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AIRSHIP LIFT — STATIC, DYNAMIC AND POWERED STATIC

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ABSTRACT

The basic principles of airship aerostatics and aerodynamics as they apply to powered Lighter Than Air vehicles are summarized. The development of static lift is discussed, as is the effect of the variation of atmospheric parameters on the lift of an aerostat. In addition, the use of dynamics and powered statics as a lift adjunct is reviewed.

INTRODUCTION

Any vehicle operating in a medium may obtain lifting forces from three primary sources, as shown in Fig. 1.

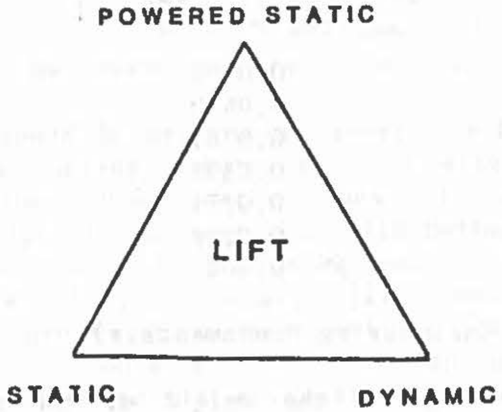

Fig. 1 The Lift Logo

The most economical of these forces from the production of lift point of view is undoubtedly the static lift wherein a buoyant force is generated by the displacement of a portion of the supporting medium by the body. For a waterborne vehicle, this lift is embodied in the displacement ship, and for the airborne vehicles, this is the balloon.

The inefficiency of the static lift vehicle comes when it is required to move through the surrounding medium. Due to the nature of displacement buoyancy, these vehicles tend to be very large and, as a result, they develop a great deal of dynamic drag when in motion. The dynamic effects of the motion can be used to an advantage, however, if the motion can be used to generate lift. By shaping the body, or a portion thereof, as a lift producing foil, a lifting force may be developed to support the weight of the body, provided sufficient forward speed is attained. In air this is the airplane, while in water (hydro) this is the hydrofoil craft.

A principal disadvantage of the dynamic lift vehicle is that it requires forward motion at some finite velocity to generate the lift. As a result, this vehicle can neither fly very, very slowly nor can it remain airborne at zero forward velocity (hover). If these attributes are required, one must provide some sort of internal powering for the static lift, such as a vertical jet exhaust or a propellor with a vertical downflow. In air this is the helicopter and on water (or in close proximity to the earth) this is the Air Cushion Vehicle, sometimes called the Ground Effect Machine.

Having defined these primary sources of lifting force, one might observe that it is possible to use two of these sources, or even all three, in combination. By so doing one moves from the pure lifting force source, for example static lift, to a hybrid source, such as a partial static lift and a partial dynamic lift.

STATIC LIFT

The principal tenet of static lift is that a body displaces a volume of the surrounding medium whose weight is equal to or greater than the total weight of the immersed body. If the weight is equal, the body is said to have neutral buoyancy, while if the weight of the body is less than that of the displaced air, the body has a positive buoyancy.

Inasmuch as the general structure of the vehicle, that is to say the outer cover, the internal framework (if required), the payload compartment, the control surfaces, et cetera, all have a weight considerably in excess of the weight of an equal volume of air, the interior of a static lift aircraft must be filled with some substance that is considerably lighter than the surrounding medium. Hence the name "Lighter-Than-Air".

Table 1 Specific Lift of Gases

Units: Specific lift in pounds per cubic feet

Gas	Specific Lift
Hydrogen	0.0702
Helium	0.0650
Steam (212 °F)	0.0381
Methane	0.0337
Air (350 °F)	0.0271
Natural Gas	0.0248
Ammonia	0.0052

(Source: Handbook of Engineering Fundamentals)

If one were to ignore the weight of the required enclosure (the 'envelope') and consider only the static lift of various gasses, one would find a relationship of specific lift (pounds of lift per cubic foot of gas) as is shown in Table 1.

The data for Table 1 (Ref. 1) were obtained by subtracting the specific weight of the gas in question from the specific weight of air (0.0754 lb/ft^3). For example, the specific weight of Helium is 0.0104 lb/ft^3 and subtracting that from the specific weight of air gives a specific lift for Helium of 0.0650 lb/ft^3.

The data of Table 1 are based on a 100 percent pure gas at standard sea level conditions and at the same temperature as the air that is displaced. It can be seen from Table 1 that the greatest static lift is to be obtained from Hydrogen with Helium a close second. It is to be noted that although the weight of a given volume of Helium is approximately twice of that of an equal volume of Hydrogen, inasmuch as the lift is the difference between the weight of the gas and the weight of air, the lifting capacity of Hydrogen is but about eight percent (8%) greater than that of Helium.

When one considers the high degree of flammability of Hydrogen, one might ponder why that gas is even considered as a static lift source. The answer lies in the economics of its procurement. Wherein Helium must be mined or extracted from minute quantities in the atmosphere, Hydrogen can be obtained and inexpensively from the electrolysis of water.

