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Maritime Patrol Airship Study (MPAS)

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This paper highlights the results of a 2-year joint study by the U.S. Navy and the U.S. Coast Guard. The purpose of this study was to address the feasibility of using modern Lighter-Than-Air vehicles in maritime patrol operations. The Maritime Patrol Airship Study was conceived as a first-order systems application study. The principal ingredients were: 1) mission requirements and rationale; 2) mission analysis and effectiveness; 3) vehicle sizing and parametrics; 4) estimated life-cycle costs (LCC) and logistics; and 5) vehicle case studies.

Background

LIGHTER-THAN-AIR (LTA) vehicles exist as proof of the fundamental principle of buoyancy. Airships are categorized by three different approaches to the hull structure—rigid, semirigid, and nonrigid. This study concentrates on nonrigid airship designs, since their performance abilities match the Coast Guard mission requirements.

The potential of airships for coastal patrol operations is based on demonstrated capabilities.[1] The following features typified airship operations by the U.S. Navy throughout World War II (Ref. 2) and the following Cold War years[3]: long endurance; stable, low-vibration sensor platform; low installed power requirements; high degree of survivability; high fuel efficiency; high availability; and all-weather ability.

With the recent advent of the Coast Guard's 200-mile coastal patrol zone, these same features appear highly desirable. Recent technology studies indicate that state-of-the-art materials, structures, propulsion, and flight controls make modern airships viable for long endurance missions.[4]

A major obstacle to the renewed development of a modern airship is the perception of many that airships are large and unwieldy, vulnerable to both damage and the environment. Much of this is based upon misconception. Experience indicates that:

1) Airships do not burst like balloons when punctured. Holes, many square feet in size, are necessary to bring down an airship. Vital components ae widely spaced.

2) Under normal operating conditions airships do not need hangars at each airship base. Initial erection and major overhaul require hangar facilities, but at the operational bases, airships are maintained outdoors at fixed or mobile mooring masts.

3) Modern ground-handling equipment minimize the size of the ground crew. With a hover-capable airship, the ground-handling operations should be performed by a crew of less than ten.

4) A modern airship should be no more vulnerable to adverse weather than modern aircraft. Historical operations have shown that airships can maintain station in extremely severe weather.

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Assumptions

Based on the past performance of airships and the infusion of modern technology for propulsion, structures, materials, and flight controls,[5] the attributes of airships assumed for MPAS are: hover capable; 90-knot max speed; vertical takeoff and landing; able to tow (sensors and vessels); all-weather operation; and low power requirements.

The lifting gas presumed for all vehicles is 95% pure helium. In the interest of expendiency, the avionics and sensor suites for the conceptual designs were not optimized for airship use, but were assumed to be the same as those designed for the Coast Guard's HU-25 jet aircraft intended for medium-range search operations.

Scope

The emphasis of this study has been on the determination of the suitability of LTA platforms in the performance of current Coast Guard operations. Consideration has been given only to operations as they are currently being performed in a manner consistent with the utilization of the Coast Guard's available air and sea assets. No consideration was given to missions that required handoff of operations from one airship to another or to another platform type, nor was consideration made of operations requiring refueling or remanning of the airship, both of which are feasible and consistent with past airship operations. If a mission was expected to exceed the capabilities of a single airship, it was not evaluated as part of this analysis.

Approach

Because of the broad scope of this study, a general approach was required. Potential missions were identified under the existing Coast Guard program structure. These missions were subdivided into a small set of tasks. These tasks or modes are then mixed to represent realistic missions. This approach provides a broad but systematic method for evaluating airships for Coast Guard missions. The emphasis is not on detailed task analysis but rather on the multimission effectiveness. The single most important aspect of the approach is the determination of the total airship force level requirement and the missions that they can perform.

