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# THE EFFECTS OF SELECTED MODERN TECHNOLOGICAL CONCEPTS ON THE PERFORMANCE AND HANDLING CHARACTERISTICS OF LTA VEHICLES

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ABSTRACT: The results of an airship design sensitivity study, a prelude to a more in-depth, impending follow-on analysis is presented. A wide variety of airship design concepts, including the classical and high aero-lift augmented-hybrids are examined with regard to specific technological improvements and consequent gains in performance, stability and control and flying qualities. Variations in size, payload, power required and airspeed are quantitatively analyzed for airships representing aero-to-buoyant lift ratios of zero to 3.0 over a range of technology improvements implying reduced drag, reduced structural weight fractions and lighter, more efficient propulsion systems. Qualitatively, future airships are discussed in terms of stability, control and flying qualities requirements dictated by projected demands for vastly improved operational effectiveness and ease of handling. Such topics include stability augmentation systems, load-alleviation systems and total computer state-sensing and controls management systems. It has been shown that, for the most part, highly refined conventional designs offer attractive gains in both performance and ease of handling. Hybrid airships represent a good potential for missions requiring the transport of heavy payloads at higher airspeeds over shorter ranges without the capability for sustained hover and vertical flight.

## NOMENCLATURE

$A$ = Aspect ratio
$C_D$ = Drag coefficient
$C_L$ = Aerodynamic lift coefficient
$d$ = Maximum diameter of airship (ft)
$D$ = Vehicle air displacement (lbs)
HP = Horsepower ($550 \frac{\text{ft lbs}}{\text{sec}}$)
$k$ = Burgess "inverse drag factor"
= $\frac{2\, V^{2/3}}{C_D\, S_{ref.}}$ (for drag non-dimensionalized in conventional aircraft terms)
$L_a$ = Aerodynamic total lift = $C_L\, q\, S$ (lbs)
$L_b$ = Buoyant lift (lbs)
$l$ = Overall length of airship (ft)
$pC_D$ = Percentage change in drag coefficient
$pw_f$ = Percentage change in $w_f$
$pw_p$ = Percentage change in $w_p$

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$q$ = Dynamic pressure = $1/2 \rho_{air} V^2$ (lbs/ft$^2$)
$R$ = Range (naut. miles)
$S_w$ = Main lifting surface area of hybrids (ft$^2$)
$t_m$ = Mission duration (hrs.)
$V$ = Total volume of airship (ft$^3$)
$V_{GAS}$ = Volume of buoyant gas (ft$^3$)
$v$ = Airspeed (ft/sec)
$W_1$ = Weight of air and gas (lbs)
$W_2$ = Weight of structure (inner and outer) (lbs)
$W_3$ = Weight of ballast, crew and misc. (lbs)
$W_4$ = Weight of propulsion system (incldg. engines, fuel, etc.) (lbs)
$W_5$ = Weight of payload (lbs)
$W_n'$ = Component weight fraction = $\frac{W_n}{D}$
$w_f$ = Specific fuel consumption (lbs/HP hr)
$w_p$ = Propulsion system weight per unit power (lbs/HP)
$\rho$ = Mass density (slugs/ft$^3$)
$\rho'$ = Weight density = g (lbs/ft$^3$)

## FOREWORD

The material contained in this paper has been drawn, in part, from a current Naval Air Development Center Study entitled, "Advanced Technology Airships: Feasibility for Naval Application", tasked by the Naval Air Systems Command H.Q., Washington, D.C. (AIR-03P3). The scope of the Center study includes the examination of LTA vehicles for military applications with emphasis on the Naval **escort**/surveillance mission as a tentative design reference. Included as a final output of this year's effort will be a technical parametric data base for a variety of LTA concepts, associated cost projections and an analysis of several other candidate Naval missions for Lighter-than-Air Vehicles.

Despite the interest in the feasibility aspects of the study, a position will not be adopted until late in the investigative period. Therefore, a smaller but nonetheless interesting segment of the Center study has been selected for this LTA Workshop paper.

## BACKGROUND

Airships compiled an impressive record commercially and militarily, both for scope of endeavor and safety during their operations; first by Germany during WWI, through the commercial years of the twenties and thirties and finally by the United States Navy, which terminated airship operations in the early sixties. Throughout a period of over thirty-five years of development the airships evolved from the fragile and short-lived LZ.1 of Count Zeppelin in 1900 to the magnificent LZ.127 Graf Zeppelin of 1928 and finally the ill-fated LZ.129 Hindenburg, representing the pinnacle of airship technology, which exploded and burned at her mooring mast at Lakehurst on 6 May 1937. The Hindenburg disaster signifies for many the unequivocal end of the rigid airship as a practicable airborne vehicle. However, it is more realistic to recall that Germany, which contained by far the strongest nucleus of airship technology, was forced to exclude the airship from further development because of a lack of helium and because of pressing commitments to develop her heavier-than-air power for the impending WWII. Having built 138 airships, most of which were technologically highly successful, Germany brought an abrupt halt to the technology by destroying the Hindenburg's sister ship the LZ.130 Graf Zeppelin II, the facilities and all peripheral airship equipment then based at Friedrichshafen. Until recently no nation with the potential capability to follow through with a major airship program has attempted seriously to assume responsibility to carry on the development of a modern rigid airship.

