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Tilt and Vertical Float Aircraft for Open Ocean Operations

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Introduction

PRESENT Naval Aircraft are seriously limited in antisubmarine and search and rescue missions by their inability to operate on and from the open ocean, except under relatively advantageous conditions. The high response of these shallow draft aircraft to waves results in seasickness and subsequent drop in crew effectiveness. Continuous power is usually required to retain some degree of control over the aircraft and to prevent capsizing. The impracticability of operating antisubmarine warfare (ASW) aircraft on the ocean surface has resulted in the near extinction of the seaplane and the transfer of its missions to land and carrier-based aircraft using either sonobuoys or shallow depth dipped sonar. Deep depth sonar installations are restricted to surface craft. Helicopter sonar operations are conducted during hovering flight with attendant high power requirements, high rate of fuel consumption, high cabin noise level, and limited on-station endurance. Fixed wing aircraft must expend sonobuoys in large numbers, resulting in excessive and expensive demands upon the sonobuoy supply and manufacturing system. Maintenance of a barrier line several hundred miles from shore poses many difficulties, for example, time consumed in transiting to and from station, large numbers of back-up aircraft, and severely limited time on station. Even the most sentimental of traditionalists acknowledge that further construction and operation of seaplanes cannot be justified unless substantial technological improvements are incorporated, which would enable flying boats to perform important missions beyond the capability of land or carrier-based aircraft or carry out present missions in such a superior fashion that a "cost effectiveness" analysis would provide conclusive proof of their need.

Missions Requiring All-Weather Seaplanes

True sea-based aircraft must routinely land, operate on and take off from the open ocean in all but the most severe sea states, and provide the crew with a comfortable environment during the long period of water-borne operation. This capability would enable aircraft to remain on station for several watches, if need be, to maintain surveillance over an extensive sonar system, use retrievable deep-depth sonar, and provide immediate attack or related services without loss of time because of departure from a shore station. Without leaving station, they could refuel from submarines, ships, or "tanker" open ocean seaplanes, resulting in added time where needed rather than in flights to and from shore. Conversely, these aircraft could provide logistic support to nuclear-powered ships or submarines which would enable them to remain at sea instead of returning to port, thereby disclosing their position and losing time on patrol. The seaplane could transport alternate "blue and gold" crews to the vessel and supply it with provisions and equipment now loaded from dock side or a moored tender. A meeting at sea between a submarine and seaplane would require only a short time, and the subsequent seaplane takeoff and submarine submergence would leave no trace of the meeting nor disclose the submarine's position.

Devices Alleviating Impacts, Loads, and Motions

Seaplane loads encountered during rough water takeoffs and landings can be alleviated by aerodynamic or hydrodynamic devices. Large flaps, deflected slipstream, tilt wings, and other V/STOL techniques can lower the takeoff speed and minimize impacts; or conventional seaplanes can be fitted

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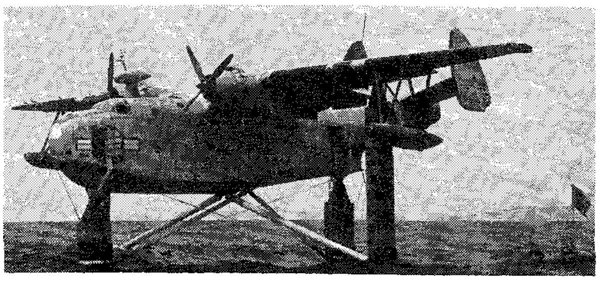

Fig. 1 The "Floating Texas Tower"—this battered PBM in company with an unaltered sistership served as floating laboratories in the early stages of the Convair vertical float program.

with hydro-skis or foils to sustain the hull above the ocean surface until the high speeds associated with impact damage and discomfort have been dissipated.

It remains then to develop aircraft that can rest virtually motionless in the open ocean, providing a suitable platform for extended water-borne missions. Should the conventional buoyant hull be restrained only through damping devices or variable thrust systems, high waves will cause unacceptable structural loads and partial or complete submergence of the hull. Consequently, it is necessary to raise the hull or fuselage above the wave system and support it by long slender vertical floats of adequate length to insure that passing waves cause only small changes in total displacement. The "tilt float" system, described previously by Ref. 1, provides the simplest method of minimizing the motions of water-borne aircraft; it therefore has been the subject of an extensive Naval Air Systems Command program, encompassing analytic, model, and full-scale studies and evaluations.

Parameters Affecting Float Design

The steadiness of the platform depends upon the vertical floats' low degree of hydrodynamic stability. A stable float accurately follows wave contours; in contrast, the vertical floats are essentially indifferent to the passage of waves. This indifference remains a virtue only if it does not become so exaggerated as to erase the restoring moments required to right the craft after it has rolled or pitched because of wave impacts, wind loads, motion through the water, or other external forces. The degree of heave alleviation is determined by the float cross-section area at the water plane, or, in the case of a cylinder, by the ratio of length to diameter. If float diameter is decreased to reduce righting moment, the length must be increased to hold the volume fixed; and the center of buoyancy is lowered, further reducing stability. Since the floats are subjected to compression and buckling loads, the higher this ratio, the greater the float weight. Once the dimensions have been chosen, righting moment depends upon the distance between the floats. The greater the spacing, the greater the weight of the supporting structure. The design engineer must compromise between motion alleviation, structural weight, and crew safety, since, in general, the metacentric height is not easily changed once a configuration has been chosen and a hull height above the water has been selected.

Should there be a requirement for the vertical float aircraft to move through the water, the cross-section shape of the float must be considered in terms of hydrodynamic resistance, added weight, complexity, and its effect upon drift and weather-cocking tendencies.

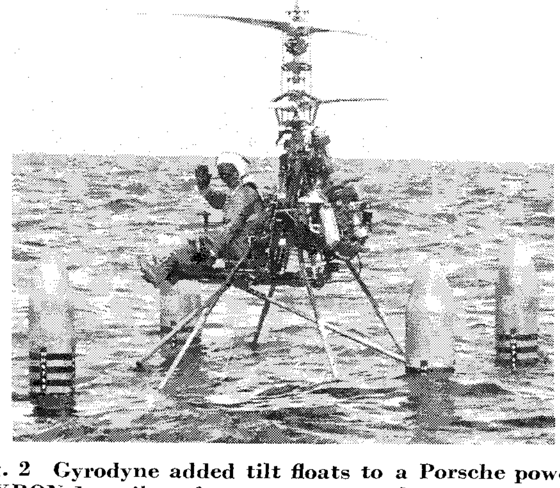

Fig. 2 Gyrodyne added tilt floats to a Porsche powered XRON-1; tail surfaces were removed to save weight.

