger airplane is restricted to a cruise Mach Number of 0.74. This results because the airfoil/wing optimized to cruise at M = 0.74 cannot be made to cruise at 0.82 except through very large increases in engine power and, concomitantly, size.

Another design alternative is to size the Flatbed to fly the 4815 km (2600 n.mi.) mission at the design Mach Number of 0.82 and at the alternate altitude of 5486 meters (18,000 feet). The last column of Table 18 summarizes the re-sized airplane performance characteristics. The increase in cruise Mach Number at 5486 meters (18,000 feet) causes a 11,546 kg (25,458 pounds) increase in fuel required which translates into a 10,526 kg (23,209 pounds) increase in OWE. The takeoff gross weight increases by 22,071 kg (48,667 pounds) and the wing area increases by 16 percent.

Table 18a Comparative Aspects of Alternate Sizing/Optimization (Metric)

		ORIGINAL SIZING		ALTERNATIVE SIZING		ALT. SIZING @ HIGHER MACH NO.
		Pass. Module (Sized)	Unpress. Cocoon (Fallout)	Unpress. Cocoon (Sized)	Pass. Module (Fallout)	Unpress. Cocoon (Sized)
Mach		.82	.74	.74	.74	.82
Altitude	m	10668.0	5486.4	5486.4	10668.0	5486.4
Range	km	4815.2	4815.2	4815.2	4815.2	4815.2
W/S	kg/sq m	99.7	110.2	99.7	89	99.7
S	sq m	91340.0	→	95761.0	→	129663.0
t/c		.1057		.167		.1324
Thrust (Rated) N		91381.0		43445.0		58829.0
AR		8.0		8.0		8.0
c/4		25		25		25
Structure	kg	38748.8	→	37065.9	→	43593.1
Wing	kg	(13165.5)		(10552.0)		(14646.2)
Empennage	kg	(2489.7)		(2932.3)		(3542.7)
Fuselage	kg	(14671.6)		(14671.6)		(14671.6)
Landing Gear	kg	(5622.9)		(5983.0)		(6812.0)
Nacelle/Pylon	kg	(2799.0)		(2926.8)		(3920.5)
Propulsion System	kg	10240.4		10997.3		14626.7
Systems & Equip.	kg	8458.2		9157.5		9525.7
OWE	kg	57447.5	57447.5	57220.8	57220.8	67746.0
Fuel	kg	32455.6	44221.6	49740/2	33891.8	60194.4
Payload	kg	37970/5	36075.9	36075.9	36869.5	36075.9
TOGW	kg	126772.7	137745.1	141945.9	127982.2	164016.4
Fuel Efficiency	kg/kg/km	5.5×10^{-4}	7.7×10^{-4}	8.5×10^{-4}	5.8×10^{-4}	10.3×10^{-4}

[ ] DENOTES PARAMETERS USED TO SIZE AIRPLANES

Table 18b Comparative Aspects of Alternate Sizing/Optimization (U.S. Units)

		ORIGINAL SIZING		ALTERNATIVE SIZING		ALT. SIZING @ HIGHER MACH NO.
		Pass. Module (Sized)	Unpress. Cocoon (Fallout)	Unpress. Cocoon (Sized)	Pass. Module (Fallout)	Unpress. Cocoon (Sized)
Mach		.82	.74	.74	.74	.82
Altitude	ft.	35,000	18,000	18,000	35,000	18,000
Range	nm	2600	2600	2600	2600	2600
W/S	psf	99.7	110.2	99.7	89	99.7
S	ft^2	2717		3091		3578
t/c		.1057		.167		.1324
F_N (Rated)	lbs	20,535		21,529		29,151
AR		8.0		8.0		8.0
$\Lambda_{c/4}$	deg	25		25		25
Structure	lbs	85,444		81,733		96,126
Wing		(29,031)		(23,268)		(32,296)
Empennage		(5,490)		(6,466)		(7,812)
Fuselage		(32,352)		(32,352)		(32,352)
Landing Gear		(12,399)		(13,193)		(15,021)
Nacelle/Pylon		(6,172)		(6,454)		(8,645)
Propulsion System	lbs	22,581		24,250		32,253
Systems & Equipment	lbs	18,651		20,193		21,005
OWE	lbs	126,676	126,676	126,176	126,176	149,385
Fuel	lbs	71,567	97,512	107,275	74,734	132,733
Payload	lbs	81,300	79,550	79,550	81,300	79,550
TOGW	lbs	279,543	303,738	313,001	282,210	361,668
Fuel Efficiency	lbs/lbsxnm	3.01×10^{-4}	4.19×10^{-4}	4.62×10^{-4}	3.17×10^{-4}	5.68×10^{-4}

[ ] DENOTES PARAMETERS USED TO SIZE AIRPLANES

A comparison of the cargo versions at low altitude and low cruise Mach number can be made (Columns 2 and 3). The effect of the larger wing and slightly larger engines is clearly evident in the fuel required. These comparisons show that a smaller and better performing airplane is available when the otpimization is based on high altitude mission requirements. Low altitude performance is not sacrificed in this manner although there is a decrease in speed.

Economic Analysis

One of the most significant aspects affecting the viability of the Flatbed concept is its economic feasibility. Although all of the previous study results have confirmed its technical feasibility, the fact remains that if Flatbed is relatively more expensive in operations, the merits of its versatility are negated. Accordingly, an economic evaluation was made to determine acquisition and operating costs (both Direct Operating Costs (DOC) for civil operations and Life Cycle Cost (LCC) for military operations).

Costing Criteria - An essential element of acquisition cost is the production run schedule which is given by Table 19.

Table 19 Production Run Schedule

	Case 1	Case 2	Case 3
Flatbed civil cargo airplane	150	300	300
Pressurized containers (civil)	1000	2000	2000
Reference civil cargo airplane	150	300	300
Flatbed military cargo airplane	150	150	150
Pressurized containers (military)	500	500	500
Reference military cargo airplane	150	150	150
Flatbed passenger airplane	250	0	400
Passenger modules	300	0	480
Reference passenger airplane	250	0	400
Total number of Flatbed backbones	550	450	850

The purpose of varying the numbers of backbones and reference airplanes procured is to test the thesis that buying more backbones at a lower unit cost versus lesser numbers of multiple conventional aircraft would offset the apparent higher fuel cost of Flatbed.

One of the key elements of civil DOC is the aircraft utilization. For this study, the following was assumed:

a. Reference passenger airplane - 10 hours per day.
b. Flatbed passenger airplane - 12 hours per day.
c. QC Flatbed - 18 hours per day.
d. Cargo Flatbed and reference cargo airplane - 10 hours per day.

Assumption b is predicated on the fact that turnaround time for conventional passenger airliners is about 1.5 hours based on available airline data. Preliminary analysis indicated that the Flatbed can be turned around in 30 minutes because of its modular approach. Hence, assuming two turnarounds per day means a savings of 2 hours which is added to the usual 10-hour per day utilization. Assumption c is predicated on 6 hours per day utilization of Flatbed in a cargo mode over and above its use in the passenger mode. This value allows sufficient downtime for maintenance and inspection required every 24 hours by FAA regulations.

Specific DOC Criteria - The depreciation period is 15 years with a residual value of ten percent. Only domestic operations are considered. Assumptions included a fuel price of 46 cents per gallon* and a crew of three. DOC is estimated for passenger and civil cargo versions of both reference and Flatbed aircraft. DOC's for Flatbed include the effect of Quick-Change (QC) operations converting from daytime passenger service to nighttime cargo operations.

Specific LCC Criteria - As in the civil case, a key element in life cycle costing is utilization. Peacetime operations assumed utilization of 1080 hours per year per AFP 173-10. Base and depot maintenance as well as replenishment spares are estimated from AFP 173-10. The crew ratio is established on the basis of current MAC experience and/or by AFP 173-10 for C-141-type aircraft. Fuel cost was 46¢/gallon.* Finally, life cycle costs were calculated for a period of 20 years.

For military LCC, pressurized containers are included as an integral part of that portion of the Flatbed military aircraft fleet utilizing these units. The balance of the Flatbed fleet is assumed to be using unpressurized containers or outsized vehicles.

Production and development costs are based on 1980 dollars.

Acquisition Costs - Acquisition costs are divided into RDT&E (non-recurring) and Production (recurring). Costs are tabulated in Table 20 for varying production rates and the total price (including amortization of non-recurring costs) is graphically portrayed in Figure 72. Table 21 gives a typical breakdown of non-recurring and recurring costs for the various technical and manufacturing disciplines involved for the backbone.

Costs for the Flatbed and reference aircraft were parametrically estimated using equations based on Lockheed's historical aircraft cost data. These data include both commercial passenger and military cargo aircraft. Inputs to the equations include weights, engine thrust, state-of-the-art factors, speed, testing span, fuselage density, and other various aircraft parameters including factors for usage of composite materials. Variation in the cost as a function of the total number of production units was based upon a conventional "learning curve."

The primary difference between Flatbed and conventional aircraft is its fuselage structure. This unique fuselage has a higher total development cost than the reference aircraft because design analysis costs will be about 20 percent higher and ground testing costs

* Subsequently studied for effect of increasing fuel costs up to $1.20/gal.

Table 20 Summary of Non-Recurring and Recurring Costs

	REFERENCE AIRCRAFT			FLATBED							
	CARGO	O/S CARGO	PAX	FLATBED BACKBONE	PAX MODULE	INTERMODAL CONTAINER	PRESSURIZED COCOON	UNPRESS. COCOON	FAIRING	RAMPS	PRESSURIZED "D" CONTAINERS
NON-RECURRING	839	983	886	814	299	14	165	23	6	6	20
RECURRING / UNITS PROD.											
150	34.3	38.3					3.7	1.2		.4	
250			31.1								
300	28.6				8.1		2.7	.8			
400			27.5	25.2							
450				24.5					.2		
460				24.4							
480					6.7						
500						.4					.5
550				23.3					.1		
850				21.3					.1		
1000						.3					.4
2000						.3					.4

NOTES:

