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# Land-Based Aircraft Options for Naval Missions

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Society of Automotive Engineers

Aerospace Meeting
Airport Sheraton Inn, Los Angeles
November 14-17, 1977

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ALTHOUGH IT IS NOW MORE THAN THIRTY YEARS PAST, World War II remains the basic point of reference in analysis of naval warfare, for there has never been a major naval campaign since. In the naval sphere the lesions of that conflict were truly revolutionary, so much that they have yet to be fully assimilated by many.

As Admiral of the Fleet of the Soviet Union Sergei G. Gorshkov has observed (1)*, in World War II, "Experience in combat operations in the sea and oceanic theaters showed that submarines and aircraft had become the main, more versatile and effective types of naval forces." The naval air power which proved so important in that war was, in significant measure, land based. Land based aircraft accounted for about half of all the U-boats destroyed or put permanently out of action. Minelaying and strike aircraft operating from land bases were among the major killers of logistic shipping. And land-based aircraft scored notable successes against warships.

But land-based aircraft fell far short of meeting all needs for naval air power in World War II. The essence of air power is getting enough aircraft with the proper capabilities over the target, when they are needed. The principal factor limiting land-based aircraft as instruments of air power, particularly at sea, was lack of range performance. To achieve transoceanic ranges in the face of low propulsion system efficiencies, low lift/drag ratios, and high empty weight fractions, designers had to accept large size, poor agility, limited speed, and/or low ratios of payload to gross weight. This meant that long range land-based aircraft were too costly and too limited in capability for many missions, while aircraft with the needed capabilities and low costs could not reach many vital targets from available land bases.

The geographically-imposed need for naval operations has not changed since the Second World War (although the political-military factors which affect base availability have fluctuated). But the range potential of aircraft has improved significantly as aeronautical technology has advanced (2), bringing many more important ocean areas within reach of aircraft flying from land bases securely in our possession. Moreover, the rapid advance in sensor and weapon

*Numbers in parentheses designate References at the end of paper.

ABSTRACT

Advances in aeronautical technology favor increased application of land-based aircraft to naval missions. A number of aircraft types now combine attractive mission capabilities with good coverage of ocean areas from available bases. Further developments can be expected to improve mission capabilities and/or range. The result is a broader range of options for naval planners.

technologies has made factors such as aircraft agility and low-altitude performance less important for many missions, and this operates in favor of longer-range aircraft.

To again quote Admiral Gorshkov, "Considering the importance of the missions being accomplished by aircraft, and looking at the possible nature of naval warfare, it is fully logical to believe that the importance of aircraft in comparison with the last war is greatly increasing." (1) In particular, it seems likely that the roles which land-based aircraft can efficiently and economically play in sea war are expanding in scope and importance.

This paper will examine the major naval mission areas and some possible roles for land-based aircraft in each. No attempt will be made to define precise mission requirements or to compare land-based aircraft with other possible alternatives.


Fig. 1 - Photograph of P-3C

ANTI-SUBMARINE WARFARE

The greatest single threat to Western maritime security at this time is the submarine. It is worthwhile to note that this is not a result of the strength of the submarine as a fighting ship--for its size and cost it is among the weakest and most vulnerable of naval vessels. Rather, the severity of this threat is a direct reflection of the difficulty of finding submarines in the first place.

Aircraft were the major killers of submarines during World War II, and there is every reason to believe that this would continue to be true if a naval campaign were to be fought today. To those who are unfamiliar with modern air ASW (anti-submarine warfare) it is often surprising to learn that aircraft can successfully hunt submarines which do not come to the surface. By dropping sensitive acoustic sensors, packaged as sonobuoys, into the water the aircraft is able to obtain detection results which compare quite favorably with those for ships and anti-submarine submarines.

There are several reasons why aircraft are particularly efficient and effective submarine hunters, including,

1. Speed of Response. Since detections of submarines will be infrequent and fleeting the airplane's ability to reach the scene quickly is of considerable importance.

2. Lack of Vulnerability. It is relatively difficult for submarines to attack aircraft.

3. Flexibility. The high mobility of aircraft, particularly long-range aircraft, permits the ASW commander to concentrate their effort where and when it is needed.

4. Low Cost. The unit costs of ASW aircraft, while large by absolute standards, are small compared to those of submarines, so that one can afford a large force of them compared to the number of targets.

The principal land-based ASW aircraft of the U.S. Navy at this time is the Lockheed P-3C Orion (Fig. 1). The P-3 series aircraft are derivatives of a commercial transport design of the mid-1950s, the Lockheed L-188 Electra. Principal data for the P-3C are shown in Table 1.

It is frequently asserted that an ASW aircraft is only as good as its ASW avionics. This is certainly true in the sense that the vast superiority of the P-3C over roughly similar ASW aircraft produced in other countries is very largely a matter of the excellence of the avionics system developed for this aircraft through the combined efforts of the U.S. Naval Air Development Center, Lockheed, and a number of avionics equipment contractors.