The third gas listed in Table 1 is minimum temperature (212 °F) steam. Although steam will provide over one-half the lifting capacity of either Hydrogen or Helium, the temperature is hazardous and the generation equipment is usually bulky and of heavy weight. One must also consider the effects of hot moisture on the airship envelope fabric.

Although Methane is flammable, its flammability is significantly less than that of Hydrogen. Even though its specific lift is only about one-half of the two top candidates, a form of Methane Gas was used in some early airships. Because it is both lighter than air and flammable, Methane offers the unique capability of furnishing not only the lifting force, but also a portion of the fuel for the engines. For an airship with long flight duration, as the fuel is consumed less static lift is required. Therefore, with a judicious use of the standard fuel and the Methane fuel, one might maintain an equilibrium condition.

Although it stands a poor fifth on the list of static lift gases, heated air is currently the most popular for sport Lighter-Than-Air vehicles. The reason for its popularity is, of course, its low cost and ready availability. And by the use of a heat control, such as a propane burner, the amount of heat imparted to the air in the envelope (and therefore the lift) can be closely controlled.

The lifting capacity of heated air comes from the decreased density of a heated gas. This is a property of all gases, not air alone, and offers the possibility of increasing the lifting capacity of other gases, say for example Helium, by heating the gas. There have been many proposals to use the excess heat from the propulsion engines to heat the lifting gas of an airship, but little has been done in the way of a practical demonstration of this phenomena.

Natural gas could be used in a manner similar to that of Methane as both a lifting and fueling medium, but its slightly lower specific lift together with its lower heat content does not make it a viable candidate for operations as might be accomplished with Methane.

Ammonia, while extremely corrosive and difficult to handle, offers another unique possibility for static lift. Ammonia has the property of being able to be absorbed into a very small quantity of water under certain temperature conditions. Once absorbed, it can be removed from the water very easily and returned to its original gaseous state. While this has the appearance of a laboratory demonstration, consider the possibilities of deflating an airship when it is not is use, storing the gas in a very simple manner and then reinflating the envelope when the airship is once again required.

From an examination of Table 1, it might be said that nothing will provide more static lift than Hydrogen. And 'nothing' will, if by nothing one means the complete evacuation of the envelope so as to have a perfect vacuum. But even a perfect vacuum will only provide approximately sixteen percent more specific lift that will Helium! The problem with attempting to use this approach lies in the weight of the container necessary to maintain the pressure differential between atmospheric on the outside and zero pressure on the inside. For the other gasses, a slight overpressure on the internal gas is required only if this pressure is needed to maintain a shape of the envelope. The U. S. Navy's pressure airships of the 1940-60's used an overpressure of about a quarter of a percent of standard atmospheric pressure (about one and a quarter inches of water pressure) to maintain the envelope shape.

PARAMETER EFFECTS

Purity

When the specific lift of the various gases was listed in Table 1, it was considered that the lift was available from one hundred percent pure gas. Due to the natural impurities that are present in Helium as it is recovered from the earth and due to the cost of extensive refining, commercial Helium is seldom available at greater than ninety eight percent purity. When the Helium is placed in a container with some degree of porosity, say as in a fabric envelope, air mixes with the Helium and further reduces the purity. It is the custom in pressure airships to 'purge' the Helium at intervals by pumping in high purity Helium and pumping out the more impure gas. The latter may then be recycled through a purification process and reused.

One may easily compute the lifting effects of non-pure Helium by considering that it is mixed with air. For example, since the lifting force equals the specific weight of the air minus the specific weight of the contained gas, the specific lifting force of Helium of X% purity may be calculated by,

$$\text{Lift} = (0.0754 \times 100\ \text{lb/ft}^3) - ((100-X) \times .0754) - (X \times .0104\ \text{lb/ft}^3) \qquad (1)$$

where the first term is the weight of the displaced air, the second term is the air in the mix and the last term is the Helium in the mix

Table 2 shows the specific lift for Helium at various percentages of purity.

Table 2 Effect of Gas Purity on Lift

Units: Purity in percent; Specific Lift in pounds per cubic foot

Purity	Specific Lift
100	.0650
99	.0644
98	.0637
97	.0631
96	.0624
95	.0615
94	.0611
93	.0605
92	.0598
91	.0592
90	.0585

(Source: Equation 1)

As an approximation to the lifting capacity of Helium, one might use the ninety two percent (92%) purity because it gives a round number of sixty (60) pounds per one thousand (1,000) cubic feet. Although this is a lower than would normally be used in airship operations, it is a conservative figure in that the actual lift will probably be larger than predicted. The essential fact to note from Table 2 is that as the purity decreases so does the specific lift. By the time the purity has dropped from ninety six percent (96%) to ninety percent (90%), six and one-half percent (6.5%) of the Static Lift has been lost.