- 1980 DOLLARS (MILLIONS)
- RECURRING IS THE CUM $\overline{AV}$ FOR THE QUANTITY SHOWN

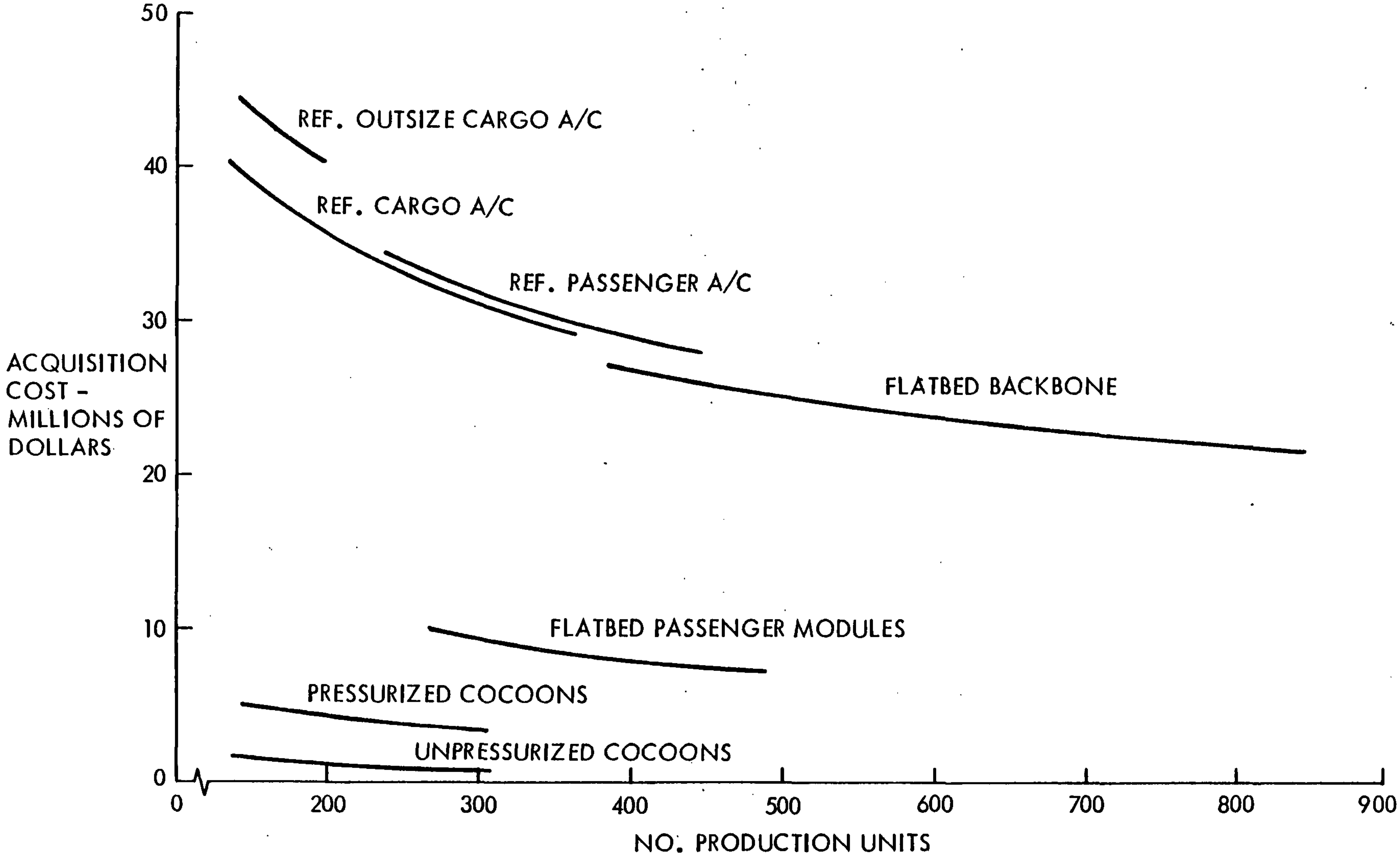


Figure 72 Effect of Production Run on Unit Aircraft Price

Table 21 Typical Acquisition Cost Breakdown for Flatbed Backbone
(Millions of Dollars)

Non-Recurring	
Engineering	
Design	$ 74
Design Support	124
Ground Test	19
Static Test	11
Fatigue Test	30
Flight Test	62
Program Peculiars	37
Engineering Materials	50
Handbooks	25
Handbook Materials	9
	$441
Tooling	
Direct Labor	$206
Tool Materials	56
	$262
Production	
Static Test Article	$ 30
Fatigue Test Article	26
Mockup	26
Test Article Material	11
	$ 93
Quality Assurance	
Tooling Inspection	$ 12
Production Inspection	6
	$ 18
TOTAL NON-RECURRING	$814

Recurring	
Cumulative Average for 450 Units	
Material & Equipment	$14.2
Production Labor	7.6
Sustaining Engineering	1.0
Sustaining Tooling	.7
Quality Assurance	.8
	$24.5

will be about 29 percent higher. However, the component design costs and tooling costs will be about 25 percent and 9 percent lower, respectively, for Flatbed. These lower costs result because there are fewer fuselage components requiring design and tooling development.

The net total effect is that Flatbed's overall airframe non-recurring cost is about 3 percent higher. However, the recurring cost of Flatbed would be significantly lower because there is less fuselage to build and many of the furnishings and systems usually associated with fuselages have been eliminated.

The cost of acquiring the special pressurized D-shaped containers and the cocoon was estimated from data available on similar elements.

It should be noted that the front passenger module and pressurized cocoon are virtually identical, except for windows, floor and front loading door. Thus, a considerable savings in RDT&E (non-recurring) costs would accrue should their development be simultaneous.

Hence, for the cases in which passenger aircraft are considered (Cases 1 and 3) the non-recurring cost for the passenger module is $299 million and for the pressurized cocoons it is $74 million. In Case 2 there are no passenger aircraft so the pressurized cocoons assimilate the full development cost of $165 million. In the two cases in which commonality is assumed, the savings in non-recurring costs are therefore $91 million. The same philosophy is applied to production costs of pressurized cocoons which makes them relatively less expensive in Cases 1 and 3 when they can be included on the passenger module learning curve.

Operating Costs - Operating costs were estimated for civil cargo and passenger aircraft as well as military cargo. The cases investigated for each varied as a function of the production rates specified in the criteria. The effect of QC operations was included.

With specific regard to QC operations, it is assumed that the total number of backbones procured for civil operations would be reduced in proportion to the increase in daily utilization. Otherwise stated, an airline would reduce the total number of backbones being procured if they could get 18 hours per day utilization per backbone instead of 12 hours. The effect of this reduced procurement would be to increase the unit production price in accordance with the learning curve, Figure 72, and it would also reduce the total fleet procurement cost. This reduction in procurement and concomitant increase in recurring cost is reflected in the analyses for both civil and military operating costs.

The DOCs for civil operations were estimated using a modification to the ATA 1967 DOC equations. Equations were inflated to 1980 dollars (e.g., 1980 crew costs were 2.52 times the 1967 values, and 1980 maintenance labor rates were taken as $12/hour). In addition, the following four basic maintenance elements were adjusted to reflect experience from use of wide-bodied jets since 1967:

o Airframe maintenance labor cost	0.52
o Airframe maintenance material cost	0.68
o Engine maintenance labor cost	0.62
o Engine maintenance material cost	1.31

The foregoing maintenance cost elements are calculated per the 1967 ATA formula adjusted for 1980 dollars and are then multiplied by the noted factors to reflect recent widebody experience.

The basic tool for cost calculations was Lockheed-Georgia Company's "Aircraft Life Cycle Cost Evaluation (ALICE)" model. (Note: This model can estimate either military or civil operational costs.) Military cargo cost estimation used the basic data presented in AFP 123-13, May 1979.

Both Flatbed and reference aircraft DOC for cargo operations have been calculated for the "net" payload carried. This amounts to 29,365 kg (64,750 lbs.). The net payload was used because, in airline operating terms, this is the revenue generating payload -- the tare weight of containers and pallets does not contribute to the airplane's economic efficiency. DOC for Flatbed and reference aircraft passenger operations were computed using available seat-miles.

Civil Operating Costs - DOC values for Cases 1 through 3 for civil cargo and passenger operations as a function of payload configuration are summarized in Tables 22 through 27. The tables present costs for each of the major elements prescribed by the ATA formula with the end product being cost per megagram kilometer (cost per ton statue mile) or cost per seat kilometer (cost per seat mile) for cargo and passenger operations, respectively. Costs are given with and without QC operations.

Presentation of DOC values, computed in accordance with the ATA formula, involve a level of detail which tends to obscure the interpretation of results. For example, it is difficult to assess the relative effect of numbers of units procured and the unit production price without referral to Tables 19 and 20 as well as Figure 72. Accordingly, three typical examples are given in Tables 24b through 24d for the configuration of unpressurized containers with cocoon at low altitude.

Table 24b presents an abridged summary of DOC values for cargo operations, Case 1 (this case is marked in Table 24a with a single asterisk and the reference airplane with an arrow). Table 24b notes the effect of units procured (550 Flatbeds vs 150 reference aircraft) on the unit aircraft price -- $28 million for Flatbed vs $39.9 million for the reference airplane. The lower aircraft price of Flatbed results in lower costs for maintenance, insurance, and depreciation which offsets the higher costs for crew and fuel - both of which are caused by the higher drag of Flatbed which also means higher block times. The offset affects the total DOC so that Flatbed is 0.8¢ per statue mile lower than the reference aircraft.

Table 24c presents a comparable summary for passenger operations (marked with a double asterisk in Table 24a). Although Flatbed's unit price is higher ($35.7 million vs. $34.6 million reflecting cost of passenger modules) and again the fuel and crew costs are higher, the maintenance, depreciation, and insurance costs are lower -- this time because the utilization of Flatbed is 12 hours per day vs. 10 hours per day for the reference aircraft. The net effect is a lower DOC for Flatbed by 0.04¢ per seat mile.

Table 24d presents comparable costs for cargo operations for Case 2 (marked with a triple

Table 22 Summary of Direct Operating Costs - Unpressurized Containers Without Cocoon - Low Altitude

	CASE 1						CASE 2		CASE 3							
	Reference A/C		FLATBED				(ALL CARGO)		Reference A/C		FLATBED					
			No Quick Change		With Quick Change						No Quick Change		With QC			
	Cargo	Pax	Cargo	Pax	Cargo	Pax	Reference	Flatbed	Cargo	Pax	Cargo	Pax	Pure Cargo	Avg. Cargo[2]	QC Cargo	QC Pax
Number of Aircraft - Ops.	150	250	150	250	250		300	300	300	400	300	400	60	460	400	
DOC/Trip - $[1]																
Crew	2117	2099	2236	2114	2236	2114	2117	2236	2117	2099	2236	2114	2236	2236	2236	2114
Fuel	4757	3944	6156	4382	6156	4382	4757	6156	4757	3945	6156	4382	6156	6156	6156	4382
Maintenance																
Airframe																
Labor	244	236	234	225	234	225	244	234	244	236	234	225	234	234	234	225
Material	564	450	346	467	81	364	431	373	431	374	305	395	338	119	64	301
Total Airframe	808	686	580	692	315	589	675	607	675	610	539	620		353		526
Engines																
Labor	226	209	225	216	225	216	226	225	226	209	225	215	225	225	225	216
Material	1132	1133	1185	1133	1185	1133	1132	1185	1132	1133	1185	1133	1185	1185	1185	1133
Total Engines	1358	1342	1410	1349	1410	1349	1350	1410	1358	1342	1410	1348		1410		1349
Burden	846	800	827	793	827	793	846	827	846	800	827	793	827	827	827	793
Total Maintenance	3012	2828	2817	2834	2552	2731	2879	2844	2879	2752	2776	2761		2590		2668
Insurance	1293	1069	877	918	573[3]	747[3]	1031	932	1030	917	794	798	861	585	516[3]	643[3]
Depreciation	4422	3682	3056	3158	2164[3]	2596[3]	3554	3240	3554	3181	2783	2763	3007	2180	1973[3]	2251[3]
Total DOC/Trip[1] - $	15601	13623	15142	13405	13681	12570	14337	15409	14337	12893	14745	12819		13747[2]		12058
Net Payload - Mega Grams	29.37		29.37		29.37		29.37	29.37	29.37		29.37			29.37		
Net Payload - Tons	32.375		32.375		32.375		32.375	32.375	32.375		32.375			32.375		
Seats		180		180		180				180		180				
Cost/Mega Gram km - ¢	11.03		10.69		9.66		10.14	10.88	10.14		10.41			9.70		
Cost/Ton SM[1] - ¢	16.11		15.63		14.13		14.80	15.91	14.80		15.22			14.19		
Cost/Seat km - ¢		1.57		1.54		1.44				1.48		1.47				1.39
Cost/Seat SM[1] - ¢		2.53		2.49		2.33				2.39		2.38				2.24

Unpressurized Containers Without Cocoon - Low Altitude

(1) Based on a trip of 2992 SM (2600 NM)
(2) Weighted average for pure cargo and quick change aircraft
(3) Initial purchase price prorated between cargo and Pax Ops.