Any implication that the qualities of the aircraft itself are unimportant is not correct, however. In the first place, employment of the AN/ASQ-81 MAD (magnetic anomaly detection) equipment, which is used to obtain final target verification and localization, requires that the aircraft be flown in a very tight and precise pattern quite close to the water. Thus it is essential that the aircraft have good maneuverability and handling qualities during low-speed maneuvering at low altitudes and that pilot workload be kept to a minimum under these conditions.

Beyond the requirements for low-speed, low-altitude maneuvering imposed by current ASW equipment and tactical concepts, and those for ruggedness, simplicity, and corrosion resistance common to all naval aircraft, there is the matter of range, or, more specifically, radius of action. (Radius of action is that distance from its base to which the aircraft can fly, perform its designated mission, and return with specified reserves.) As will be seen from Table 1, for a mission requiring four hours patrol time on station the radius of action of the P-3C is a little more than 1400 nautical miles. Actual operational radii will usually be less than this, due to needs to operate the aircraft in non-optimal configurations, crew-fatigue considerations, or unfavorable disposition of available alternate bases.

Operating from presently-available U.S. and allied bases the P-3C can give good coverage of many important ocean areas, as is shown in Figure 2. (Figure 2 includes some bases from which U.S. Navy P-3s do not regularly operate at present but which are suitable for P-3 operations and which lie in the territory of allies with whom we have mutual defense agreements.) There are other important ocean areas, however, which remain beyond the P-3's reach. Moreover, certain of the bases shown in Figure 2 might not be available, in one eventuality or another, for political or military reasons. An aircraft with greater range would thus be even more useful.

One possibility is to stretch the P-3. Lockheed has conducted a feasibility-level conceptual design study of a P-3 with increased span and fuselage length, greater fuel capacity, refined engines, and strengthened structure for higher gross weights. Preliminary details are given in Table 2 and it will be seen that the stretched P-3 has sub-

Table 1 - Lockheed P-3C Orion (Update III version)

| | |
|---|---|
| Configuration | |
| Overall length | 116' 10" |
| Span | 99' 8" |
| Wing area | 1300 sq.ft. |
| Weights | |
| Empty | 66,795 lb. |
| Fuel capacity (@6.8 lb./gal.) | 62,560 |
| Design gross | 139,465 |
| ASW payload | 19,853 |
| Propulsion | |
| 4 Detroit Diesel Allison T56-A-14 turboprop engines | |
| Rated power, per engine | 4,591 SHP |
| Equivalent cruise TSFC (installed) | 0.58 lb./lb-h. |
| Performance (Clean, at design gross weight unless specified) | |
| Maximum speed (15,000 ft.) | 380 knots |
| Service ceiling | 27,000 feet |
| Radius of action* | |
| Zero time on station | 2,020 n.m. |
| 4 hour time on station** | 1,440 |
| 8 hour time on station** | 900 |
| Flight duration* | |
| Normal mission | 12 hours |
| Maximum (4 engine loiter) | 14.0 |
| Maximum (2 engine loiter) | 15.6 |
| Average long-range cruise speed (25,000 ft.) | 350 knots |
| Ferry range | 4,830 n.m. |
| Load factors | |
| 142,000 lb. gross weight | +2.5, -0.8 |
| 135,000 lb. gross weight | +3.0, -1.0 |
| Mission Equipment | |
| A-NEW digital computerized integrated anti-submarine and anti-ship combat system. Advanced acoustic signal processor, APS-115 surface search radar, FLIR, ALQ-78 ESM. | |
| Stores: | |
| Sonobuoy chutes | 52 |
| Internal weapons bay length | 154 inches |
| External stores stations | 6 x 2000 lb. |
| | 2 x 1000 lb. |
| | 2 x 500 lb. |
| Weapons delivery capability includes Mk. 46 torpedo, HARPOON anti-ship missile, and various mines. | |

*With reserves equal to 10% of initial fuel plus fuel for 20 minutes at sea level, 5% increased fuel flow, and four-engine loiter unless specified.