Atmospheric Effects

Ambient Air Pressure (Altitude) Airships may be divided into two general configuration types: the non-rigid, or pressure airship and the rigid airship. In the former, the slight overpressure of the lifting gas provides the shape of the vehicle within the limitations of the shape of the envelope. In the rigid airship, the shape of the vehicle is determined by the structural framework, hence the term rigid, and the lifting gas is contained in a series of individual cells within the framework.

In a rigid airship, the lifting gas cells are but partially filled at sea level and as the pressure of the surrounding air decreases with an increase in altitude, the lifting gas expands as the internal (gas) pressure decreases to match the external (air) pressure. Although it might seem that inasmuch as the same weight of lifting gas is displacing a larger volume of however, because the larger volume of air that is now being displaced has also decreased in density and therefore weighs less.

Once the rigid airship has reached an altitude where the lifting gas cells are one hundred percent full, any additional increase in altitude will result in a spilling of the lifting gas. As long as the airship is maintained in a condition of one hundred percent full cells, there is little change in static lift due to the fact that a volume of air with decreasing weight is being displaced by a volume of gas of decreasing weight. As the rigid airship descends, however, the less-than-full lifting gas cells displace less air and the static lift is decreased. The fullness of the lifting gas cells at sea level defines the amount of static lift that can be developed and this fullness also defines the maximum operating altitude of the airship.

In a non-rigid airship, the lifting gas is kept at a small overpressure above atmospheric in order to maintain the shape of the envelope. This is accomplished by one or more small air bags, called ballonets, inside the envelope. Pumping air into the ballonets produces an increase in the internal pressure of the airship. As the airship ascends, the lifting gas expands due to the reduction of the ambient air pressure, and in order to prevent overpressurization of the envelope, air is permitted to escape from the ballonets. It is customary to have automatic valves on airships that open at preset pressures to permit the ballonet air to escape when the pressure reaches a predetermined value above the normal lifting gas pressure. As the airship descends, air must be pumped into the ballonets to maintain the internal pressure and envelope shape. This is usually accomplished by using a powered blower and/or wash from the thruster system

When the pressure airship reaches an altitude where the ballonets are completely empty and the envelope is completely full of lifting gas, if the internal pressure is to be maintained a constant as the airship continues to rise, some of the lifting gas must be allowed to escape. Although values may be provided that will open automatically at a preset overpressure to vent Helium, it is customary to manually valve the Helium, if this is required, so that the operator can have an indication of how must Helium has been permitted to escape.

There is some altitude at which, with the ballonets completely empty, it is just possible to return to the ground with the ballonets filled to capacity. This altitude is called Pressure Height. Flight above Pressure Height will result in the ballonets becoming completely filled prior to the airship reaching the ground on its descent and then some other measures must be taken to maintain the shape and pressure of the envelope. The most common measure is the addition of air to the lifting gas. This, of course, reduces the purity.

Below Pressure Height, a change in altitude or a change in barometric pressure has little effect on static lift. Above Pressure Height with a constant temperature and increased presure in the envelope, an increase in altitude or a decrease in barometric pressure produces a change in static lift as shown by:

$$\Delta \text{Static Lift (\%)} = 100 \times (7.25 \times (p_1/P_0) - 1)/(7.25 - 1)) \quad (2)$$

where

7.25 = Ratio of gas constant, Helium to Air

P_1 = Reduced atmospheric pressure

P_o = Initial atmospheric pressure

The relationship for static lift percentage change may be simplified as:

$$\Delta \text{Static Lift (\%)} = 116 \times (P_1/P_o) - 16 \quad (3)$$

The relationship for the pressure change with altitude can be found from the International Committee of Aviation Organizations (ICAO) relationship for pressure (P), in pounds per square feet, as a function of altitude (H), in feet, as:

$$P_i = (1 - 6.875 \times 10^{-6} \times H_i)^{5.2561} \qquad (4)$$

As a general rule of thumb, one may consider that above Pressure Height, a one percent reduction in static lift will occur for each two hundred thirty feet in altitude increase or for each 0.25 inches of mercury decrease in the barometric temperature.

Unless the pressure airship is considerably above the Pressure Height, a decrease in altitude or an increase in barometric pressure will have little or no effect on the static lift inasmuch as the lifting gas will contract and the airship will no longer be at Pressure Height.

Ambient Air Temperature Below Pressure Height, any increase or decrease in the ambient air temperature will have insigificant effects on the static lift, provided that the lifting gas and the ambient air are at the same temperature.

Above Pressure Height, an increase in ambient air temperature reduces the static lift approximately two percent for every 10 °F. This change is due to the relative expansion rates of air and Helium. A decrease in ambient temperature above Pressure Height (unless is occurs a considerable distance above the Pressure Height) has neglibible effect on the static lift, inasmuch as the decrease in temperature results in a cooling of the lifting gas with a contraction of the gas and the airship is no longer at Pressure Height.

