SAN DIEGO AIRCRAFT ENGINEERING, INC.

PRELIMINARY DESIGN OF A THIRTY-SIX PASSENGER AMPHIBIAN AIRPLANE

SAE 69-109

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prepared for

ANTILLES AIR BOATS, INC.

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St. Thomas, U.S. Virgin Islands 00801

by

SAN DIEGO AIRCRAFT ENGINEERING, INC.

The report presented herein documents a preliminary design and analysis of a twin-engine, thirty-six passenger amphibian airplane. This study was performed by San Diego Aircraft Engineering, Inc. in response to an indicated interest in, and definition of such an airplane, by Antilles Air Boats, Inc.

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SUMMARY

This report documents the preliminary design and analysis of a new twin-engine, thirty-six passenger amphibian airplane. It is designed to meet the specific requirements of Antilles Air Boats, Inc., for service in the Virgin Islands.

Briefly, these requirements are: (1) to break water at 50 knots in 1000 feet, (2) a 60 knot landing speed (with enough flap for steep approach), (3) a cruise speed of 150 mph to 200 mph at 1000 ft altitude, (4) a grossly simple retractable, tricycle landing gear, (5) powered by two P&W R-2800 engines, (6) no pressurization, de-icing, heating, airconditioning, electronics, and only an emergency-use lavatory (7) a cargo door and a passenger door on each side of the fuselage, and (8) a $300,000 unit price on a total production of ten airplanes.

Specific objectives of the program, documented herein, are:

1) To prepare a combination three-view and general arrangement drawing.

2) To perform an aerodynamic analysis of the subject airplane in order to size and arrange its aerodynamic components to satisfy mission requirements.

3) To prepare a weight summary and analysis for use in the aerodynamic analysis.

4) To estimate the purchase price of the airplane.

Weight analysis of the proposed airplane yielded an estimated gross weight of approximately 35,500 pounds, and an empty weight of approximately 22,900 pounds. A weight summary is provided in the Weight Section of this report.

At the above gross weight, takeoff speed is calculated to be 56.5 knots. Cruise speed with fixed wing tip floats was calculated to be 149 knots. Retracting the floats would increase cruise speed by only six knots. Using the graphs in the Aerodynamics section, the relationship of gross weight, wing area and takeoff speed can be determined.

The proposed airplane would have either a 99 foot span tapered wing, or a 110 foot span rectangular (constant section) wing. Both wings would have an area of approximately 1200 square feet, but the simpler rectangular wing would weigh approximately 1000 pounds more than the multi-dissimilar part tapered wing.

The unpressurized fuselage will have the latest in hydrodynamic hull design. The empennage is initially envisioned as a "T-Tail", but the horizontal tail might subsequently be relocated near the vertical tail root to guarantee constant immersion in the prop-wash. This would provide for more constant elevator trim and better low speed effectiveness.

The landing gear is all dual wheel tricycle type, with a castoring, forward retracting nose gear, and outboard retracting (into the wing) main gear. The wing tip floats would likely be fixed, for simplicity and economy, at just a small cruise speed penalty.

The passenger cabin is arranged in nine rows of two-plus-two economy spaced seats with a seventeen inch center aisle. A minimal lavatory and a four-step-up Type IV emergency exit is located at the aft end of the cabin. Thirty by fifty inch exit doors are located on each side of the fuselage both at the forward end of the passenger cabin and in the cargo compartment, forward of the passenger cabin. A ladder in the cargo compartment leads to an overhead hatch for access to the fuselage and wing top surfaces. A floor hatch in the cockpit, between the pilot seats, leads to a bow compartment, which has an overhead hatch and bow post.

The powerplant and minimal system requirements mentioned above are satisfied.

All the primary structure will be conventional sheetmetal construction. Secondary structure, such as the aerodynamic control surfaces, fairings, access covers, doors and hatches could be of plastic composite construction.

It is estimated that it would be impossible to purchase the specified and proposed airplane for $300,000. Even when considering the use of remanufactured engines, and essentially no systems, the airplane will likely cost at least $750,000. Refer to Figures 3 and 4 for a graphical comparison of the cost of similar airplanes.

INTRODUCTION

Development of new amphibian airplanes has been almost nonexistent since the 1940's, and existing equipment still in service are vintage airplanes. These early airplanes were put into service long before many of the contemporary improvements in material and hull design became available.

This report documents the preliminary design and analysis of a new twin-engine, thirty-six passenger amphibian. It is designed to meet the specific requirements of Antilles Air Boats, Inc., for service between the United States and the Virgin Islands.

San Diego Aircraft Engineering, Inc. (SAE) is particularly qualified to perform such a study, based on the company's preliminary and production design and technical analysis experience with other airlines and prime aircraft manufacturers. SAE's personnel have experience in the design and program management of the Convair series of flying boats. Several of SAE's staff also have pilot experience in amphibian and float aircraft.

Specific objectives of the study program, documented herein, are:

1) To prepare a combination three-view and general arrangement drawing.
2) To perform an aerodynamic analysis of the subject airplane in order to size and arrange its aerodynamic components to satisfy mission requirements.
3) To prepare a weight summary and analysis for use in the aerodynamic and cost analyses.
4) To estimate the cost of the airplane.

Following sections of this report discuss mission, weight, aircraft description, its construction, and the estimated cost of the airplane. The appendix contains pertinent supporting data.

MISSION AND FUNCTIONAL REQUIREMENTS

The airplane described in this report is designed around the following requirements, defined by Antilles Air Boats, Inc.

Performance

1. Takeoff - 1000 feet to break water at approximately 50 knots, in calm standard temperature air.
2. Landing - 60 knots, with sufficient flap for steep approach.
3. Cruise speed - 150 to 200 mph at 1000 feet.

Functional

4. Amphibious
   a) Tricycle landing gear with grossly simple, electrically or hydraulically actuated retraction mechanism, with manual mechanical backup for extension and retraction.
   b) Landing gear design to allow for visual inspection before takeoff and landing. Gear warning devices must be simple and gear lock mechanisms must be foolproof.
   c) Nose gear to be designed for repeated impact on a one-in-six ramp at ten knots.
   d) Wing tip floats are preferable and should be retractable only if cheap and reliable.
5. Nonmetallic or "plastic" approach is preferred for every part of wing, hull and accessories.

