ASW Patrol Aircraft of the Future

CLIFFORD E. OLSEN* AND MARCO A. ROMERO†
The Boeing Company, Renton, Wash.

Certain key considerations in the development of future antisubmarine warfare (ASW) patrol airplanes are discussed. Among these are: the importance of speed; the problem of providing all the features required for the collateral missions traditionally performed by Navy patrol aircraft such as shipping and coastal surveillance, counter-insurgency, and electronic intercept, without prejudicing the basic ASW capability; the advisability of designing for the most probable rather than for the maximum mission radius; and the need to determine realistic limits of crew endurance and effectiveness. The various types of available powerplants and a number of possible types of ASW patrol airplanes including supersonic, amphibians, seaplanes, and landplanes are examined. The subsonic landplane powered by turboprops or turbofans is found to be operationally and economically the most attractive system. Operational and cost effectiveness criteria are developed and employed in a parametric comparison of two families of hypothetical ASW patrol landplanes, one powered by turboprops and one by high-bypass-ratio turbofans. The authors conclude that although the turboprop airplane is smaller and has lower cost per unit up to a rather high gross weight, the high-bypass-ratio turbofan has a considerable advantage in operational effectiveness which more than offsets its higher unit cost.

Introduction

CERTAIN of the new aircraft being developed in design work today show significant technical promise as ASW vehicles. Although a consideration of potential ASW vehicles could be extended to include many types of aircraft such as rotary-wing, STOL, VTOL, and air cushion machines, this discussion will be restricted to aircraft that can be envisioned as potential antisubmarine patrol airplanes, a class of airplanes for which the need has long been established. ASW patrol aircraft are regarded as those designed primarily for antisubmarine warfare and which are capable of independent or coordinated operations against submarines in the farthest reaches of the oceans.

As advancements are made in propulsion systems and aerodynamic characteristics, it is appropriate that each successive stage be examined to determine what applications might be served. The commercial aviation industry, served first by propeller-driven aircraft, later by turbojets, now by turbofans, and tomorrow by supersonic turbojets or turbofans, is a prime example of such a progressive application of technology. It is the intent of this paper to examine the prospects of applying some of the available technological advancements to ASW patrol aircraft.

Considerations in the Development of Future ASW Airplanes

Evolution of ASW Patrol Aircraft

The early patrol airplanes were general in purpose with the mission of surveying the ocean areas and attacking any enemy, including submarines. World War II changed this, more or less, to a division of basic missions: some of the aircraft were equipped for and specialized in destruction of submarines, while others were heavily armed defensively and offensively and concentrated on armed reconnaissance and bombing missions. Most importantly, after World War II, both the ASW and the armed reconnaissance requirements continued, but the ASW requirements eventually prevailed as a result of budgetary limitations and of a submarine threat of such proportions that only the best in equipment, unprejudiced by other mission requirements, would be acceptable. This resulted in patrol aircraft evolving almost exclusively toward the ASW role as aircraft development was paced by the rapidly developing submarine.

Speed

In addition to the shift toward pure ASW design, speed to the contact area has become important. The advent of the snorkel and nuclear power, coupled with vastly increased underwater speed and depth capabilities, has made the modern submarine increasingly difficult to detect and localize. The sooner the ASW airplane can reach the contact position, the smaller the area to search and the higher the chance of localizing and killing the submarine.

Collateral Missions

It is also important to recognize that the armed reconnaissance capability continues to be an absolute requirement. A dilemma exists. While the design of patrol airplanes has been moving toward pure ASW, the missions flown by deployed squadrons have for the most part been reconnaissance. During periods of actual conflict, such as the Korean War and the present armed action in South Viet Nam, patrol squadrons are called upon to revert to World War II-type armed reconnaissance missions. Before a new ASW patrol airplane is chosen, a careful evaluation should be made of those requirements that have to be met in addition to the ASW mission in a hot war situation.

One of the missions routinely performed by patrol squadrons is the surveillance of ocean traffic, particularly in aeras close to the shores of the Communist bloc countries or contested areas such as South Viet Nam. This task, considered vital to the interests of the United States, includes the observation of movements of naval forces, including submarines,

Presented as Paper 66-727 at the AIAA/USN 2nd Marine Systems & ASW Conference, Los Angeles—Long Beach, Calif., August 8–10, 1966; submitted August 22, 1966; revision received December 2, 1966. The authors gratefully acknowledge valuable contributions made towards the preparation of this paper by R. D. FitzSimmons, Manager of Exploratory Development, and by all members of the staff of the ASW Project, Exploratory Development, in particular G. G. Upton, D. J. Selvig, E. R. Wolff, W. G. Stewart, D. G. Andrews, and F. G. Reese—all of the Commercial Airplane Division of The Boeing Company. [2.04]

* Project Engineer for ASW, Exploratory Development, Commercial Airplane Division. Member AIAA.

† Research Engineer, Exploratory Development, Commercial Airplane Division.

routine shipping, fishing fleets, missile range ships, junks, barges, and all other waterborne traffic. To execute this assignment properly, aircraft must be capable of visual observation, accurate photography, sophisticated electronic interception, and other work of a classified nature.