Full-Scale Demonstrations

Evaluation of the two original test-bed aircraft established the validity of the tilt float concept. The PBM floats were rigidly mounted on a stricken unpowered airframe (Fig. 1) that was towed by tug to and from the test site during the Convair-Navy program.[2] The obsolete one-man XRON-1 (Fig. 2) served admirably as a small and inexpensive test-bed, but carried neither payload nor equipment. The rigid floats were rotated about their centers of gravity to lessen pilot effort and hold the design as simple as possible.[3]

The attainment of virtually motionless floating platforms by the use of vertical floats on aircraft was clearly demonstrated and documented. Motion pictures of the Gyrodyne tilt float DSN-1 operations show that even in choppy, state 3 seas (Table 1), the tiny helicopter reacted with slow and gentle motions. Motions of the vertical float PBM were imperceptible to its crew, whereas, simultaneously, the crew of a conventional PBM soon became seasick, with effectiveness and usefulness severely reduced. Both seaplanes were set adrift in state 4 seas (5 to 8-ft waves); maximum pitch amplitude for the conventional seaplane was 13°–14°, compared to 2° for the vertical float seaplane. Equally important, frequency was reduced from 15–20 cycles/min to 3 cycles/min. The corresponding reductions in roll and heave amplitude and frequencies were equally significant; heave amplitude was reduced by 90%. The silence and lack of vibration provided habitability conditions suitable for several days' occupancy without undue fatigue and irritation to the crew. Furthermore, the stationary aircraft is barely susceptible to detection by enemy craft because it generates no noise either from the engines or from waves striking the hull. Photographs of the DSN-1 tiltcopter in flight (Fig. 3) were proof that a tilt-float helicopter could fly; photographs of the PBM "Floating Texas Tower" seemed to prove precisely the opposite for vertical float seaplanes; and accompanying captions asserting that "the floats are retractable in flight" were read with scepticism or disbelief. The success or failure of the vertical float concept obviously depends upon their volume, weight, and manner of stowage during flight.

Table 1 Beaufort scale with corresponding sea states[a]

Sea state		Wind	
Code	Term and ht of wave in ft	Beaufort no.	Speed, knots
0	Calm, 0	0	Under 1
1	Smooth, less than 1	1	1–3
2	Slight, 1–3	2	4–6
3	Moderate, 3–5	3	7–10
4	Rough, 5–8	4	11–16
		5	17–21
		6	22–27
5	Very rough, 8–12	7	28–33
		8	34–40

[a] Hydrographic office.

Design Criteria

Preliminary criteria were established to serve as a guide for a contractor's early studies to incorporate tilt or vertical float systems into modern aircraft, and to provide some degree of conformity in the associated stress analyses. The following operating conditions used for the Boeing-Vertol study are typical of criteria used by other groups in both Navy-sponsored and company-funded studies.

1) Calm and sheltered water, floats horizontal: a) Wave heights of $1\text{–}1\frac{1}{2}$ ft and wavelength/height ratios from 15 to 30; b) helicopter sink speed, 5 fps; c) helicopter forward speed, 15 knots; d) wind velocities, 30 knots from ahead, side, and aft; and e) yawed landings in crosswinds, 15°.

2) Rough water, floats vertical: a) Wave heights of 5–8 ft (sea state 4) and wavelength/height ratios from 20 to 50; b) helicopter sink speed, 5 fps; c) helicopter forward speed, 5 knots; d) wind velocities, 30 knots from ahead, side, and aft; e) yawed landings in crosswinds, 30°; and f) wind-induced drift speed, 5 knots.

A 10–15 knot maneuvering speed on the water is desirable, but may exact such a severe float weight penalty as to force acceptance of a lesser value. Although floats of circular cross section provide entirely adequate sea-keeping characteristics, their high translational drag requires that more streamline forms be developed; this represents a minor change for rigid floats, such as used by Gyrodyne, but a major change in the internal structures of inflatable-retractable floats.

Vertical floats may be divided into two categories: those inflated, deflated, or tilted while the helicopter or VTOL aircraft is hovering prior to landing or after takeoff; and systems on STOL and conventional airplanes which operate when the aircraft is at rest, lifting it above the ocean surface after landing, and lowering it back into the water for takeoff. The latter system poses a difficult design problem because each float must have adequate column rigidity to prevent buckling at any time during the extension-retraction cycle.

Types and Arrangements

Metal floats composed of numerous co-axial cylindrical segments, resembling an elder generation's "hygienic" drinking cup, have been considered. Extension by air pressure and retraction by evacuation of the air or by rewinding a cable attached to the floats' lowest segment eliminate the need to rotate the floats to horizontal attitudes. A rigid damping plate, contoured to retract against the hull or nacelle bottom, is required at the lower end of each float. These floats could be accommodated in a conventional seaplane hull or in external fairings resembling sponsons. Outboard units could be housed in "button floats" designed to combine suitable planing characteristics with low aerodynamic drag.

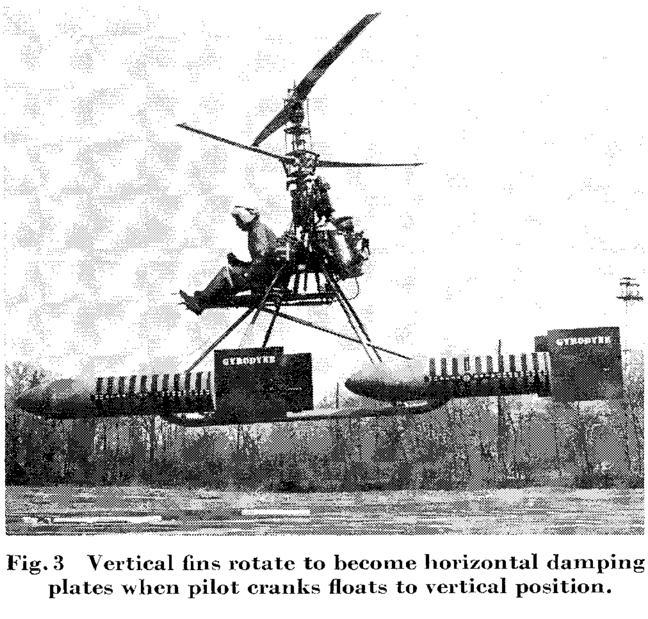

Fig. 3 Vertical fins rotate to become horizontal damping plates when pilot cranks floats to vertical position.