Table 23 Summary of Direct Operating Costs - Unpressurized Containers Without Cocoon - High Altitude

	CASE 1						CASE 2		CASE 3							
	Reference A/C		FLATBED				(ALL CARGO)		Reference A/C		FLATBED					
			No Quick Change		With Quick Change						No Quick Change		With QC			
	Cargo	Pax	Cargo	Pax	Cargo	Pax	Reference	Flatbed	Cargo	Pax	Cargo	Pax	Pure Cargo	Avg. Cargo(2)	QC Cargo	QC Pax
Number of Aircraft - Ops.	150	250	150	250	250		300	300	300	400	300	400	60	460	400	
DOC/Trip - $ (1)																
Crew	2117	2099	2146	2114	2146	2114	2117	2146	2117	2099	2146	2114	2146	2146	2146	2114
Fuel	4757	3944	4329	4382	4329	4382	4757	4329	4757	3945	4329	4382	4329	4329	4329	4382
Maintenance																
Airframe																
Labor	244	236	228	225	228	225	244	228	244	236	228	225	228	228	228	225
Material	564	450	337	467	79	364	431	364	431	374	297	395	330	116	62	301
Total Airframe	808	686	565	692	307	589	675	592	675	610	525	620		344		526
Engines																
Labor	226	209	219	216	219	216	226	219	226	209	219	215	219	219	219	216
Material	1132	1133	1150	1133	1150	1133	1132	1150	1132	1133	1150	1133	1150	1150	1150	1133
Total Engines	1358	1342	1369	1349	1369	1349	1350	1369	1358	1342	1369	1348		1369		1349
Burden	846	800	804	793	804	793	846	804	846	800	804	793	804	804	804	793
Total Maintenance	3012	2828	2738	2834	2480	2731	2879	2765	2879	2752	2698	2761		2517		2668
Insurance	1293	1069	849	918	555(3)	747(3)	1030	902	1030	917	768	798	834	566	499(3)	643(3)
Depreciation	4422	3682	2958	3158	2094(3)	2596(3)	3554	3136	3554	3181	2694	2763	2910	2110	1910(3)	2251(3)
Total DOC/Trip(1) - $	15601	13623	13019	13405	11603	12570	14337	13277	14337	12893	12635	12819		11667(3)		12058
Net Payload - Mega Grams	29.37		29.37		29.37		29.37	29.37	29.37		29.37			29.37		
Net Payload - Tons	32.375		32.375		32.375		32.375	32.375	32.375		32.375			32.375		
Seats		180		180		180				180		180				180
Cost/Mega Gr. km - ¢	11.03		9.20		8.20		10.14	9.39	10.14		8.93			8.25		
Cost/Ton SM(1) - ¢	16.11		13.44		11.98		14.80	13.71	14.80		13.05			12.04		
Cost/Seat km - ¢		1.57		1.54		1.44				1.48		1.47				1.39
Cost/Seat SM(1) - ¢		2.53		2.49		2.33				2.39		2.38				2.24

(1) Based on a trip of 2992 SM (2600 NM)
(2) Weighted average for pure cargo & quick change A/C
(3) Initial purchase price prorated between cargo & Pax Ops

Table 24a Summary of Direct Operating Costs - Unpressurized Containers in Unpressurized Cocoon - Low Altitude

	CASE 1						CASE 2		CASE 3							
	Reference A/C		FLATBED				(ALL CARGO)		Reference A/C		FLATBED					
			No Quick Change		With Quick Change						No Quick Change		With QC			
	Cargo	Pax	Cargo	Pax	Cargo	Pax	Reference	Flatbed	Cargo	Pax	Cargo	Pax	Pure Cargo	Avg. Cargo(2)	QC Cargo	QC Pax
Number of Aircraft - Ops.	150	250	150	250	250		300	300	300	400	300	400	60	460	400	
DOC/Trip - $ (1)																
Crew	2117	2099	2210	2114	2210	2114	2117	2210	2117	2099	2210	2114	2210	2210	2210	2114
Fuel	4757	3944	5978	4382	5978	4382	4757	5978	4757	3945	5978	4382	5978	5978	5978	4382
Maintenance																
Airframe																
Labor	244	236	232	225	232	225	244	232	244	236	232	225	232	232	232	225
Material	564	450	342	467	70	364	431	342	431	374	291	395	309	102	50	301
Total Airframe	808	686	574	692	302	589	675	574	675	610	523	620		334		526
Engines																
Labor	226	209	223	216	223	216	226	223	226	209	223	215	223	223	223	216
Material	1132	1133	1172	1133	1172	1133	1132	1172	1132	1133	1172	1133	1172	1172	1172	1133
Total Engines	1358	1342	1395	1349	1395	1349	1358	1395	1358	1342	1395	1348		1395		1349
Burden	846	800	818	793	818	793	846	818	846	800	818	793	818	818	818	793
Total Maintenance	3012	2828	2787	2834	2515	2731	2879	2787	2879	2752	2736	2761		2547		2668
Insurance	1293	1069	864	918	531(3)	747(3)	1030	865	1030	917	763	798	799	533	466(3)	643(3)
Depreciation	4422	3682	3014	3158	2022(3)	2596(3)	3554	3016	3554	3181	2679	2763	2797	2004	1806(3)	2251(3)
Total DOC/Trip(1) - $	15601	13623	14853	13405	13256	12570	14337	14857	14337	12893	14366	12819		13272(2)		12058
Net Payload - Mega Grams	29.37		29.37		29.37		29.37		29.37		29.37			29.37		
Net Payload - Tons	32.375		32.375		32.375		32.375	32.375	32.375		32.375			32.375		
Seats		180		180		180				180		180				180
Cost/Mega Gr. km - ¢	11.03		10.50		9.37		10.13	10.50	10.13		10.15			9.38		
Cost/Ton SM (1) - ¢	16.11		15.34		14.13		14.80	15.91	14.80		15.22			14.19		
Cost/Seat km - ¢		1.57		1.54		1.44				1.48		1.47				1.39
Cost/Seat SM(1) - ¢		2.53		2.49		2.33				2.39		2.38				2.24

• •• ••• Unpressurized Containers in Unpressurized Cocoon - Low Altitude

(1) Based on a trip of 2992 SM (2600 NM)
(2) Weighted average for pure cargo & Quick Change A/C
(3) Initial purchase price prorated between cargo & Pax Ops

Table 24b Abridged DOC - Unpressurized Container
With Cocoon - 18,000 Ft - Case 1

	REF. AIRCRAFT	FLATBED (NO QC)
NO. A/C PROCURED	150	550
UNIT A/C PRICE - $	39.9M	28.0M
NO. A/C IN OPS.	150	150
COSTS - $ / TRIP		
CREW	2117	2210
FUEL	4757	5978
MAINTENANCE	3012	2787
INSURANCE	1293	864
DEPRECIATION	4422	3014
TOTAL DOC	15601	14853
COST/TON/ST.MI.	16.1¢	15.3¢

Table 24c Abridged DOC - Civil Passenger Operations - Case 1

	REF. AIRCRAFT	FLATBED (NO QC)
NO. A/C PROC.	250	550
UNIT A/C PRICE - $	34.6M	35.7M
NO. A/C IN OPS.	250	250
UTILIZATION - HRS/DAY	10	12
COSTS - $/TRIP		
CREW	2099	2114
FUEL	3994	4382
MAINTENANCE	2828	2834
INSURANCE	1069	918
DEPRECIATION	3682	3158
TOTAL DOC	13622	13406
COST/SEAT ST. MI.	2.53¢	2.49¢

Table 24d Abridged DOC - Unpressurized Container
With Cocoon - 18,000 Ft - Case 2

	REF. AIRCRAFT	FLATBED (NO QC)
NO. A/C PROCURED	300	450
UNIT A/C PRICE - $	31.4M	28.9M
NO. A/C IN OPS.	300	300
COSTS - $/TRIP		
CREW	2117	2236
FUEL	4757	6156
MAINTENANCE	2879	2844
INSURANCE	1031	932
DEPRECIATION	3554	3240
TOTAL DOC	14338	15408
COST/TON/ST.MI.	14.8¢	15.9¢

Table 25 Summary of Direct Operating Costs - Unpressurized Containers in Unpressurized Cocoon - High Altitude

	CASE 1						CASE 2		CASE 3							
	Reference A/C		FLATBED				(ALL CARGO)		Reference A/C		FLATBED					
			No Quick Change		With Quick Change						No Quick Change		With QC			
	Cargo	Pax	Cargo	Pax	Cargo	Pax	Reference	Flatbed	Cargo	Pax	Cargo	Pax	Pure Cargo	Avg. Cargo (2)	QC Cargo	QC Pax
Number of Aircraft - Ops.	150	250	150	250	250		300	300	300	400	300	400	60	460	400	
DOC/Trip - $ (1)																
Crew	2117	2099	2164	2114	2164	2114	2117	2164	2117	2099	2164	2114	2164	2164	2164	2114
Fuel	4757	3944	4469	4382	4469	4382	4757	4469	4757	3945	4469	4382	4469	4469	4469	4382
Maintenance																
Airframe																
Labor	244	236	230	225	230	225	244	230	244	236	230	225	230	230	230	225
Material	564	450	338	467	69	364	431	339	431	374	288	395	306	101	50	301
Total Airframe	808	686	569	692	299	589	675	569	675	610	518	620		331		526
Engines																
Labor	226	209	220	216	220	216	226	220	226	209	220	215	220	220	220	216
Material	1132	1133	1159	1133	1159	1133	1132	1159	1132	1133	1159	1133	1159	1159	1159	1133
Total Engines	1358	1342	1379	1349	1379	1349	1358	1379	1358	1342	1379	1348		1379		1349
Burden	846	800	810	793	810	793	846	810	846	800	810	793	810	810	810	793
Total Maintenance	3012	2828	2758	2834	2488	2731	2879	2758	2879	2752	2707	2761		2520		2668
Insurance	1293	1069	854	918	525(3)	747(3)	1030	855	1030	917	754	798	789	526	460(3)	643(3)
Depreciation	4422	3682	2977	3158	1998(3)	2596(3)	3554	2980	3554	3181	2646	2763	2764	1980	1784(3)	2251(3)
Total DOC/Trip - $ (1)	15601	13623	13221	13405	11643	12570	14337	13226	14337	12893	12740	12819		11659(3)		12058
Net Payload - Mega Grams	29.37		29.37		29.37		29.37	29.37	29.37		29.37			29.37		
Net Payload - Tons	32.375		32.375		32.375		32.375	32.375	32.375		32.375			32.375		
Seats		180		180		180				180		180				180
Cost/Mega Gr. km - ¢	11.03		9.34		8.23		10.13	9.35	10.13					8.24		
Cost/Ton SM(1) - ¢	16.11		13.65		12.02		14.80	13.66	14.80					12.04		
Cost/Seat km - ¢		1.57		1.54		1.44				1.48		1.47				1.39
Cost/Seat SM(1) - ¢		2.53		2.49		2.33				2.39		2.38				2.24

(1) Based on a trip of 2992 SM (2600 NM)
(2) Weighted average for pure cargo & quick change A/C
(3) Initial purchase price prorated between cargo & Pax Ops

Table 26 Summary of Direct Operating Costs - Pressurized D-Shaped Containers

	CASE 1						CASE 2		CASE 3							
	Reference A/C		FLATBED				(ALL CARGO)		Reference A/C		FLATBED					
			No Quick Change		With Quick Change						No Quick Change			With QC[2]		
	Cargo	Pax	Cargo	Pax	Cargo	Pax	Reference	Flatbed	Cargo	Pax	Cargo	Pax	Pure Cargo	Avg. Cargo[2]	QC Cargo	QC Pax
Number of Aircraft - Ops.	150	250	150	250	250		300	300	300	400	300	400	60	460	400	
DOC/Trip - $[1]																
Crew	2117	2099	2435	2114	2435	2114	2117	2435	2117	2099	2435	2114	2435	2435	2435	2114
Fuel	4757	3944	4432	4382	4432	4382	4757	4432	4757	3945	4432	4382	4432	4432	4432	4382
Maintenance																
Airframe																
Labor	244	236	252	225	252	225	244	252	244	236	252	225	252	252	252	225
Material	564	450	383	467	106	364	431	396	431	374	339	395	396	138	74	301
Total Airframe	808	686	635	692	358	589	675	648	675	610	591	620		390		526
Engines																
Labor	226	209	245	216	245	216	226	245	226	209	245	215	245	245	245	216
Material	1132	1133	1289	1133	1289	1133	1132	1510	1132	1133	1289	1133	1289	1289	1289	1133
Total Engines	1358	1342	1534	1349	1534	1349	1358	1755	1358	1342	1534	1348		1534		1349
Burden	846	800	895	793	895	793	846	895	846	800	895	793	895	895	895	793
Total Maintenance	3012	2828	3064	2834	2767	2731	2879	3298	2879	2752	3020	2761		2819		2668
Insurance	1293	1069	986	918	695[3]	747[3]	1030	1046	1030	917	895	798	1046	676	584[3]	643[3]
Depreciation	4422	3682	3432	3158	2592[3]	2596[3]	3554	3663	3554	3181	3132	2763	3663	2512	2224[3]	2251[3]
Total DOC/Trip[1] - $	15601	13623	14350	13405	12942	12570	14337	14874	14337	12893	13913	12819	14874	12919[2]	12430	12058
Net Payload - Mega Grams	29.37		29.37		29.37		29.37	29.37	29.37		29.37			29.37		
Net Payload - Tons	32.375		32.375		32.375		32.375	32.375	32.375		32.375			32.375		
Seats		180		180		180				180		180				
Cost/Mega Gr. km - ¢	11.03		10.14		9.15		10.14	10.51	10.14		9.13			9.14		
Cost/Ton SM[1] - ¢	16.11		14.82		13.36		14.80	15.36	14.80		14.37			13.34		
Cost/Seat km - ¢		1.57		1.54		1.44				1.48		1.47				1.39
Cost/Seat SM[1] - ¢		2.53		2.49		2.33				2.39		2.38				2.24

(1) Based on a trip of 2992 SM (2600 NM)
(2) Weighted average for pure cargo and quick change aircraft
(3) Initial purchase price prorated between cargo and Pax Ops.