Visual observation is of primary importance, for the more eyes brought to bear on a ship being "rigged" or observed on a single low pass, the better. In the past, a bow observer's station has served very well for one of the lookout positions and has been very useful for ASW. This station was eliminated from the P3A for the very good reason that the area was required for a radar antenna. To have put a large radome on the underside of the fuselage would have cost considerably in drag. As more modern aircraft with higher dash speed capabilities are considered, radome drag becomes even more costly.

As for the other observation positions, the drag and weight penalties must likewise be considered. Contoured windows projecting outward add to the drag. Large cutouts for windows add to the airframe weight and are more expensive in manufacturing. For a photographic capability, a patrol aircraft should ideally have large, optically plane glass windows from which precision photos could be taken using a large focal length lens. This again is an expensive design feature that adds to the weight and cost of the airplane. Such features are not necessary for pure ASW and must be ruled out if only ASW dictates the design of the aircraft.

The electronic intercept equipment used in reconnaissance missions is vastly more sophisticated than that required for ASW. It must have extensive range as well as accurate bearing and classification capability. From an aircraft design standpoint, this means a considerably greater allowance for volume, weight, and electrical power. It also means a radome, either permanently affixed or retractable, to house the required antenna system.

If the observation of shipping in a cold war situation is to be extended to destruction or at least deterrence of shipping in a limited war situation the aircraft must have an offensive and possibly a defensive capability. It should probably have provisions for a radio-controlled or wire-controlled air-to-surface missile. It might require provisions for heavy forward fire power employing machine gun pods. The bomb bays would probably be designed to provide space, weight, and dropping provisions for weapons peculiar to the collateral mission.

Defensive armament is a more difficult problem. Protection from enemy aircraft can no longer be achieved by providing a number of machine gun stations. A measure of defense against a fighter carrying heat-seeking or radar-homing missiles can only be achieved by shielding, decoying, or jamming.

The problem of providing all the features required for an adequate armed reconnaissance aircraft in an ASW patrol airplane without prejudicing the design of the ASW aircraft is difficult. It can probably be done, but to find out how well requires considerable additional study.

Crew Endurance

Although it is possible to design aircraft having extended time on station at extreme distances, and hence long total mission times, such aircraft should not be considered without carefully examining the physiological factors affecting the crews. The effectiveness of a patrol aircraft crew is a function of the time spent in a state of alertness while flying the airplane, operating sensor equipment, visually scanning the ocean surface, or observing a radar scope, etc. In actual practice the period of fatigue-inducing activity commences long before the flight begins. For a typical ASW or surveillance mission, the crew is involved at least three hours over the mission flight time. Two hours of this crew involvement time is spent in mission briefing, dressing, weather briefing, filing flight plan, preflight inspection and preparation of the aircraft for flight, taxiing, and reviewing takeoff checklist. On return, time is spent in shutdown, postflight inspection, debriefing, and removing flight clothing. To assess crew endurance clearly, this time should be taken into account while examining the various types of missions.

The most arduous mission is contact investigation. Upon arrival in the contact area, the aircraft is flown at medium altitudes in a relatively smooth manner while searching passively with sonobuoys. The radar may or may not be operated, depending on the circumstances, and other sensors are alert or ready to go into full operation. Once a submarine has been located, the aircraft is flown close to the water and rapidly maneuvered in the mildly rough air generated by wave action. All sensor station operators have duties requiring maximum concentration and alertness, and piloting of the aircraft demands continuous attention to safety, coordination, and concentration on instruments. Experienced personnel, both pilots and other crewmen, give varying estimates on how long a period of mixed search and localization a crew can withstand before becoming ineffective. The average appears to be between 4 and 5 hr. Considering all information available, it appears that a mission time of about 10 hr, which implies a total crew involvement time of 13 hr, should be considered a maximum under ordinary circumstances.

Missions not requiring low-altitude maneuvering and intense concentration by all sensor operators, such as radar patrols and submarine barrier surveillance, can probably be extended somewhat, but indications are that the flights should not exceed 12 hr. Convoy coverage and certain types of coastal surveillance approach the same intensity as contact investigation and should be held to the lower maximum.

The concept of multiple crews is often brought into discussions of crew endurance but is not regarded as a good solution. The relief members, though supposedly at rest, are nevertheless fatigued along with the crew as a result of airplane vibrations, altitude changes, and maneuvers, although to a lesser degree. For ASW operation in general, the multiple-crew concept demands a larger aircraft and is wasteful of the employment of flight personnel.

The entire question of crew endurance and effectiveness needs further investigation and study. The effect of these factors on mission time, which in turn dictates size of aircraft, is considered very important.

Radius of Action

Another important factor of patrol plane operation is that of time on station at extreme ranges. The requirement existing at the time the P3A was developed called for 3 hr on station at a range of 1200 naut miles. This requirement arose from the need to reach the area of the Atlantic ocean farthest from land bases and remain in the area for what was then considered to be a reasonable time to process a submarine contact. The requirement to reach such a distance still exists today, but much longer periods on station have been mentioned. Before such a requirement is made firm, all aspects of this matter of radius and time on station should be examined.