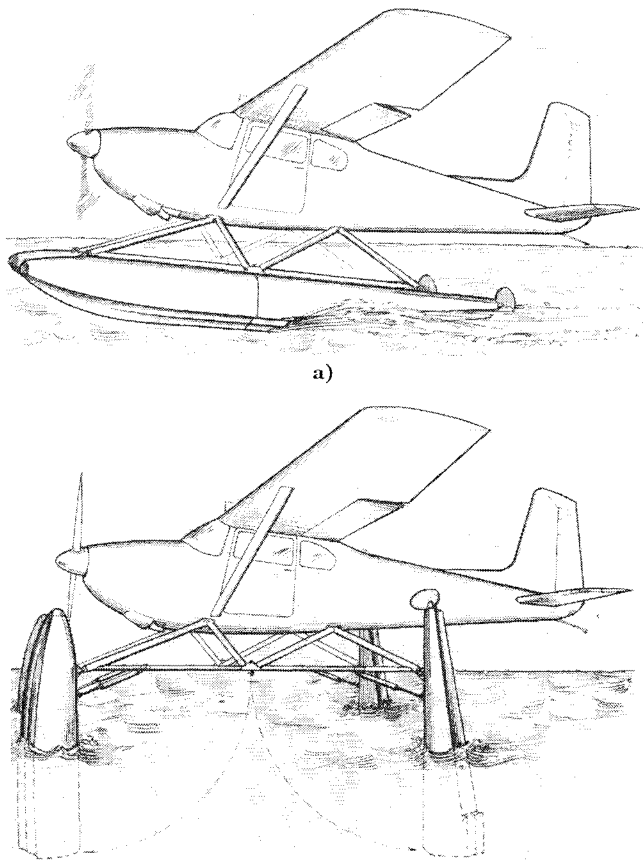

Fig. 4 A Cessna 150 could operate in moderate seas if fitted with Edo-conceived "twin-tilt" floats.

Rigid Floats

A retractable rigid tilt-float system was proposed by General Dynamics/Convair. The lower forebody and afterbody of a conventional type hull were pivoted at the hull bow and stern, respectively, to rotate downward to vertical positions. The extremely long outboard floats were also pivoted so that the seaplane could be supported by a diamond configuration of rigid floats. The hull floats would be allowed to fill with water to lower them into position, then pumped dry to raise the seaplane hull several feet above the static water line. The buoyancy of the floats facilitates rapid retraction.

The rigid tilt float concept also can be applied to aircraft equipped with twin floats, since they represent a fixed volume external to the fuselage. Edo Corporation suggests that each seaplane float separate into two components that then rotate and translate to a suitable "four-poster" arrangement (Fig. 4). Similarly, a single float airplane with small wing floats (like the old Navy catapult scout planes) could become a seasitter with a diamond array of two large and two small vertical floats.

The ultimate application of the rigid tilt float principle would result in a design with all possible equipment, fuel, and possibly crew and power plants transferred to the floats, thereby minimizing the size, weight, and drag of the fuselage. The centerline floats of a diamond array and the tandem floats of square or rectangular arrays could be aligned horizontally end to end to reduce aerodynamic drag. If this concept were carried to its logical conclusion, and the number of floats reduced to one, than a "tilt-hull" aircraft would result, which in flight would generally resemble a conventional aircraft, and at rest in the sea, a "tail-sitter."

Inflatable-Retractable Floats

Aircraft lacking the immense hull volume of conventional seaplanes would be severely handicapped by the necessary external stowage of tilting rigid floats. In general, rigid floats are too bulky and heavy for use in fixed wing or V/STOL aircraft intended to cruise at speeds expected from land-based aircraft.

Several types of inflatable-retractable floats have been studied.[4] Convair modified the rigid float system described previously by combining the advantages of rigid and inflatable systems in a recommendation that pivoted keel-like channels be rotated from their in-flight positions beneath the hull to vertical attitudes and inflatable cylindrical floats expanded from within them. The channels provide the required rigidity. Damping plates would be hinged to the lower end of each channel. Floats would be deflated during rotation of the supports to their in-flight position. Similar systems are also well suited for use on VTOL aircraft that require float extension and retraction while hovering.

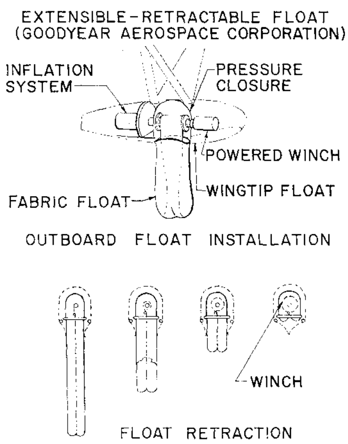

Fig. 5 The Goodyear retractable vertical float concept.

Convair, Curtiss-Wright, and Ling Temco Vought (LTV) each concluded that rubberized fabric inflatable floats could provide necessary buoyancy and rigidity for the least weight, yet be retractable and stowable in acceptably small volumes. All three contacted Goodyear Aerospace Corporation, a company considered best qualified to design and develop inflatable structures such as described in Ref. 5. In contrast to emergency floatation gear, which cannot be deflated and stowed while the aircraft is in flight, the vertical floats must be routinely extended and retracted, often in the adverse environment of high-velocity downwash, salt spray, and possibly forward motion. If a float were deflated prior to retraction, the downwash could cause the fabric to flap violently and possibly rip. Goodyear proposed a design that overcomes this and other problems by maintaining the constant pressure throughout the entire extension-retraction cycle.