** With two hours of loiter time spent at sea level.

Source: Lockheed

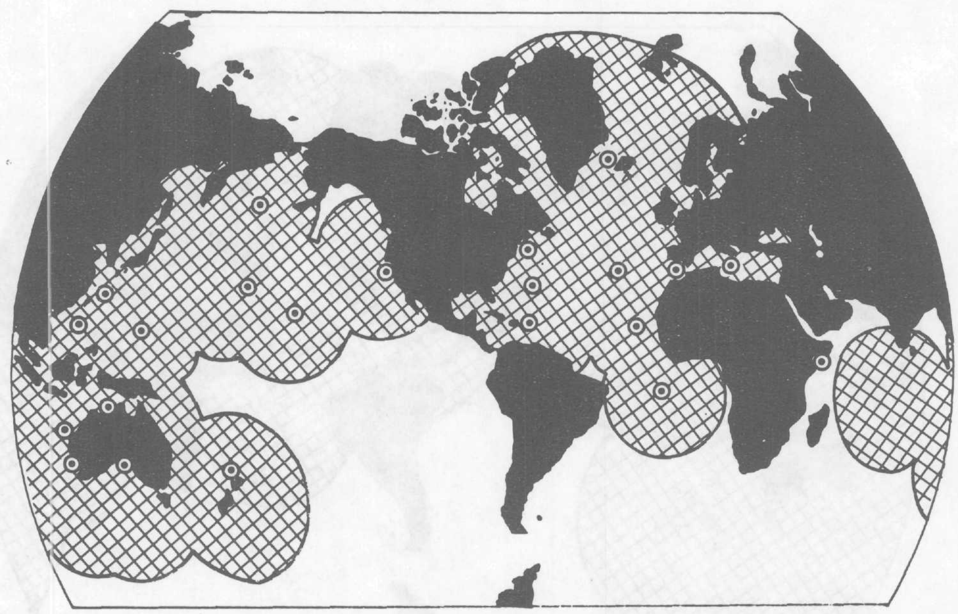

**Fig. 2 - P-3C potential coverage from selected bases (1440 n.m. radius)**

stantially greater range than the P-3C. This increased range can be used to extend the area which may be covered from existing bases, increase times on station in present patrol areas, or cover present areas with fewer or less favorably located bases. Figure 3 illustrates the fact that it is possible with the increased radius of the stretched P-3 to simultaneously increase coverage and cut back on bases.

Both the time and costs to develop such a stretch P-3 would be small by comparison with those for any entirely new aircraft and the production costs would probably be less than those for a new aircraft of comparable capabilities, given comparable production rates.

Some questions remain concerning the stretched P-3. One of these concerns the effects of sixteen to seventeen hour missions on crew efficiency. It probably will be necessary to increase the normal crew size from the P-3C's 10 to 14 or so to provide on-board reliefs for critical personnel. Special attention will have to be paid to crew efficiency and comfort in any long-endurance aircraft.

The vast decreases in the weight and cost of electronic systems, per unit of capability, over the past twenty years, have made possible the tremendous improvement in ASW effectiveness from the P-3A to the Update III P-3C, with little growth in aircraft or payload size. In order to substantially expand the area ASW surveillance capabilities of aircraft, however, or to add further to the non ASW capabilities, a larger payload will be needed. The stretched P-3 could probably accept some limited additional payload, thanks to the six-foot stretch of the fuselage, but at the sacrifice of some range. (A thousand pounds of payload would cost 20 to 50 nautical miles of radius of action.) If very much additional payload is required, or if growth in both payload and range is needed, then another aircraft entirely will be necessary.

Table 2 - Stretched P-3

| | |
|---|---|
| **Configuration** | |
| Overall length | 123' 2" |
| Span | 110' |
| Wing area | 1,498 sq.ft. |
| **Weights** | |
| Empty | 72,475 lb. |
| Fuel capacity (@6.8 lb./gal.) | 80,520 |
| Design gross | 163,450 |
| ASW payload | 19,883 |
| **Propulsion** | |
| 4 Detroit Diesel Allison 501-M69 turboprop engines | |
| Rated power per engine | 4,678 SHP |
| Equivalent cruise TSFC (installed) | 0.52 lb./lb-h. |
| **Performance** (Clean, at design gross weight unless specified) | |
| Maximum speed (15,000 ft.) | 370 knots |
| Service ceiling | 27,000 ft. |
| Radius of action* | |
| Zero time on station | 2,750 n.m. |
| 4 hour time on station** | 2,110 n.m. |
| 8 hour time on station** | 1,430 n.m. |
| Flight duration* | |
| Normal mission | 16 hours |
| Maximum (4 engine loiter) | 20 |
| Maximum (2 engine loiter) | 21 |
| Ferry range | 6,500 n.m. |
| Load factors | |
| 163,450 lb. gross weight | +2.5, -0.8 |
| 155,500 lb. gross weight | +3.0, -1.0 |
| **Mission Equipment** | |
| Identical to P-3C (Update III) except that length of weapons bay is increased to 173 inches. | |

*With reserves equal to 10% of initial fuel plus fuel for 20 minutes at sea level, 5% increased fuel flow, and four-engine loiter unless specified.

**With 2 hours of loiter time spent at sea level.

Source: Lockheed feasibility-level conceptual design study.