In addition to the considerations of crew endurance discussed, the anticipated frequency of patrol aircraft visits to these remote areas should be reviewed. If a graph were to be constructed showing frequency of visits vs distance from base, it would very likely take the form portrayed in Fig. 1, an asymmetrical curve peaking at midrange or closer to base and sloping to zero at the origin and maximum range. It is not likely that an enemy will operate a large number of submarines in the middle of the Atlantic away from convoy routes. The same applies to the Pacific where ranges from bases to remote areas are somewhat less. Accordingly, the

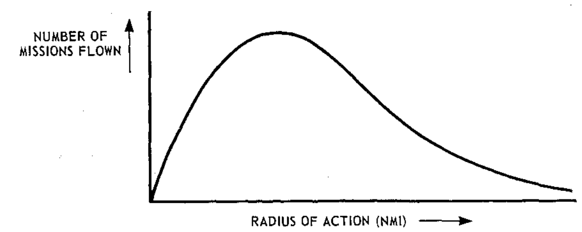

Fig. 1 Mission radius probability.

likelihood of infrequent visits to extreme ranges should be taken into account in developing an aircraft requirement. It would be more economical in aircraft size and crew endurance to match the design to the requirements of medium-range operation, settling for a shorter time on station at extreme range with a plan for more rapid cycling of on-station aircraft on these infrequent occasions. Rapid data-exchange systems being developed will facilitate relief of aircraft on station without reduction of kill probability.

Propulsion Systems

Before undertaking a discussion of future aircraft, a consideration of the propulsion systems that will be available in the 1970 to 1980 period is in order. Three basic systems have been studied—turboprop, turbofan, and the composite fan or dual cycle.

Turboprop engines will continue to be available and further improvements can be expected. However, the development of a regenerated engine of a size adequate to power ASW patrol aircraft has been discontinued, and the likelihood of any new, large, turboprop engine being developed has diminished with the trend to turbojet and turbofan engines on commercial transports and large military aircraft. Nevertheless, this engine provides capabilities that continue to be of interest.

The high-bypass-ratio turbofan engine shows definite promise as a propulsion system for patrol aircraft. It combines the thrust and fuel efficiency for high-speed dash capability at altitude with low fuel consumption during loiter at low altitude. Further, the turbofan system provides an almost noiseless, vibration-free platform for sensor work and crew comfort. Engines of this type are now being developed by several companies and are programmed for such aircraft as the Lockheed C-5A and the Boeing 747. Manufacturers of commercial transport aircraft are exploring the use of these engines on whole new families of aircraft to take advantage of their greatly improved efficiencies.

Supersonic engines are designed for maximum efficiency at high altitude and Mach number; consequently, the fuel consumption at lower altitudes and loiter speeds is high. Although recently developed engines such as the Pratt and Whitney TF-30 for the F-111 fighters and those now being designed for the SST increase the availability of supersonic propulsion systems, they do not appear attractive.

The composite fan, or dual-cycle engine as it is also referred to, employs gas generators mounted remotely and blowing the tips of externally mounted turbofan engines. This system permits the use of all power units for dash and cruise while the fan engines alone provide the thrust required for loiter at maximum efficiency. Although the composite fan appears inferior to the turbofan in all modes of operation except loiter, it presents attractive possibilities that should be kept in mind. For example, if regenerators should be developed sufficiently to render them operationally feasible, the interior-mounted gas generators would afford a means of avoiding high drag penalties while providing substantial gains in efficiency. Further, features such as variable-pitch fan blades could substantially improve fuel consumption. Nevertheless, for the purposes of this study, the composite engine will be dropped, since it is not an established developmental program, and the turbofan and turboprop will be further compared.

Figure 2 shows a plot of airplane pound-nautical miles per pound of fuel at loiter, dash, and cruise altitudes for the turboprop and turbofan. Airplane pound-nautical miles is a parameter similar to the commonly used "ton-miles," except that it refers to the total aircraft weight in the range of gross weights under consideration (100,000 to 400,000 lb). This plot portrays the over-all aircraft efficiency resulting from the use of these propulsion systems.

It may be noted that although the turbofan is inferior in the loiter, low-altitude cruise, and dash modes, it is superior during high-altitude cruise. During loiter, power requirements are in the 30 to 40% range and the turboprop specific fuel consumption (SFC) is slightly lower. This gives the turboprop a small advantage in aircraft efficiency during loiter since the speeds are about the same. During high-altitude cruise, power requirements are in the 75 to 85% range, and although the turboprop has a 15% lower thrust SFC, it is about 25% slower. This results in about a 10% advantage for the turbofan in high-altitude cruise. During maximum dash, the turbofan, because of its higher speed, operates in the region of drag rise. This results in a lower efficiency for the turbofan airplane in the dash mode. The implications of these facts on aircraft operations and on the important dimension of time (not shown) will be accounted for in the discussions that follow.

Potential ASW Aircraft

Supersonic Aircraft

Often in a discussion of future ASW aircraft, the question is asked, "Why not a supersonic airplane?" This point arises naturally, for if speed to contact is of critical importance, then the fastest aircraft that is feasible according to the state-of-the-art should be considered.