6. Powerplant - Two Pratt & Whitney R-2800(piston)engines.

7. Main entry door on both sides, either forward or aft.

8. Cargo doors forward of cabin, but aft of cockpit, on both sides.

9. Entry door to area forward of cockpit, plus a bow hatch with bow post.

Interiors

10. Seating capacity for 30 to 40 passengers; economy class, but with no three-abreast arrangements.

11. No galleys, or other "creature comforts", except for a small lavatory for emergency use only.

Systems

12. No electronics, no deicing, no pressurization, no heating; just good direct ventilation.

Price and Quantity

13. Ten airplanes at $300,000 each.

AERODYNAMICS

The following analysis determines the relationship between takeoff speed and wing area for several gross weights varying from 30,000 pounds to 40,000 pounds. The affect of retractable floats on cruise speed is also analyzed. These analyses are based on the following performance criteria:

1. $V_{T.O.}$ = 50 kt
2. V_{ref} = 1.3 $V_{50'}$ = 60 kt
3. V_{cruise} = 150 kt to 200 kt
4. Powerplants: (2) R2800's

Power per eng.:	T.O. wet	2,400 HP
	T.O. dry	2,100 HP
	Cruise	1,050 HP

Design Considerations

1. Preliminary weight study yields 35,000 lb for a target design weight.
2. Drag buildup:

Component	S_{wet}	$f = C_D S$
Fuselage	2,200	14.0 ft^2
Tail (V & H)	1,006	4.67 ft^2
Floats (2)	87 X 2	2.84 ft^2
Nacelles ($C_{D_\square}$ =.2)	$S_\square$ =36.8	7.36 ft^2
Sub Total		28.87 ft^2
Wing	2 S	.0093 S

3. The 50 kt T.O. requirement is the most critical criteria from a design standpoint. From the relation,

$$q = \frac{V^2}{295} = \frac{(W/S)}{C_L},$$

it is obvious that the lowest possible flying speed will occur at a combination of the lowest wing loading (W/S) and the highest lift coefficient (C_L).

Gust load considerations put a practical minimum on wing loading of approximately 25 lb/ft^2. At lighter wing loads, the aircraft would be very uncomfortable and the design load factors would dictate structural penalties. The minimum T.O. speed then becomes a function of the maximum T.O. lift coefficient obtainable. For a seaplane of this type the only practical high lift device is full span, double slotted, trailing edge flaps. Leading edge devices require too high an angle of attack to develop C_{Lmax} (a seaplane is normally not rotated more than a few degrees to break water during water takeoff). Boundary layer control was not considered practical due to certification problems with " engine-out " criteria. Slipstream deflection is a powerful STOL device. However, to take advantage of it, would require four turboprops with approximately 5500 total SHP. It was estimated that slipstream deflection will increase the T.O. lift coefficient by about 15% with the two R 2800's.

Maximum lift coefficient for full span double slotted flaps in approximately 2.9. Assuming a speed 10% above stall yields a takeoff C_L of 2.4; with

15% power effects, $C_{L_{T.O.}}$(power on) = 2.76.

Figure 1 shows the variation of wing area with T.O. velocity for this lift coefficient and 30, 35 and 40 thousand pounds.

From Figure 1 it is seen that the design weight of 35,500 pounds and wing area of 1200 square feet, yields a takeoff speed of 56.5 knots.

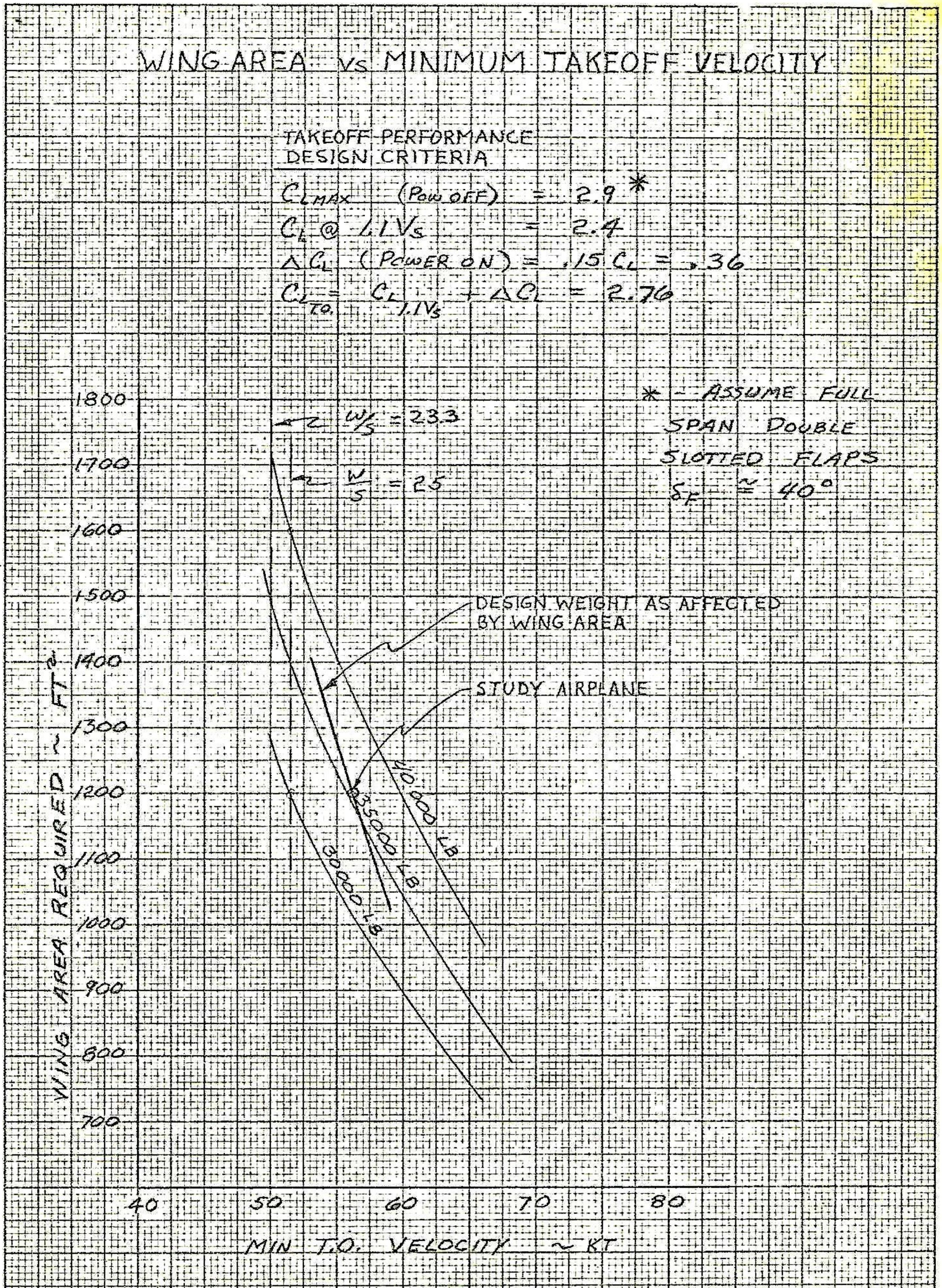
The heavy line through the design point represents the variation in takeoff speed with wing area. This plot takes into account the variation of design weight with wing area.