Differential Air Temperature Because of local heating, usually from the sun on the envelope, it is possible for the lifting gas to be at a different temperature than the surrounding air. If the sun were to heat the lifting gas so that it is at a higher temperature than the surrounding air, a condition called 'Superheat', the same weight of lifting gas would be displacing a larger volume of air, and therefore a larger weight of air. This produces an increase in static lift. Inasmuch as the specific density of the gas is inversely proportional to the ratio of absolute temperatures, the percentage increase in static lift due to a temperature increase (positive Superheat) may be found from the relationship:

$$\Delta \text{ Static Lift } (\%) = ((T_1/T_o) - 1) \times 100 \qquad (6)$$

where

T_o = Air temperature °R

T_1 = Lifting gas temperature °R

For one hundred percent pure Helium at standard sea level conditions, below Pressure Height, a 10 °F Superheat will increase the static lift about 2%.

Above Pressure Height the loss of the lifting gas as it heats results in a very slight increase in static lift.

A negative Superheat results in static lift decreases both above and below Pressure Height. In both cases the change in static lift if approximately 2% for each 10 °F temperature differential. The decrease in static lift above Pressure Height is due to the fact that the gas contracts and the airship is no longer at Pressure Height.

An interesting possibility arises with the use of gross Superheat. As shown in Fig. 2, the use of 50 °F or 60 °F Superheat can provide as much as six to eight thousand pounds of lift at standard sea level conditions. One must consider, however, the amount of heat energy that must be added to reputed to have been tried, most considerations of augmenting the static lift by heating have been abandoned due to the excessive weight of a heat producing device that can maintain a high value of superheat over a long period, and the decrease of Pressure Height with a heated lifting gas. What may be possible, however, is the short-term heating of the lifting gas in order to provide extra lift in the takeoff and transition phases of flight when dynamic lift is at its least value.

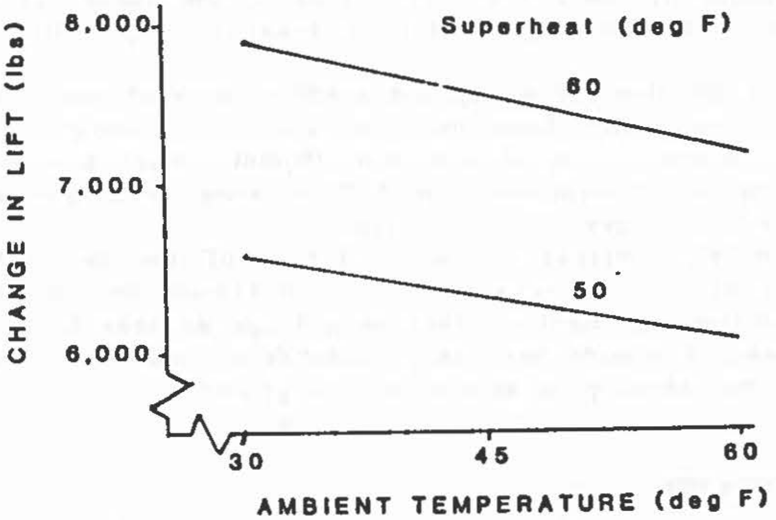

Fig. 2. Effect of Gross Superheat

Humidity The basic calculations for static lift were based on the assumption that the air was dry. When the air is humid, there is a loss of static lift capability. Table 3 shows the effect of one hundred percent humidity on static lift at various temperatures. The Table shows the percentage changes in Static Lift from dry air (zero humidity).

Values for less than one hundred percent humidity may be approximated by straight line interpolation between the zero loss of lift at zero humidity and the loss listed in Table 3 at one hundred percent humidity.

Table 3 Effect of 100% Humidity on Static Lift

Units: Temperature in degrees Fahrenheit; loss of lift in percent

Temperature	Loss of static lift
21	0.1
32	0.2
50	0.5
70	1.0
86	1.6

Rain Because of the nature of many of the cloth materials used for the outer cover of an airship, the airship can accumulate large water loads in rainstorms. It is practically impossible to predict the amount of these loads inasmuch as they are a function of the severity of the rain, the temperature of the envelope, the postrain ambient conditions and, of course, the nature of the material covering. The increased weight, which acts to reduce the useable static lift, may be as much as one-third of the maximum static lift that can be developed. For example, 0.05 inches of water on the upper surface of a million cubic foot airship would add approximately eight thousand pounds of weight. Even though this phenomena is usually one to be avoided, it has been used frequently to increase the net heaviness of an airship after it has become light during a long flight. The act of flying through a small rain squall prior to landing may improve the landing capability.

Snow/Ice It is possible for an airship in flight, especially at very low velocities, to pick up snow loads if the snow has a high moisture content. In particular, these loads may concentrate on horizontal or upper X-configured control surfaces and at the nose. Because of the large flat surfaces on the top panel of the rigid airships Akron and Macon, it was customary to manually sweep any snow accumulation from the top prior to commencing a landing.