Although the speed and range capabilities of high-altitude, supersonic aircraft would be assets to ASW aircraft, the requirement for low-speed, low-altitude endurance on station presents a problem because of the propulsion system employed in supersonic aircraft of today's technology. In supersonic flight, almost 50% of the total compression ratio utilized in the engine is attained from ram effect, while the balance is furnished by the engine compressor. In contrast, in subsonic flight almost 95% of the required engine compression ratio is furnished by the engine compressor. Accordingly, supersonic engine compressors are considerably lower in compression ratio than subsonic engine compressors and depend on high-speed flight for the attainment of reasonable efficiencies. It follows that a supersonic engine is grossly mismatched for low-speed, low-altitude flight.

Present technologies for inlets and compressors are such that large variations in mode of operation can not be tolerated without suffering high losses in efficiency. In a typical loiter mode, supersonic engines have a fuel consumption from

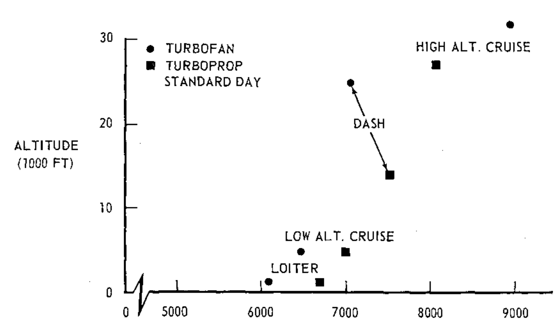

Fig. 2 Relative aircraft efficiency.

20 to 45% higher than high-bypass-ratio turbofans. Accordingly, the gross weight of the supersonic airplane would be excessively high. The requirement for low-speed, low-altitude maneuverability also presents a problem when supersonic aircraft are considered for an ASW role. A variable-sweep wing would be required, again adding to weight, complexity, and cost. It is estimated that supersonic airplanes cost between 1.1 and 4 times as much per pound as subsonic airplanes having transonic speed capabilities at medium altitudes. In summary, it does not appear that a supersonic aircraft is a good choice for ASW at this time. Future developments in propulsion and other areas could change this, of course.

Amphibious Aircraft and Seaplanes

Any discussion of potential ASW patrol aircraft would be incomplete without the inclusion of amphibious aircraft and seaplanes. The principal advantages of seaplanes and amphibians center around their capability to operate free of land bases, at least for short periods. Changing political situations and a fluid cold war that erupts all too frequently in local conflicts in remote areas of the world can deny adequate air fields to the free-world allies. The South Viet Nam campaign is an example of the type of situation in which seaplanes can fulfill an important role.

It is within the state-of-the-art to design an amphibious aircraft that would in every respect match the performance of a comparable landplane and have the additional capability of operating in the open ocean in sea state 4 when required. This would extend the sensor capability of the aircraft to a dunking or towed sonar. However, the aircraft would suffer a penalty of additional gross weight in the order of 20%, resulting from increases in fuel weight to compensate for the higher drag of the hydrodynamic hull and in landing gear weight, the latter being heavier than that of a comparable landplane owing to the increase in over-all gross weight. To operate in sea state 4, it is conceivable that a sufficiently high coefficient of lift could be attained through the use of devices such as the leading-edge and trailing-edge flaps employed on modern transport aircraft. However, should a boundary-layer control system be required, additional gross weight allowances would have to be made. The thrust loading for an amphibious aircraft would be about the same as for its landplane counterpart.

The attractiveness of an amphibian lies in the fact that it could operate a large part of the time as a landplane, performing the same missions, and have the additional capability of operating as a seaplane when required. Since waterborne, advanced base operations would occur only under conditions such as those existing in South Viet Nam at this time, the support system of tenders and ancillary equipment for waterborne operation would be small as compared with that required for a seaplane. Additional support for open ocean ASW sensor operations would not be necessary. Basically an amphibian would be home-based and maintained in the same manner as existing landplanes.

A seaplane could be designed for sea state 4 at about the same gross weight as a comparable landplane. A trade-off would be made between the increased drag of a hydrodynamic hull and the decrease in weight resulting from the absence of landing gear. The high-lift devices discussed previously for the amphibian model would apply.

The disadvantages of the seaplane are much more serious than those of the amphibian:

1) A seaplane system requires a vast and expensive support system. Moreover, the existing home bases and aircraft tenders are for the most part inadequate for modern, higher-gross-weight, high-performance seaplanes.

2) In the northern latitudes in the wintertime, many of the home bases are rendered inoperable by ice formation on the bays and inlets utilized for seadromes. Ice accretion on moored or even taxiing aircraft becomes a problem.

3) Except for minor repairs and small maintenance items, the maintaining of seaplanes while waterborne can be a problem. In the past, patrol seaplanes were of such a size that they could be lifted aboard tenders for major maintenance work. Aircraft of the size under discussion would not be capable of being lifted aboard, although means have been designed, such as stern lifting ramps, for medium-sized airplanes. The same disadvantage can be attributed to amphibious aircraft although they could be flown to fields in the forward areas for some of their major maintenance work. As aircraft grow in size, following the trend of the Boeing 747 and the Lockheed C-5A, a seaplane or amphibian could contain a majority of its own maintenance and some of its support.