Cruise Performance

Using 1050 THP per engine and a propeller efficiency of .85, the cruise speeds for "floats retracted" and for "fixed floats" was computed. They are:

Floats retracted	155 knots
Fixed floats	149 knots

The six knot increase in cruise speed with retracted floats would hardly seem worth the higher cost, weight and complexity. Figure 2 illustrates the insensitivity of cruise speed to wing area.


WING AREA vs MINIMUM TAKEOFF VELOCITY
TAKEOFF PERFORMANCE DESIGN CRITERIA
$C_{L_{MAX}}$ (POW OFF) = 2.9 *
C_L @ 1.1 V_S = 2.4
ΔC_L (POWER ON) = .15 C_L = .36
$C_{L_{T.O.}} = C_{L_{1.1V_S}} + \Delta C_L$ = 2.76
* - ASSUME FULL SPAN DOUBLE SLOTTED FLAPS
$\delta_F \approx 40°$
W/S = 23.3
W/S = 25
DESIGN WEIGHT AS AFFECTED BY WING AREA
STUDY AIRPLANE
40,000 LB
35000 LB
30000 LB
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
WING AREA REQUIRED ~ FT²
40
50
60
70
80
MIN T.O. VELOCITY ~ KT
FIGURE 1

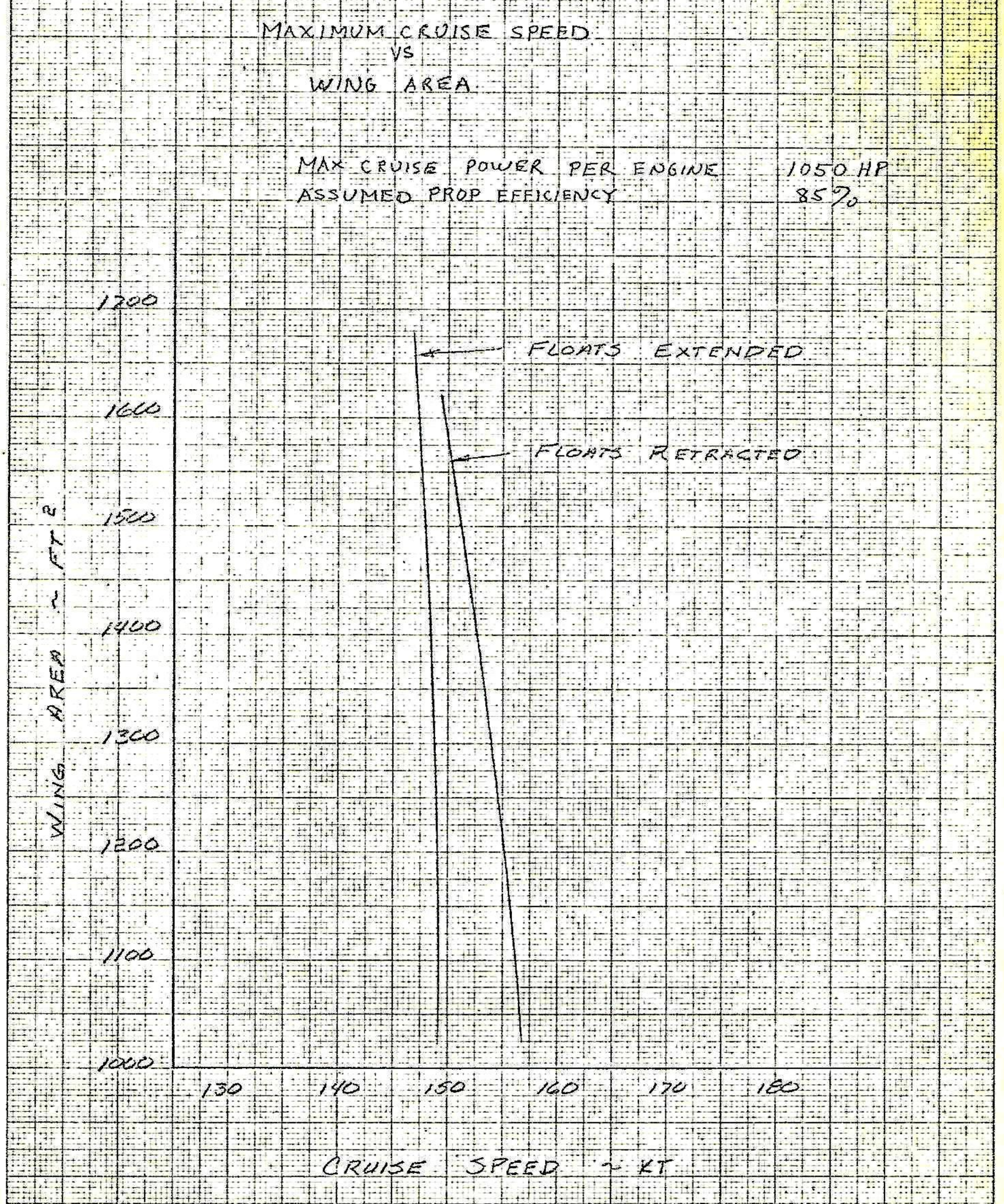

MAXIMUM CRUISE SPEED
VS
WING AREA
MAX CRUISE POWER PER ENGINE 1050 HP
ASSUMED PROP EFFICIENCY 85%
FLOATS EXTENDED
FLOATS RETRACTED
WING AREA ~ FT²
1700
1600
1500
1400
1300
1200
1100
1000
130
140
150
160
170
180
CRUISE SPEED ~ KT

FIGURE 2

WEIGHT

The attached weight summary for a twin engine, 36 passenger STOL amphibious type commercial airplane, is based mainly on statistical data for a number of present-day sea planes. This includes weight data on both the present Canadair Model CL-215 and the Grumman Model UF-2. Both of these amphibians are in the same gross weight size range as SAE's proposed configuration.