Analysis

To approach this effort, a review of existing Coast Guard operations was undertaken. The Coast Guard's operations are organized into 13 programs.[6] Of these, with the assistance of Coast Guard operational personnel, the following were

Table 1 Maritime patrol airship study missions summary

Tasks	Enforce laws and treaties; search and board	Marine environmental protection; cleanup	Military operation/ military preparedness; tow ASW arrays; attack	Port safety and security; hazardous vessel escort	Search and rescue; search, board, and tow	Aids to navigation; buoy maintenance	Marine science activities; ice patrol (St. Johns)	Ice mapping (Great Lakes)
Duration, h	27.5	12.5	26.5	8.35	13.6	17.0	35.5	20.5
Total payload, lb	7,669	22,372	10,929	6,237	7,910	7,396	7,761	7,482
Cruise speed, knots	50	50	40	40	60	50	60	60
Dash speed, knots	90	–	90	–	90	–	–	–
Crew (200 lb each)	11	6	11	6	8	8	–	–
Maximum altitude, ft	5,000	5,000	5,000	5,000	5,000	1,000	5,000	5,000
Tow	–	–	Sonar	–	Ship	–	–	–

identified for possible airship participation:

1) short-range aids to navigation (A/N)
2) enforcement of laws and treaties (ELT)
3) marine environmental protection (MEP)
4) military operation/preparedness (MO/MP)
5) marine science activities (MSA)
6) port safety and security (PSS)
7) search and rescue (SAR)
8) ice operations (IO)

Mission Analysis

For each of the eight programs, realistic missions were identified. These were keyed to actual Coast Guard operations, currently performed by more than one asset (air and sea, for instance). For the eight programs, a total of 264 mixed-task missions were identified. In order that conceptual vehicles could be formulated, it was necessary to provide detailed profiles for each program. These representations, or script scenarios, represented median difficulty and complexity. Each scenario specified the operations in sequence, the parameters associated with the operations (speed, weight, payload, etc.) and the duration of the operation. A summary of these scenarios is given in Table 1. The maximum required capability for each of the parameters is underlined.

Vehicle Sizing and Parametrics

Based on the mission requirements specified by the script scenarios, a computer sizing and performance program, Naval Airship Program for Sizing and Performance (NAPSAP),[7] was utilized to arrive at conceptual vehicles. The program is a tool developed by the LTA Project Office at the Naval Air Development Center (NAVAIRDEVCEN) for use in analyzing model LTA vehicles performing various missions.

The program has been designed to operate on a minimum of input data (only five cards are necessary), but has the capability to evaluate the influence of over 40 key parameters. NAPSAP provides easy parametric analysis for several optional levels of detail. Once the design section of NAPSAP converges on a vehicle that meets the input requirements, this vehicle can then be evaluated against a specified mission profile with all key parameters monitored by mission time increments.

The data input for NAPSAP was determined primarily by the eight predetermined mission profiles. Variables such as design speed, design altitude, payload, endurance, and crew size are examples. Other design variables used for MPAS are based on other recent Navy parametric analyses of modern LTA vehicles. Variables in this category include hull fineness ratio (length over diameter), number and type of engines, and propeller characteristics.

NAPSAP was exercised to arrive at eight conceptual vehicles (one for each of the different profiles). These vehicles are described in Table 2. Note that factors such as payload, design speed, and endurance requirements result in a wide variety of vehicle sizes.

To continue MPAS the eight conceptual vehicles were reduced to one vehicle capable of performing all profiles. It was determined that in the interest of minimizing vehicle size (cost), the vehicle sized for the MEP profile was able to perform all profiles with one exception.‡ This conceptual vehicle was designated ZP-X and was used to complete MPAS in terms of cost-effectiveness considerations. ZP-X characteristics are shown in Table 3.

Additional analyses were conducted on the ZP-X to explore the effects of parameter variation. Parameters addressed were design dash speed, design altitude, structural weight, and total drag coefficient. An example of the resulting sensitivity data is presented for design dash speed variation in Table 4.

Estimated Life-Cycle Cost (LCC) and Logistics

The cost estimates contained in this study are based upon projections of historical data, and on the comparison of the cost of construction and the operation of modern heavier-than-air craft. All the data used are based on the extrapolation of cost data generated in other recent studies.[8-11] Based on a preliminary estimate of the total Coast Guard mission requirements, a potential annual utilization of airships was projected to be 100,000-125,000 h/yr. It reasonably assumed that each airship flies 2400 h/yr, resulting in a requirement of 42 to 52 airships. A geographic distribution of airships similar to the MRS basing was assumed, resulting in nine airship bases. If each base has 5 airships, a total of 45 airships for operations could be required. An additional 5 airships could be purchased for training, research and development, and backup, making a total buy of 50 airships.