In summary, while amphibious aircraft and seaplanes offer attractive operational capabilities, they both suffer significant penalties when compared with landplanes of the same performance level.

Landplanes

This category of ASW aircraft will be dealt with most extensively for several reasons. It is the type of patrol airplane most widely used, and indications are that the free-world allies will choose landplanes for future patrol aircraft. In addition, since the support systems—bases, hangars, ancillary equipment—already exist for the most part, landplanes provide the most economical ASW patrol airplane system. Further, a practice of converting existing transport-type aircraft to maritime patrol airplanes has been established: Britannia to Argus, Electra to P3A, and now Comet IV to Hawker Siddeley 801.

What can be shown in a parametric study of land-based ASW patrol airplanes will also be applicable, at least to some degree, to other systems such as amphibious aircraft and seaplanes. In developing a parametric study of potential landplanes without benefit of a specific military requirement, an attempt has been made to relate the parameters considered most important. These include speed, total mission time, endurance on station, search time and distance, cruise speed, gross weight, and unit cost. These basic parameters extend to others considered important to ASW. For example, speed is related to time late and to time on station for a specific mission time.

Two typical ASW missions have been considered: contact investigation and patrol. For each mission, besides investigating the various parametric relationships, an attempt has been made to develop factors of operational effectiveness which, in turn, have been related to unit cost, thus providing a basis for comparison of different types of aircraft. In consonance with the previous discussion of the limitations imposed by crew endurance and effectiveness, mission flight time has been used as a common denominator or unifying parameter.

The potential landplanes are considered to have one of two possible propulsion systems: a high-bypass-ratio turbofan of the technology being developed for the Boeing 747 and Lockheed C-5A, or a modern nonregenerated turboprop with the technology found in the Rolls Royce Tyne 20. A hypothetical family of airplanes powered by each propulsion plant has been analyzed. Each family contains dynamically similar airplanes of varying sizes incorporating technology available today. The airplanes are not necessarily optimized for each of the required ASW missions. The design assumptions made for these families of airplanes are listed in Table 1.

In the analysis of all missions, standard day and zero wind conditions have been assumed, as well as fuel reserves for 400 naut miles to alternate field and $\frac{1}{2}$-hr holding at 1000 ft plus 5% of initial fuel.

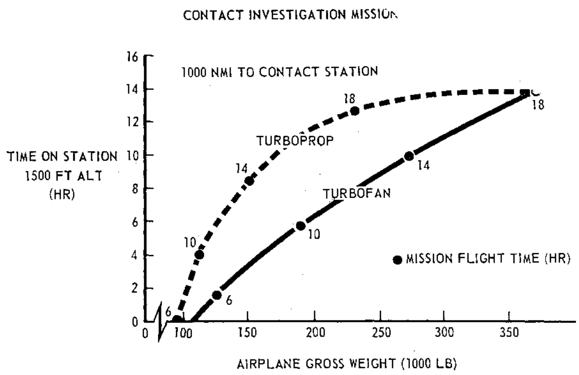

Fig. 3 Time on station vs airplane weight.

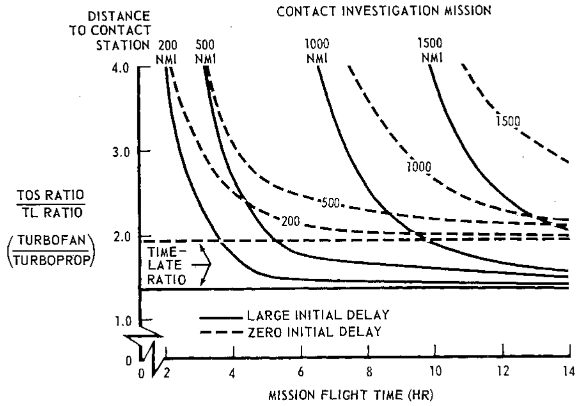

Fig. 5 Relative operational effectiveness.

Contact Investigation Mission

On this mission the aircraft dashes to the contact (datum) at high altitude and maximum continuous speed, proceeds to search out and kill the submarine at loiter speed, and returns to base at high altitude and maximum range speed. For the analysis of this mission a loiter altitude of 1500 ft has been assumed.

The investigation of the contact can take several forms or combinations of forms. It may consist of a single passive sonobuoy dropped on datum, or the enclosure of an area by sonobuoys. It may very likely be a combination of an enclosing pattern with sonobuoys interspersed in the closed area. Radar may or may not be used, depending on circumstances. Thus the initial detection phase may be regarded as extending from a point or line search to an area search.

Two factors of aircraft performance appear paramount in contact investigation: speed to contact area and time on station after arrival. Aircraft speed will be considered first. Assuming that a contact is at some finite position at a given time (in effect establishing a datum), and assuming that following the establishment of a datum a submarine will proceed at a cruising speed of advance if not alarmed, and at maximum noncavitating speed if alarmed, a circle can be drawn enclosing all possible submarine positions. It is recognized that this is an idealized assumption, since in many actual cases the datum is an "area of probability" of irregular shape covering a large number of square miles. For simplicity in this analysis, however, the concept of a point datum has been used as a basis for the following discussion of search area expansion vs time.