It should be pointed out that the weight-estimated configuration does not include a galley, nose wheel steering or anti-skid devices, etc.

The weights are based on current technology and have not been reduced for some of the present day composite materials, i.e. carbon and boron reinforced composite.

Based on SAE's experience, use of composites could possibly save from 15% to 20% of basic structural weight. However, the $300,000 price maximum just about prohibits use of these more sophisticated materials.

A weight summary is tabulated on the following page.

Weight Summary

			lbs
Structure			10,970
Wing	4660		
Tail	850		
Hull	3610		
Landing Gear	1550		
Floats	300		
Power Plant (Incl. Nacelles)			8,327
Equipment			1,847
Furnishings			1,722
Weight Empty			22,866
Operating Items			1,270
Crew (3)		470	
Unusable Fuel		27	
Usable and Unusable Engine Oil		513	
Crew Baggage & Data Cases		90	
Cabin Supplies		170	
Operating Weight Empty			24,136
Passengers and Baggage(36 X 195)			7,020
Zero Fuel Weight			31,156
Trip Fuel (300 Miles) (530 Gallons)			3,200
Reserve Fuel (45 Minutes) (200 Gallons)			1,200
Take off weight			35,556

AIRCRAFT DESCRIPTION

This section describes the airplane proposed by SAE to meet the Antilles requirements previously enumerated. See SAE Drawing 69-102 for three-view and general arrangement illustrations, on page iv.

Configuration

A tapered wing and a constant section rectangular wing were considered in this study. Both are conventionally constructed sheetmetal. Each wing has an area of approximately 1200 square feet, and both are illustrated on the three-view drawing. Performance for each wing is essentially the same. The 110 foot span rectangular wing is simpler, in that it has fewer dissimilar parts, four completely interchangeable flap segments, interchangeable ailerons, interchangeable access doors, fittings, ribs, skins, etc. Maximum parts similarity would reduce tooling, inventory and spares costs. The disadvantage of the rectangular wing is its heavier weight, estimated to be an additional 1000 pounds. This must be paid for initially (i.e., 1000 lb times "X" dollars per pound of structure) and also in higher operating costs. Not only must the operator pay for hauling this 1000 pounds of extra weight, on each flight, but there would be no revenue for hauling it.

The 99 foot span tapered wing would be lighter, but has many more dissimilar parts and fewer interchangeable parts. This means high tooling costs, but if enough airplanes are built, these higher tooling costs would be more than offset by the lower operating costs. Maximum similarity and interchangeability of parts is more important when only a small quantity of airplanes are to be fabricated. Before any decision could be made on which wing to use, a simple cost analysis should be made to determine which wing offers the greatest economies. This would depend on the tooling cost and weight for each wing, the number of airplanes to be built, and the utilization rate for the airplane. Both wings would employ double-slotted Fowler Flaps.

The unpressurized fuselage (hull) incorporates the latest hydrodynamic improvements. It also is conventionally constructed of sheet metal. Except for the nose wheel, the hull bottom is unbroken.

The empennage shown in the three-view is a conventionally constructed "T-Tail". It has the advantage of "end-plating" the vertical; making the vertical more effective. Atop the vertical, the horizontal stabilizer and elevator are farther away from water spray during takeoff and landing. Conversely, the high positioned horizontal tail can constitute a disadvantage, being out of the wing-wash and thus having reduced low speed effectiveness. Another possible disadvantage could be sudden trim changes caused by being near the edge of the wing wash where the horizontal could be immersed in the wash one moment, and out of it the next moment. For these reasons, it might subsequently be necessary to relocate the horizontal near the root of the vertical. The three-view drawing illustrates both a tapered and a rectangular horizontal tail. The same cost considerations as those associated with the rectangular and tapered wing are applicable here.

The landing gear is tricycle type and consists of a dual wheel castoring nose gear which retracts forward into the hull, and 2 dual wheel main gear (7.50 X 14) which retract outboard into the wing. Dual wheels have the advantages of being lighter (in this case, 46 lbs lighter for the main gear) and more fail-safe than single-wheel gear. Although the main gear are long, they are feasible. They cannot be retracted forward as is done on the Fokker F-27, since this amphibian has its nacelles located above the wing. The F-27 has underwing nacelles. The main gear were not arranged for retraction into or onto the fuselage for several reasons. Retraction into the fuselage would be at the expense of passenger seats. Retraction onto the fuselage would add aerodynamic drag. Any fairing, added to reduce the aerodynamic drag of an outside-the-fuselage retracted gear, would introduce hydrodynamic drag and steerage complications during water-taxi. Retracting the gear into the wing keeps them out of the water and simplifies the design, fabrication and sealing of the hull.

The wing tip floats are shown in the three-view as retractable, but as pointed out in the Aerodynamics section, fixed floats reduce the cruise speed by only six knots. Considering the added design cost, higher manufacturing costs and the added maintenance of the retraction mechanism, actuators and controls, it would probably be more practical to use fixed floats. Retractable floats could add as much as $10,000 to the cost of the airplane.

Interior

The interior of the airplane is arranged in nine rows of two-plus-two economy spaced seats. The ninety-four inch wide cabin has a seventeen inch wide center aisle. A minimal lavatory compartment is located at the aft end of the passenger cabin. If this lavatory is actually for "emergency use only", an off-the-shelf portable toilet could be considered for this compartment, to save design and manufacturing time. A Type IV emergency exit is located at the aft end of the passenger cabin, but is placed four steps above the aisle to keep the door opening well above the waterline.

Immediately forward of the passenger cabin is a passenger entry-way with two interchangeable 30 x 50 inch doors located on opposite sides of the fuselage. These doors are located a minimum of fifteen inches above the waterline.

Just forward of the passenger entry-way is a 60 x 94 inch cargo compartment with two 30 x 50 inch doors located on opposite sides of the fuselage. These two doors are interchangeable with the two passenger doors. The compartment bulkheads separating the passenger compartment, the passenger entry-way, the cargo compartment, and the cockpit, all have centerline doors.

A ladder on the aft bulkhead of the cargo compartment leads to an overhead access (or escape) hatch which leads to the fuselage and wing top surface.