This study, being a first-order study, has not evaluated the real estate requirements of the airship operations and the analysis of the availability of the real estate at the MRS bases. Hangar facilities would not be provided at each base. Hangars will exist at depot maintenance facilities. Routine maintenance can be provided at the mast.

Based upon the current Coast Guard requirement that restricts aircrews to 800 h flying time per year, it will be

‡In the interest of choosing the smallest vehicle to minimize cost, it was determined that the MEP vehicle could perform the MSA mission at a permissible reduced altitude of 1000 ft.

Table 2 Vehicles sized for eight U.S. Coast Guard representative profiles

Mission	ELT	MEP	MO/MP	PSS	SAR	A/N	MSA	IO
Volume, ft^3	586,494	783,696	700,045	282,390	392,154	447,330	992,165	607,678
Static lift, lb	32,092	46,917	38,305	15,452	21,458	24,477	54,289	33,251
Dynamic lift, lb	5,224	7,638	6,236	2,515	3,493	3,985	8,838	5,413
Length, ft	277	305	294	217	242	253	330	280
Diameter, ft	63	69.3	67	49	55	57.5	75	64
Fineness ratio, l/d	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Buoyancy ratio	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Horsepower required	1,471	1,927	1,651	942	1,142	1,236	2,076	1,506
Gross weight, lb	37,316	54,554	44,541	17,967	24,951	28,462	63,127	38,664
Empty weight, lb	20,850	27,674	24,527	10,816	14,478	16,289	33,717	21,540
Useful load, lb	16,466	26,880	20,014	7,151	10,473	12,173	29,410	17,124
Empty weight fraction	0.559	0.507	0.551	0.602	0.580	0.572	0.534	0.557
Fuel weight, lb	8,812	5,057	6,650	915	2,568	4,752	21,638	9,706

Table 3 Maritime patrol airship study

NAVAIRDEVCEN ZP-X design
Volume: 783,696 ft^3
Gross weight: 54,554 lb
Empty weight: 27,674 lb
Horsepower required: 1927 (3 gas turbine engines)
Length: 305 ft
Diameter: 69 ft
Static lift: 46,917 lb
Dynamic lift: 7638 lb
Fineness ratio: 4.4
Useful load: 26,880 lb
Buoyancy ratio: 0.86

Table 4 Sensitivity of ZP-X vehicle to changes in design dash speed

Change in design dash speed, %[a]	Hull vol.	Total mission time	Empty weight[b]	Useful load	Horsepower required
	Effects on key parameters, %				
−20	−12.9	+22.8	−6.7	−6.3	−48.0
−10	−7.5	+11.7	−3.7	−3.5	−23.4
0	0	0	0	0	0
+10	+7.8	−12.9	+4.3	+4.4	+19.6
+20	+20.5	−30.5	+9.9	+10.9	+44.9

[a] Baseline value for design speed is 90 knots. [b] Baseline value for gross weight is 54,554 lb.

Table 5 MPAS conceptual vehicles comparison

	GAC ZP3G	BAT MPA	NADC ZP-X
Envelope vol., ft^3	875,000	858,437	783,696
Length, ft	324	326	305
Diameter, ft	73.4	72.4	69.3
Static lift @ 2000 ft, lb	52,164	44,658	44,243
Dynamic lift, lb	8,500	17,917	7,638
Horsepower required	2,400	4,306	1,927
Gross weight, lb	60,664	65,274	54,554
Empty weight, lb	33,740	33,019	27,674
Useful load, lb	22,504	32,256	26,880
Buoyancy ratio	0.86	0.73	0.86
Maximum altitude, ft	10,000	10,000	10,000
Maximum speed, knots	97	104	90

assumed that three crews are required per airship, and that an airship will be utilized for 2400 flight hours/year.§ This is equivalent to a 27% mission utilization. The airship is assumed to have a 12-yr lifetime. Crew size varies from 5 to 13 depending upon mission duration.