The airship has long been seen, although somewhat skeptically, as an attractive Anti-Submarine Warfare (ASW) platform because of its long endurance and considerable payload capability. However, considerations of low speed, vulnerability and all-weather performance have in the past offset these assets. Today, however, with the application of modern technologies in materials, avionics systems, propulsive systems, structural design, stability and control and meteorology the airship is again being considered because its potential for sustained and effective surveillance appears to be well-matched to todays' threat. In fact, the ASW Search and Surveillance Program Advisory Board sponsored by NAVMAT 03, concluded in November 1972, in their summary report that "Airships warrant another look in light of current trends in sensors, operating missions, and the threat".

The U. S. Navy, as in the past, is once more considering the rigid airship as a means of potentially satisfying a number of future mission roles. In 1968 a parametric study of conceptual LTA vehicles was completed by the Goodyear Aerospace Corp. for the Naval Air Development Center (reference 1). The conclusions arrived at in the work of reference 1 still stand as an indication of the technical feasibility and operational attractiveness of the modern LTA vehicle and further, point out the need for serious research and development to achieve more nearly optimum and operationally effective airships.

## INTRODUCTION

There are a number of technologies which, during the past forty years since airship design has been laid to rest, have advanced to a point of offering a modern dirigible "obvious" benefits. Such technologies as structural mechanics, materials and even meteorology belong in this category. Another technological branch which has grown very rapidly within the same period which offers perhaps less obvious benefits is aerodynamics; including stability, control and handling qualities. Several aerodynamic concepts have evolved from development work in low-speed boundary layer control alone which could be applied to reduce drag and render control surfaces more effective on a future airship. Likewise, developments in the field of airborne real-time digital flight control systems can potentially provide not only direct control of an LTA vehicle but could be of great benefit in presenting the pilot and crew with a continuous, up-dated status of the location and amount of ballast and valving gas available for retrimming the ship at any time.

This paper reviews the advantages of the following specific aerodynamic and stability and control concepts and/or considerations with regard to performance and overall handling qualities of future airships.

a. Optimal Aerodynamic Shapes; including the classical symmetrical/cylindrical shape, a derivative therof and the lifting body/hybrid configurations.

b. Augmented Lift and Maneuvering Devices; i.e., the use, primarily, of thrusting devices for augmenting buoyant lifting and aerodynamic controls.

c. Boundary Layer Control; as a means for improving the aerodynamic efficiency of the vehicle and for improving the effectiveness of aerodynamic control surfaces.

d. Automatic Flight Control and Stability Augmentation Systems; including automatic trimming functions, load-alleviation functions, stability augmentation and total computer state-sensing and controls management systems.

Although limited in scope quantitatively (primarily due to the short span of time since this study was initiated but certainly also due to a lack of hardened experience in the, perhaps lost, art of airship design), the objectives of this paper are to; 1, point out the advantages of the more practicable, least-risk modern technological wares and concepts afforded to the rigid airship now, 2, communicate the U. S. Navy's commitment to ascertain the feasibility of LTA for future mission roles and 3, stimulate the thinking and communication among those who will comprise the new airship technological community.

## CONCEPTUAL DESIGNS

Four generically different design concepts have been chosen for analysis. These are illustrated in Figure 1 and are identified as: A. Classical, B. Modified Classical, C. Delta and D. Wing-Augmented.

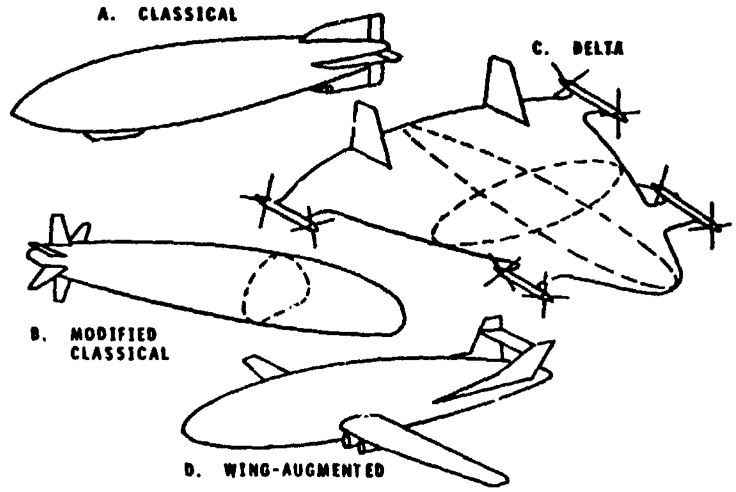


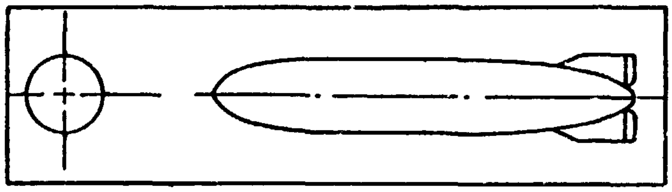

FIGURE 1. AIRSHIP DESIGN CONCEPTS: CONVENTIONAL TO HYBRID

Designs A through D represent a reasonable cross-section of the spectrum of both old and recently discussed and proposed concepts. They range from the neutrally-buoyant ($L_a/L_b = 0$), optimum fineness ratio cylindrical type to the high lift-augmented ($L_a/L_b = 2$ to 3) "Megalifter" (see reference 2) hybrid type.