The cockpit has space for installation of electronics and for "crew stowage" just behind the pilot and co-pilot seats on the bulkhead which separates the cockpit from the cargo compartment. Between the pilot and co-pilot seats is a floor hatch leading down two steps and forward to the bow compartment. The compartment has an overhead hatch and snubbing post for water handling and mooring convenience.

Powerplant and Systems

The airplane, as proposed, is powered by two Pratt & Whitney R-2800 (piston) engines, installed above the wing for water clearance.

The electronics would be installed by the airline. The airplane, as illustrated, has no provision for pressurization, deicing, heating or air-conditioning. The airplane would have only a direct ventilation system. The control system would be conventional, except the engine controls (quadrant) would probably be located overhead, for most direct routing to the engines.

CONSTRUCTION

Composite plastic would be ideal for application on the proposed amphibian. It can be lighter than conventional aluminum structure; it is far less susceptible to damage by salt spray and sea water; it has greater impact resistance and is relatively easy to repair; and it requires little to no maintenance; but it is far more expensive as applied to aircraft structure. Minimum weight applications require the use of boron or graphite reinforcing, and these fibers are still selling at approximately $300 to $350 per pound, respectively. Glass fiber reinforced plastics are reasonably priced, but, considering the extremely low targeted price for the proposed amphibian, composite primary structure cannot even be considered. Development, tooling and certification costs would be very high and would require a large number of airplanes for cost-spreading (amortizing). SAE has, in the past, proposed an all plastic airplane (in a NASA study) but that was based on producing 100,000 airframes per year.

There would be practical applications for composite plastics on the proposed amphibian. These would be secondary structures such as the aerodynamic control surfaces, fairings, access covers, hatches and doors. All the primary structure would have to be conventional sheet metal.

For all its attributes, composite plastics still have problems associated with application to aircraft. SAE surveyed several agencies and aircraft operators concerning the problem of lightning strikes on composite plastic structures. A discussion of the results of this survey is in Appendix A.

Summary

SAE proposes to design an aluminum airframe while following the latest state-of-the-art techniques to assure a highly durable, minimal-maintenance, aircraft.

The following is an outline of the concepts which will be employed to meet the above goal.

1) Use those aluminum alloys which offer the best corrosion resistance.

2) Make extensive use of clad aluminum.

3) Completely clean all parts at the detail level.

4) Treat all structural elements with a solution such as Alodine 1200. This will be accomplished by complete immersion of each detail part.

5) Anodize all faying surfaces (fastener interfaces, bearing interfaces, exposed edges, etc.

6) Prime all details with zinc chromate prior to assembly.

7) Apply final primer coat at final assembly level.

8) Seal all faying surfaces at the assembly and final assembly level.

9) Thoroughly paint all airframe surfaces on the detail level using a polyester resin base coating of the highest quality.

NOTE:

1. The above steps apply to all airframe areas including wing, empennage and fuselage interior surfaces. This is necessary to protect against salt air and potentially entrapped sea water.

2. The utmost care must be taken to ensure the cleanliness of all structural elements throughout the corrosion protection treatment cycle.

3. Adequate bonding procedures must be observed to preserve the electrical continuity of the airframe when using sealants and protective coatings.

A discussion of preventative maintenance is in Appendix B.

AIRPLANE COST

The airplane proposed in this report has a conventionally constructed sheet metal airframe. Even though this airplane would be supplied with no electronics, no de-icing, no heating or air-conditioning, and no pressurization systems, it would still be priced at far more than $300,000. Purchase price of several STOL aircraft are plotted as a function of empty weight in Figure 3. The points are scattered, but it is apparent that purchase price increases as empty weight increases. A price scale for the proposed amphibian airplane is shown at its estimated empty weight of 22,866 pounds. It is obvious that a price of $300,000 is significantly below what any other manufacturer has been able to do at that weight. A more likely price for the proposed airplane would be approximately $750,000.

Referring to Figure 4, the price per pound is plotted as a function of empty weight, for the same aircraft. This plot illustrates that none of these airplanes could be sold at less than $36 per pound of empty weight. Since the proposed amphibian will probably have remanufactured engines and would be built minus the systems mentioned above, it is possible that the price might be brought down to $33 per pound. This would yield the $750,000 price estimated above. Figure 4 illustrates the unlikely $12 per pound associated with a $300,000 price. This would be one-third the demonstrated minimum for this class of aircraft.

Further, it should be pointed out that the estimated price of $750,000 is based on producing at least 50 airplanes. This would not be an unreasonable quantity to plan on, with several airlines participating. These quantities are needed to amortize design, tooling, testing and certification costs.

Data for Figures 3 and 4 are in Appendix C.