It is readily seen that the size of the circle of possible submarine positions is a function of submarine speed and of the time from datum establishment to aircraft arrival, usually called time late. Time late includes the initial delay from datum establishment to aircraft departure and the time required for the aircraft to transit from base to datum. The importance of time late in this mission can be appreciated by examining the following:

$$A = \pi V_s^2 T_L^2$$

where A is the circular area of possible submarine positions, V_s is submarine speed, and T_L is the time late. If $T_L = t_d + t_a$, where t_d is the initial delay and t_a is the aircraft transit time to datum, then the change in area size occurring during aircraft transit is

$$\Delta A = \pi V_s^2 (t_d + t_a)^2 - \pi V_s^2 t_d^2$$

If this equation is reduced and the respective changes in area due to the different dash speeds of two aircraft are compared,

$$\Delta A_1/\Delta A_2 = t_{a_1}(2t_d + t_{a_1})/t_{a_2}(2t_d + t_{a_2})$$

Examination of this expression discloses that if the airplane reaction is instantaneous, i.e., $t_d = 0$, the ratio of areas equals

$$(t_{a_1}/t_{a_2})^2 \quad \text{or} \quad (V_{a_2}/V_{a_1})^2$$

the square of the ratio of aircraft speeds, while if the reaction is slow so that t_d is large, in the limit the ratio equals V_{a_2}/V_{a_1}, the ratio of aircraft speeds. In practice, the time delay t_d will take some intermediate value, and the exponent of V_{a_2}/V_{a_1} will take some value between 1 and 2.

The second factor of significance in a contact investigation is time on station, which relates to search capacity once the airplane arrives at datum. A contact investigation even at a short range from base to datum often requires a considerable period to prosecute, and the importance of time on station clearly increases as the distance to datum increases and the locus of possible submarine positions consequently expands. Furthermore, as the capacity of modern submarines to wait out a search increases, so does the likelihood of the

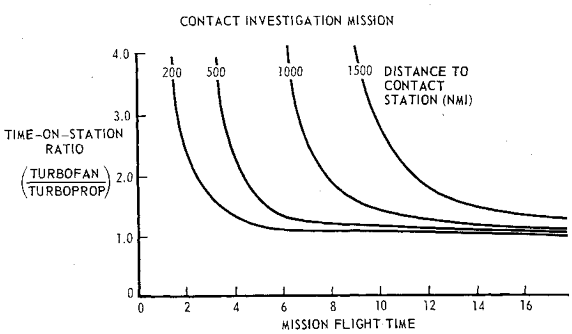

Fig. 4 Relative time on station.

Table 1 Design assumptions

Airframes	
Turbofan	Derivative of existing airplanes
Turboprop	Derivative of existing airplanes or newly developed
Powerplants	
Turbofan	High bypass ratio (Boeing 747 and Lockheed C-5A technology)
Turboprop	Most advanced existing nonregenerated (Rolls Royce Tyne 20 technology)
Wing loading	100 to 115 psf
Thrust loading	3lb airplane wt/lb thrust
Load factor	2.5
Takeoff	Less than 6000 ft, standard day
Maneuverability	30° bank with 1500-yd radius, 1500-ft alt, 36% stall margin
Payload, disposable stores	4800 lb
Avionics	8000 lb

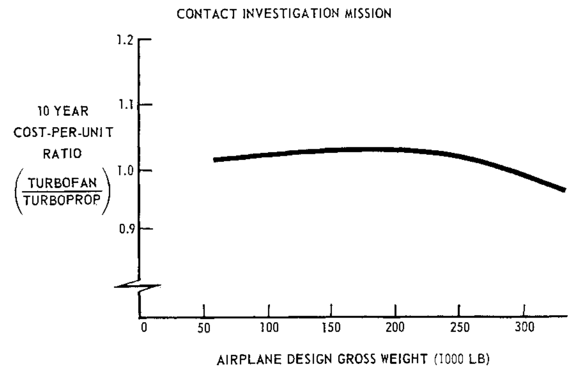

Fig. 6 Relative cost vs airplane weight.

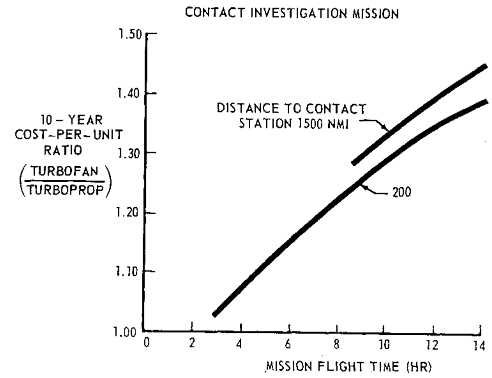

Fig. 7 Relative cost vs mission time.

contact investigation becoming a protracted search. In fact, it can be argued that the area searched, which is proportional to both time on station and airplane speed, would be a better measure of search capability than time on station. However, since on this mission the importance of area searched is not in every case as evident as that of time on station, time on station will be chosen as the parameter of search capability.