A cord, fastened to the interior center of the float bottom, passes axially upward through the float to a winding drum housed in a dome whose open end joins to the open upper end of the float along its perimeter. The inflated float and dome contain a single pressurized volume. The float is retracted by winding the cord to pull up the float inside out onto the drum (Fig. 5). A relief valve permits air to escape while maintaining fixed pressure in the float, with corresponding constant fabric rigidity.

Extension is accomplished by reversing the drum to unwind the float as it inflates under constant pressure, so that it turns right side out as it lengthens.

Conversion Studies of Four Representative Aircraft

The Naval Air Systems Command Tilt and Vertical Float Program includes four studies covering spectra of factors involved in any open ocean aircraft. Two operational aircraft (the P-5A seaplane and the CH-46A helicopter) and two research aircraft (the VTOL X-19 and the V/STOL XC-142A) represent those general configurations most likely to be used for on-surface ASW, search and rescue (SAR), or other missions requiring protracted time in the open ocean.

The four proposed open sea aircraft are compared in Table 2. Results of these studies will provide a comprehensive source of information to companies contemplating proposal or construction of all-weather water-based aircraft. The information anticipated from this unified program will include detailed background on rigid and inflatable floats arranged in various arrays, depending upon the choice of fixed or rotary wing V/STOL or conventional aircraft operating from water, airfield, or carrier.

Table 2 Aircraft conversion studies—float characteristics

Type aircraft	Helicopter	VTOL	V/STOL	CTOL
Designation Contractor	CH-46A Boeing-Vertol	X-19 Curtiss-Wright	XC-142A LTV	P-5A GD/C
Type-float	Rigid-tilt	Inflatable-retractable	Inflatable-retractable	Inflatable-retractable
Array	Wire-braced triangular	Cantilever-trapezoidal	Cantilever-diamond	Cantilever-diamond
When operated	Hover	Hover	a) VTOL-hover b) STOL-operation raises and lowers A/C	Operation raises and lowers A/C
Location of retracted float	Rotation and alignment on side and bottom of hull	Ends of propeller gearbox nacelle	Hull bottom and wingtips or outboard floats	Hull bottom, tip floats
Extension environment	Rotor downwash	Propeller downwash	a) Partial downwash b) Into water	Into water
Type and disposition of damping plates	Rigid folding plate	Inflatable C-W "damping tabs"	Inflatable	Inflatable
Site of model tests	SIT	SIT	Analytic study	GD/C model and full scale
Conditions for emergency floatation	Floats retracted	Floats partially extended	a) Partial inflation, b) Retracted	Retracted
Bases	Land, ships, carriers	Land, carriers	Land, carriers, water	Water

Boeing-Vertol CH-46A Helicopter

Boeing-Vertol, in its study of an open ocean version of the CH-46A helicopter,[6] originally considered extension of the sponson structure to the necessary span to support rigid tilt floats at each wing tip, with either two floats forward on a similiar wing or one float mounted beneath the nose of the fuselage.

Flight deck, hangar deck and elevator limitations, and aerodynamic, structure, and weight considerations necessitated a more conservative approach, resulting in the complex appearing arrangement (Fig. 6). The beauty of this system, like that of the ubiquitous jeep, lies in its functionality rather than sleek contours. The retracted bow float is configured to align with the fuselage, and so has a flattened crescent cross section in contrast to the right circular cylindrical stern floats (Fig. 7). Bow float hydrodynamic drag will cause the helicopter to head into the wind and, generally speaking, into the major wave system, so that greater heave and pitch rather than roll alleviation must be provided. Each float is is compartmented to minimize loss of buoyancy from damage or leakage.

Aerodynamic drag of this prototype CH-46A is substantially increased by the floats and booms. A production version would be refined by the addition of appropriate fairings to mate with the retracted floats, reshaped to blend into the sponsons (Fig. 7).

Routine operation in low sea states will be possible with floats retracted, since static lateral stability would substantially exceed that of the unmodified assault helicopter. If forced to ditch in this configuration, the helicopter would, under normal circumstances, remain upright and seaworthy. A sea anchor should be provided.

Capabilities of CH-46A helicopters with and without tilt floats were studied by Vertol. A standard aircraft was considered to be converted to an ASW configuration by the addition of 1500 lb ASW gear and an internal 130-gal fuel tank to supplement the existing sponson tanks. The tilt-float helicopter weighs about 2553 lb more than the preceding configuration. Five hundred gallons of fuel are carried internally. Added weight and drag are reflected in increased fuel flow during cruise and hover. It is assumed that the tilt-float vehicle rests on the water with engines idling and auxiliary power plant inoperative, or else with engines off and the auxiliary power plant (APP) providing electrical power and engine starting power. The two aircraft are compared in Table 3, and their hovering capabilities on a short ASW mission are presented in Fig. 8.

Figure 8 shows the greatly increased on-station time of the tilt-float version. Even with engines operating, the on-station time is approximately three times that of the conventional helicopter. Should the unorthodox but practical procedure of shutting down the engines be employed, the on-station time is, for all purposes, limited only by the endurance of the crew. These extended on-station watches permit the use of variable depth or deep dip (10,000–15,000 ft) sonar operations that require considerable time to lower and raise.

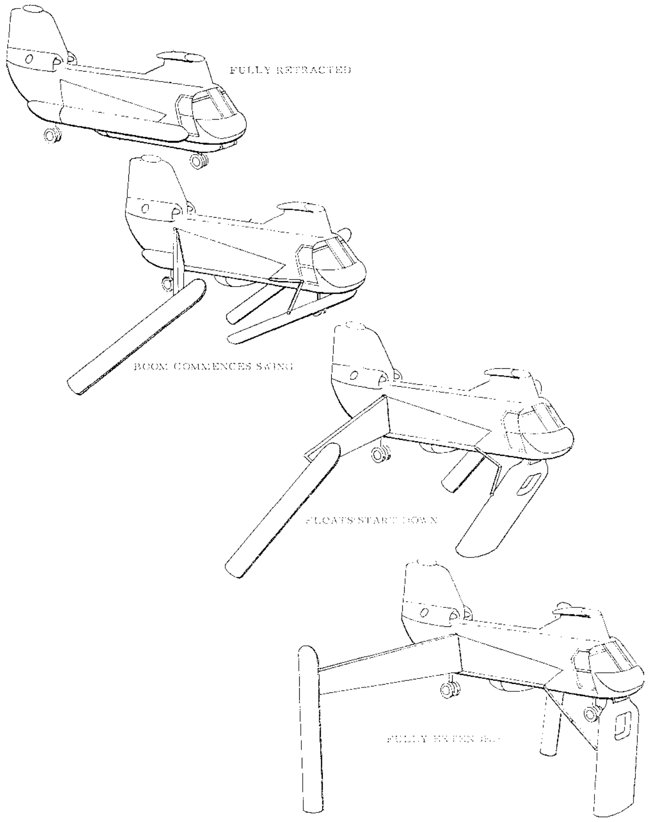

Fig. 6 Boeing-Vertol tilt-float CH-46A, extension cycle.