The determination of initial LCC procurement or acquisition cost was based on the following four approaches:

1) Costing based on speed and volume of the airship, using regression analysis of historical airships. An 80% learning curve was used.

2) Costing based on analysis of a modern nonrigid Navy design (ZPG-X) cost as calculated on a weight basis. An 80% learning curve was used.

3) Costing based upon systems weights. The learning curve was a function of system.

4) Cost estimates of Goodyear Aerospace Corporation for a Maritime Patrol Airship. An 85% learning curve was assumed.

These approaches to the unit acquisition cost have produced four different estimates which range from $3.9 to $8.45 million (in 1979 dollars). It has been assumed that the unit cost of 50 airships is $5.0 million/airship. In addition, the cost of facilities for both bases and maintenance facilities including GSE is about $900,000, prorated for each airship. The initial training cost is projected to be $500,000. Therefore, the total investment cost is approximately $6.4 million/airship.

Of all the costs calculated, the single largest cost of operating the airship is the personnel cost. Depending on crew size (which is a function of flight duration) and composition, and assuming an 800-h annual flight hour limit, the personnel cost varies from $235.38 to $567.88/flight hour.

§World War II airship operation proved that higher flight time for aircrews is achievable due to the benign environment of the vehicle. Modern technology would certainly enhance this feature. However, for MPAS, the current Coast Guard restriction was used.

The maintenance of an airship is an area in which improvements in technology will have significant impact. With the increased reliability of systems and the advent of sophisticated electronic test equipment, there can be little comparison between the historical airship maintenance requirements and the maintenance of a modern airship. The additional LCC component for direct maintenance has been assumed to be $23.20/flight hour.

Based upon these costs, the LCC prorated on a flight hour basis runs from $750 to $1150/flight hour. The difference in the rate depends on the type of mission in which the airship is employed. For long-endurance missions, costs increase because of high crew costs. High-speed operations or missions requiring lift of heavy payload consume fuel at a higher rate and are, therefore, more expensive.

An alternative approach to calculating the cost of performing a Coast Guard mission is through the use of the Standard Rate Calculation.[12] Using the standard rate

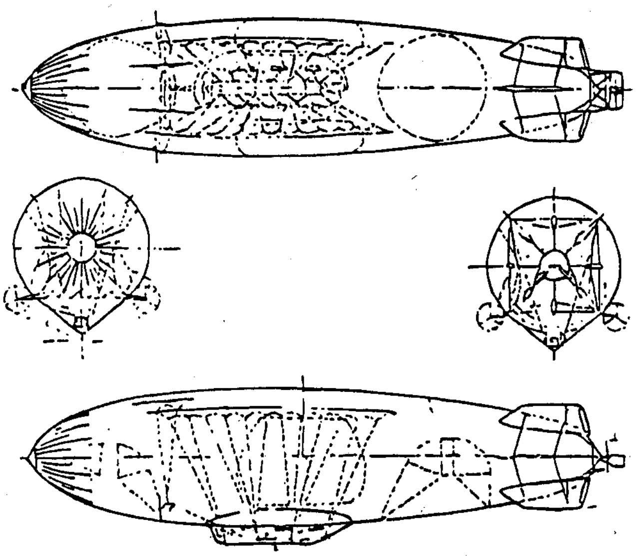

Fig. 1 Goodyear Aerospace ZP3G design.