Table 27 Summary of Direct Operating Costs - Unpressurized Containers in Pressurized Cocoon

	CASE 1						CASE 2		CASE 3							
	Reference A/C		FLATBED				(ALL CARGO)		Reference A/C		FLATBED					
			No Quick Change		With Quick Change						No Quick Change		With QC			
	Cargo	Pax	Cargo	Pax	Cargo	Pax	Reference	Flatbed	Cargo	Pax	Cargo	Pax	Pure Cargo	Avg. Cargo[2]	QC Cargo	QC Pax
Number of Aircraft - Ops.	150	250	150	250	250		300	300	300	400	300	400	60	460	400	
DOC/Trip - $[1]																
Crew	2117	2099	2114	2114	2114	2114	2117	2114	2117	2099	2114	2114	2114	2114	2114	2114
Fuel	4757	3944	4371	4382	4371	4382	4757	4371	4757	3945	4371	4382	4371	4371	4371	4382
Maintenance																
Airframe																
Labor	244	236	225	225	225	225	244	225	244	236	225	225	225	225	225	225
Material	564	450	340	467	71	364	431	346	431	374	294	395	303	102	52	301
Total Airframe	808	686	565	692	296	589	675	571	675	610	519	620		327		526
Engines																
Labor	226	209	216	216	216	216	226	216	226	209	216	215	216	215	215	216
Material	1132	1133	1327	1133	1327	1133	1132	1327	1132	1133	1327	1133	1327	1327	1327	1133
Total Engines	1358	1342	1543	1349	1543	1349	1350	1543	1358	1342	1543	1348		1542		1349
Burden	846	800	793	793	793	793	846	793	846	800	793	793	793	793	793	793
Total Maintenance	3012	2828	2901	2834	2632	2731	2879	2907	2879	2752	2855	2761		2662		2668
Insurance	1293	1069	879	918	573[3]	747[3]	1030	891	1030	917	786	798	805	567	508[3]	643[3]
Depreciation	4422	3682	3081	3158	2193[3]	2596[3]	3554	3123	3554	3181	2777	2763	2840	2151	1979[3]	2251[3]
Total DOC/Trip[1] - $	15601	13623	13346	13405	11882	12570	14337	13407	14337	12893	12903	12819		11866[2]		12058
Net Payload - Mega Grams	29.37		29.37		29.37		29.37	29.37	29.37		29.37			29.37		
Net Payload - Tons	32.375		32.375		32.375		32.375	32.375	32.375		32.375			32.375		
Seats		180		180		180				180		180				180
Cost/Mega Gm km - ¢	11.03		9.43		8.40		10.13	9.48	10.13		9.12			8.39		
Cost/Ton SM[1] - ¢	16.11		13.78		12.27		14.80	13.84	14.80		13.32			12.25		
Cost/Seat km - ¢		1.57		1.54		1.44				1.48		1.47				1.39
Cost/Seat SM[1] - ¢		2.53		2.49		2.33				2.39		2.38				2.24

(1) Based on a trip of 2992 SM (2600 NM)
(2) Weighted average for pure cargo and quick change aircraft
(3) Initial purchase price prorated between cargo and Pax Ops.

asterisk in Table 24a). In this case, the number of units of Flatbed procured is only 150 more than the reference aircraft and the disparity between unit production price is such that Flatbed is only $2.5 million lower. This relatively close price is not sufficient, in this case, to offset the higher fuel and crew costs and the DOC for Flatbed is 7 percent higher.

Military Operating Costs - Life Cycle Costs for Cases 1 through 3 for military cargo operations as a function of payload configuration are summarized in Tables 28 through 30. All military costs are increased by the cost of the ramps. Those payloads without cocoons also include the cost of fairings prorated between military and civil cargo versions. Costs are given with and without QC operations. In this regard, there are no QC operations per se in the military operational scheme; however, estimation of operating costs in the QC mode is made only as an artifice to realize the effect of buying fewer total numbers of backbones reflecting reduced civil procurement as previously discussed.

As for civil operating costs, the complexity of Tables 28 through 30a tend to obscure relative effects without cross referencing to other tables. Accordingly, a typical configuration and case was abridged and is given in Table 30b. The case used is marked with an asterisk. Notice that the very large disparity in numbers of units produced (850 Flatbeds vs. 150 reference aircraft) has a very significant effect on unit production price -- nearly 2 to 1 in favor of Flatbed. Nevertheless, the higher drag and block times result in a total 20 year operating and support cost (O&S) for Flatbed which is only about 3 percent lower than the reference aircraft. However, the total fleet life cycle cost for Flatbed is about 25 percent lower because of the lower unit production price.

A typical breakdown of military LCC elements is given by Table 31. These include operating costs per se (flight crew and support staff), recurring investment (AGE, spares, maintenance), pay and allowances, personnel support, and pipeline support (acquisition of personnel, training, etc.). These costs, in turn, are listed in terms of the total for 20 years, annual squadron costs, total annual costs, and costs per flight hour.

No military LCC were required to be estimated for the Flatbed vs. reference outsize cargo airplane and none were calculated. This results because of the obvious disparity between the size of the conventional airplane required to haul the tank and the relatively small cargo payloads being carried on the smaller Flatbed. To carry such a small payload on the outsize airplane would be an unfair comparison to either airplane.

Table 32 presents a summary of comparative operating costs of Flatbed versus the reference airplanes. These costs are given in percentage terms. For example, under CIVIL CARGO, with a payload of unpressurized containers without cocoon, cruising at low altitude, Case 1 without QC operations (line 1, column 1), the table shows that Flatbed's DOC is 97 percent that of the reference cargo airplane. Or again, for CIVIL PAX operations, Case 3 with QC (line 7, column 5), the table shows that Flatbed has DOCs 94 percent those of a reference passenger airplane.

Cargo DOC Analysis - In general, Table 32 shows that Flatbed operating costs are lower than conventionally configured reference aircraft for the cases representing varying production units. In Case 2 (smallest number of Flatbed backbones procured vs. highest number

Table 28 Military Cargo Fleet Costs - Case 1

Initial Costs	FLATBED WITHOUT QUICK CHANGE					FLATBED WITH QUICK CHANGE			
	Reference Aircraft	Unpressurized Container/ No Cocoon	Unpressurized Container/With Unpressurized Cocoon	Unpressurized Container/ Pressurized Cocoon	Pressurized Container/ No Cocoon	Unpressurized Container/ No Cocoon	Unpressurized Container/With Unpressurized Cocoon	Unpressurized Container/ Pressurized Cocoon	Pressurized Container/ No Cocoon
o Aircraft									
Total Produced	150	550	550	550	550	400	400	400	400
Non Recurring R&D (1)	983	826	820	820	826	826	820	820	820
Pro-Rata R&D (1)	6.55	1.54	1.50	1.50	1.54	2.09	2.08	2.08	2.09
Unit Production	38.30	23.90	23.70	23.70	23.90	25.80	25.60	25.60	25.80
Total Unit Acquisition	44.85	25.44	25.20	25.20	25.44	27.89	27.68	27.68	27.89
o Containers									
Total Produced	500	1500	1500	1500	1500	1500	1500	1500	1500
Non Recurring R&D	14.00	14.00	14.00	14.00	20.00	14.00	14.00	14.00	20.00
Pro-Rata R&D	.03	.01	.01	.01	.01	.01	.01	.01	.01
Unit Production	.40	.30	.30	.30	.40	.30	.30	.30	.40
Total Unit Acquisition	.43	.31	.31	.31	.41	.31	.31	.31	.41
Acquisition Cost/Aircraft	1.43	1.03	1.03	1.03	1.38	1.03	1.03	1.03	1.38
o Cocoons									
Total Produced			300	300			300	300	
Non Recurring R&D			23.00	74.0			23.00	74.00	
Pro-Rata R&D			.08	.25			.08	.25	
Unit Production			.80	2.10			.80	2.10	
Total Unit Acquisition			.88	2.35			.88	2.35	
Acquisition Cost/Aircraft			.88	2.35			.88	2.35	
Total Initial Unit Costs	46.28	26.47	27.11	28.58	26.82	28.92	29.59	31.06	29.27
Total Initial Costs (150 Aircraft)	6941.50	3969.75	4066.00	4286.50	4023.00	4338.00	4438.50	4659.00	4390.50
20 Years (O&S) (126 U.E. Aircraft)	7455.94	7275.32	7229.91	6404.03	6124.97	7286.53	7241.12	6415.23	6136.18
Total Fleet LCC	14397.44	11245.07	11295.91	10690.53	10147.97	11624.53	11679.62	11074.23	10526.68
Annual Fleet Costs	719.87	562.25	564.80	534.53	507.40	581.23	583.98	553.71	526.33

All costs in millions of 1980 dollars

(1) Total R&D for Flatbed of $814 million is prorated over all backbones (including passenger versions) produced

Table 29 Military Cargo Fleet Costs - Case 2

Initial Costs	FLATBED WITHOUT QUICK CHANGE					FLATBED WITH QUICK CHANGE			
	Reference Aircraft	Unpressurized Container/ No Cocoon	Unpressurized Container/With Unpressurized Cocoon	Unpressurized Container/ Pressurized Cocoon	Pressurized Container/ No Cocoon	Unpressurized Container/ No Cocoon	Unpressurized Container/With Unpressurized Cocoon	Unpressurized Container/ Pressurized Cocoon	Pressurized Container/ No Cocoon
o Aircraft									
Total Produced	150	450	450	450	450				
Non Recurring R&D	983.00	826	820	820	820				
Pro-Rata R&D	6.55	1.86	1.85	1.85	1.86				
Unit Production	38.30	25.10	24.90	24.90	25.10				
Total Unit Acquisition	44.85	26.96	26.75	26.75	26.96				
o Containers									
Total Produced	500	2500	2500	2500	2500				
Non Recurring R&D	14.00	14.00	14.00	14.00	20.00				
Pro-Rata R&D	.03	.01	.01	.01	.01				
Unit Production	.40	.30	.30	.30	.40				
Total Unit Acquisition	.43	.31	.31	.31	.41				
Acquisition Cost/Aircraft	1.43	1.02	1.02	1.02	1.37				
o Cocoons									
Total Produced			450	450					
Non Recurring R&D			23.00	165.00					
Pro-Rata R&D			.05	.27					
Unit Production			.66	2.20					
Total Unit Acquisition			.71	2.57					
Acquisition Cost/Aircraft			.71	2.57					
Total Initial Unit Costs	46.28	29.00	28.48	30.34	28.33				
Total Initial Costs (150 Aircraft)	6941.50	4350.50	4272.00	4551.00	4249.00				
20 Years (O&S) (126 U.E. Aircraft)	7455.94	7282.40	7236.99	6411.10	6132.05				
Total Fleet LCC	14397.44	11632.90	11508.99	10962.10	10381.05				
Annual Fleet Costs	719.87	581.65	575.45	548.10	519.05				