The aerodynamic characteristics of concepts C and D are as significantly different from either the classical or modified-classical designs as are the missions to which such progressive designs might be usefully applied. In general, the power requirements for the high lifting body and hybrid classes of airships rise rapidly with increasing departure from the classical form thereby tending to reduce significantly the range over which reasonably large payloads may be carried. Such designs as the delta and wing-augmented types invariably preclude a VTOL and hover capability as well; a characteristic long considered highly useful in conventional airships. However, the comparison of these characteristics (and others as well) among concepts A through D will be presented in more explicit terms below.

Since the primary objective of this paper is to determine the advantages of applying improved technology to the airship, a reference classical design was chosen about which to perturbate the design parameters and the consequent improvements in performance.

An airship of circular lateral cross-section with parallel mid-body and assumed elliptical nose and aft-body longitudinal cross-sections was chosen and sized to a total volume of 10,000,000 $ft^3$. This airship, referred to herein after as the "basic design", is intended to represent approximately a 1930 state of technology. Figure 2 presents a two-view drawing of the basic design and a summary of its characteristics.



$V = 10,000,000\ ft^3$
D = 763,500 lbs
V(cruise) = 63.5 kts
Payload ($W_5$) = 100,000 lbs
HP = 3900
Range = 1900 nautical miles (out and return)
= 3800 nautical miles (out only)

$V_{GAS}$ = .85V (at S.L.)
Gas: Helium
Gas weight fraction ($W_1'$) = .288
Structural weight fraction ($W_2'$) = .300
Crew, Ballast and Misc. weight fraction ($W_3'$) = .055
l = 836.4 ft
d = 139.4 ft

FIGURE 2. TWO-VIEW DRAWING AND GENERAL CHARACTERISTICS OF REFERENCE CONVENTIONAL AIRSHIP DESIGN

## PERFORMANCE AND SIZING TRENDS

In order to show the potential advantages of reducing drag, structural weight and propulsion system weight (regardless of means) the basic (conventional) design was perturbated using a range of improvements believed to be representative of the current technology. Volume, power, airspeed and range are indicated over the assumed range of improvements in drag and component weights.

To provide some insight into the possible advantages afforded by severe shape changes it was decided to examine, as a class, those airships which employ either lifting bodies or surfaces to derive a significant percentage of their toal lifting capability. Such airships can be considered to be represented by a range of designs varying from concepts B to D previously introduced.

### Trends in Conventional Airships

All performance calculations for this and the following section on lift-augmented airships were made to preliminary design levels of accuracy. Several assumptions were made to "lump", respectively, drag contributions, propellor efficiencies, variations in power output and propulsion system factors and weight components in order to facilitate rapid calculation of the trends. It is believed that the results arrived at are in no way significantly compromised by the assumptions made. On the contrary, the simplistic approach taken in these calculations is necessary to gain a quick, quantitative feel for the design sensitivities in order to plan for more effective follow-on analyses.

One of the limitations of airships, viewed as serious by many, is airspeed. Airspeeds were usually in the 50 to 70 kts range; very slow by comparison with today's aircraft standards. In attempting to increase the speed, for instance, of a 10,000,000 $ft^3$ conventional airship from 70 to 90 kts we see in figure 3 that the total horsepower required more than doubles; and for yet another 10 kts the power more than triples. However, additional speed attained through increased power yields quickly to diminished returns with regard to payload since, in this case, a one to one tradeoff must be made between every pound of additional propulsion system and fuel weight and the payload.

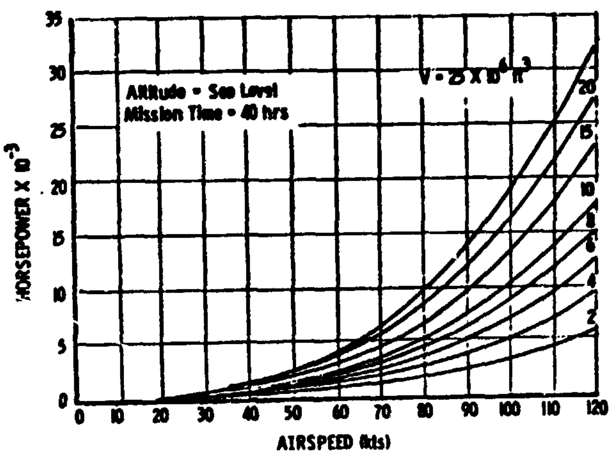



FIGURE 3. SIZING TRENDS OF CONVENTIONAL AIRSHIPS

The payload would have suffered greater still because of the increased weight of a stronger structure and outer covering to compensate for the greater loads imposed on the airship. Today more practical tradeoffs in power, speed and volume may be possible through significant reductions in drag and structural weight and through improvements in propulsion system characteristics.