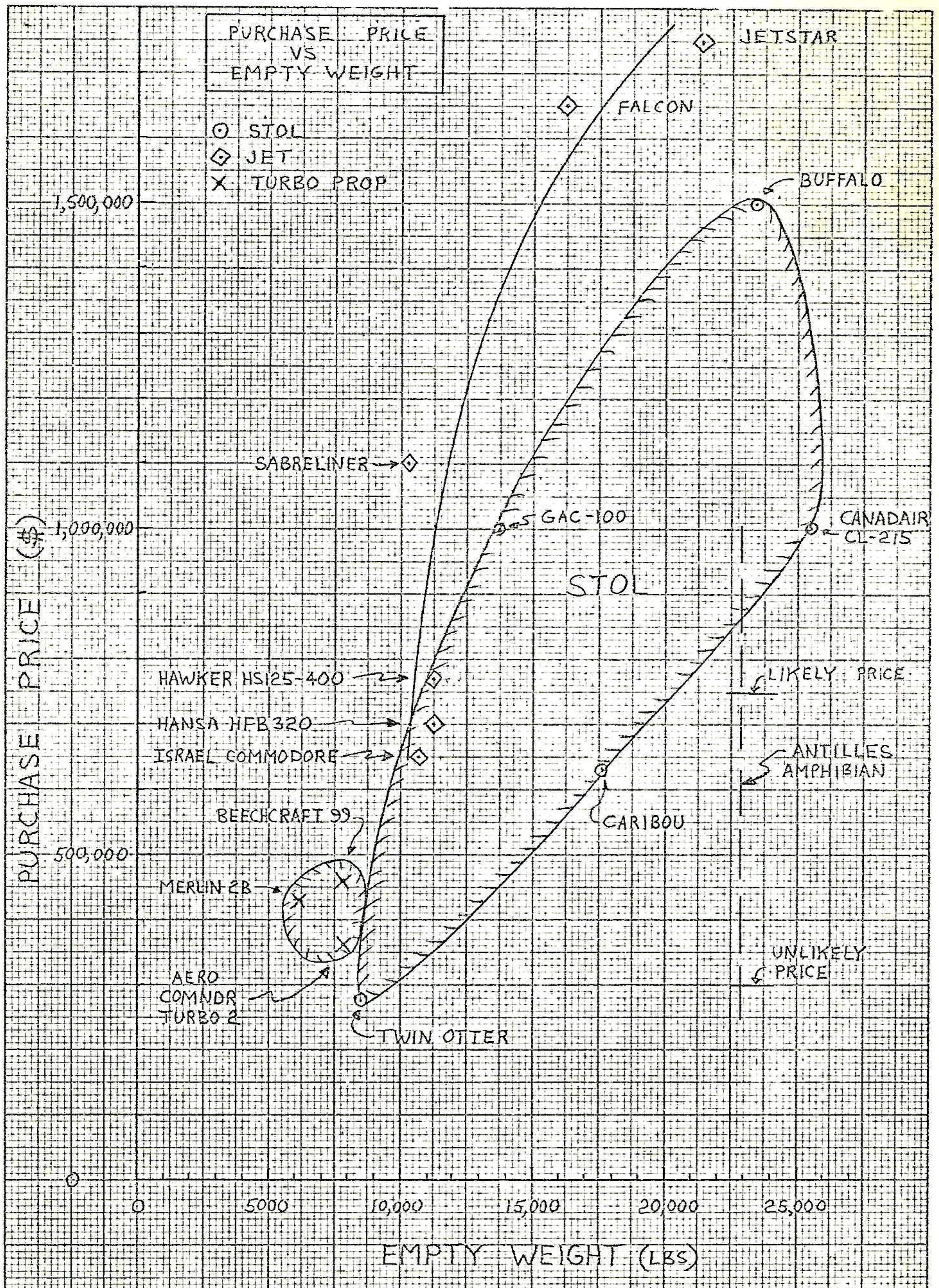

PURCHASE PRICE VS EMPTY WEIGHT
STOL
JET
TURBO PROP
JETSTAR
FALCON
BUFFALO
1,500,000
SABRELINER
GAC-100
1,000,000
CANADAIR CL-215
STOL
HAWKER HS125-400
LIKELY PRICE
HANSA HFB 320
ISRAEL COMMODORE
ANTILLES AMPHIBIAN
BEECHCRAFT 99
CARIBOU
500,000
MERLIN 2B
UNLIKELY PRICE
AERO COMNDR TURBO 2
TWIN OTTER
0
5000
10,000
15,000
20,000
25,000
PURCHASE PRICE ($)
EMPTY WEIGHT (LBS)

FIGURE 3

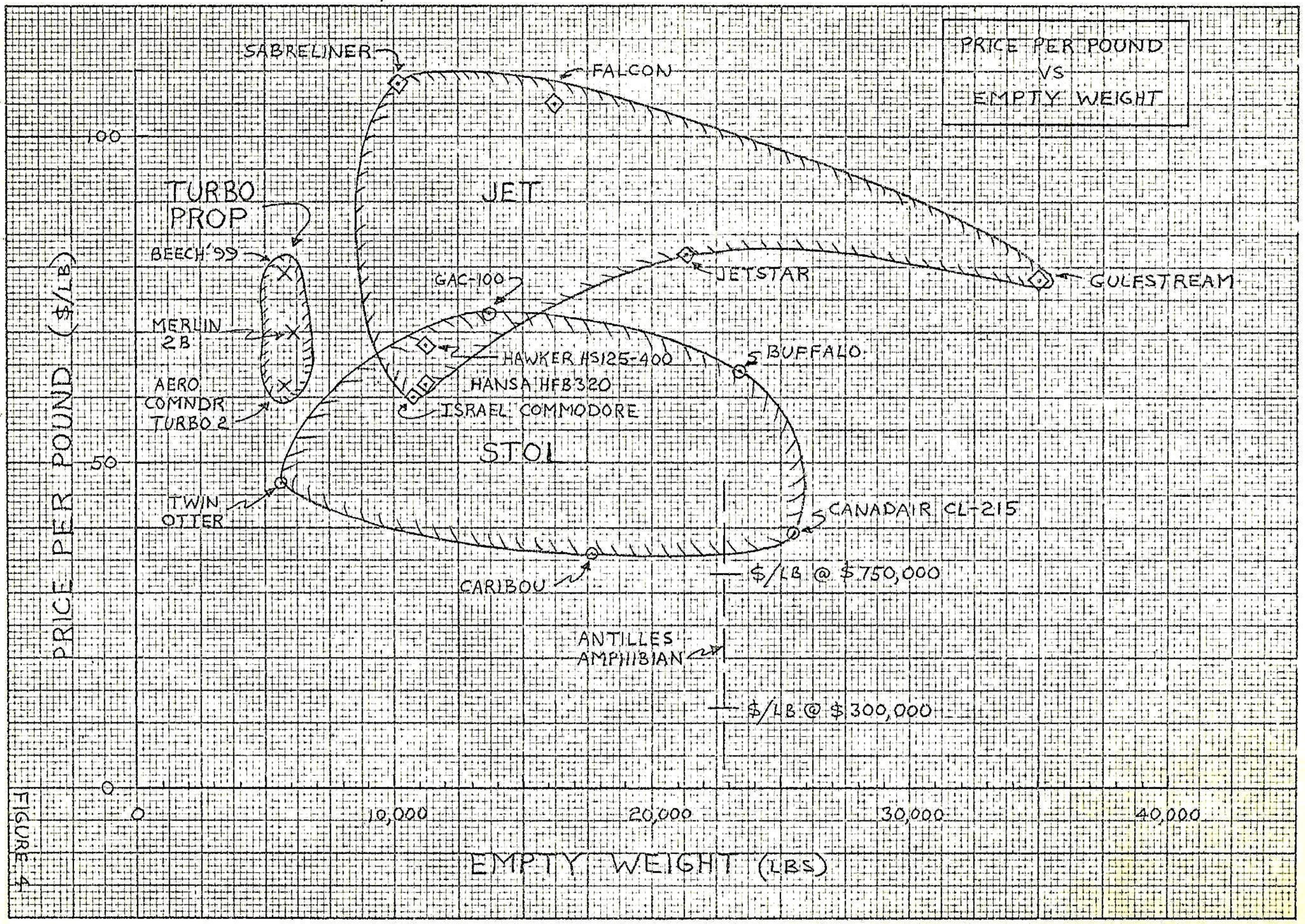

PRICE PER POUND
VS
EMPTY WEIGHT
PRICE PER POUND ($/LB)
EMPTY WEIGHT (LBS)
100
50
0
0
10,000
20,000
30,000
40,000
TURBO PROP
BEECH 99
MERLIN 2B
AERO COMNDR TURBO 2
JET
SABRELINER
FALCON
GULFSTREAM
JETSTAR
GAC-100
HAWKER HS125-400
HANSA HFB 320
ISRAEL COMMODORE
STOL
TWIN OTTER
BUFFALO
CANADAIR CL-215
CARIBOU
$/LB @ $750,000
ANTILLES AMPHIBIAN
$/LB @ $300,000