All costs in millions of 1980 dollars

Table 30a Military Cargo Fleet Costs - Case 3

Initial Costs	FLATBED WITHOUT QUICK CHANGE					FLATBED WITH QUICK CHANGE			
	Reference Aircraft	Unpressurized Container/ No Cocoon	Unpressurized Container/With Unpressurized Cocoon	Unpressurized Container/ Pressurized Cocoon	Pressurized Container/ No Cocoon	Unpressurized Container/ No Cocoon	Unpressurized Container/With Unpressurized Cocoon	Unpressurized Container/ Pressurized Cocoon	Pressurized Container/ No Cocoon
o Aircraft									
Total Produced	150	850	850	850	850	610	610	610	610
Non Recurring R&D	983.00	826	820	820	826	826	820	820	826
Pro-Rata R&D	6.55	1.01	1.00	1.00	1.01	1.39	1.37	1.37	1.39
Unit Production	38.30	21.90	21.70	21.70	21.90	23.60	23.40	23.40	23.60
Total Unit Acquisition	44.85	22.91	22.70	22.70	22.91	24.99	24.77	24.77	24.99
o Containers									
Total Produced	500	2500	2500	2500	2500	2500	2500	2500	2500
Non Recurring R&D	14.00	14.00	14.00	14.00	20.00	14.00	14.00	14.00	20.00
Pro-Rata R&D	.03	.01	.01	.01	.01	.01	.01	.01	.01
Unit Production	.40	.30	.30	.30	.40	.30	.30	.30	.40
Total Unit Acquisition	.43	.31	.31	.31	.41	.31	.31	.31	.41
Acquisition Cost/Aircraft	1.43	1.02	1.02	1.02	1.37	1.02	1.02	1.02	1.37
o Cocoons									
Total Produced			450	450			450	450	
Non Recurring R&D			23.0	74.0			23.0	74.0	
Pro-Rata R&D			.05	.16			.05	.16	
Unit Production			.66	1.71			.66	1.71	
Total Unit Acquisition			.71	1.87			.71	1.87	
Acquisition Cost/Aircraft			.71	1.87			.71	1.87	
Total Initial Unit Costs	46.28	23.93	24.43	25.59	24.28	26.01	26.50	27.66	26.36
Total Initial Costs (150 Aircraft)	6941.50	3589.50	3664.50	3838.50	3642.00	3901.50	3075.00	4149.00	3954.00
20 Years (O&S) (126 U.E. Aircraft)	7455.94	7263.53	7218.46	6392.23	6113.18	7281.81	7236.74	6410.51	6151.46
Total Fleet LCC	14397.44	10853.03	10882.96	10230.73	9755.18	11183.31	11211.74	-0559.51	10105.45
Annual Fleet Costs	719.87	542.65	544.15	511.54	487.76	559.17	560.59	527.98	505.27

All costs in millions of 1980 dollars

Table 30b Abridged Military Cargo Fleet Costs - Case 3

	REF. AIRCRAFT	FLATBED (NO QC)
NO. A/C PROC.	150	850
UNIT A/C PRICE - $	44.9 M	23.4 M
NO. A/C IN OPS.	150	150
COSTS - $M		
RECURRING SPARES	4630	4426
PAY	2148	2121
PERSONNEL SUPPORT	306	302
PIPELINE SUPPORT	372	368
TOTAL 20-YR. O&S COST - $M	7456	7217
TOTAL FLEET LCC - $M	14397	10883
ANNUAL FLEET COSTS - $M	720	544

Table 31a Typical Elements Comprising Military Life Cycle Costs – Flatbed

USAF FLATBED, UNPRESSURIZED COCOONS, CASE 3, NO QC A/C

OPERATING COSTS– 7 SQUADRONS 18 AIRCRAFT/SQD

PERSONNEL	OFF	AMN	CIV	TOTAL	P & A $M/YR
FLIGHT CREW	108	144		252	4,590
MAINTENANCE	11	471	60	542	7,094
SECURITY	0	78		78	,936
WING BASE STAFF	9	10	1	20	,378
OTHER	0	0	0	0	,000
PRIMARY PROGRAM ELEMENT	128	703	61	892	12,998
BASE OPERATING SUPPORT	3	113	24	140	1,896
MEDICAL SUPPORT	3	10	3	16	,257
TOTAL	134	826	88	1048	15.151

CR	UR-N(H/Y)	UR-C(H/Y)	MMH/FH	FUEL FW(G/H)
2.00	1080.00	1080.00	22.20	2337.00

COST ELEMENT	20-YR COST-$M	$M/YR/SQD	$M/YR	$/FH
RECURRING INVESTMENT & MISC LOGISTICS	4426.07	31.61	221.30	1626.28
COMMON AGE & SPARES	105,46	,75	5.27	38.75
AVIATION FUEL	2925,77	20,90	146,29	1075,02
BASE LEVEL MAINTENANCE MATERIALS	443,62	3,17	22.18	163.00
DEPOT LEVEL MAINTENANCE	755,70	5.40	37,78	277.67
CLASS IV MOD & SPARES	27,56	.20	1.38	10.12
REPLENISHMENT SPARES	160,57	1.15	8.03	59.00
VEHICULAR EQUIPMENT	7.39	.05	.37	2.72
PAY & ALLOWANCES	2121.12	15.15	106.06	779.36
MILITARY	1884.82	13,46	94,24	692.54
CIVILIAN	236.30	1.69	11.81	86.82
PERSONNEL SUPPORT	302.38	2.16	15.12	111.10
BOS/RPM SUPPORT OF PPE	120.26	,86	6,01	44,19
BOS/RPM SUPPORT OF BOS & MEDICAL	21,03	,15	1,05	7,73
MEDICAL SUPPORT OF OFFICERS	13.60	,10	,68	5.00
MEDICAL SUPPORT OF AIRMEN	73,78	,53	3,69	27,11
PCS COST--OFFICERS	17,39	.12	.87	6.39
PCS COST--AIRMEN	56.32	.40	2.82	20.69
'PIPELINE' SUPPORT	368.89	2.63	18.44	135.54
ACQUISITION--OFFICERS	75,44	,54	3,77	27.72
ACQUISITION--AIRMEN	61,98	,44	3,10	22,77
TRAINING-RATED PILOTS	125.61	,90	6.28	46,15
TRAINING-OTHER RATED OFFICERS	21.94	.16	1.10	8.06
TRAINING-NONRATED OFFICERS	1,77	,01	,09	,65
TRAINING-MAINTENANCE AIRMEN	59,68	,43	2,98	21,93
TRAINING-OTHER AIRMEN	22.47	.16	1.12	8.26
TOTAL OPERATING COST	7218.46	51.56	360.92	2652.28

Table 31b Typical Elements Comprising Military Life Cycle Costs - Reference Airplane

USAF REFERENCE CARGO CASE 3

OPERATING COSTS- 7 SQUADRONS 18 AIRCRAFT/SQD

PERSONNEL	OFF	AMN	CIV	TOTAL	P & A $M/YR
FLIGHT CREW	108	144		252	4.590
MAINTENANCE	11	481	61	553	7.233
SECURITY	0	78		78	.936
WING BASE STAFF	9	10	1	20	.378
OTHER	0	0	0	0	.000
PRIMARY PROGRAM ELEMENT	128	713	62	903	13.137
BASE OPERATING SUPPORT	3	115	24	142	1.920
MEDICAL SUPPORT	4	10	3	17	.284
TOTAL	135	838	89	1062	15.341

CR	UR-N(H/Y)	UR-C(H/Y)	MMH/FH	FUEL FW(G/H)
2.00	1080.00	1080.00	22.70	2160.00

COST ELEMENT	20-YR COST-$M	$M/YR/SQD	$M/YR	$/FH
RECURRING INVESTMENT & MISC LOGISTICS	4630.03	33.07	231.50	1701.21
COMMON AGE & SPARES	178.94	1.28	8.95	65.75
AVIATION FUEL	2704.18	19.32	135.21	993.60
BASE LEVEL MAINTENANCE MATERIALS	552.48	3.95	27.62	203.00
DEPOT LEVEL MAINTENANCE	941.34	6.72	47.07	345.88
CLASS IV MOD & SPARES	46.91	.34	2.35	17.23
REPLENISHMENT SPARES	198.68	1.42	9.93	73.00
VEHICULAR EQUIPMENT	7.49	.05	.37	2.75
PAY & ALLOWANCES	2147.67	15.34	107.38	789.12
MILITARY	1908.69	13.63	95.43	701.31
CIVILIAN	238.98	1.71	11.95	87.81
PERSONNEL SUPPORT	306.39	2.19	15.32	112.58
BOS/RPM SUPPORT OF PPE	121.74	.87	6.09	44.73
BOS/RPM SUPPORT OF BOS & MEDICAL	21.44	.15	1.07	7.88
MEDICAL SUPPORT OF OFFICERS	13.70	.10	.69	5.03
MEDICAL SUPPORT OF AIRMEN	74.85	.53	3.74	27.50
PCS COST--OFFICERS	17.52	.13	.88	6.44
PCS COST--AIRMEN	57.13	.41	2.86	20.99
'PIPELINE' SUPPORT	371.85	2.66	18.59	136.63
ACQUISITION--OFFICERS	76.04	.54	3.80	27.94
ACQUISITION--AIRMEN	62.88	.45	3.14	23.11
TRAINING-RATED PILOTS	125.61	.90	6.28	46.15
TRAINING-OTHER RATED OFFICERS	21.94	.16	1.10	8.06
TRAINING-NONRATED OFFICERS	1.84	.01	.09	.67
TRAINING-MAINTENANCE AIRMEN	60.95	.44	3.05	22.39
TRAINING-OTHER AIRMEN	22.60	.16	1.13	8.30
TOTAL OPERATING COST	7455.94	53.26	372.80	2739.54

Table 32 Relative Operating Cost of Flatbed vs. Reference Aircraft - Percent

		Cruise Alt	(1) Case 1	(2)	(3)	(4) Case 3	(5)
			No QC	W/QC	Case 2	No QC	W/QC
	CIVIL CARGO						
(1)	UNPRESSURIZED/CONTAINER/NO COCOON	Low	97	88	(107)	(103)	96
(2)	UNPRESSURIZED/CONTAINER/NO COCOON	Hi	83	74	93	88	81
(3)	UNPRESSURIZED CONTAINER/UNPRESS.COCOON	Low	95	85	(103)	(100)	93
(4)	UNPRESSURIZED CONTAINER/UNPRESS.COCOON	Hi	85	75	92	89	81
(5)	CONTAINERS/PRESSURIZED COCOON		86	76	94	90	83
(6)	PRESSURIZED CONTAINERS/NO COCOON		92	83	(104)	89	83
(7)	CIVIL PAX		98	92		99	94
	MILITARY CARGO						
(8)	UNPRESSURIZED CONTAINER/NO COCOON	Low	75	78	81	78	81
(9)	UNPRESSURIZED CONTAINER/NO COCOON	Hi					
(10)	UNPRESS. CONTAINERS/UNPRESS. COCOON	Low	76	78	80	78	81
(11)	UNPRESS. CONTAINERS/UNPRESS. COCOON	Hi					
(12)	UNPRESS. CONTAINERS/PRESS. COCOON	Hi	71	73	76	74	77
(13)	PRESSURIZED CONTAINERS/NO COCOON	Hi	68	70	72	70	73

NOTE: CIVIL COSTS RELATIONSHIPS BASED ON RELATIVE DOC;
MILITARY BASED ON RELATIVE LIFE CYCLE COST

of civil reference aircraft) there are three civil payload configurations wherein Flatbed has higher costs (three to seven percent). These are unpressurized containers, unpressurized containers in cocoon, and D-shaped pressurized containers (column 3, lines 1, 3, and 5). In Case 3 there are two civil configurations where Flatbed has higher operating costs (unpressurized containers with and without cocoon), column 4, lines 1 and 3.

Analysis of those configurations where Flatbed has higher DOC values shows several aspects worthy of comment as follows:

1. The 4 percent higher DOC for Flatbed with D-shaped, pressurized containers in Case 2 (line 6, column 3) probably results because of the low number of backbones procured (450) in relation to the high number of containers procured (2000). Such a relatively low procurement cannot provide a unit cost sufficiently low to offset higher fuel costs when operating Flatbed.

2. It is opined that a 4 percent operating cost differential is of little significance in terms of the scatter induced by the scope and depth of the study as well as the accuracy as pertains to general assumptions, drag estimates, etc.

3. In regard to the payload configuration carrying unpressurized containers, all four of these relatively higher operating costs (lines 1 and 3, columns 3 and 4) occur while operating at low altitude (5986 meters - 18,000 ft.). Flight at a more realistic cruise altitude (10,668 meters - 35,000 ft.) makes Flatbed between 8 to 12 percent better than reference aircraft (line 4, column 3 and line 2, column 4).