Equation (1), below, was obtained from reference 3. It provides a convenient form to relate the design factors of drag airspeed, power and propulsion system characteristics to the sizing factors of volume, displacement and payload.

$$\left.\begin{aligned} (1-W_1'-W_2'-W_3')\,D &= (w_p + w_f\, t_m)\,\frac{D^{2/3}\,\rho_{air}\,V^3}{99K} + W_5 \\ V &= \frac{D}{\rho_{air}} \end{aligned}\right\} \quad (1)$$

Exercising equation (1) about the characteristics of the basic design (figure 2) the sensitivity of diminishing drag on volume airspeed, payload and power was determined. Percentage changes in the drag coefficient $C_D$ (relating to K) of -5, -10, -15 and -20 percent were conservatively chosen to represent drag reductions which might be readily achieved through body design changes (submersed protuberances and re-shaping to minimize base drag).

Figure 4 (a through d) presents the results of first reducing drag (figure 4 (a)), reducing $W_2'$, $w_p$ and $w_f$ (figure 4(b)), increasing power (figure (c)) and finally, in figure (d), effecting all improvements. A total mission duration of 60 hrs. was kept constant. Only modest gains in airspeed are seen to be realized. Even with a 20 percent reduction in drag only 5 kts additional speed is gained. Sacrificing payload 50 percent only yields a total gain in airspeed of 8.5 kts. Considering improvements in both structural weight and propulsion system a total airspeed increase of over 11 kts or an improvement of 18 percent in airspeed can be realized. Doubling the power to overcome the drag, the best airspeed that can be achieved (under the present assumptions) for a 10,000,000 $ft^3$ airship would be 87 kts (an improvement of almost 40 percent), but for this, 20,000 lbs of payload would have to be sacrificed.

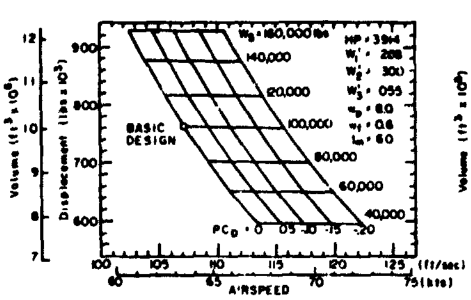



FIG 4(a) REDUCING HULL DRAG ONLY

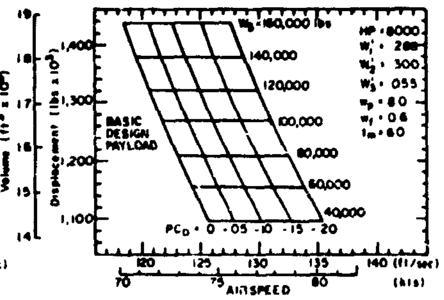



FIG 4(b) REDUCING HULL DRAG, STRUCTURAL WEIGHT FRACTION, IMPROVING ENGINE CHARACTERISTICS

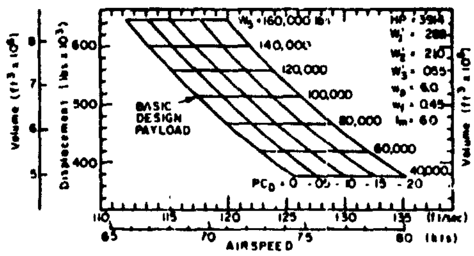



FIG 4(c) REDUCING HULL DRAG, INCREASING POWER

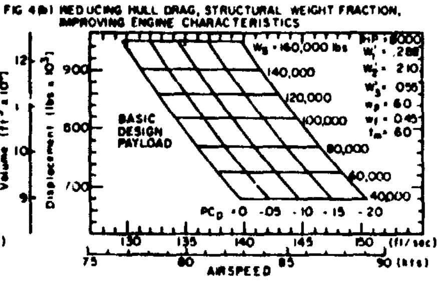



FIG 4(d) ALL MAJOR TECHNOLOGY IMPROVEMENTS

Table I below presents a summary of the technology perturbations and the percentage improvements in airspeed.

TABLE I
SUMMARY OF AIRSPEED IMPROVEMENTS
(CONVENTIONAL AIRSHIP)

| Figure | Drag | Structural Fraction ($W_2'$) | Propulsion ($w_p$, $w_f$) | Power (HP) | Payload ($W_5$) | Airspeed (v) | $\frac{\Delta V}{V}$ |
|---|---|---|---|---|---|---|---|
| 4(a) | Basic | → | → | → | → | 63.5 kts | - |
| 4(a) | -20% | Basic | → | → | → | 68.6 kts | 8.0% |
| 4(b) | -20% | -30% | -25% | Basic | → | 75.3 kts | 18.6% |
| 4(d) | -20% | -30% | -25% | +100% | -20% | 87.0 kts | 37% |

The most significant reductions in the drag of a conventional rigid airship can be achieved through boundary layer control. Experiments conducted on non-rigid (pressure) airships have indicated a reduction of approximately 15 percent in, primarily, base drag for small ($V < 1,000,000$ $ft^3$) designs employing propulsion units within a circular shroud located at the approximate normal flow separation point on the aft section of the airship. The use of a large, active boundary layer control system on a non-rigid airship is limited to external design implementations. Such external systems can introduce significant drag components in themselves. It appears that if boundary layer control is to be accomplished effectively the system must be designed within the hull envelope. It is believed that such "submerged" systems for rigid airships could yield drag improvements approaching 25 to 30 percent if designed in conjunction with aerodynamically cleaner hulls.