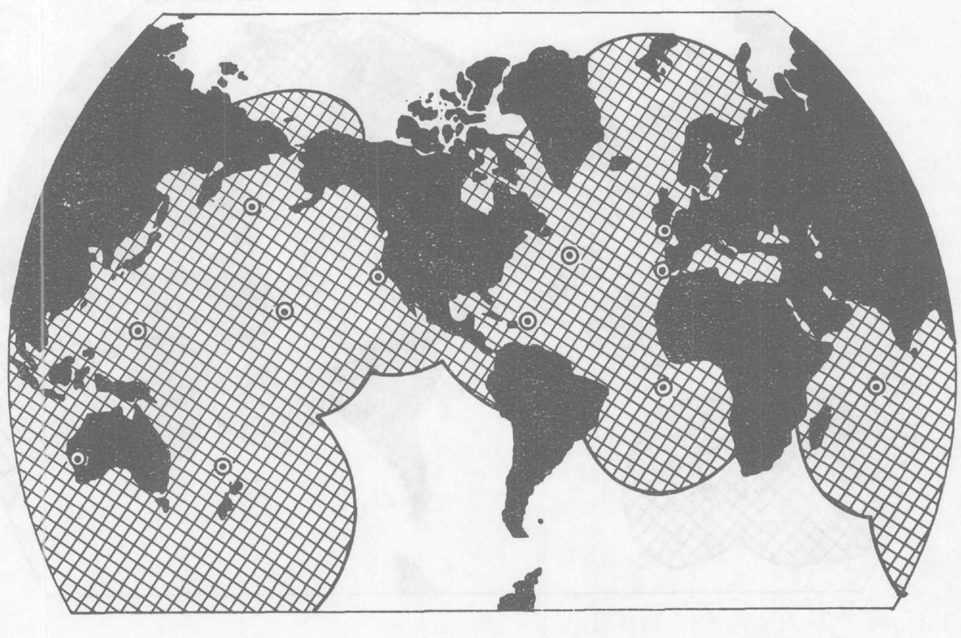

**Fig. 3 - Stretched P-3 potential coverage with reduced basing (2120 n.m. radius)**

In the past, many land-based ASW aircraft have been adaptations of then-current bomber or transport types--the Lockheed PV, the Consolidated P4Y, the Short Sunderland, the Avro Shackleton, the Hawker-Siddeley Nimrod, the Canadair Argus, the Ilyushin Il-38, and the P-3 itself are all examples. Thus it is natural to consider whether it might be attractive to repeat the trick.

Table 3 provides data on a selection of current bomber and transport aircraft, operated on patrol mission profiles. One of these, the B-52, is of questionable suitability for ASW missions since its 23-foot length of pressurized fuselage would not accommodate normal ASW equipment and crew.

It is likely that any of the remaining aircraft of Table 3 (and others in the same class) could be modified to serve as an ASW vehicle with better range-payload performance than the stretched P-3. This might be necessary if it were desired to use aircraft to supplement ASW surveillance, requiring carriage of surveillance equipment and stores on long-term patrol. (The maximum radius for efficient long-term patrol is about half of the maximum radius for zero time on station; this point will be discussed at greater length later in this paper.) These aircraft could also expand the area of land-based ASW aircraft coverage, reduce the number of bases required for equivalent coverage, and/or permit ASW aircraft to carry equipment and stores for additional missions. None of them is so well adapted to low-altitude maneuvering as is the P-3, but new systems and tactics may permit ASW aircraft to do most of their work from high altitudes, seldom if ever descending for MAD detections.

The cost and time to develop a modified version of such an aircraft, outfitted for ASW, should be roughly comparable to that to develop the stretched P-3. In terms of empty weight, however, these aircraft are 80% to 375% larger than the stretched P-3. Aircraft costs are very heavily influenced by empty weight and it is safe to assume that ASW versions of these aircraft would be substantially more expensive than the stretched P-3. Since, under existing circumstances, the Navy can only spend more on system X if it spends less on system Y, the acquisition of larger, more expensive aircraft would appear to be feasible only if: (a) their improved efficiency permitted enough reduction in numbers bought to outweigh the added unit cost, or (b) they could take over missions which would otherwise have to be performed at greater expense by other forces. It has not been demonstrated, to this time, that any of these aircraft could fulfill these conditions.

The alternative to adaptation of an existing type is development of an all-new aircraft. Figures 4 and 5 present performance estimates for new-development aircraft derived from a highly-simplified parametric model (discussed in Appendix A). Data are shown