   It is again emphasized that USAF operating procedures regarding flight in unpressurized airplanes only restrict carriage of vehicles to 5986 meters (18,000 ft.). Therefore, having once accepted other general cargo for unpressurized flight there is no reason (in terms of pressure or temperature) to limit cruise flight to such a low altitude, since the cockpit is fully pressurized.

Table 32 thus shows Flatbed to be generally economical for both civil and military operations. This statement is made assuming that flight with unpressurized cargo (other than military vehicles) would be made at current jet aircraft cruising altitudes. Except for D-shaped pressurized containers, the minimum advantage for civil operations is thus 8 percent (line 4, column 3) and the maximum 26 percent (line 2, column 2). For military operations, Flatbed is minimally 19 percent lower (line 8, column 3) than reference aircraft and as much as 32 percent lower (line 13, column 11) in Life Cycle Cost. These ranges of values for both civil and military operations indicates that Flatbed's estimated operating costs are significantly lower and beyond the scatter induced by the scope of the study.

Passenger DOC Analysis - DOC for passenger operations, Table 32, indicates Flatbed to be up to 8 percent lower (line 7, column 2) than the reference passenger aircraft. Without QC operations, the values are essentially identical. It is thus concluded that while Flatbed's DOCs appear to be lower than those of conventional airplanes, the accuracy of this study and its scope preclude using the term "significantly" lower. It should be noted however, that the revenue potential of the conventionally configured passenger airplane is better because of its ability to haul "belly" cargo.

Analysis of Q.C. Operations - When the same aircraft is used for both passenger and cargo service (i.e., QC operations) the total number of aircraft required is reduced. Otherwise stated, the total number of airplanes actually required or procured is less than the total of dedicated passenger plus dedicated cargo airplanes if the cargo can be flown when there is no passenger service demand and if the average utilization for the QC aircraft is greater than that for the pure passenger aircraft. For example, in Case 1, 250 passenger-only aircraft fly an average of 12 hours per day and 150 cargo-only aircraft average 10 hours per day (for a total of 1500 cargo hours daily). If the 250 passenger aircraft are converted for cargo operation at off-peak passenger times and if the total daily utilization can thereby be increased from 12 to 18 hours per day, then the extra 6 hours per day may be used for cargo operations. The 250 aircraft may then satisfy the cargo requirements of 1500 cargo hours daily (250 aircraft x 6 hours = 1500 aircraft hours) and the 150 cargo-only aircraft need not be procured. In Case 3, there are 400 passenger aircraft and a requirement for 3000 cargo hours daily (300 cargo only aircraft at 10 hours/day). In this case the 400 passenger aircraft each flying 6 hours daily in a QC cargo configuration will generate only 2400 cargo hours. The additional 600 daily cargo hours must be supplied by 60 cargo only aircraft (flying 10 hours/day). Thus in Case 1 no cargo-only aircraft need be purchased if a QC configuration is available. In Case 3 only 60 instead of 300 cargo-only aircraft would be required.

In both of these "quick change" cases (Cases 1 and 3), the aircraft procurement costs, as reflected in the depreciation and insurance elements of the DOC equation, were prorated between the passenger and cargo functions on the basis of hours of utilization used for each. The cost for the quick change situations is less therefore than for the non-quick change aircraft cases. Tables 22 through 27 show that a savings (ranging from 15 to 17 percent) can be realized by the use of a quick change aircraft.

Effect of Variations in Fuel Costs - At the time of issuance of the work statements of Reference 1, airline fuel was costing 46¢/gallon or 12.1¢/liter. As of December 1979, the average cost of fuel for domestic airline operation was 75¢/gallon or 19.8¢/liter; current cost is about 90¢/gallon (23.8¢/liter). While the results of the DOC study previously discussed have shown Flatbed to have generally lower DOCs, the possibility existed that higher fuel costs might cause Flatbed to have generally higher DOC values.

Accordingly, DOCs were estimated for fuel costs up to $1.20/gallon or 31.7¢/liter. These results are presented in Figure 73 for Case 1, and Figure 74 for Cases 2 and 3. These data indicate that Flatbed DOCs do not exceed those of the reference airplanes for any of the cargo modes/configurations. However, the trend of the data seems to indicate that Flatbed might lose its advantage if fuel prices approach the range of $1.75 to $2.00 per gallon (46¢/liter to 52¢/liter). This, of course, assumes that there is no mitigating impact on the other elements of the DOC equations which, should fuel prices rise, will probably also increase. For example, a rise in airplane fuel costs would undoubtedly mean higher gasoline prices which would mean increased labor rates for aircraft maintenance workers which would, in turn, increase maintenance costs for aircraft. Hence, it is doubtful whether Flatbed would lose its advantage on the basis of this simple extrapolation.

CONTAINERS IN UNPRESSURIZED COCOON - HIGH ALT. CRUISE

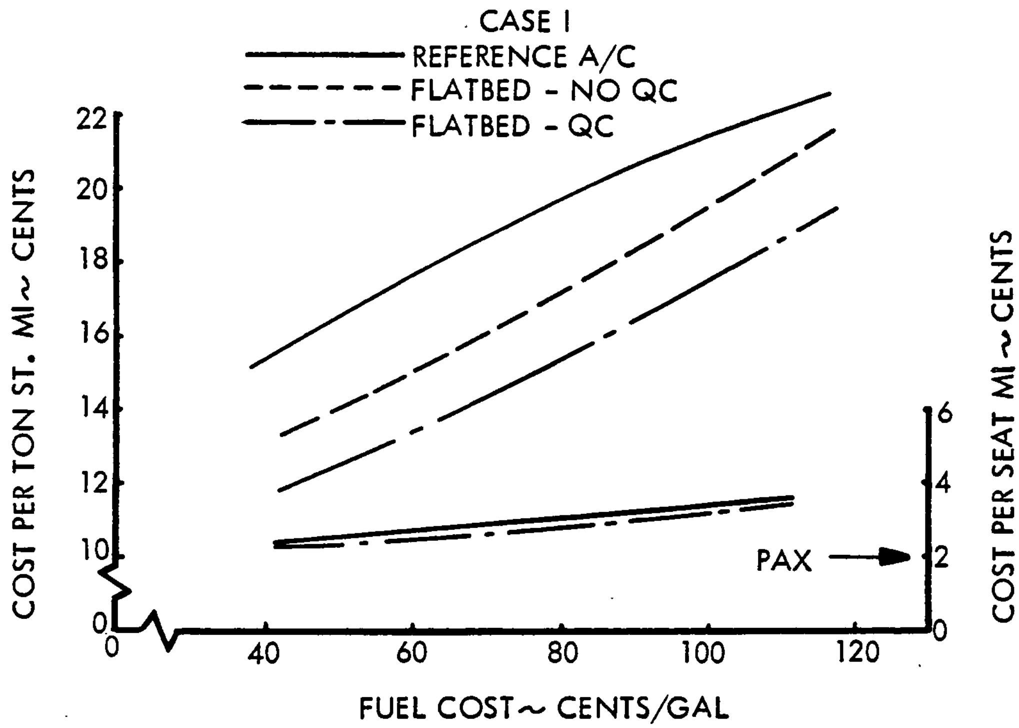


Figure 73 Effect of Fuel Cost on DOC - Case 1

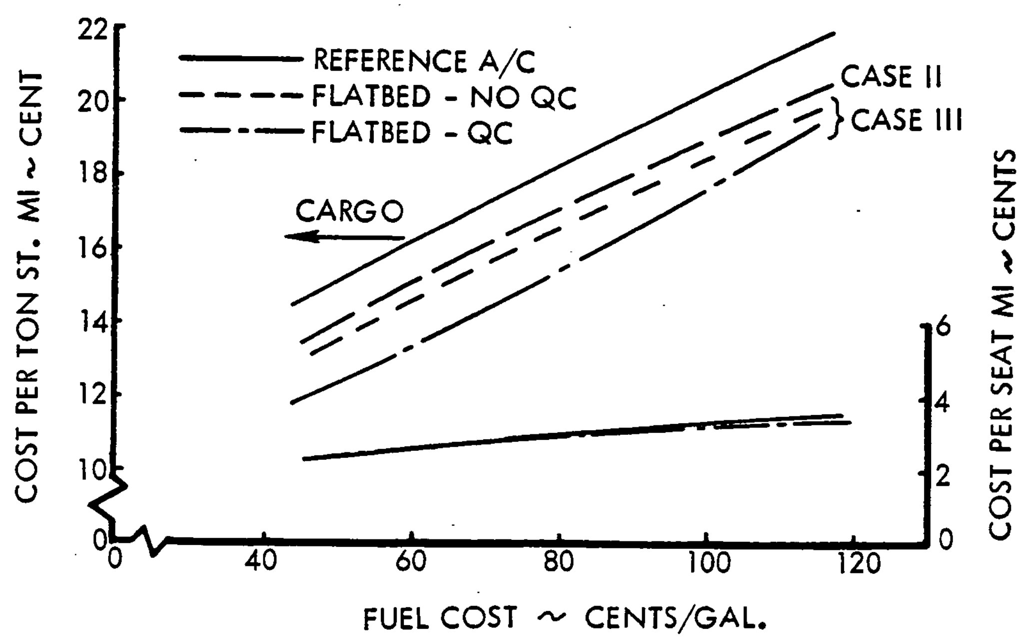


Figure 74 Effect of Fuel Cost on DOC - Cases 2 and 3

There is a slightly higher DOC in seat-mile costs for the passenger Flatbed above a fuel cost of 23.7¢/liter (90¢/gallon). However, the increase relative to the reference passenger airplane is so slight as to be negligible. (Note: The plot exaggerates the difference only for clarity in showing the increase.)

Recommended Additional Studies

Overview/Priorities - During the course of the study, it became apparent that certain areas or aspects were worthy of, or in fact demanded, additional technical study. The following is a summary of these aspects/areas listed in order of priority.

1. Wind-tunnel tests (with possible re-evaluation of the results of this study based upon wind-tunnel data).
2. Aftbody constructed of metal matrix for backbone.
3. Study of costs associated with ground support facilities specifically related to Flatbed.
4. Airloads on Army vehicles.
5. High altitude effects on unpressurized cargo.
6. Potential for ice accumulation on vehicles.
7. Analysis of military operations in a specific scenario.
8. Analysis of commercial airline operations over specific route structure.
9. Relative effect of size of Flatbed aircraft (small through "jumbo").
10. Effect of bicycle landing gear.
11. Incorporation of prop-fans vis-a-vis fan jets.
12. Effect of design for higher payload in the passenger mode plus incorporation of cargo capacity in "belly holds".
13. Vehicle tie-down problems.
14. Vortex control aft of cockpit section in lieu of fairing.
15. Improved cargo handling systems.

Discussion - Each of the studies recommended above are discussed in the following paragraphs.

Wind-Tunnel Tests - The following are areas of concern or areas of relatively low confidence:

- o Drag effect of over-the-wing nacelles.
- o Drag and stability effects of Vee tail.
- o *Drag of various "open air" cargoes (tanks, trucks, containers, etc.)*
- o Basic stability levels associated with backbone and cargoes.
- o Optimizing backbone for minimum drag.
- o Buffet levels associated with "open" cargoes.

It would seem desirable that both low and high speed wind-tunnel tests should be performed.

The study reported herein used the best information available in application to estimation of Flatbed's performance, stability, and control. Results from any wind-tunnel testing should be applied to a re-evaluation of the study results of this report to ascertain significance of revised parameters.

Metal Matrix Aftbody - Metal matrix material applications hold promise of providing relatively high stiffness for a given unit of weight. Thus, the Flatbed aftbody, which has inherent stiffness problems becomes a prime candidate for an application. It is anticipated that such material could effectively increase the stiffness so that the size of the empennage could be reduced with attendant weight savings. As noted previously in this report, the Flatbed empennage was increased in size to account for the aero-elastic effect of downbending on the aftbody.

Studies of Relative Costs of Ground Support Equipment - Flatbed would require purchase and installation of some unique support equipment. Typical would be the flatbed truck for offloading the passenger module. It is considered desirable that a study of these costs be undertaken. For example, a conventional tug for pushing an airliner (of reference size) away from the gate currently costs just under $100,000. A flatbed truck and trailer costs about $50,000; but the flatbed truck to support Flatbed would cost considerably more with its alignment system. How much more is the question.