One such design is conceptually shown in figure 5.

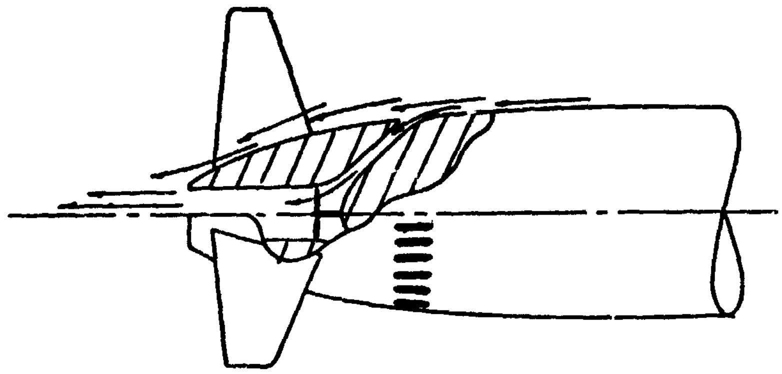


FIGURE 5. BOUNDARY LAYER DESIGN CONCEPT COMPRISING SUCTION AND STERN PROPULSION

Depicted is a boundary layer control system comprising suction in the region of normal flow separation and stern propulsion which, in-turn, aids in maintaining the momentum of the flow near the base of the airship. If feasible with regard to other considerations, i.e., weight distribution, structural design and duct losses this system affords considerable attraction in that it also improves the flow in the vicinity of the high aspect ratio tri-tailed empennage shown also in the illustration. Higher energy flow which is less disturbed in the region of the fins could yield higher control powers with reduced tail areas as well as improved static stability.

Maintaining the 10,000,000 $ft^3$ "basic design" volume and payload it is projected that the speed of conventional airships utilizing the above new technology or its derivatives could well surpass 100 kts.

Trends in Aero-Lift-Augmented Airships

A new class of airships have been proposed in recent years which combine aerodynamic lifting with buoyant lifting in an attempt, primarily, to gain airspeed and improve payload capacity. Such aero-lift-augmented airships derive aerodynamic lift either integrally through high-lifting hull designs or externally through the addition of lifting surfaces on an otherwise classical appearing hull (fuselage). This class of airships may be generally represented by design concepts ranging from B to D previously shown in figure 1.

To examine the sensitivity of sizing and performance factors of aero-lift-augmented airships the parameter $L_a/L_b$ (the ratio of aerodynamic to buoyant lift) was introduced into equation (1) along with other terms reflecting induced drag, increased structural weight fraction and hull/lifting-surface interference drag. Equating the total weight of the hybrid to the lift we obtain

$$W_1 + W_2 + W_3 + W_4 + W_5 = L_a + D \qquad (2)$$

where $D = L_b$ is the displacement of the airship portion of the hybrid, exclusive of the displacement of lifting surfaces which are considered negligible. In expanding equation (2) a number of useful relationships emerge in addition to the final expression sought for $L_a/L_b = f$ (Sizing + Performance Factors). A short derivation is given below.

Expanding (2) and dividing by $L_b$:

$$W_1' + W_2' + W_3' + \frac{(w_p + w_f t_m)HP}{D} + W_5' = \frac{L_a}{L_b} + 1 \qquad (3)$$

The power required is assumed equal to the basic airship drag plus the induced drag of the main lifting surfaces. In addition, a 20 percent increase in basic hull drag was assumed to account for the zero-lift drag of the lifting surfaces and the wing/hull interference drag. Induced drag was optimistically assumed equal to the theoretical minimum through the expression

$$\text{Induced drag} = \frac{L_a \frac{L_a}{S_w}}{q\pi A} \qquad (4)$$

The horsepower can then be expressed as,

$$HP = \frac{v}{550}\left[\frac{6.67\, D^{2/3} \rho_{air}\, v^2}{k} + \frac{L_a \left(\frac{L_a}{S_w}\right)}{\pi \frac{1}{2}\rho_{air}\, v^2 A}\right] \qquad (5)$$

Substituting (5) into (3) and rearranging we obtain the final sizing equation,

$$W_1' + W_2' + W_3' + (w_p + w_f t_m)\frac{v}{550}\left[\frac{6.67\,\rho_{air}\, v^2}{\sqrt[3]{D}\; k} + \frac{\left(\frac{L_a}{L_b}\right)\left(\frac{L_a}{S_w}\right)}{\pi\frac{1}{2}\rho_{air}\, v^2 A}\right] + W_5' = \frac{L_a}{L_b} + 1 \qquad (6)$$

The aero-lift augmented airships were examined over a range of augmentation ratios ($L_a/L_b$) of zero to 2.0. A wing loading ($L_a/S_w$) for the hybrids of 35 lbs/ft$^2$ and an aspect ratio (A) of 8.0 was assumed constant throughout the calculations. An overly optimistic specific fuel consumption of 0.45 was assumed to represemt an average modern technology engine of unspecified type. However, the powerplant weight factor, $w_p$, was conservatively chosen at 6.0 lbs/HP and may offset the low specific fuel consumption. The structural weight fraction was varied lineraly from 0.2 to 0.4 over an $L_a/L_b$ range of zero to 3.0 i.e.,

$$W_2' = 0.2 + .065\left(\frac{L_a}{L_b}\right) \qquad (7)$$

to account for an increase in the structural weight of these airships with increasing aero-lift augmentation ratio. A nominal zero lift hull drag factor of k = 70.6 (corresponding to a $P_{C_D}$ = -10%) was assumed.