Table 3 - Bomber and Transport Aircraft

| | Boeing B-52D Re-engined | Boeing 707-320B Modified & Re-engined | Douglas DC-10-30 | Boeing 747-200 |
|---|---|---|---|---|
| Configuration | | | | |
| Overall length | 156' 6" | 148' 0" | 182' 3" | 225' 2" |
| Span | 185' 0" | 142' 6" | 165' 4" | 195' 8" |
| Wing area | 4000 sq.ft. | 2892 sq.ft. | 3647 sq.ft. | 5500 sq.ft. |
| Weights | | | | |
| Operating Empty* | 187,500 lb. | 132,200 lb. | 236,400 lb. | 344,000 lb. |
| Assumed Mission Payload | 45,000 | 30,000 | 50,000 | 70,000 |
| Assumed Fuel Load | 217,500 | 177,800 | 303,600 | 406,000 |
| Maximum Gross | 450,000 | 340,000 | 590,000 | 820,000 |
| Performance (Clean, Maximum Gross Weight) | | | | |
| Radius of Action** | | | | |
| 0 TOS | 3910 n.m. | 3140 n.m. | 3900 n.m. | 3700 n.m. |
| 4 hr. TOS | 3100 | 2300 | 2900 | 2900 |
| 8 hr. TOS | 2400 | 1400 | 1900 | 2100 |
| Total Mission Time | 20.1 hr. | 15.0 hr. | 15.5 hr. | 19 hr. |
| Typical Cruise Speed | 390 kt. | 445 kt. | 475 kt. | 480 kt. |
| Load Factor at Max. Gross Weight | 1.8g | 2.5g | 2.5g | 2.5g |
| Major Changes from Basic Aircraft | CF6 or JT9D or RB 211 Engines | Minimum equipment changes; JT10D or CFM 56 Weapon Bays | Minimum equip-changes; Body Fuel | Minimum equip-changes; Body Fuel |

*As normally equipped, without naval mission equipment.
**With reserves equal to 10% of initial fuel plus for 20 minutes at sea level, and 5% increased fuel flow.

Source: Estimates based on manufacturer's data.

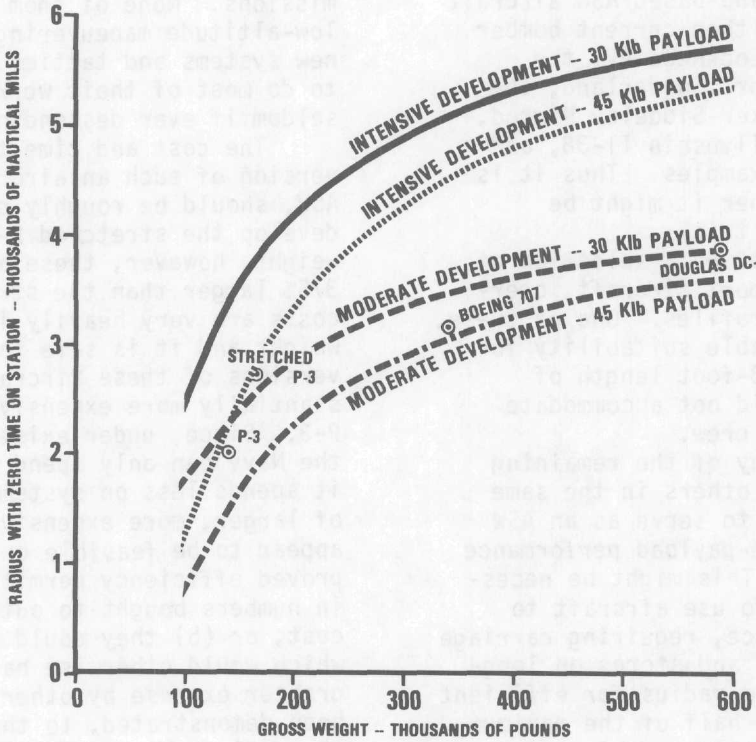


Fig. 4 - Radius with zero time on station

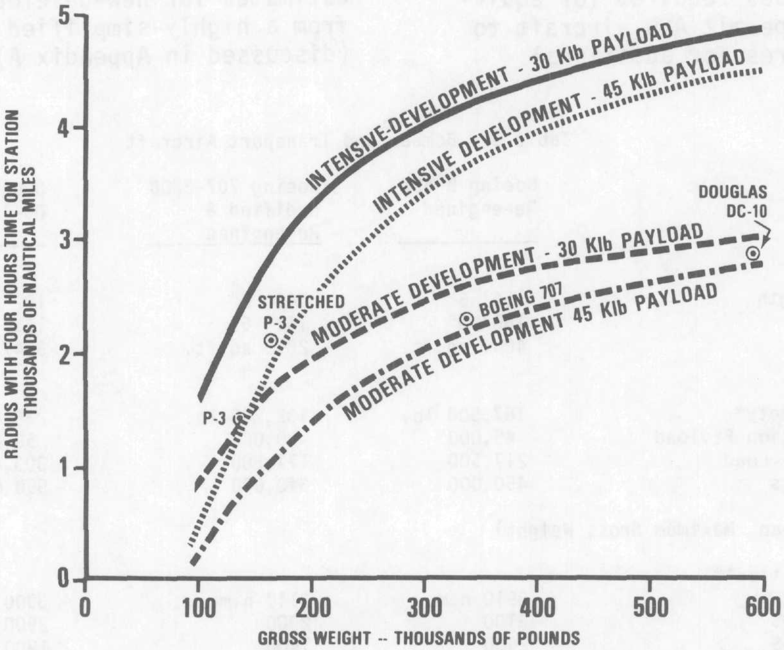


Fig. 5 - Radius with four h time on station

for both "moderate-development" and "intensive-development" aircraft. A moderate-development aircraft, in this context, is one which stays with technology which is available more-or-less "off the shelf" in an effort to minimize development costs. It would for instance employ engines already developed for other applications, largely metal primary structure, relaxed but non-negative static stability margins, fixed planar array antennas, etc. The designers of an intensive-development aircraft, by contrast, would pay the price to reduce developmental technology to practice in order to produce an aircraft with a better performance relative to its size and, hopefully, cost. It might embody improvements such as composite materials in primary structure, negative static stability margins, high-Mach-number turboprops, new-development engines, conformal-array antennas, etc.