The relative operational effectiveness (ROE) of the two types of airplanes can be evaluated by combining the two factors discussed previously, remembering that aircraft effectiveness is proportional to time on station and inversely proportional to time late. For a very small initial delay,

$$\text{ROE} = \frac{\text{Time on station}_{a_1}/\text{Time on station}_{a_2}}{(\text{Time late}_{a_1}/\text{Time late}_{a_2})^2} = \left[\frac{\text{Time-on-station ratio}}{(\text{Time-late ratio})^2}\right]_{a_1/a_2}$$

For a very large initial delay, this becomes

$$\text{ROE} = \left[\frac{\text{Time-on-station ratio}}{\text{Time-late ratio}}\right]_{a_1/a_2}$$

Having established these guidelines, the performance and operational characteristics of turbofan and turboprop airplanes on contact investigation missions will be compared. Figure 3 indicates that for a given distance to a contact and for all practical airplane gross weights up to 350,000 lb, a turboprop yields a higher time on station than a turbofan of the same weight. This is typical of the two families of airplanes on the missions being considered and is largely due to the superior fuel efficiency of turboprop powerplants in the loiter and dash modes. However, it is also to be noted in Fig. 3 that for equal time on station at equal distance to a contact, the turbofan typically has shorter total mission times. This is significant because it relates to the endurance of a very important component of the system—the crew.

To give the limiting human factors of crew effectiveness and endurance due consideration, performance has been appraised in terms of time spent on station for a given total mission time in Fig. 4. Viewed in this manner, and assuming employment of single crews, the turbofan time-on-station capability is uniformly superior, with its advantage increasing at longer distances to contact and decreasing with increasing mission time. Since time late to a contact is proportional to airplane speed, the turbofan will have a lower time late by a factor approximately equal to the ratio of dash speeds, or 1.4 for the airplanes in this study.

Combining relative time on station and relative time late by the method outlined previously, the turbofan operational effectiveness in the spectrum of contact investigation missions considered is superior by a factor of at least 2.0 for the case of zero initial delay and at least 1.5 for the case of a large initial delay (Fig. 5). As with the time-on-station ratio, the advantage increases at longer distances to contact but decreases at the longer mission times.

Ten-year costs per unit aircraft based on the following assumptions have been calculated for airplanes of the same design gross weight: 10-yr program duration; 350 unit equipment aircraft; 1.33 crews per unit equipment aircraft; 900 hr/yr unit equipment aircraft utilization. The costs included design, development, tests, engineering; initial investment including command support, attrition, spares, training; and operation and maintenance including all personnel and spares.

The calculated 10-yr costs per unit aircraft are found to be slightly unfavorable to the turbofan up to a gross weight of about 285,000 lb (Fig. 6). The principal reason for this is the higher weight of swept wings and associated structural features of the higher-speed turbofan airplane.

It may be recalled that Fig. 3 gave indications that to satisfy any given mission time, a turbofan has to have a higher design gross weight than a turboprop. Primarily because of this characteristic, the ratio of 10-yr costs per unit is unfavorable to the turbofan by about 8% for a 4-hr mission and by about 30% for a 10-hr mission (Fig. 7).

When the relative 10-yr costs per unit are combined with the relative operational effectiveness, the result is the over-all figure of merit depicted in Fig. 8. This figure of merit is similar to the well-known "how much bang for a buck." Following the pattern just noted for operational effectiveness, this final comparison is uniformly favorable to the turbofan for the mission times and distances to station being considered, the turbofan showing up better at the longer distances to station and at the shorter mission times. Within the region of what is considered to be the most probable mode of operation for contact investigation missions, i.e., 200 to 1000 naut miles to a contact and not over 8 hr flight time (11 hr total crew involvement time), the turbofan is superior by a factor

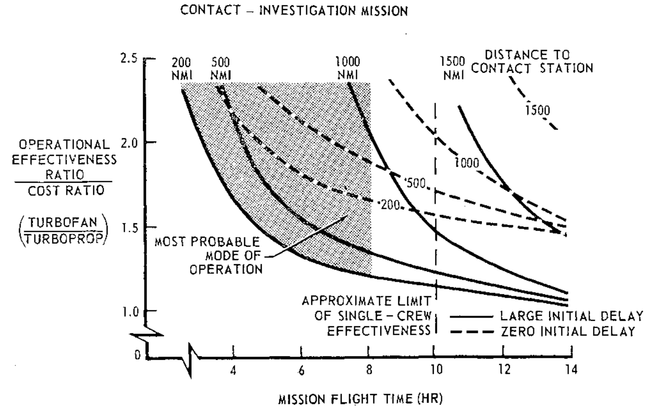

Fig. 8 Ratio of operational effectiveness to cost.

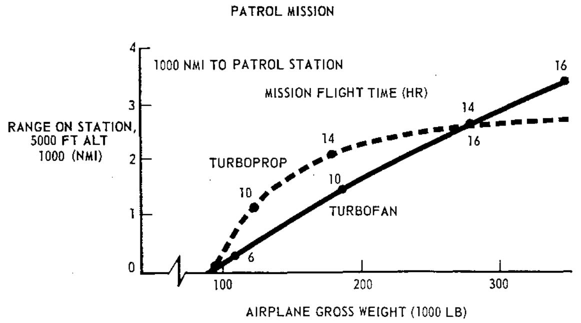

Fig. 9 Range on station vs airplane weight.

of at least 1.6 for the case of zero initial delay and at least 1.2 for the case of a large initial delay.