In order to select a reasonable mission duration for the bulk of this brief analysis the payload and augmentation ratio was computed for $t_m$ = 10, 20 and 30 hrs over a range of $L_a/L_b$ of zero to 3.0. The airspeed and hull volume assumed were, respectively, 150 kts and 7,000,000 $ft^3$. Figure 6 shows the resultant plot.

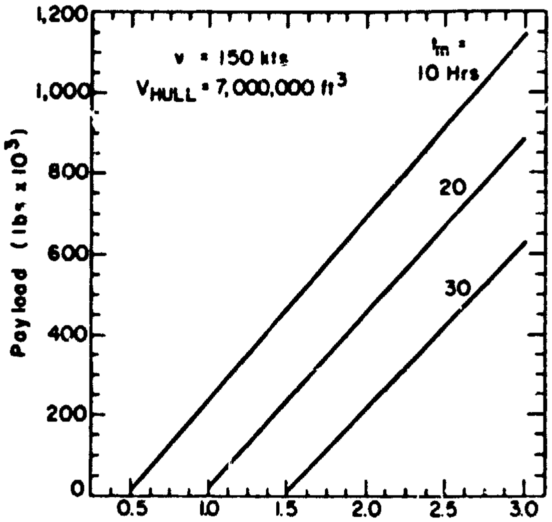
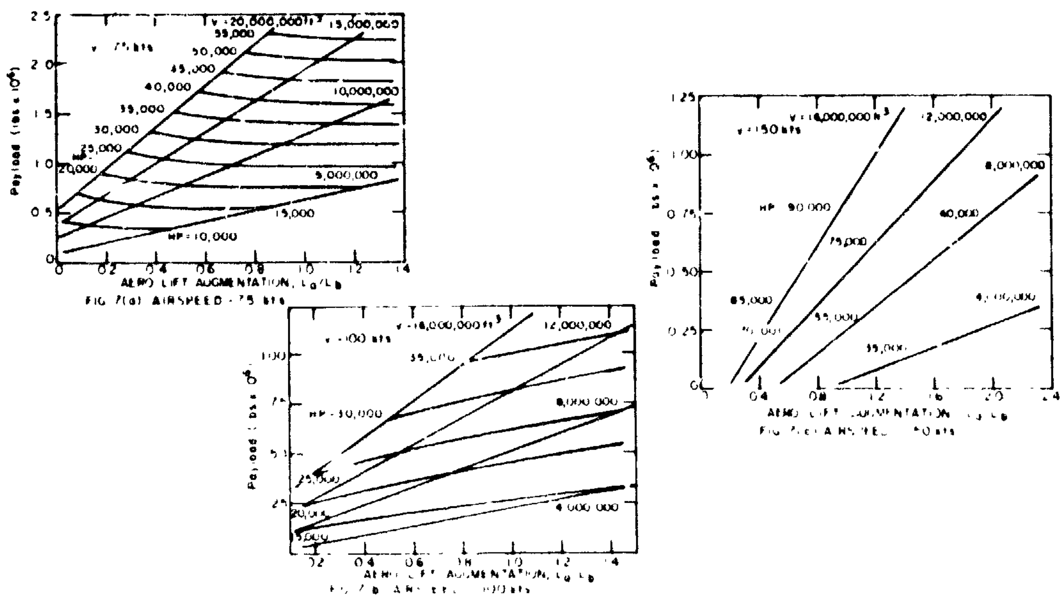



FIG. 6 VARIATION OF AERO-LIFT-AUGMENTATION RATIO AND MISSION TIME ON PAYLOAD CAPACITY FOR HYBRID AIRSHIPS

The payloads obtainable for the assumed conditions are seen to be sizeable and are sensitive to both $L_a/L_b$ and mission time. It was decided to choose a $t_m$ = 20 hrs despite proposed mission times approaching 50 hrs for the pure hybrids (the larger mission times being selected undoubtedly to gain economic cargo-carrying feasibility).

Figure 7 (a through c) presents the trends in payload, size and power for varying $L_a/L_b$ and for each of three assumed airspeeds, i.e., 75, 100 and 150 kts. Referring once again to a "basic" hull volume of 10,000,000 $ft^3$ at 75 kts (figure 7 (a)) and an $L_a/L_b$ = 1.0 the payload capability is indicated to be 750,000 lbs; almost 10 times the payload capability of a conventional airship at 75 kts.