Airloads on Army Vehicles - Review of Army manuals and contact with Army agencies has not revealed aspects precluding carriage of vehicles by Flatbed in the open. However, some concerns are usually expressed over the airloads on the lighter elements of trucks (fender flaps, radiator cores, rear view mirrors, etc.). It is recommended that a study be made of the airloads on various Army vehicles at speeds producing dynamic pressures of 2.0 psi.

If possible, it is recommended that a full-scale vehicle be placed in a wind tunnel -- even if it must be stripped of engine, transmission, etc. to achieve a weight compatible with balance systems. (Note: a 2-1/2 ton, 6x6 Army truck weighs about 5850 kg (12,900 pounds) in an air transportable condition.) However, a brief review of Army vehicles indicates that a smaller vehicle may be representative and provide adequate answers.

High Altitude Effects on Unpressurized Cargo - Carriage of cargo in unpressurized containers is a realistic operational condition for Flatbed in terms of Flatbed's inherent versatility of payloads carried. It takes advantage of the roughly 70 percent of air eligible cargoes not demanding of pressurization and environmental control. However, while a broad identification of these items is known, an assessment of the effects of lack of environmental control on such qualities as perishability, operational capability, reduction in life, etc., is considered necessary.

Potential for Ice Accumulation on Vehicles - Icing during flight does not appear to present a major problem for several reasons. Reference 14 indicates that ice formation occurs only on the front part of the aircraft components. Thus, water droplets would initially impact the cockpit section and fairings. Further, icing occurs more readily on a thin profile than on a tank or truck because blunt profiles tend to displace the water droplets. It is recommended, however, that additional study be made of icing potential. It is specifically suggested that wind-tunnel tests of icing be made in an environmental wind-tunnel (such as at NASA Lewis or Lockheed-California Company).

Analysis of Military Operations - It is considered that the operational feasibility of Flatbed in military operations should be explored. Specifically, a study of productivity, fleet size, sorties required, and specific loadings is necessary in, say, a NATO scenario to permit assessment of the relative capability against conventional cargo aircraft such as the C-141 and C-5A.

Analysis of Commercial Airline Operations - The capability of Flatbed in commercial airline cargo operations would provide comparisons with conventional aircraft configurations. These studies should include response to a demand for cargo service on a route structure between specified city pairs.

Effect of Flatbed Size - The study reported herein has analyzed the merits of a medium-sized transport. A logical question concerns whether there is any degradation of Flatbed's effectiveness and efficiency if it were larger. Alternatively, is there an application of the Flatbed concept to smaller transport-type airframes? (Note: in this regard, Lockheed-Georgia's independent studies have shown high potential for application to carrier-based aircraft which use transport-type airframes.) It is accordingly recommended that additional studies be undertaken exploring both larger and smaller sizes.

Effect of Bicycle Landing Gear - Incorporation of a bicycle gear is, in some ways, a natural design feature for Flatbed in that it provides a reasonable solution to the problem of locating and retracting the main landing gear (see page 41). It also has potential for further lowering of the cargo floor. However, detailed studies are required to assess weight aspects, ground control, effect on takeoff performance, need for outrigger gears, etc.

Incorporation of Prop-fans - Various USAF personnel have suggested the possibility of incorporating prop-fans instead of fanjets on Flatbed. There are several advantages. Primary, of course, is the potential fuel savings. However, it is also considered that prop-fans might alleviate some of the penalties associated with fan engine nacelles on pylons atop the wing.

A study of the effects of prop-fans would include ability to include them on the reference aircraft, weight and performance aspects, and effect on DOC via possible increases in maintenance costs. It is considered possible to coordinate this analysis with the NASA Prop-Fan study.

Effect of Adding Belly Hold Capacity in Flatbed - This study has indicated some potential benefit by adding belly hold capacity to Flatbed in the passenger mode. Effect on size, weight and performance would require a small optimization study.

Vehicle Tie-Down Problems - Both Army and USAF personnel prefer to check tie-down cables and attachments (and adjust as necessary) following loads imposed during takeoff. This is obviously impossible during Flatbed flight. It is recommended that this problem be explored in terms of determining the necessity of such adjusting action and possible means of correction or improvement.

Vortex Control Aft of Cockpit - As previously discussed, independent Lockheed-Georgia studies have shown that the boundary layer aft of the cockpit section can be controlled by introduction of suction (see Figures 25 and 26). For reference, preliminary calculations indicate that such additional power would increase the mission fuel by about 1043 kg (2300 pounds), with attendant effect on performance. However, the 363 kg (800 pounds) fairing weight and the logistics of locating fairings at various bases would be eliminated.

While vortex control in itself is not a new concept, its potential to eliminate the need for a fairing aft of the cockpit is worthy of exploration. Further study might trade the relative merits of using a special engine or the APU's as a source of air. Such study might also include the feasibility of using the extracted flow to blow the surface of the empennage.

Improved Cargo Handling System - It is opined that improvements can be made to the so-called conventional roller/rail/track cargo handling systems incorporated into Flatbed. Such improvements would obviously be compatible with containers. However, one objective of improved systems would be to ameliorate the maintenance and weather aspects previously discussed.

Other - While no major problems were identified for which potential solutions do not exist, there are several general areas worthy of investigation which are not areas demanding of prime study effort. For example, it is considered desirable to explore aspects of hauling civil vehicles on Flatbed in terms of FAA regulations in regard to qualification for carriage. Another aspect is the subject of flight safety in terms of impact on design of Flatbed, containers, and passenger module.

CONCLUDING REMARKS

The results of the cursory study reported herein indicate that the Flatbed concept is a viable transport design configuration. It is technically, and more importantly, economically feasible. There are no problem areas identified without solutions.

The practicality of Flatbed represents an advance in the state-of-the-art of airplane design configurations especially arranged for transport of people and cargo. The improvement in transport capability is beneficial to the operators and the manufacturers who ship goods.

Flatbed's benefits to an airline are: versatility of load (cargo, passengers or vehicles), true quick change capability, ease of load/unload, lack of dimensional restrictions, potential for opening of new markets (carriage of large construction equipment/vehicles), and lower operating costs. Other advantages accrue in terminal operations.

Flatbed's benefits to shippers are those primarily accruing through reduced cost and time of distribution - both of which could result in improvements in sales. Flatbed's versatility also makes additional products "air eligible" and provides true intermodality.

Flatbed's benefits to military operations reside primarily in the ability to haul outsize Army vehicles and other military equipment plus the ready availability of civil Flatbed backbones for use in the Civil Reserve Air Fleet (CRAF). It is important to note that the USAF could haul every vehicle in the inventory of a mechanized division on Flatbed airplanes about 50 percent the size of a conventionally configured airplane designed to carry the same payload in terms of weight and dimensions. This means considerably lower acquisition costs and, as previously shown, lower operating costs.

The key feature, versatility, extracts a penalty in fuel for passenger and outsize cargo missions. This aspect assumes some importance in terms of the scarcity of fuel -- in terms of total operating cost it does not. In addition, it must be remembered that the carriage of outsize military vehicles/equipment is considered for contingency or wartime situations only. Thus, a penalty is not continuously paid for the larger conventional aircraft necessary to have wartime capability throughout its operational life.

It is opined that the Flatbed concept is worthy of additional study -- study which might lead in a logical plan to experimental hardware. Thus, it is specifically recommended that the additional studies discussed in this volume be implemented in order to further define feasibility and capability.

```
13 DEC 79     10:39:57

 FLATBED PASSENGER SIZING VERSION,SELECTED V-TAIL ****    DEC. 13,1979  *
   RANGE= 2600. N.M.    PAYLOAD= 81300.    CRUISE MACH= .620  DELTA MACH= .000

CENTER SECTION FUEL WAS USED IN Y-RANGE CALCULATION.  MISC. DRAG= 11.0 COUNTS.
       .0 PERCENT 2-ND SEGMENT L/D

THRUST  ETA H-1000 W/S   CL    AR  SWEEP  T/C   SW   W-RAMP    OW     CR-L/D  FVR

 20535.  .95 35.  99.73 .425 8.00 25.00 .1057 2717. 279543. 126676. 17.27 1.795

                                                            /--DESIGN POINT DATA--/
 W-RAMP DOC/SM   WTTO      WTLND    FAAFL   LDIST   T/W  GRAD CLMXT CLMXL FLPT FLPL

 279543.  .000  279543.  243759.  5613.  3721. .2938 .0543 2.12 2.50 20.0  40.0

 BPR   TRATE  FNTTO  TCRUS   SFC  FDWT  DENG   LNAC  MISFUEL  BLKFUEL CD    LFCWT
                                            (IN)  (IN)

 6.00 20535. 19465. 4127. .754  3838.  68.9 199.   71587.   63550. .0246     0.

 /--FAA TAKEOFF  DATA--/ /NOISE CERT DATA/
 HCP  HTOFO PTHCB PTHLF  CLPT CLML FLT FLL WLAPR   VFAPR TODIST  LDIST  FATIO

1317. 1390.  .694  .000   .00  .00  0.  0. 243759. 173.89     0.     0.     0.

 2  1  0  0  0  0  0  1  1  2  1  2  4  4  1  1  0  1  0  0  0  1  0  0
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 0  0  1  1  0 37  0
 0.  1.  0.  0.
```

		TOTAL AIRCRAFT WEIGHT	TOTAL AIRCRAFT ARM	FUS MOUNTED COMPONENTS WEIGHT	FUS MOUNTED COMPONENTS ARM	WING MOUNTED COMPONENTS WEIGHT	WING MOUNTED COMPONENTS ARM
STRUCTURE		79272.	926.	39453.	952.	39819.	899.
1	WING	29031.	887.	0.	0.	29031.	887.
2	HORIZONTAL	2410.	1759.	2410.	1759.	0.	0.
3	VERTICAL	2880.	1634.	2880.	1634.	0.	0.
4	FUSELAGE	32352.	859.	32352.	859.	0.	0.
5	NOSE GEAR	1612.	360.	1612.	360.	0.	0.
6	MAIN GEAR	10787.	934.	0.	0.	10787.	934.
PROPULSION		28753.	769.	133.	821.	28621.	769.
7	ENGINE INBD	13051.	706.	0.	0.	13051.	706.
8	ENGINE OUTBD	13051.	810.	0.	0.	13051.	810.
9	FUEL SYS	2650.	883.	133.	821.	2518.	887.
10	NUCLEAR REACTOR	0.	0.	0.	0.	0.	0.
11	LH2 TANKS	0.	0.	0.	0.	0.	0.
12	LFC ENGINES	0.	0.	0.	0.	0.	0.
SYSTEMS		15404.	710.	12479.	668.	2925.	889.
13	AUX. POWER SYS.	562.	1193.	562.	1193.	0.	0.
14	SURFACE CONTR.	3481.	1011.	1323.	1179.	2158.	908.
15	INSTRUMENTS	1205.	697.	1061.	678.	145.	840.
16	HYD & PNEU	1622.	946.	1330.	954.	292.	910.
17	ELECTRICAL	2697.	764.	2525.	763.	161.	769.
18	AVIONICS	2400.	305.	2400.	305.	0.	0.
19	FURNISHINGS	1713.	168.	1662.	150.	51.	734.
20	AC & AI	1682.	765.	1564.	763.	118.	786.
21	AUX. GEAR SYS.	52.	735.	52.	735.	0.	0.
22	LFC CLEAN SYS	0.	0.	0.	0.	0.	0.
23	MISSLE LAUNCH	0.	0.	0.	0.	0.	0.
WEIGHT EMPTY		123429.	862.	52068.	884.	71360.	847.
24	OPERATING EQUIP.	3247.	914.	3072.	916.	175.	875.
25	WT MARGIN	0.	0.	0.	0.	0.	0.
OPERATING WEIGHT		126676.	864.	55136.	885.	71540.	847.
26	PAYLOAD PASS	0.	0.	0.	0.	0.	0.
27	PAYLOAD CARGO	81300.	866.	81300.	866.	0.	0.
ZERO FUEL WEIGHT		207976.	864.	136436.	874.	71540.	847.
28	FUEL	71567.	880.	0.	0.	71567.	880.
29	FLUIDS	0.	0.	0.	0.	0.	0.
GROSS WEIGHT		279543.	868.	136436.	874.	143107.	863.