Patrol Mission

On the patrol mission assumed for this study, the aircraft maintains maximum range cruise speed throughout the flight, flies at high altitude to and from the patrol station, and maintains an average altitude of 5000 ft on patrol station. The patrol can take several forms, depending on whether the mission is an area patrol, a barrier patrol, surveillance of shipping along a coast, or some other specific mission. While on station, the airplane flies close to an optimum radar altitude, most commonly between 3000 and 8000 ft. Although improved technology may increase this altitude, there are insufficient assurances at this time of increased altitude capability. Although it is recognized that the aircraft mode of search could be with radar silent, dropping sonobuoys from high altitude, the lower altitude was chosen for conservatism. The aircraft may occasionally descend to low altitude in order to identify or photograph surface craft, but only rarely will it remain steadily at low altitude.

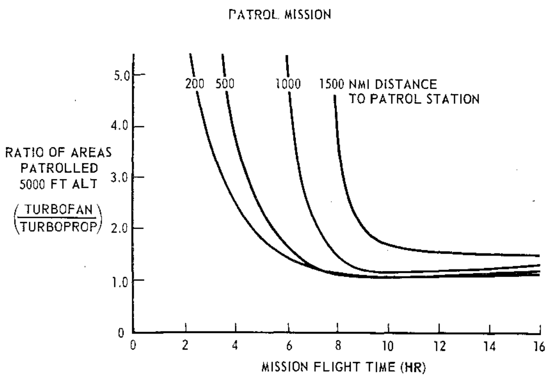

Fig. 10 Relative operational effectiveness.

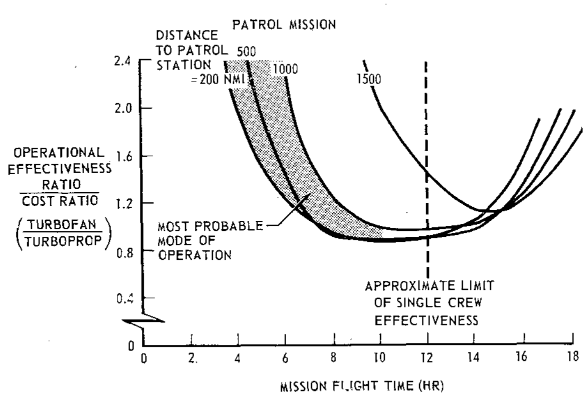

Fig. 11 Ratio of operational effectiveness to cost.

Table 2 Patrol times favorable to turbofan

Distance to station, naut miles	Maximum favorable flight time, hr
200	7.4
500	7.4
700	8.0
1000	10.0

Depending on the exact nature of the mission, either total area patrolled or total distance covered may be suitable measures of the work performed while on station. It can be assumed that the patrol pattern consists of a series of straight lines, as is most commonly the case, and that effective radar range defines the width of the area investigated during straight-line flight. Then for patrol missions in general, the relative range on station can be utilized to compare the relative operational effectiveness of two airplanes in the following manner:

$$\text{ROE} = \text{Range on station}_{a_1}/\text{Range on station}_{a_2}$$

This can be represented as

$$\frac{\text{Time on station}_{a_1}}{\text{Time on station}_{a_2}} \times \frac{\text{Av speed on station}_{a_1}}{\text{Av speed on station}_{a_2}}$$

Bearing this in mind, the performance and operational characteristics of turbofan and turboprop airplanes on ASW patrol missions will be compared using a method similar to that used in the preceding section on contact investigation.

Figure 9 indicates that, for a given airplane gross weight between 100,000 and about 380,000 lb, a turboprop flies a longer distance while on station. The primary reason for this is the superior airplane efficiency of the turboprop on low-altitude cruise (Fig. 2). In terms of area patrolled for a given mission flight time, however, it is found that the turbofan is superior throughout the range of times and distances to station being considered (Fig. 10), and as in the case of contact investigation, the advantage increases at longer distances but decreases at longer mission times. The conservative 5000-ft patrol altitude is particularly harsh on the turbofan aircraft. If radar improvements alleviated this altitude requirement, the turbofan airplane would improve its search rate by 50% while the turboprop airplane would improve by only 35%, and the turbofan airplane would then be superior in aircraft efficiency (Fig. 2). Again, similar to what was found before for the contact investigation mission, relative airplane gross weights are unfavorable to the turbofan, and because of this the ratio of 10-yr costs per unit is also unfavorable to the turbofan.

But combining 10-yr costs per unit with relative operational efficiency, the over-all figure of merit obtained (Fig. 11) is predominantly favorable to the turbofan, with the turbofan showing up better at the longer distances to station and at the shorter mission times. Because of the less strenuous physical demands imposed on the crew by this type of mission, it has been assumed that most probable mission times extend to 10 hr (13 hr total crew involvement time). For the most probable distances to patrol station, i.e., 200 to 1000 naut miles, the turbofan is superior to the turboprop up to the mission flight times given in Table 2.