However, as higher speeds are demanded of the hybrid greater hull volumes and/or larger augmentation ratios are required to maintain equally impressive payloads. The drag rise incurred at the greater airspeeds is reflected in the additional power (fuel and power plant weight rising) required and consequently higher hull volumes. The trends, it will be recalled are similar for conventional airships but are of an order of magnitude less. This analysis gives no accurate indication of an optimum augmentation ratio for hybrid airships however, for payloads neighboring a half-million pounds an $L_a/L_b$ of 1.7 and a hull volume no greater than 10,000,000 $ft^3$ are indicated. Figure 8 clearly shows that to maintain payload capability at increased airspeeds the lift augmentation ratio must rise.

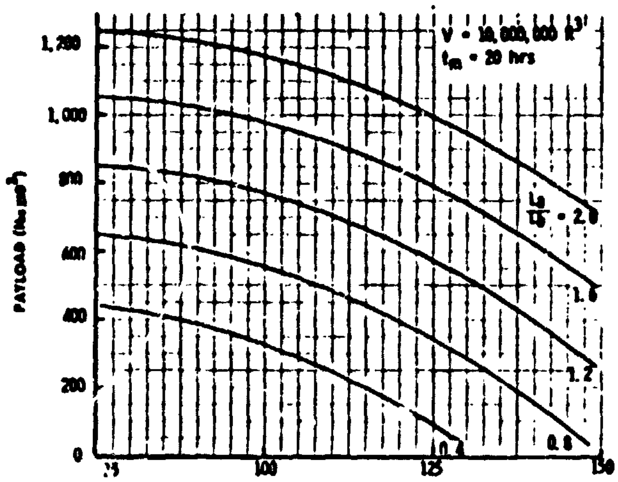



FIGURE 8 - VARIATION OF AUGMENTATION RATIO AND AIRSPEED ON PAYLOAD FOR A FIXED VOLUME HYBRID AIRSHIP

## STABILITY, CONTROL AND HANDLING CHARACTERISTICS

A quotation from reference 4 by Max M. Munk addressing the topic of airship maneuvering reminds us clearly of the fundamental necessity for stability in airships.

"Bare airship hulls are immaneuverable, and bare spindle shaped arrows have been known since time immemorial to fly unsatisfactorily. The remedy has likewise been known since before the dawn of history - the spindle is provided with fins near its rear end, flexible feathers for arrows, and more substantial ones for airship hulls."

In this section various topics in stability, control and handling qualities will be considered with regard to the impact modern technology may have on them. No quantitative data has been provided with which to support the projections postulated. Considerable attention is yet to be directed toward the "maneuvering" of a modern Naval airship as this is a topic which bears heavily on the future operational success of all Lighter Than Air vehicles.

### Basic Stability and Control

The airship, regardless of the actual shape or size to which it may someday evolve, will always be a slow-responding and fundamentally difficult vehicle to maneuver without stability augmentation/anticipatory devices. The bare hull characteristics of the classical (conventional) airship are unstable but easily "remedied" with suitably designed fins. Reference 4 and others relate the absence of good theoretical techniques with which to design the fins for minimum drag and acceptable levels of static stability. We can assume that if little theory was available for designing the fins even less was available for designing optimum control power into the control surfaces. Nothing was knwon back in the 1920's and 30's concerning the design of dynamic systems using pilot/vehicle closed-loop systems analysis; giving rise to much empiricism in design (some of which continues today). The introduction of higher lifting bodies for the hulls of future airships will undoubtedly be accompanied by additional problems in static stability. The delta airship (concept c in figure 1) is usually severely unstable in pitch and requires careful mass distribution in order to achieve acceptable static margins. The hybrid airship should be more design manageable with regard to providing good static stability since there is some freedom in locating the center of pressure of the wing relative to the hull's center of buoyancy and the overall vehicle's center of gravity.

Direct Thrust Maneuvering

It appears almost certain that future airships will not employ ballasting as a means for providing attitude trim. It is desirable to eliminate the use of ballast entirely but this may not be possible due to its role, along with gas valving, in providing altitude trim as well. To insure more positive, faster responding control for both trimming and maneuvering direct, vectorable thrust control will undoubtedly emerge as a practicable control design. Direct, vectorable thrust control can provide active control throughout the entire flight envelope of the airship but will be especially useful in ground proximity operations such as takeoff, landing and off-loading/on-loading cargo. The most efficient manner by which to effect such control would be to incorporate it with the main propulsion system, vice an auxiliary system. Much has been learned throughout the past 20 years of VSTOL aircraft development which can be directly transferred to airship control technology. Deflected slipstream, tilt-propellor, vectored jet-thrust and many more concepts common to the great variety of VSTOL aircraft can be considered in searching for available airship control system. The necessity and operational attractiveness of automatic flight control systems in airships will do much to force the use of vectorable controls because of their response compatibility (transferring ballast is a slow-to-respond process and not a reliably repeatable one).

Computer State Sensing and Automatic Management of Controls

Dr. H. Eckner, in his written piloting instructions for the flight personnel of the airship "Delag" (reference 5) often cites the awesome consequences of "inattentiveness" on the part of the airship captain and the flight crew. The successful operation of airships required the highly skillful sensing of crucial airship/environment states and management of controls. All records, it is certain, are not clear concerning the loss of airships due to pilot/crew error but it can be reasonably assumed that a large percentage of airship accidents were primarily due to such causes.