The Coast Guard showed outstanding initiative in developing rescue techniques making use of the excellent rough water capabilities of the Sikorsky HH-52A (Fig. 9). This military version of the S-62A has been used repeatedly to make rescues that could not have been accomplished by a hovering helicopter. It has landed in heavy surf, in the open ocean, and alongside overturned and swamped boats to take aboard exhausted, unconscious, or injured persons. Use of the rescue platform eliminates hazards associated with conventional rescue procedures employing a hovering helicopter.

Rough water survivability by itself does not provide a effective rescue vehicle. Even the crews of whale boats and life boats, which are certainly seaworthy, are frequently

Table 3 CH-46A, ASW configurations

	Conventional external configuration	Boeing-Vertol tilt-float model
Basic	12,458	15,011
Fuel JP-5 6.8 lb/gal	Add 130 gal internal 3400	Internal tanks 500 gal = 3400 lb
Crew	913	913
Oil plus trapped liquids	120	120
ASW gear	1500	1500
Gross wt	18,391	20,944
Av. wt during mission	16,830	19,384
Cruise speed	122	122
Fuel flow, lb/hr	1200	1304

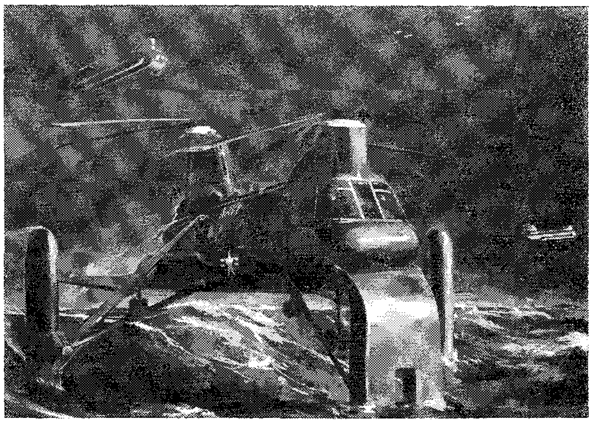

Fig. 7 The prototype vertical float CH-46A at rest and a production model in flight.

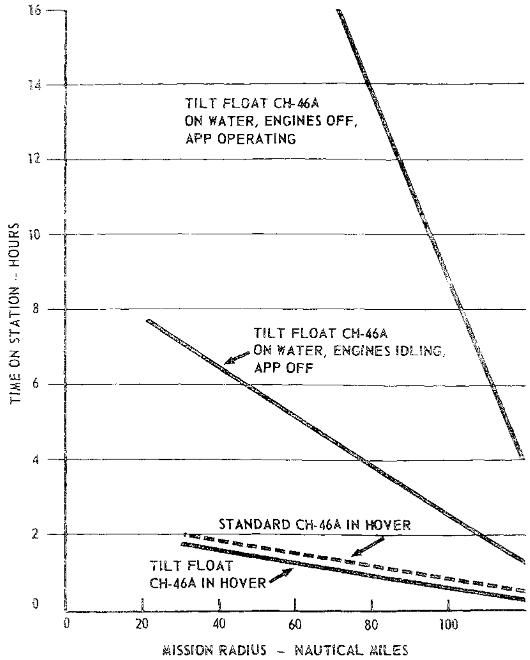

Fig. 8 ASW CH-46A time on station vs mission radius.

hampered or incapacitated by violent motions in a seaway. A vehicle floating nearly motionless would permit the rescue crew to work rapidly and effectively, unhindered by strenuous efforts to brace themselves against erratic and violent pitching and rolling.

If, in addition, the rotors could be set in flat pitch or slowed to idling speed, the crew could devote all their efforts to rescue efforts without the hindrance of rotor downwash (always an unwelcome and dangerous factor).

The tilt-float CH-46A design study provides for possible conversion into a rescue helicopter. The optimum location of hand grips and footholds on the hull and floats and the most effective use of rescue platform ramp and large hatches would be verified by simulated rescues with a well-equipped mock-up. Assignment of the converted helicopter to shore and carrier units would provide experience leading to recommendations of improvement for inclusion into a production open sea rescue helicopter having capabilities beyond those of any present day aircraft.

Curtiss-Wright X-19 VTOL Aircraft

Aircraft of the Curtiss-Wright X-19 type appear well suited for modification to open sea VTOL aircraft, requiring only redesign of the nacelle after-bodies to accommodate inflatable-retractable floats.[7] Existing structure was more than adequate to carry water induced loads resulting from normal maneuvers. The trapezoidal arrangement of Goodyear floats superficially resembles the square array of the DSN-1 tiltcopter. The large pitching moment of inertia and considerable distance between the fore and aft floats provide maximum steadiness when headed into waves. The effect of high-velocity down-wash upon water was studied under several Bureau of Naval Weapons contracts. Reference 8 reported that on the basis of powered model tests it could be "concluded that an X-19 fitted with tilt floats would result in a water-based VTOL airplane free from any operating limitations due to formation of spray." It is considered desirable, however, to include spray separators in the intakes to the fuselage-mounted turbo-shaft engines. Design of the floats is complicated by their location in the high-velocity slipstream of the lifting propellers, (Fig. 10). This environment poses severe problems, probably requiring operation at constant high internal pressure. A new intake, visible just ahead of the fin, cools the air pumped from the engine compressors into the inflatable floats.