Because of the large exposed surface area of even the smallest airship, ice accumulation from freezing rain is a more serious problem. A quarter inch accumulation of ice over 30,000 square feet of envelope has a weight in excess of eighteen tons! This area is approximately the upper surface of a U. S. Navy ZPG-2 airship.

Fortunately, unless the accumulation of ice is heavy and rapid, it may be possible to alleviate the ice build-up by varying the internal pressure and thus making the envelope a large de-icer boot.

A potentially more serious problem from snow and ice accumulation may occur while the airship is moored on the ground.

PSEUDO-STATIC LIFT

Even at zero or near zero airspeeds, a pilot of a Lighter-Than-Air vehicle may experience false indications of the static condition of the aircraft due to air thermals. This is obvious near cloud formations that have updrafts and down drafts, but similar (although usually less severe) thermals exist over land and water in clear air. These thermals are usually the result of differential heating of the surface of the earth and are particularly noticeable when flying close to the surface and passing from a plowed field (no rising air) over to a green field or a wooded area (rising currents). A similar condition usually exists when passing from over the ocean to an over the shore position. In both of these cases the airship has a tendency to rise as though it had an increase in static lift.

In-Flight Validation of Static Condition

Due to the generation of dynamic lift by the envelope and the horizontal fins, the only way to validate the static condition of an airborne airship is to reduce the forward velocity to zero or to near zero. The pilots and/or flight engineer usually have at least a mental running total of weight changes during a flight, but the effects of Superheat, moisture on the envelope, et cetera may result in a different static condition. By slowing the airship to remove the effects of dynamic lift, the pilot can at least validate the static condition trend, and, perhaps even of greater importance, the pilot can determine the static trim of the airship. Particularly for a pressure airship with multiple ballonets, the static trim of the airship may have changed significantly since take-off and this trim can easily be masked by dynamic lift and/or automatic control systems.

The procedure for slowing the airship (to zero airspeed if it does not have too much static heaviness) and checking the static trim is called "Weighing Off".

DYNAMIC LIFT

form, as with the Megalifter concept, or from a 'lifting body' shape, as with the Aeron design, the envelope and fins of an airship are capable of providing a considerable amount of dynamic lift.

The United States Navy's pressure airships of the 1940's - 1960's were traditionally launched with a negative buoyancy. This meant that these airships took off and flew at least the first part of their mission in a heavier-than-air state. In fact due to the poor handling qualities of a 'light' airship, provisions were added in the late 1950's that would allow the airship to recover water ballast from the sea in order to maintain a negative buoyancy.

Although the airship envelope has the general shape of an airfoil, and even though it has an extremely large planform area, the envelope usually provides but a small portion of the dynamic lift with a major portion of this force coming from the fixed and moveable horizontal surfaces. With a 'heavy' airship this dynamic lift is required throughout the flight, but development of this lift adjunct is of special importance during the take off maneuver where the dynamic lift can amount to as much as ten percent (10%) to sixteen percent (16%) of the entire weight of the airship. Inasmuch as large amounts of dynamic lift are required at very low velocities during take off, the lifting surces must be efficient, the drag of these surface must be small and/or the power available must be very large.

To obtain lift from a symmetrical airfoil, such as the envelope or a conventional fin, the lifting surface must be at an angle of attack with respect to the airstream. This is easily accomplished with a pressure airship due to the unique trim capabilities of the ballonet system. By pumping air into the aft ballonet and valving air from the forward ballonet (in order to maintain a constant lifting gas overpressure), the center of buoyancy shifts forward and the nose rises. The pilot has the sensation that he is shifting weight (air) aft and the tail section is pitching down. This technique permits the airship to fly at a positive pitch angle (angle of attack) to generate dynamic lift, with very little longitudinal control surface deflection. Unfortunately, the angles of attack required for high values of dynamic lift also produce a large increase in drag.

The drag increase that results from tilting a large airship envelope up at an angle of attack could be reduced if a dedicated airfoil were used for the generation of dynamic lift. To gain an appreciation of the size of a dedicated airfoil that would be required to generate a lift equal to ten percent (10%) of the total weight of an airship at ten (10) knots, consider a million and a half (1.5×10^6) cubic feet airship with a total weight of eighty thousand (80,000) pounds. With a simple, symmetrical airfoil such as the NACA 0012 with a lift curve slope of 5.73/radian and an angle of attack of eight degrees (8°), an airfoil would have to have an area of approximately three thousand (3,000) square feet. This is approximately the size of both the horizontal and vertical tail surfaces of the ZPG airship. If more lift is required at this angle of attack, the area of the lifting surface must increase in direct relationship to the lift.

Fig. 3 shows the wing area required to produce dynamic lift at takeoff (velocity of ten (10) knots). The airfoil that will produce this lift also produces an additional drag and, unfortunately, this drag is not only present during the lower speed takeoff, but the power required to overcome the airfoil profile drag increases as the cube of the forward velocity.