At the nucleus of an airship automatic flight control system will be a modest, real-time, airborne digital computer (within the current state of technology). The computer will serve to receive all data related to (1) trim state, (2) fuel and gas states, (3) translational and angular motion states, (4) environmental states, (5) structural load states, and (6) pilot control commands. All of these and more (such as navigational, meterological, etc. data) will be sensed at frequencies up to and possibly greater than 20 times each second. The information will be processed and signals continuously outputted to drive (1) stability augmentation systems, (2) flight-director displays, (3) crew-station monitors, (4) altitude and attitude hold modes, (5) load alleviation systems, (6) gust alleviation systems and (7) specific flight path maneuvering (for approaches to landing, docking, etc.). All of the above automatic functions are available for use in the modern airship. Some, and probably most, will become an absolute necessity. Figure 9 provides a functional diagram of a conceptual automatic flight control system for a modern airship.

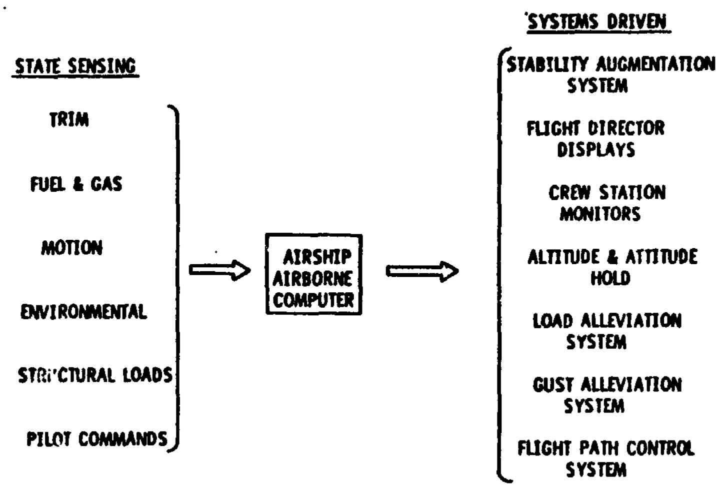



FIGURE 9. FUNCTIONAL DIAGRAM: AIRSHIP STATE SENSING AND CONTROLS MANAGEMENT SYSTEM

Simulation and Handling Qualities Requirements

Another beneficial advantage which the designers of modern airships will enjoy in comparison with their 1930 predecessors will be the use of piloted simulation. Flight simulation has advanced over the past decade to the point where its use has become an indispensable aid in the development of all of today's aircraft. The statics and dynamics of airships are no less complicated than is the static and dynamic behavior of a modern airplane. It is interesting to note that the flight simulation of airships will, in all probability, require far less sophistication with regard to visual outside-world displays and motion displacement. Modest display systems and motion bases of only limited angular and translational displacement and speed of response will be required.

It is expected that serious simulation efforts will soon get underway to begin providing designers with the guidance, now totally lacking, concerning stability, control and handling qualities requirements for a range of airship classes. The cost and time required for the successful development of an airship more than warrants serious attention to the systematic development of flight dynamics design requirements.

CONCLUSIONS

This paper clearly represents only the bare beginning of a vast amount of research and eventually development which must be undertaken by government and industry alike in order to build up an airship technology base which has been neglected now for over thirty-five years.

Airships representing a drastic departure from the classical form have been examined (albeit briefly) and found to promise attractive performance characteristics for equally non-classical missions. The effect of a radical change in shape (typified by the aerodynamic lift-augmented hybrids) has been found to add to the design problems normally associated with the conventional airships all of the problems (and more) associated with the design of heavier than air aircraft as well. Aero-lift augmentation ratios in the vicinity of 1.7 for a ten million cubic foot hull volume were found to yield a hybrid airship capable of carrying half-million pound payloads at speeds of over 150 kts. Concepts such as these and many others which were not discussed in this paper offer potential advantages to both the military and commercial communities and as such should be regarded as serious candidates for future Lighter Than Air vehicles.

By far, the least risk, shortest development time and highest payoff airship for Naval applications appears to be a highly modified form of the classical design. This position, though admittedly premature, is founded principally on the basis of the necessity for very lengthy mission durations, an acceptance of modest improvements in speed ($v \leq 120$ kts), respectable improvements in payload ($\geq 100{,}000$ lbs) and reliance on an established operational experience base with this class of airships. It has been shown that modern technological improvements can readily yield such airships without the necessity of assaulting entirely new technological problems.

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REFERENCES

1. Anon., Parametric Study of Dynamic Life Aerostats for Future Naval Missions, Goodyear Aerospace Corp., Akron, Ohio, 1968.

2. Fink, D. E., Hybrid Heavy-Lift Vehicle Under Study, Aviation Week and Space Technology, pages 49 to 51, 29 July 1974.

3. Burgess, C. P., Airship Design, The Ronald Press Company, New York, 1927.

4. Durand, W. F., et al, Aerodynamic Theory, Vol. VI, Division Q and R, Aerodynamics and Performance of Airships, Durand Reprinting Committee, 1943.

5. Eckner, H., Dr., Brief Instructions and Practical Hints For Piloting Zeppelin Airships For the Flight Personnel Of The "Delag", a revised extract appearing in D. H. Robinson's LZ. 129 Hindenburg, Arco, Publishing Co., Inc., New York, 1964.