A similar float system could be installed on the Bell X-22A VTOL aircraft outboard of the ducted fans with floats partially rather than completely immersed in the propeller slipstream. The difficulty of mounting rigid or inflatable damping plates on retractable floats prompted Curtiss-Wright to propose the use of many rows of regularly spaced "damping tabs."[7] Effectiveness of a damping plate is indicated roughly by the ratio (perimeter of water-plate boundary)^2/area of the plate. The coefficient of drag of a conventional automobile radiator, for example, is substantially higher than that of a flat plate of equal dimensions. During the DSN-1 tiltcopter model tests at Stevens Institute of Technology, the end plate c_d was doubled by cutting eight large holes in the square platform, resulting in further decrease in wave-induced motion and damping plate weight.[9]

The damping tab concept is yet to be demonstrated; the decrease in effectiveness due to partial submergence in the cylinder boundary layer must be assessed, and optimum spacing and tab dimensions must be chosen. Its advantage lies in ease of retraction. The tabs are inflated from the float, and as the float is wound up, inside out, it and the tabs are rolled flat on the storage drums. It is possible that flexible metal plates rather than inflatable appendages would give best results.

Ling-Temco-Vought XC-142A VTOL Aircraft

The Ling-Temco-Vought report[10] presents both VTOL and STOL versions of amphibious XC-142A tilt wing aircraft. The VTOL design (Fig. 11) is generally free of additional problem areas, in many respects resembling the X-19 tilt float concept. The basic fuselage is retained with only minor modifications to provide a spray and corrosion-proof structure. Air intake water separators are considered necessary because of anticipated recirculation of airborne water resulting from the high-velocity downwash. The tip vertical float pods are rigidly fixed to the wing with the floats extending from the pod afterbodies. Conventional rigid outboard floats are not required.

The comparison in Table 4 shows the reduction in VTOL payload to compensate for the modifications, converting it to an open ocean aircraft. The decrease in payload is more than compensated by the emergence of a unique aircraft that

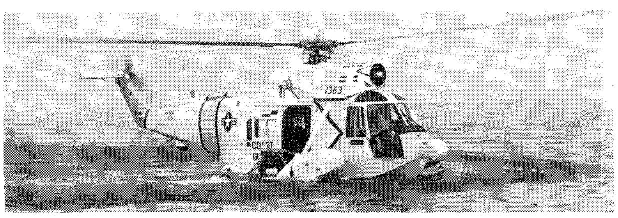

Fig. 9 The Coast Guard makes full use of the HH-52A amphibious capabilities.

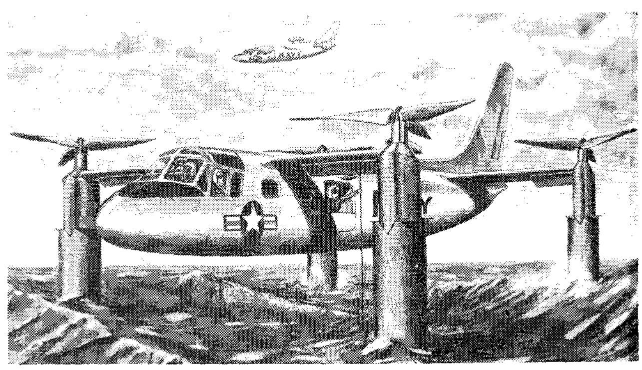

Fig. 10 Curtiss-Wright vertical float X-19 VTOL aircraft.

Table 4 XC-142A, land and amphibious configurations

	XC-142A land plane	Amphibious VTOL version
Weight empty	23,045	26,555
Fixed useful load	785	785
Operating weight empty	23,830	27,340
VTOL payload	8000	4490
VTOL fuel (200 mm)	5644	5644
VTOL takeoff gross wt	37,474	37,474

can carry-4490 lb payload at 250 knots over a distance of 200 naut miles and conduct missions on and from state 4 seas.

The preliminary study of an amphibious STOL version of the XC-142 emphasized the traditional inherent problems bedeviling the designer of conventional seaplanes. Wing, engines, and propellers must be raised above the hull or the hull deepened to an excessive degree (compared with the fuselage of a land plane). Use of a parasol tilt wing requires incorporation of a substantial pylon and related structure to carry the tilt mechanism and wing. Present XC-142 fuselage volume was adequate, requiring the addition, however, of a vee-bottom step and chines, to permit a planing takeoff. A "tail cone" would be necessary to provide the elevation for the tail surfaces and after propeller.

The alternate simpler conversion requires far less redesign. It would be necessary to remove the cargo ramp in order to blend a conventional seaplane hull into the fuselage, giving it sufficient depth to support the wing, propellers, engines, and tail surfaces at the necessary height above the static waterline. Conventional outboard floats provide static lateral stability. Unfortunately, the need for a low length/beam hull to match the fuselage guarantees a lumpy machine of surpassing ugliness which lacks payload, performance, and promise. It was obvious that the proven VTOL capabilities of this airplane precluded further serious consideration of an STOL amphibious version, and the LTV study was thereafter concerned solely with the far superior VTOL amphibion.

The Goodyear float system for the VTOL version is lighter and simpler than the corresponding STOL installation. The XC-142 fuselage remains unchanged except that it has been made spray and corrosion-resistant so that the over-all increase in airframe weight is primarily that of the vertical float system and auxiliary equipment. In contrast to the STOL amphibious design, conventional outboard seaplane floats are not required. The fuselage-mounted vertical floats are out of the propeller slipstream and so need not be extended or retracted at constant pressure, as in the case of the slipstream immersed X-19 floats.

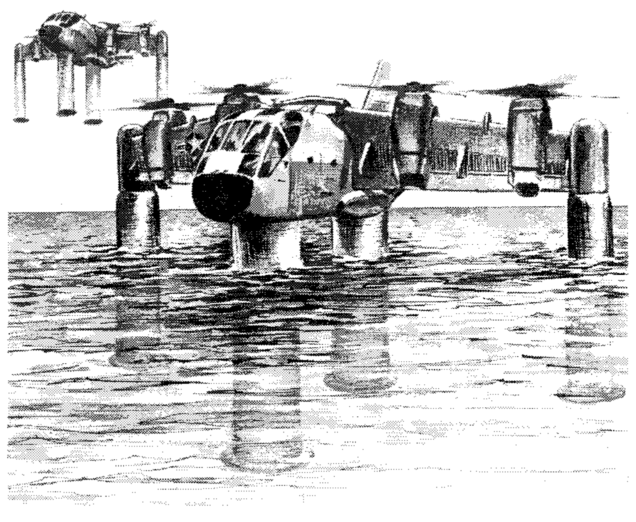

Fig. 11 A logical prototype for a VTOL patrol seaplane, the LTV XC-142A fitted with vertical floats.