Consideration might be given to having a retractable airfoil surface that is placed in the airstream only when dynamic lift is required. Such retraction could be by a 'swing wing' similar to that of the F-111 airplane with the wing folding within the car when not required and swinging out for lift production. However, not only would the support and control mechanism of such a wing be prohibitive as to weight but, to get back to basics, a dedicated airfoil is required principally to augment the static lift during the heaviest mode of flight, i.e., take off, and this is the airspeed band at which dynamic lift is the most inefficient.

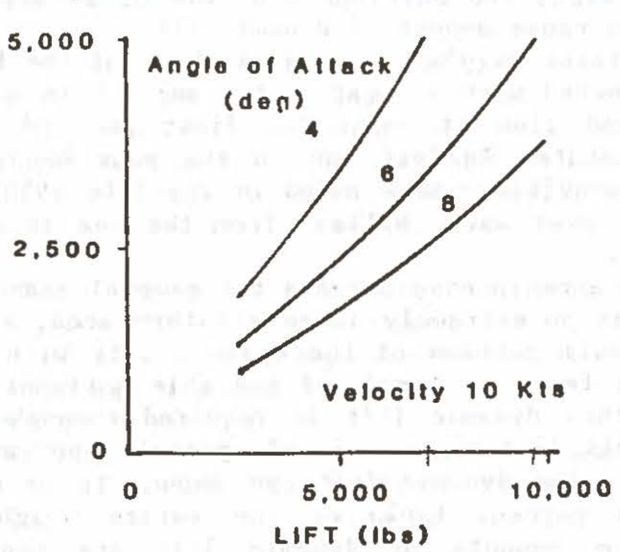

Fig. 3 Wing area required to augment takeoff lift

Although an airfoil of the size required to assist takeoff or augment lift in forward flight would provide a large adjunct on even something as long as a three hundred and fifty (350) foot airship, similar surfaces are already attached as horizontal stabilizers and elevators.

With the engine thrust vector below the metacenter of the airship, the thrust tends to produce a nose-up moment. The very fact that an airship can fly in moment equilibrium gives an indication that much of the dynamic lift is generated on the fins producing a nose-down moment. A simple experiment can be used to demonstrate the inherent dynamic lift capabilities of the elevator surfaces of an airship. During a ground take off roll of a heavy airship trimmed at a zero angle of pitch, a rapid application of engine thrust will produce a nose-up pitch. If, at the same time, full down elevator is applied, a tail-up moment results - and the airship will lift off the ground with full down elevator!. A word of caution Even though the airship lifts off the ground, something must be done to the controls to prevent the airship from returning violently to the ground.
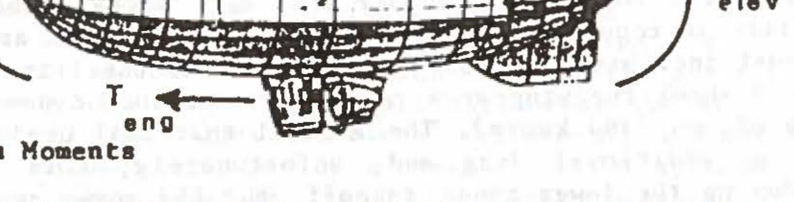
Fig. 4 Thrust/Fin Moments

As early as the 1920's (Ref. 2,3,4,5) wind tunnel and water tunnel tests demonstrated that less than twenty percent (20%) of the dynamic lift is generated by the envelope and that the major portion of the dynamic forces come from the horizontal stabilizer and fins. This offers the possibility of the use of the control surfaces to generate dynamic lift with a smaller drag than if the lift were generated by envelope angle of attack.

tests of a ZPG model at the Naval Postgraduate School (Ref. 7). The dynamic lift coefficient (C_L') was calculated on an area base of the total volume to the two-thirds power ($V^{2/3}$). The flight test airship had 'X' planform control surfaces and the longitudinal control deflection is a sum and average of the actual control movement.