CONDITION	WEIGHT POUNDS	C G INCHES	BASIC % MAC	TOTAL % MAC	NOSE GEAR LOAD % GW	X25MAC FOR .460 TOTAL
WEIGHT EMPTY	123429.86	862.35	34.60	34.63	11.25	.40294
OPERATING WEIGHT	126675.79	863.67	35.16	35.13	11.05	.40568
ZERO FUEL WEIGHT	207975.79	864.43	35.48	35.42	10.93	.41783
GROSS WEIGHT	279543.01	868.34	37.15	36.91	10.31	.41440
GROSS WT NO PAYLOAD	198243.01	869.46	37.63	37.34	10.13	.39719

APEX = 584.06 LEMAC = 781.19 MAC = 234.57

GEOMETRIC SUMMARY

FUSELAGE

LENGTH	MAX HEIGHT	MAX WIDTH	WETTED AREA	FLOOR LENGTH	FLOOR WIDTH
[illegible]	17.59[illegible]	[illegible]	7192.00		

BASIC WING

	TAPER	SPAN	25 SWP	LE SWP	TE SWP	RT CHD	TP CHD	M.A.C.	X APEX	X LE	Y LE	AREA	X25MAC	AR
	.[illegible]7	147.[illegible]	25.[illegible]	27.459	17.027	26.294	10.562	19.548	48.672	65.100	31.613	2716.83	.4400	8.0000
TOTAL WING								21.861	48.672	64.293	30.061	2911.46		7.4652

COMPLETE WING

LE RAT SWEEP	TE RAT SWEEP	ROOT TOTAL	OUTBRK ETA	OUTBRK CHORD	INBRK ETA	INBRK CHORD	GLOVE AREA	TOTAL AREA	SPOILR AREA	SPOILR % CHD	LE FLP AREA	LE FLP % CHD	TE FLP AREA	TE FLP % CHD
27.[illegible]	.[illegible]	[illegible]	.[illegible]	20.914	.3[illegible]20	20.914	97.36	2814.19	199.75	.0890	306.57	.1400	471.19	.2810

EMPENNAGE (IF NMAIN=2, HORT IS ONE ENDPLATE)

TOTAL WING BASIS

	T/C	TAPER	VBAR	SWEEP	AR	ROOT	TIP	MAC	YBAR	ARM	SPAN	AREA	VBAR	ARM
HOR	.[illegible]	.[illegible]	.[illegible]	30.000	4.9[illegible]	14.378	6.183	10.825	9.828	74.40	45.34	466.09	.5465	74.63
VER	.[illegible]	.[illegible]	.[illegible]	35.[illegible]	[illegible].240	24.609	19.719	22.275	13.245	61.70	27.51	610.26	.0880	61.92

ENGINES & NACELLES

NUMBER ENGINES	ENGINE LOC	PROP DIA	ENGINE LENGTH	ENGINE DIA	NACELLE DIA	NACELLE LENGTH	INSTLD LENGTH	ENGINE SPANWISE AND LONGITUDINAL LOCATIONS			
4	.000	.000	16.562	5.744	7.254	16.562	16.562	-27.57	-45.85	58.80	67.52
								-.3740	-.6220		

NUMBER PYLONS	PYLON THICK	PYLON CHORD	PYLON HEIGHT	PYLON AREA
4.[illegible]	.0[illegible]	[illegible]	1.741	136.87

FUEL VOLUME SUMMARY

FVR	CSFVR	FV	WGFUEL1	WGFUEL2	WGFUEL3	WGFUEL4	WGFUEL5
1.452	1.795	2254.999	26681.43	20727.17	.00	11905.03	44619.64

WGFUELT	CSFTOT	TPFUEL	EXTFUE	FUECAP	OPTION	CSFVRT	CSFUEL	FVRT
103933.3	24503.6	.0	.0	128436.9	.000	1.795	24503.6	1.795

ETA1= .100 ETA2= .221 ETA3= .342 ETA4= .342 ETA5= .429 ETA6= 1.000

C1	TOC1	C2	TOC2	C3	TOC3	C4	TOC4	C5	TOC5	C6	TOC6
30.18	.1057	25.55	.1057	20.91	.1057	20.91	.1057	19.55	.1057	10.56	.1057

C1BASE	STRIC1	C2BASE	STRIC2	C3BASE	STRIC3	C4BASE	STRIC4	C5BASE	STRIC5	C6BASE	STRIC6
24.72	.1291	22.82	.1194	20.91	.1057	20.91	.1057	19.55	.1057	10.56	.1057

MISSION DATA

PAYLOAD	BLK RNG	BLK FUEL	BLK TIME	AV.CR. SPEED	RES FUEL	RAMP WT.	S.C. ALT.	E.C. ALT.
81300.	1294.	32624.	2.33	472.6	7096.	247696.	35.	35.
81300.	2600.	63551.	5.63	472.6	8016.	279543.	35.	35.
24428.	5993.	120209.	12.57	472.6	8230.	279543.	35.	35.
0.	6516.	120850.	13.96	472.6	7589.	255115.	35.	35.

DIST CL.A	DIST CR.	DIST DSND	FUEL 1500	FUEL CL.A	FUEL CR.	FUEL DSND	TIME 1500	TIME CL.A	TIME CR.	
400.	1184.	0.	763.	5623.	26237.	0.	.01	.23	2.51	0.
157.	2443.	0.	817.	7873.	54876.	0.	.01	.36	5.17	0.
157.	5725.	0.	817.	7873.	111534.	0.	.01	.75	12.11	0.
111.	6405.	0.	775.	5658.	114017.	0.	.01	.26	13.55	0.

APPENDIX B

COMPARATIVE GROUP WEIGHT STATEMENTS

ITEM	BASELINE AIRPLANE POUNDS	REF PASS. POUNDS	REF CARGO POUNDS	REF OUTSIZED CARGO POUNDS
STRUCTURE	(85444.)	(73034.)	(88938.)	(104284.)
WING	29031.	28711.	29851.	33419.
WING LFC PENALTY	0.	0.	0.	0.
EMPENNAGE	(5490.)	(4209.)	(3505.)	(4569.)
HORIZONTAL TAIL	2610.	1992.	1830.	2417.
HORIZ LFC PENALTY	0.	0.	0.	0.
VERTICAL TAIL	2880.	2217.	1675.	2152.
VERT LFC PENALTY	0.	0.	0.	0.
FUSELAGE	32352.	24610.	38138.	46937.
LANDING GEAR	(12399.)	(11285.)	(12445.)	(13711.)
NOSE	1612.	1467.	1618.	1782.
MAIN	10787.	9818.	10827.	11929.
NACELLE AND PYLON	(6172.)	(4220.)	(5000.)	(5648.)
NACELLE	2380.	2214.	2559.	2338.
PYLON	3793.	2005.	2441.	2909.
NOISE TREATMENT	0.	0.	0.	0.
PROPULSION SYSTEM	(22581.)	(20722.)	(24783.)	(29241.)
ENGINES	15351.	13329.	17045.	19791.
FUEL SYSTEM	2650.	2569.	2874.	3125.
THRUST REVERSERS	2579.	2323.	2864.	3325.
REACTOR SYS	0.	0.	0.	0.
HEAT EXC & DUCTS	0.	0.	0.	0.
AUX COOLING	0.	0.	0.	0.
MISCELLANEOUS	2000.	2000.	2000.	2000.
TANKER KIT	0.	0.	0.	0.
LH2 TANKS	0.	0.	0.	0.
LFC ENGINES	0.	0.	0.	0.
LFC MISC	0.	0.	0.	0.
LFC DUCTS	0.	0.	0.	0.
SYSTEMS AND EQUIPMENT	(15404.)	(33918.)	(20403.)	(21763.)
AUXILIARY POWER SYSTEM	562.	540.	571.	599.
SURFACE CONTROLS	3481.	3254.	3478.	3822.
INSTRUMENTS	1205.	1184.	1231.	1245.
HYDRAULICS AND PNEU.	1622.	1516.	1621.	1781.
ELECTRICAL	2587.	4377.	2857.	2933.
AVIONICS	2400.	2400.	2400.	2400.
FURNISHINGS	1713.	16632.	5216.	5523.
AIRCONDITIONING & ANTI-ICE	1682.	3967.	2976.	3433.
ANTI-ICE FLUID	0.	0.	0.	0.
AUXILIARY GEAR-EQUIP.	52.	47.	54.	59.
L.E. CLEAN OR ANTI-ICE SYS	0.	0.	0.	0.
MISSLE LAUNCH SYS	0.	0.	0.	0.
WEIGHT EMPTY	(123429.)	(127674.)	(134129.)	(150289.)
OPERATING EQUIPMENT	3247.	9419.	3321.	5596.
WEIGHT MARGIN	0.	0.	0.	0.
OPERATING WEIGHT	(126676.)	(137093.)	(137995.)	(157788.)
PAYLOAD-PASS.	0.	36900.	0.	0.
CARGO	81300.	13860.	75000.	75000.
ZERO FUEL WEIGHT	(207976.)	(187853.)	(212995.)	(232788.)
FUEL	71567.	68006.	77647.	88094.
EXPENDABLE FLUIDS	0.	0.	0.	0.
GROSS WEIGHT	(279543.)	(255850.)	(290092.)	(320881.)
AMPR WEIGHT	99352.)	105344.)	108286.)	125058.)

REFERENCES

1. Exhibit A, "Study of the Flatbed Transport Aircraft Concept," NASA Statement of Work, 1-60-3140.0111A, 13 June 1979.

2. R. G. Smethers and E. W. Caldwell, "Flatbed, A Unique Transport Airplane Concept," Project Memorandum 79100/1, Lockheed-Georgia Company, December 1978.

3. "L500. Distribution of Heavy Contruction Machinery Equipment," Lockheed-Georgia ER10533, March 1970.

4. "Handbook of Information Dulles International Airport," FAA, May 1967.

5. "Winds for World Air Routes," Boeing Report D6-9177, July 1962.

6. "CFM 56 Installation Manual," General Electric Company, October 1979.

7. "Letter to NASA for the ACLGCAS," Lockheed-Georgia LGD/753902, dated 7 September 1979.

8. D. E. Reubush, "An Experimental and Theoretical Investigation of the Effect of Nonmetric Over-The-Wing Nacelles on Wing-Body Aerodynamics," NASA Technical Paper 1503, August 1979.

9. "Military Specification, Air Transportability Requirements," MIL-A-8421F, October 25, 1974.

10. "Boeing 767-777 Interiors Show Flexibility," Aviation Week and Space Technology, Vol. 108, No. 18, 1 May 1978.

11. Sighard F. Hoerner, "Fluid Dynamic Drag," Midland Park, N. J., published by author, 1958.

12. H. McDonald and P. F. Hughes, "A Correlation of High Subsonic Afterbody Drag in the Presence of a Propulsive Jet or Support Sting," Journal of Aircraft, Vol. 2, No. 3, May-June 1965.

13. Georgene H. Laub and Hifer M. Kodani, "Wind Tunnel Investigation of Aerodynamic Characteristics of a Scale Model of a DS Bulldozer and an M109 Self-Propelled 155mm Howitzer," NASA TMX-62,330, January 1974.

14. O. K. Trunov, "Icing of Aircraft and the Means of Preventing It," USAF FTD MT 65490 (a translation), August 1967.

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Final Report, Project Manager, M. Winston, Aeronautical Systems Division
Langley Research Center

16. Abstract

Flatbed is a unique transport airplane configuration featuring versatility of payloads. Flatbed can haul containers, passengers in a removable module, or outsize cargoes such as large military or civil vehicles. Cargoes such as intermodal containers and large vehicles are literally carried on an open cargo floor--there is no fuselage per se--only a backbone aft of a cockpit section.

Studies have shown the technical and economic feasibility of the Flatbed concept. With the design optimized for a passenger haul at M = 0.82 at normal airliner cruise altitudes, unpressurized containers can be carried at M = 0.73 at an altitude of 5486 meters. Pressurized containers fly at normal transport altitudes. With vehicles such as an XM-1 tank, cruise speeds of M = 0.60 at 5486 meters can be achieved for a range of 4473 km.

In comparison with reference aircraft performing the same missions, Flatbed shows lower operating costs for cargo and equal to or slightly lower than operating costs for passenger service.

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