The performance here assumed for the intensive-development aircraft presupposes substantial development effort on technology and subsystems, which would add to aircraft development cost and delay its service entry. On the other hand, under present acquisition policies any new-development aircraft will have a lengthy gestation period, regardless of technology level. Given this, and the substantial reduction in size for any desired level of performance, it seems likely that an intensive-development aircraft would be the better choice unless the number to be procured was small.

But the costs of developing such an aircraft would be staggering--probably in excess of three billion dollars! It would be very difficult for the U.S. Navy to find such a sum for ASW aircraft development and there must be a strong impetus toward sharing this huge development cost with some other user. Recalling the historic association between airliners and ASW patrol aircraft one might suppose that the development cost could be spread by developing a dual-use aircraft, with commercial transport and ASW applications.

Unfortunately, the prospects for development of new air transport aircraft of any sort appear quite uncertain. Beyond this, it seems clear that the needs of the airlines and of the Navy have been diverging. In airline terms the planes we have been discussing represent the ultimate in "long-thin" airplanes--aircraft designed to carry very modest payloads over very great distances. What the airlines are looking for at this time are high-capacity aircraft for relatively short to medium stage lengths (3). There is a fundamental conflict in the design requirements between these two classes of aircraft which cannot be resolved in any way which will be economically and militarily acceptable.

Broadly speaking, the needs for ASW aircraft can be divided into two categories, which we shall class as "responsive" or "patrol". In a responsive mission the aircraft is responding to some alert of a submarine's presence - a report of a torpedoing or detection by a surveillance system or another unit, for instance - and needs to get there fairly quickly. When it arrives it will need to spend some time trying to redetect and attack the submarine but, generally speaking, will either achieve a kill within four to eight hours or have very little chance of ever making it. Thus for these missions speed is no less essential than endurance.

In a patrol mission, on the other hand, the object is to maintain a continuous search (or perhaps simply a continuous readiness to respond to contacts by nearby units) in a certain geographic area, or around a surface force, over an extended period of time - days or even weeks. This would normally be accomplished by having the aircraft fly in relays, relieving one another on station, but even so patrol missions put a premium on endurance and for them it might perhaps be desirable to develop special types of aircraft having especially great endurance.

There are at least two types of aircraft which fit this description: airships and open-ocean seaplanes. The airship, having no induced drag when operating at neutral buoyancy can loiter at low speeds with little propulsion power. An open-ocean seaplane can rest on the surface of the water with little or no propulsion power. In either case, fuel consumption while on patrol is greatly reduced.

It has been nearly half a century since the last large naval airship, the U.S.S. Macon (ZRS 5), was built by Goodyear. There has been a revival of interest in lighter-than-air (LTA) aircraft and examination of the performance predicted for a modern airship of the Macon's size will indicate some of the reasons (see Table 4). Most of the

Table 4 - Airships

| | USS MACON ZRS-5 (1933) | Modernized Macon-size Airship |
|---|---|---|
| Configuration | | |
| Overall Length | 785 ft. | 785 ft. |
| Maximum Diameter | 132.9 ft. | 132.9 ft. |
| Nominal Gas Volume | 6,500,000 cu.ft. | 6,500,000 cu.ft. |
| Weights | | |
| Empty | 242,356 lb. | 175,676 lb. |
| Fuel | 110,000 | 192,600 |
| Ballast | 20,000 | 0* |
| Gross | 403,000 | 416,625 |
| Payload | 28,244 | 45,000 |
| Propulsion | | |
| Cruise Engines | | |
| Type | 8 Maybach VL-II Diesel | 4 Gas Turbine |
| Power per Engine | 560 BHP | 1060 SHP |
| Loiter Engines | | |
| Type | (Loiter on | 2 Diesel |
| Power per Engine | cruise engines) | 250 BHP |
| Performance | | |
| Maximum Speed | 75.6 Kt. | 80 Kt. |
| Normal cruising speed | 55 Kt. | 65 Kt. |
| Service ceiling | | 5000 ft. |
| Maximum Radius of Action** | 2670 n.m. | 5630 n.m. |
| Time on station for radius of action** | | |
| 5000 n.m. | -- | 4.0 days |
| 3000 n.m. | -- | 16.5 |
| 2000 n.m. | 3.6 days | 22.7 |
| 1000 n.m. | 9.1 | 29.0 |
| Time on station for radius of action*** | | |
| 3000 n.m. | -- | 2.5 days |
| 2000 n.m. | -- | 5.5 |
| Crew | 91 | 30 |

*No water ballast at takeoff; water picked up from sea as fuel burnt off.
**Cruise out and back at normal cruising speed; loiter at 30 knots; 10% reserves; 100 lb./hr. fuel burnt for auxiliary and service purposes.
***As above but cruise at 80 knots and loiter at 50 knots.