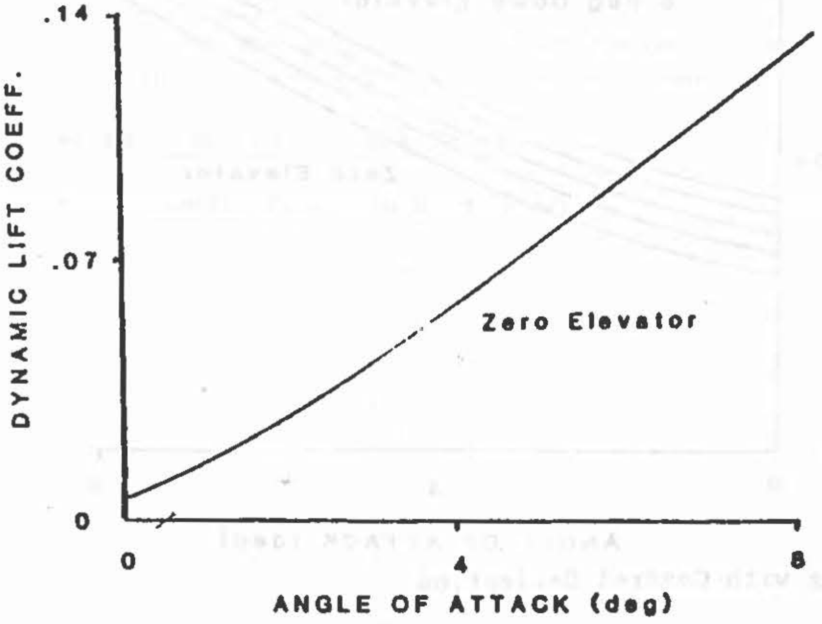

Fig. 5 Zero Elevator Dynamic Lift

Fig. 5 shows the variation of the dynamic lift coefficient with angle of attack for zero elevator deflection. Some dynamic lift is obtained even at zero angle of attack due to the positive inclination of the fins.

Deflection of the control surfaces produces an increase in lift at each angle of attack value for the envelope as shown in Fig. 6. The elevator control effectiveness (dC_L/d_δ) is 0.012 per degree.

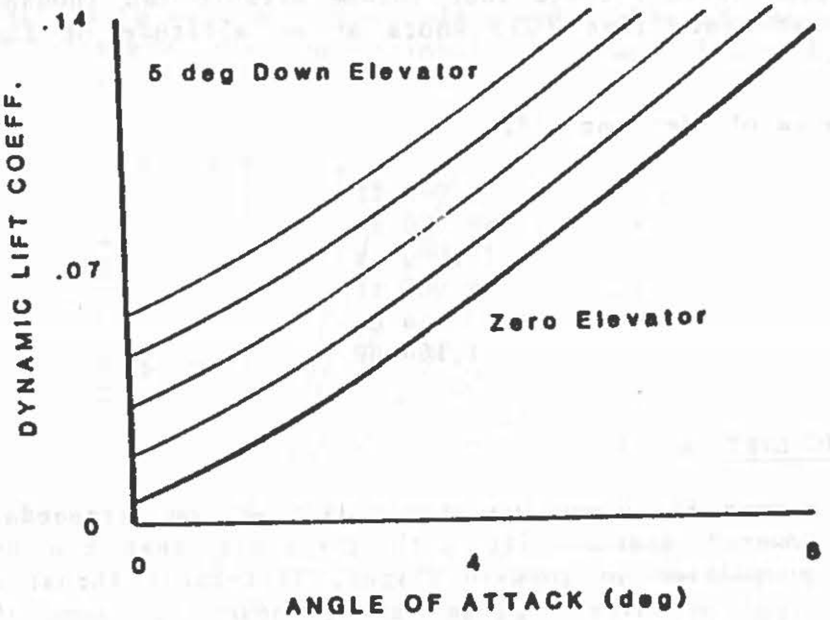

Fig. 6 Dynamic Lift with Elevator

The deflection of the control surface produces an increase in drag along with the increase in lift. The overall drag coefficient as a function of angle of attack for various elevator deflections is shown in Fig. 7. The non-dimensional drag increase due to control deflection is 0.026 per degree.

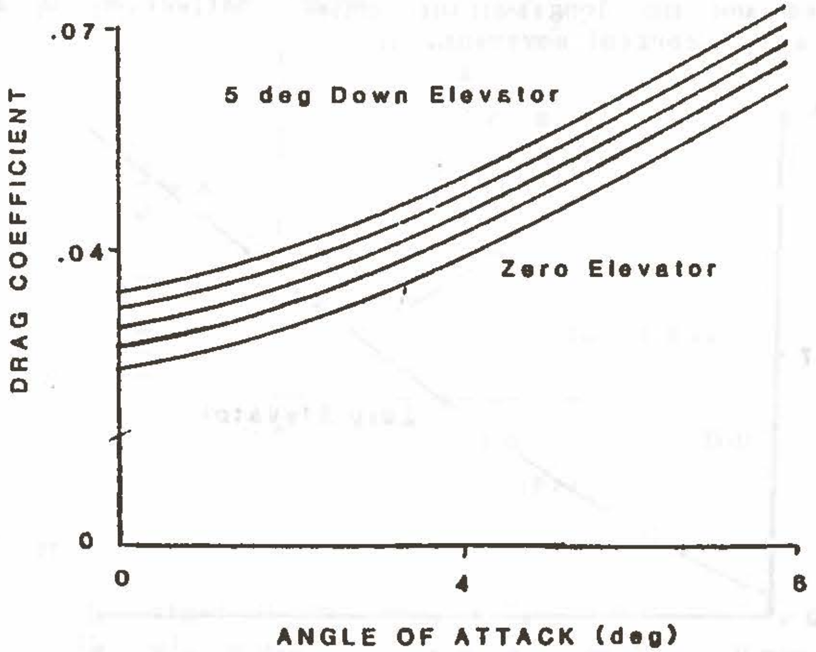

Fig. 7 Total Drag with Control Deflection

The data presented in the above figures are for the first five degrees (5°) of elevator deflection. With the full deflection authority being of the order of fifteen to twenty degrees ($15^{\circ} - 20^{\circ}$), it can be shown that the dynamic lift coefficient obtained at any angle of attack with zero elevator deflection can also be obtained at zero angle of attack by the use of down elevator. This means that a six-fold increase in dynamic lift can be obtained with less than a two-fold increase in drag coefficient.