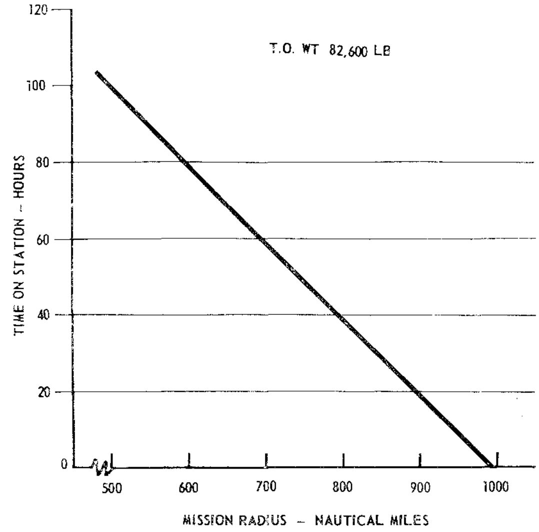

Fig. 12 LTV model 459A vertical float seaplane; time afloat on station vs mission radius.

LTV concluded its study by briefly considering a vertical float variation of the advanced design V-459, an 82,600-lb expansion of the XC-142. The V-459 can carry an 8-ton payload over a 500-naut-mile radius. If its weight and drag are increased in the same ratios as the vertical float VTOL XC-142, the amphibious V-459 could carry 4300 lb of ASW gear a maximum radius of 1000 naut miles or else trade range for on-station time while at rest in the sea (Fig. 12).

P-5A Seaplane

The General Dynamics/Convair vertical float seaplane program[2] was extended into a preliminary design study of the possible installation of inflatable-retractable floats on a P-5A seaplane (Fig. 13), the latter day version of the now extinct PBM.

The potential usefulness of a fixed wing vertical float conventional takeoff seaplane is best illustrated by the results of a related Bureau of Naval Weapons preliminary mission analy-

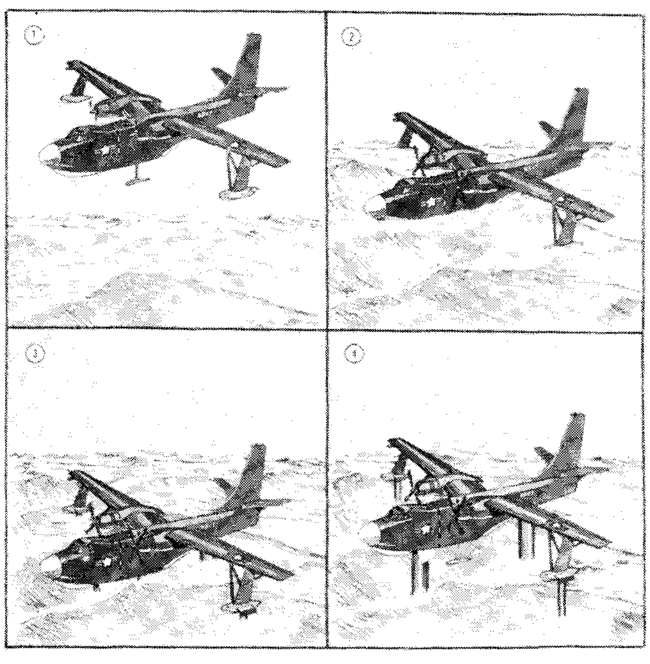

Fig. 13 The forerunner of a long-range open ocean seaplane, the P-5A with hydro-ski and vertical floats.

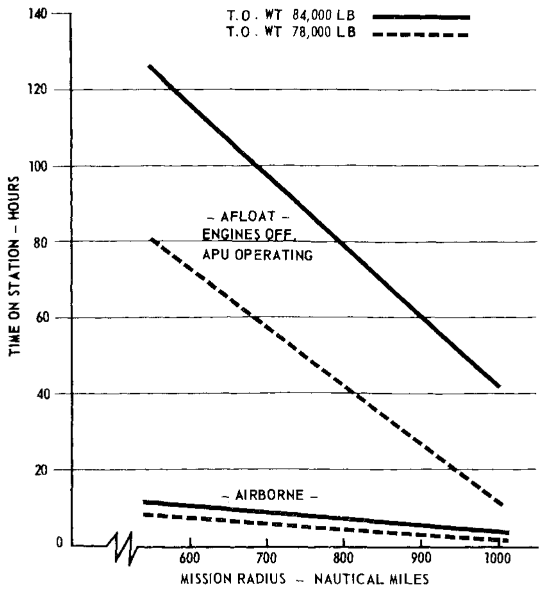

Fig. 14 P-5 vertical float seaplanes; time on station vs mission radius.

sis. It was assumed that a standard P-5A was modified by the removal of all present ASW gear and weapons and reconfigured to include refined, lightweight, inflatable-retractable vertical floats, a hydro-ski, and a representative dunking sonar system totaling 11,000 lb. The basic airframe weighs 43,464 lb, and 2000 lb was allotted for the two crews of 5 men each.

Two initial takeoff weights were selected: 78,000 lb, permitting forward area hydro-ski takeoffs in sea state 4, and 84,000 lb for takeoffs in sea state 3 or sheltered water. The former value allows 1280 lb of oil and 20,236 lb of fuel to be carried.

The arbitrary mission used as a basis of comparison consists of takeoff, cruise at 5000 ft to station, hydro-ski landing (sea state 4), inflation of vertical floats, on-station watches, float retraction, takeoff, return at 5000 ft to base. One thousand pounds reserve fuel remains at completion of mission.

During the time on station, fuel consumption of the auxiliary power unit is 100 lb/hr. The two crews would stand alternate watches in time periods to be determined by actual experience. The large internal volume of the seaplane provides adequate space for off-duty personnel, with living quarters especially designed to minimize crew fatigue and discomfort.

Comparisons of on-station times are given in Fig. 14 as a function of mission radius. The airborne times are identical to those of conventional P-5 aircraft. Return to station would likely be necessitated by crew fatigue and deterioration in performance rather than shortage of fuel.