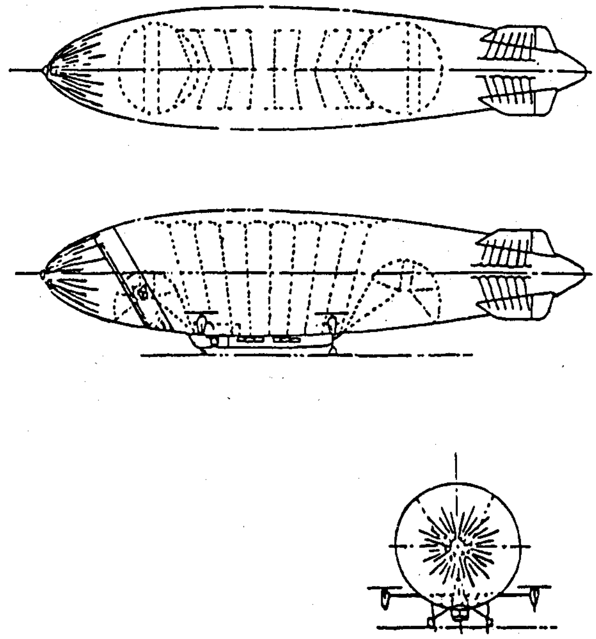

Fig. 2 Bell Aerospace MPAS design.

method, the airship's cost may vary from \$446.01 to \$654.28/flight hour. This compares to the rates of \$912.20 for an HH-3, \$614.90 for a HU-16E, \$893.91 for a HC-130H, and \$448.30 for a WMEC-210 (medium-endurance cutter).

Vehicle Case Studies

It was deemed desirable to have some means of comparing the in-house vehicle analysis with independent thinking. Goodyear Aerospace[13] and Bell Aerospace[14] were provided identical mission profile data to that used for in-house analysis from which to size vehicles. Results could then be overlaid with the NAVAIRDEVCEN ZP-X to examine similarities (or lack thereof). The resulting designs were found to be in good agreement. Table 5 provides a side-by-side comparison of the three conceptual vehicle designs. Figures 1 and 2 present the Goodyear and Bell vehicles.

The NAVAIRDEVCEN ZP-X and Goodyear ZP3G employ a three-engine configuration with aircraft propellers, while the Bell platform uses a four-engine approach with tilt rotors. All are designed to provide precision hover. Bell chose to avoid the traditional operational practice of recovering ballast (usually sea water) to trim the vehicle by utilizing large amounts of reversible thrust on the four tilt rotors.

Effectiveness Results

As previously stated, discussions with cognizant Coast Guard personnel resulted in a total of 264 mission profiles being identified for potential airship utilization. On the basis of computer analysis, the point design airship is capable of performing 211 of these profiles. Of the 53 profiles beyond the capability of this airship, 43 are associated with the Military Operations/Military Preparedness program (MO/MP). Because of the contingency nature of the MO/MP program, the specification of these profiles was not based on existing operations, but rather preliminary estimates of the airship's capability.

For these 211 profiles there is an expected requirement of 12,860 sorties. This translates into a potential for using airships 183,000 h/year. Again, assuming 2400 flight hours/year for an airship, there is a potential requirement for over 75 airships. Of this requirement, 47% of the flight hours are associated with operations of the ELT program; 30% of the flight hours are associated with SAR operations. None of the other programs account for more than 10% of the flight hour requirement. MO/MP does not have any flight hour requirements due to its special nature.

To determine the significance of endurance for the airship role in Coast Guard operation, the annual flight hours requirement, grouped by 10-h intervals of mission endurance, was calculated. The flight hour requirement remains at a fairly constant level for missions up to 50 h. The requirement varies from 27,000 h for 20-30-h missions, up to 39,000 h for 40-50-h missions. The average flight duration is 14.3 h.

Recall that in the cost analysis, a preliminary estimated buy of 50 airships was assumed. With 5 of these airships for training and research and development, there were 45 operational airships. If used at 2400 flight hours/year, the airships would be utilized 108,000 h. This availability is sufficient to satisfy all requirements up to missions between 30-40 h.

Analysis of the requirement of mission duration for each of the eight programs shows two distinct groupings. In the A/N, PSS, and SAR programs, shorter missions (less than 20 h) tend to predominate. In the ELT, MEP, MSA, and IO programs, the longer missions tend to predominate. The longer missions also tend to predominate for MO/MP operations as well. This implies that there may be a requirement for the design of two distinct airships, a smaller one about 15 h of endurance and a larger one about 40 h of endurance. The smaller airship can be designed for more economical operation, whereas the larger airship (probably of similar design as the point design airship) would have greater capability.