Sources:
For Macon: Estimates based on data from Richard K. Smith, The Airships Akron and Macon, Annapolis, U.S. Naval Institute, 1965.
For Modernized Airship: Estimates based on Goodyear data.

improvement over the Macon results from predicted reductions in empty weight through the use of modern materials, equipment, and design tools. The weight estimates are inevitably somewhat speculative in the absence of recent, directly-relevant design experience, but do reflect a well-understood and proven basic structural scheme (wire-braced built-up ring frames tied together with longitudinal girders--a structural concept very similar to that of the last Zeppelins) and a considerable body of theoretical, model-test, and empirical data on loads. While the history of the large rigid airships was not a happy one, there is little in the historical record to indicate that such vehicles are basically unfeasible (4). Many operational questions remain, however.

The virtues of airships are greatest in missions which do not make high demands for speed; at speeds much in excess of 100 knots their lift/drag ratios start to become unattractive. (Because of the square-cube law airship speed capabilities improve with size, however.) For responding to ASW surveillance contacts, for instance, the limited speed of the airship would be a serious handicap, in most cases. But for missions requiring lengthy patrol at low speeds (below, say 50 knots) the efficiency of the airship is impressive. It is interesting to note that in sprint-and-drift operations (to deploy low-speed ASW sensors, for instance) the modern airship of Table 4 could escort a 30-knot convoy for more than 5,000 nautical miles into a 20-knot headwind, without refueling. (Airships have demonstrated the ability to refuel and replenish from surface ships in the past.)

Hybrid airships, in which a major portion of the lift is produced by airflow over a flatened hull, have been investigated by several organizations, most notably Aereon Corp., Boeing-Vertol, and Goodyear. Low-speed efficiency is sacrificed but cruise speeds move upward--perhaps to 200 knots or so for vehicles in the size range of probable interest. The crucial question is structural weight. The most detailed examinations to date, by Goodyear, have tended to make the hybrids look unpromisingly heavy, but others disagree.

The PS-1, designed and built by Shin Meiwa of Japan, appears to be the closest approach to an open-ocean seaplane built to date. This aircraft, described briefly in Table 5, was actually designed for ASW. The available data do not give a very complete picture of its performance but it seems clear that a substantial penalty has been paid for open-ocean landing capability. It is claimed that the aircraft can operate in seas up to 14 feet, although one wonders what the ride must be like when sitting on the water in such conditions. It is probably unwise to try to draw any sweeping conclusions about open-ocean seaplanes on the basis of this one example.

A design study for a "sea control amphibian" aircraft with the ability to land and take off in sea state 5 (one-third highest average wave heights to 14 feet, with 20 foot waves commonly encountered) has been reported (5). A very large catamaran hull was selected to provide adequate stability and seakeeping during sea sitting. General data are given in Table 6.

Because of the paucity of relevant design data this design must be regarded as relatively speculative at this time, with open-sea landing, takeoff, and loiter being the principal question areas. There are also many mission questions, chief among which is what it is that such an aircraft can do that would justify the enormous costs which must go with its bulk. Nevertheless, it is an impressive and thought-provoking concept.

In addition to being able to stay on patrol station with low fuel consumption, both airships and open-ocean seaplanes offer the possibility of deploying anti-submarine sensors into the water and then recovering them. There are obvious economic advantages in not discarding the sensor, as a normal ASW airplane must with its sonobuoys. The recoverable sensor could either be tethered to the seaplane or left floating freely, for later pick-up.

But the virtues of recoverable sensors are not entirely clear-cut. The sensor array will normally be heavier than it could be if expendable, and the aircraft must carry heavy and bulky recovery gear. If the array is towed by or tethered to the aircraft it could be a serious embarrassment when a contact was made or a threat was reported, since recovery would normally take considerable time. If the sensor was not tethered to the aircraft its recovery is likely to involve some rather difficult feats of seamanship, particularly in rough weather. Against the possible range advantages of a recoverable sensor must be set the conventional aircraft's ability to spread its expendable sensors quickly over a large area and to monitor them all by radio from high altitude.

A wide variety of potential ASW aircraft have been discussed here; it seems likely that we neither need nor can afford all of them. But which ones should develop and acquire--if any? This question ought to be answered on the basis of detailed, quantitative evaluations of costs, military worth, and operational suitability. It is, of course, impossible to provide such an analysis here, but a highly schematized and simplified comparison will shed light on some important considerations.