The production of dynamic lift with a smaller drag means that the power requirements for flight are reduced. Table 4 shows the effect of flying a million (1×10^{6}) cubic foot volume airship ten thousand (10,000) pounds heavy at sixty five (65) knots at an altitude of five thousand (5,000) feet.

TABLE 4. Effects of Elevator Lift

Volume	1,000,000 ft^3
Static Lift	60,000 lb
Dynamic Lift	10,000 lb
Altitude	5,000 ft
Power ($\alpha = 0$)	944 HP
Power ($\alpha \neq 0$)	1,164 HP

POWERED STATIC LIFT

An efficient manner of augmenting static lift at low airspeeds is through the use of Powered Static Lift with thrusters that can be used for conventional propulsion in forward flight. Tilt-rotor thrust was used on some of the rigid airships and has been proposed for some of the newer models of airships. And, of course, the use of a tiltable, ducted fan for powered static lift has been demonstrated on Airship Industries airships.

A quick approximation of the

be obtained from momentum theory.

$$P = ((T^3)/(2\rho\pi R^2))^{.5}/550 \tag{7}$$

This power, which does not account for the power required to overcome the drag of the rotor blades, also does not account for losses due to envelope-thruster interference effects.

For fans with one and a half (1.5) foot radius blades, the total power to produce the thrust at sea level would be as shown in Table 5.

Table 5. Power Required to Produce Thrust

Units: Thrust in pounds; Power in Horsepower

Thrust	Power
1000	315
2000	887
3000	1624
4000	2504
5000	3654
6000	4604
7000	5808
8000	7097
9000	8468
10000	9918

(Source: Helicopter Performance)

From Table 5 it may be seen that an airship that is ten thousand (10,000) pounds heavy will require a like number of horsepower to hover. This is not really a negative utility inasmuch as the airship is not using its propulsive power for any other purpose when in hover.

The size of the thrusters to produce a given amount of lift is a function of the number of rotor blades and the number of thusters. Fig. 8 shows a relationship between rotor radius and number of thrusters (n) for two types of thrusters, the 'conventional' rotor with fourse blades (b = 4) and a fan with forty four blades (b =44).

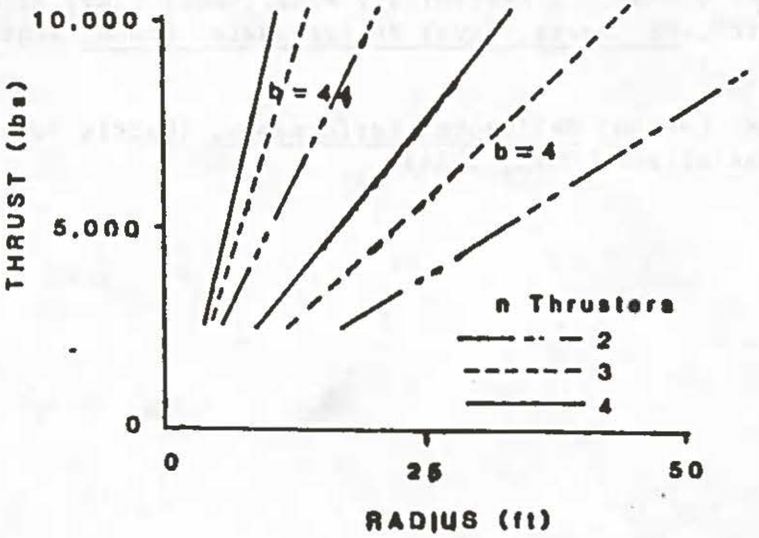

Fig. 8 Thruster Size

CONCLUSIONS

A free balloon in still air is probably the only 'pure' Lighter-Than-Air vehicle. Even without what might be called an 'aerodynamic' shape, motion through the air will produce some dynamic effects. And if the Lighter-Than-Air craft has a typical envelope shape and stabilizing horizontal fins, some sort of dynamic lift will be produced, whether it is wanted or not. It is to be remembered that a 'light' airship requires a negative dynamic lift in order to maintain equilibrium flight.

Thus it is that every airship operates somewhere between the apex points of the Lift Logo, and the designers and operators of Lighter-Than-Air vehicles have an option to augment the static lift in a manner than can be tailored to the flight situation.

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