Structural modifications are minor for a number of reasons: 1) the hull float locations are not in the region where high hydrodynamic impacts are experienced; 2) the forward hull bulkheads easily accommodate the float retraction unit; 3) the beaching gear imposes higher load than either hull-mounted vertical float; and 4) the tip floats, struts, and wing are designed to accommodate the tip float landing loads that are in excess of anticipated loads transmitted through the wing vertical floats.

The Convair report, prepared in cooperation with Goodyear Aerospace,[11] describes two vertical float systems, one for developmental use in a non-flying stricken seaplane where excess weight is of minor importance, the other for installation in a flying test-bed. This latter system, proposed for installation in a P-5A fitted with a hydro-ski, is generally dependent upon the extensive use of "off-the-shelf" auxiliary equipment in an attempt to minimize costs and added engineering related to the supporting gear. Once the concept of inflatable-retractable floats has been demonstrated successfully and further refinement is warranted, it is absolutely necessary that the weight of the floats and auxiliary gear be greatly reduced; it is believed that 5% of the airplane gross weight is a reasonable and realistic value.

Analytic Methods of Predicting Wave-Induced Motions

The Davidson Laboratory, Stevens Institute of Technology, applied analytical methods to predict the actual time history response to irregular waves of various forms of marine vehicles. Model tests showed such close correlation between the measured motions of displacement ships, hydrofoil craft, submerged bodies, and a tilt-float helicopter, with their respective analytically prepared time histories, that a Bureau of Naval Weapons contract was awarded to Stevens to conduct analytical and experimental studies of related series of tilt-float configurations and to define and catalog their amplitude response and phase angle response operators in waves. These operators will then be used to develop impulse response functions for prediction of each basic float system's motions in terms of the instantaneous time history of the surface profile of irregular seas.

This study will provide a reliable means of quickly predicting motions of tilt float vehicles relative to the instantaneous surface wave profile of irregular seas by use of a digital computer. This procedure eliminates the need for a lengthy model program, and in addition provides higher "sea states" than feasible in most towing tanks. Months of prototype operation can be represented by a few hours of computer time. A detailed discussion of the Stevens Institute of Technology technique is presented in Ref. 12.

The Hydronautics Incorporated analytic investigation[13] was planned to provide vehicle dynamic response characteristics for incorporation into the mathematical definition of any given wave system for use in preparing rational design criteria.

Conclusions

The open ocean aircraft studies of the Naval Air Systems Command emphasize practical methods and techniques. Theoretical analyses and model tests provide immediate and useable information for aircraft design engineers. Irrefutable evidence has been presented of the effectiveness of tilt and vertical floats' remarkable alleviation of aircraft motions in a seaway. Numerous contractors have cooperated in the development of inflatable-retractable float systems for research, test-bed, and prototype water-based aircraft. Following normal refinement and improvement, it is anticipated that these floats can be successfully incorporated into production aircraft. The proposed first generation of open ocean aircraft, modified from the contemporary CH-46A, XC-142A, and P-5A, will have the capability of providing structural, physiological, and mission effectiveness data to be used in the formulation of the specifications leading to the Navy's first true open ocean aircraft.

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Propulsion System Development for V/STOL Transports

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The evolution and technology development of the high bypass ratio tip turbine lift fan and lift/cruise fan propulsion systems are presented. The characteristics of the high bypass propulsion system are reviewed and compared to other subsonic propulsion concepts. Fundamental aerothermodynamic aspects of the system are examined, including internal and external aerodynamics. Significant results from extensive mechanical and aerodynamic scale model and full-scale investigations are presented. Suggested aircraft applications in light and medium V/STOL transports based on this technology are presented.

Nomenclature

TJ = turbojet
TF = low bypass ratio turbofan engine
L/CF = high bypass ratio tip turbine lift/cruise fan
F_G = gross thrust
F_N = net thrust
C_{T-D} = installed thrust coefficient = (measured thrust minus drag)/(ideal thrust)
P_{TN} = nozzle total pressure
P = ambient pressure
C_{DT} = total nacelle drag coefficient = D/q_0A
C_{DBT} = afterbody boattail drag coefficient = D/q_0A
C_{DFB} = forebody pressure drag coefficient = D/q_0A
C_{DF} = friction drag coefficient = D/q_0A
T_D = drive flow temperature
T_0 = ambient temperature
$N/\theta^{1/2}$ = rotor corrected speed
$W/\theta^{1/2}/\delta$ = drive corrected flow
$P_{T/\delta}$ = drive corrected pressure
BPR = bypass ratio

Introduction

STUDIES conducted by the General Electric Company in 1957 under sponsorship of the Transportation Research Command of the U. S. Army (TRECOM) indicated that one of the systems that showed considerable promise was a convertible system that used the jet engine for cruise flight and a lift fan driven by turbine buckets mounted at the tips of the fan rotor for takeoff and landing. These two components are coupled pneumatically through a diverter valve that enables the same gas generator to be used for both lift and cruise.

The initial phases of the development of this propulsion system have been completed and over 600 hr of full-scale static and wind-tunnel operation have been demonstrated successfully, culminating in the XV5A research aircraft application.

The initial lift fan concept was designed specifically for wing mounting or adapted to fuselage mounting but always with turbojet operation for the cruise mode. The aircraft were surveillance-type cruising at $M = 0.8$. Subsonic transport aircraft cruising at $M = 0.7$ to $M = 0.8$ will not be powered by turboject engines, since fans offer such great economy. With this basic philosophy in mind, General Electric has conducted many studies to combine the obvious advantages of the lift fan into a high bypass ratio system. Thus, was born the lift/cruise fan.

Some of the significant aspects of a development program including system studies, full-scale, and scale-model technology designed to demonstrate the system performance for the lift/cruise fan are given in this paper.

Discussion

The original lift fan system was made as 'thin' as possible so as to fit between the spars of a 10% thick wing. Initial testing at NASA Ames included both fan in fuselage and fan in wing configurations as shown in Fig. 1. Both the fan in wing and fan in fuselage installations demonstrated predictable performance, the lift being approximately 2.8 times the J85 turbojet thrust. The fan tip diameter of 62.5 in. for the fan

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