FIGURE 4

APPENDIX

APPENDIX A

LIGHTNING STRIKES ON COMPOSITE PLASTIC STRUCTURES

The question of how composite plastic structures hold up when struck by lightning is not fully known. Before embarking into known results of lightning impingement and how to design for it, the reader should be aware of the probability of the impingement taking place. Composite plastic airframes are as prone to being struck by lightning as any conventional aluminum aircraft. Studies indicate that commercial aircraft sustain an average of one lightning contact per aircraft per year.

With this statistical probability in mind, it would appear justifiable to ensure that a composite plastic airframe design incorporate some means of dissipating the large electrical current associated with a lightning bolt. Laboratory testing, together with practical experience with radomes, has proven that all composite plastic structures, regardless of the type of materials employed, cannot survive a direct hit by a lightning bolt. The severity of the damage varies with the compounding materials employed in the composite, whether or not the composite incorporates a metallic core, etc.

Experience has shown that conductive materials imbedded in a composite plastic mass can yield an explosive reaction when the mass is struck by lightning. Upon being struck by lightning, the composite body is exposed to a large (tens of thousands of amperes) instantaneous electrical current. In attempting to pass through the imbedded conductive element, the current generates heat. The heat is generated as a result of (1) the imbedded conductive material not being a perfect conductor, and (2) the conductive path is insufficient to accommodate the massive current. The amount of heat generated will necessarily vary with the type, size and shape of the imbedded conductive material. Laboratory testing and operational incidents have shown that the thermal damage varies from minor burns to complete disintegration of the composite structure. The disintegration process results from pressure and shock waves being generated by vaporizing epoxy (or other bonding agents) within the composite.

It is for this reason that many of the new composite systems using carbon, graphite or boron fibers for improved strength, literally disintegrate when struck by lightning. The use of metallic cores, such as aluminum honeycomb, results in a shaped charge effect. The nonmetallic skins overlaying the aluminum honeycomb are blown off.

Three design concepts have been employed to accommodate lightning impingement on composite plastic airframes.

The first approach has been to apply a conductive coating over the entire exterior of the airframe. To date, the conductive film idea has not met with success. One of the unsolved problems has been susceptibility of the film to erosion and cracking. Most significant has been the inability of the coatings tested to conduct sufficient current to safely dissipate the lightning charge.

The second concept calls for the attachment of foil strips (generally aluminum) to the exterior surfaces of the wings, empennage and fuselage. The foil strips have sufficient cross sectional area to transmit the lightning-originated current, but burn up in the process. This theory of operation results in a light weight lightning grid system at the expense of having to replace the foil after each usage. This design approach has worked successfully on aircraft radomes, but is prone to the erosion and cracking problems of the conductive film concept.

A third approach consists of installing permanent conductors in the wings, empennage, and fuselage. The permanent conductor system should be no smaller than five (5) number ten copper wire conductors per wing, horizontal stabilizer and vertical stabilizer. The keel of the hull must be fitted with sufficient conductors to accommodate the foregoing conductive paths. The permanent conductor approach is the most reliable of the three approaches discussed. As of this date, it is also the heaviest. If aluminum conductors are used in place of the copper conductors, the wire size must be increased to offset the poorer conductance of the aluminum.

In all three concepts, a need exists for pickup masts (lightning rods) at the major extremities of the aircraft (wings, nose, vertical stabilizer and horizontal stabilizer (s). In addition, current dissipaters must be furnished at the wing and empennage trailing edges. Without either of these conductive elements, local holes would easily be burned in the airframe.

The trend of the aircraft industry has been to employ the composite plastic structural concept on a limited basis, starting with aircraft interiors and progressing to radomes and other aerodynamic fairings. The use has now expanded to encompass flight control surfaces. This limited use has resulted in electrical bonding problems which can precipitate a catastrophy.

A typical problem involved an aircraft which employed composite flight control surfaces. The aircraft was struck by lightning. The current was discharged out through the elevator trailing edge. The elevator was a composite plastic structure tied to the hinge by metallic fittings. In the process of dissipating the charge, the elevator burned through in the area surrounding the metallic fitting.

The reader is cautioned that the lightning dissipation problem is further aggravated at a hinged interface. On numerous occasions the bearings of flight control surfaces have been frozen (welded) due to the passage of electrical current, because the electrical bonding path was insufficient to handle the instantaneously applied high current resulting from a lightning strike.

Following are listed several guides for coping with the potentially disastrous problem of lightning strikes on aircraft airframes.

1. Provide an adequate current flow path, separate from the composite plastic structure and bearing interfaces, to dissipate the current which accompanies a lightning strike.
2. Incorporate adequate electrodes at all airframe extremities for picking up and dissipating lightning strikes.
3. Do not employ metallic honeycomb design concepts unless alternate adequate conductive paths are provided.
4. Do not embed marginal metallic conductive elements in composite plastic structures.
5. Do not paint surface-mounted foils or conductive coatings.

NOTE: Items 3, 4 and 5, if violated, will have the effect of a shaped charge.

APPENDIX B

PREVENTATIVE MAINTENANCE OF ALUMINUM AIRFRAMES

A survey of Naval and Coast Guard operations centers and research and testing establishments has shown that the old rule of "an ounce of prevention is worth a pound of cure", is still the best guide to follow in the corrosion protection of aluminum airframes. Basically, the preventive maintenance consists of:

1) Daily freshwater washdowns for all structural elements,
2) Assurance that sea water is not allowed to become trapped within any portion of the airframe,
3) Scheduled airframe inspections (interior as well as exterior) to substantiate the integrity of the airframe and its protective coatings.

Where visual inspections disclose a breakdown in the aircraft protective coating system, it is common to follow the following repair process.