The potential utility of an airship for Coast Guard missions comes from its ability to perform a number of operations well. It is not so much that the airship excels at any one task, but given an aggregation of tasks typical to Coast Guard missions, it should provide superior capabilities. Because of the higher speed, aircraft will generally be better search platforms than ships. The stability and long-endurance loiter speed make airships ideal for detailed search or search for small objects. For boarding operations and long-endurance requirements, ships are better. But for the large number of operations that mix these tasks, airships offer great potential with low-energy costs.

Analysis of the task requirements for a maritime patrol airship indicates:

1) Over 90% of all the operations analyzed utilize transit or patrol at 50-60 knots.

2) Stationkeeping/trail at less than 20 knots is utilized in over 60% of the missions.

3) Only A/N and PSS operations do not require a search capability. All of the ELT, SAR, and IO missions require search of some sort.

4) Hover capability for either boarding or logistics operations is only required 33% of the time. Most of the missions requiring hover are for either the SAR or ELT. However, all of the A/N operations include tasks requiring hover.

Summary Cost Results

For missions less than 10 h, the hourly cost is approximately $750/h. For missions between 10 and 20 h, the cost is approximately $875/h, and for missions greater than 20 h, the approximate cost is $1085/h.

The cost of a mission will vary with the length of the mission. For all of the missions analyzed, the cost extremes are $1127 for a 1½-h MO/MP logistics support mission to $117,659 for a 110-h MO/MP towed-array search mission. The cost of delivering ADAPTS equipment to a MEP cleanup operation 10 miles offshore is $2823. The cost of doing an SAR operation can be as little as $1501 for an operation 25 miles from the airbase to $13,440 for an operation 500 miles offshore.

Putting the Results in Context

A brief comparative analysis was performed. Both the fuel efficiency and cost of performing selected missions were analyzed. The 13 most frequently occurring proposed airship missions were chosen for this analysis. Four of these missions were ELT missions and the remaining nine were SAR missions. The airship standard rate cost and fuel requirements for these missions were compared to those of the following Coast Guard platforms: HC-130B (long-range aircraft); HH-3F (helicopter); MEC-210 (medium-endurance cutter); HEC-378 (high-endurance cutter); and HU-25A (medium-range search aircraft).

The cutters are always more expensive to operate than the airship. The HU-25A, when capable, is less expensive to operate than the airship. In the five SAR missions that the HU-25A is capable, it could only air-drop equipment and summon a ship. In the missions the HH-3 is capable of performing, it is always more expensive than the airship.

In three of the six missions of which the HC-130 is capable, it can do so at a lower cost than the airship. For two of the missions it is more expensive, and for one mission the costs are about the same. The HC-130 currently performs all six of these missions.

Airships are very efficient users of fuel. As opposed to aircraft, which are completely dependent on dynamic lift, most of an airship's lift is provided by the buoyancy of the lifting gas. In that air is less dense than water, there is much less drag on an airship than on a ship. Data for aircraft and ships were selected from optimal economical conditions.

Based on the analysis of the comparative fuel consumption it was found that the HU-25A and the HH-3F use one and one-half to three times as much fuel as the airship. The HC-130 uses four to eight times as much fuel. In many cases, the cutters use over ten times as much fuel.

Conclusions

1) Airships appear on the basis of this first-order analysis to have direct, cost-effective application to many maritime patrol needs.

2) Airships appear technically feasible in maritime patrol roles.

3) Airships appear operationally feasible.

4) Airships deserve special notice for energy-efficient operation.

Recommendations

1) LTA vehicle flight demonstrations are recommended for technical and operational validation in performance of maritime patrol missions.

2) It is recommended that detailed analyses be conducted to determine logistic and operational factors for Coast Guard requirements (training, maintenance, basing, utilization, etc.) in light of the unique abilities of airships.

3) It is recommended that in-depth point design studies of candidate vehicles address issues such as hover techniques, ground equipment definition, vehicle fabrication methods, detailed vehicle layouts, and scaling effects for a demonstration vehicle.

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