1) Thoroughly clean the immediate area surrounding the point of coating failure. Stripping is generally accomplished by glass bead blasting (blasting is not recommended on clad aluminum surfaces because of the risk of penetrating the clad finish).
2) Treat the blasted surface with a mild acid solution such as Alodine 1200.
3) At this point, an electrolytic type protective surface may be deposited or a primer, for a conventional wet application coating, may be applied. The most common electrolytic finishes are anodizing or alodyning. Zinc chromate is still the accepted standard primer for painted surfaces.
4) The final step is, of course, the application of the finish protective coating.

Considerable time and money has been spent in developing dependable protective coatings which are easy to handle and relatively inexpensive. Our survey has shown that polyester resins are rapidly dominating the protective coating market. One product that was recommended is Laminar X500, manufactured by the Magna Chemical Company of Los Angeles, California.

Reasons for the increasing popularity of the polyester resin coatings are:

1) Superior resistance to salt air, sea water and sea life. Prolonged immersion in sea water has shown that most sea life which may attach itself to polyester resin coated surfaces are easily rinsed off with fresh water.

2) Long life in direct sunlight. Extended exposure to direct sunlight indicates that polyester resin coating systems do not experience the sunlight deterioration that is common among standard paints.

3) Improved abrasion resistance. Testing has shown some polyester resin coatings display an abrasion resistance of 60% that of silica glass. The average for epoxy coatings is 40% that of glass.

4) Relative ease of application.

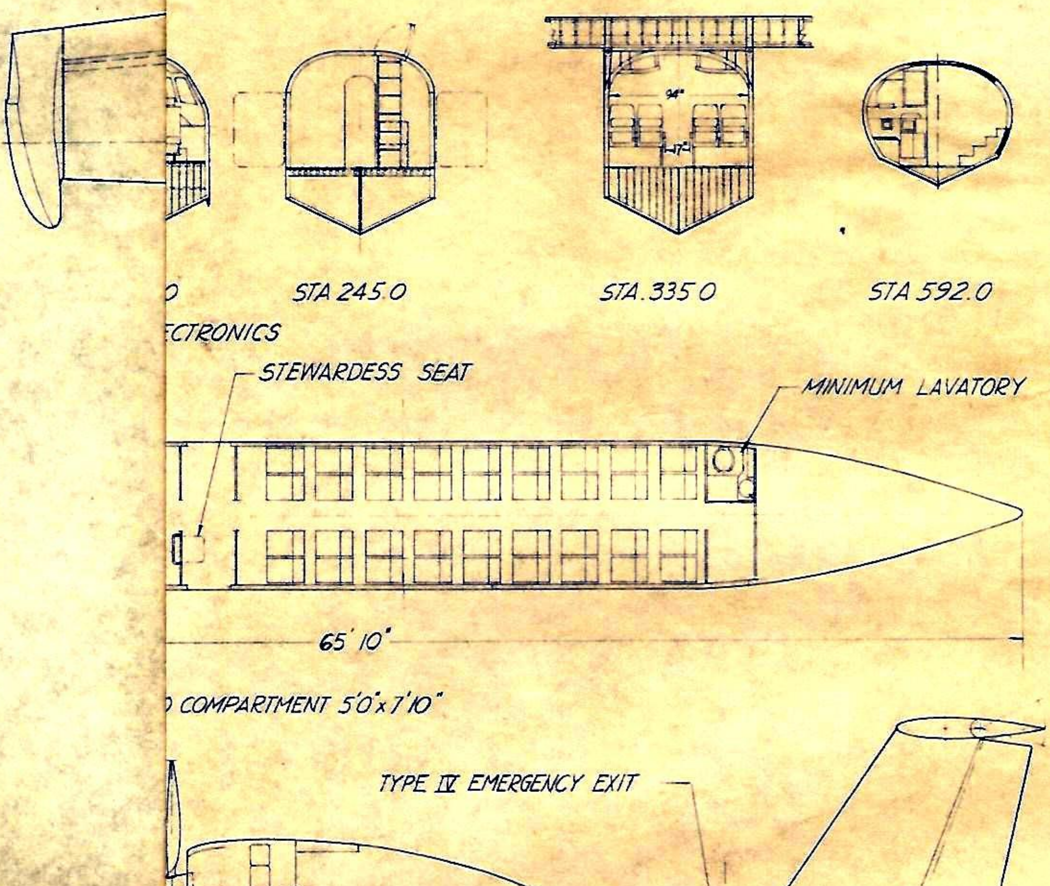
5) Good storage qualities. Polyester resin coatings are of the normal two part system. Each element exhibits good shelf life when stored individually at room temperature.

6) Relatively low cost. The volumetric cost of the polyester resin system is quite high, when compared with standard paints, but when the life of the coating is considered, the polyester resin represents a relatively inexpensive investment.

APPENDIX C

TABLE - AIRCRAFT EMPTY WEIGHTS AND PRICES

AIRPLANE	EMPTY WT.	NO. OF PASS.	PRICE		$/LB
Dassault Falcon	16,250	10	1,650,000		105
Grumman Gulfstream	35,000	19	2,745,000		78
Hawker HS125-400	11,260	10	769,000		68
Hansa HFB 320	11,225	11	700,000	Jets	62
Israel Commodore	10,700	8	650,000		60
Lockheed Jetstar	21,337	10	1,750,000		82
N.A. Sabreliner	10,150	8	1,100,000		108
Aero Commander Turbo 2	5,783	9	362,000		62
Beechcraft 99	5,780	16	460,000		79
Fairchild FH-227D	29,300	48		Turbo	
Swearingen Merlin 2B	6,150	8	430,000		70
DHC - 16 - Twin Otter	5,850	20	276,000		47
DHC - 4 - Caribou	17,630	34	636,000		36
DHC - 5 - Buffalo	23,370	50	1,500,000	STOL	64
GAC - 100	13,743	36	1,000,000		73
Canadair - CL 215	25,534		1,000,000		39



CONTR	SAN DIEGO AIRCRAFT ENGINEERING, INC. SAN DIEGO, CALIFORNIA	
DATE NOV. 7 1969		
DRAFTSMAN L. Pozmony	36 PASSENGER AMPHIBIAN PRELIMINARY DESIGN STUDY	
CHK		
SUPERVISOR		
MAINT		
APPROVAL	SIZE / CODE IDENT NO. 25727	69-102
APPROVAL	SCALE 1/40	CALC. WT. LB / SHEET —