For this comparison, the following assumptions will be made:

1. The mission is one of continuous patrol of a fixed area, not one of contact investigation or escort;

2. Mission effectiveness is simply proportional to the weight of payload carried aloft on station--more payload is always better;

3. Aircraft life-cycle cost is proportional to some weighted sum of aircraft empty weight (unequipped) and payload weight;

4. Utilization rate and availability are the same for all aircraft, regardless of type or mission duration.

It is clear that one will wish to minimize, in this case, the cost per unit effectiveness and that this ratio may be expressed, under these assumptions, as,

$$\frac{C}{E} = k\left(\frac{aWu + bWp}{FSWp}\right) \tag{1}$$

where,

$C/E$ = Cost per unit effectiveness
k, a, and b are suitable constants
$Wu$ = Unequipped aircraft empty weight
$Wp$ = Payload weight
F = Fraction of its total time which the aircraft can spend in flight
S = Fraction of its flight time the aircraft is able to spend actually on station

For the purposes of this example the following values of the constants have been employed:

$k = a = 1$
$b = 5$
$F = 0.3$

Figure 6 is a plot of C/E vs. radius for a variety of aircraft. (Recall that it is desired to minimize C/E.) It will be observed that C/E is very sensitive to the radius, and that an aircraft which is attractive when operations must be conducted far from base may be quite uneconomical for patrolling nearby areas, and vice-versa.

Having presented this seductively-simple cost/effectiveness comparison it is important to point out some of its more glaring weaknesses. First, of course, assumption number 2 (proportionality of payload and effectiveness) is so artificial that it would be difficult to think of a mission to which it applied literally. Assumption number 3 is a moderately good first approximation for aircraft procurement cost but it ignores development costs, and the dependence of the constants, a and b, on aircraft type and size of buy has been glossed over. Assumption number 4 seems innocuous enough, superficially, and the value chosen (30% of the aircraft's time spent aloft) is roughly consistent with airline experience. But on closer examination it seems clearly unrealistic to suppose (as this implies) that an aircraft which flies one-hour missions can be turned around for another mission in two hours and twenty minutes but that an aircraft of comparable complexity which flies for a day at a time will need 56 hours for turn-around. In general, the longer the mission duration, the greater the fraction of its time the aircraft will be able to spend in flight. (This effect can be seen in airline operations.)

One feature of this comparison which is quite fundamental and which does not depend upon any of the more dubious aspects of the assumptions is the "knee" which will be found in all of the curves in Figure 6. For virtually any sort of patrol mission costs will rise fairly slowly with radius out to a certain critical point, beyond which costs (representing numbers of aircraft needed to keep one continuously on station) begin to rise very steeply, becoming asymptotic at the aircrafts maximum radius. This critical point corresponds closely with the radius at which the aircraft is spending half of its flight on station, with the other half devoted to transit to and from station. For convention-

Table 5 - Shin Meiwa PS-1

| | | |
|---|---|---|
| <u>Configuration</u> | | |
| Overall length | 109.8 ft. | (33.46m) |
| Span | 102.2 ft. | (31.15m) |
| Wing area | 1462 sq.ft. | (135.8 sq.m) |
| <u>Weights</u> | | |
| Operating empty | 51,260 lb. | (23,250 kg) |
| Normal fuel capacity (@6.5 lb./gal.) | 15,400 lb. | ( 8,971 l) |
| Maximum fuel capacity | 33,430 lb. | (19,468 l) |
| Payload | 5,560 lb. | ( 2,530 kg) |
| Normal gross | 71,870 lb. | (32,600 kg) |
| Maximum gross | 86,860 lb. | (39,400 kg) |
| <u>Propulsion</u> | | |
| 4 G.E. T64-IHI-10 turboprop engines | | |
| Rated takeoff power per engine | | 2,970 ESHP |
| <u>Boundry Layer Control</u> | | |
| 1 G.E. T58-IHI-10B BLC turboshaft engine | | |
| Rated power | | 1,250 ESHP |
| <u>Performance</u> | | |
| Takeoff run (rough water) | 190 ft. | (57 m) |
| Touchdown speed | | 49.2 kt |
| Maximum speed @4900 ft. (1500 m) | | 295 kt |
| Normal cruise speed @4900 ft. (1500 m) | | 170 kt |
| Range | | |
| Normal | | 1170 n.m. |
| Maximum | | 2560 n.m. |

<u>Source</u>: Kunio Fushimi, "PS-1, Its Tradition and Technology," Aireview (Japanese), v. 12, n. 325, 1973.

Table 6 - Lockheed Open-Ocean Amphibian

| | |
|---|---|
| <u>Configuration</u> | |
| Overall length | 268.3' |
| Span | 317.3' |
| Wing area | 15,000 sq.ft. |
| <u>Weights</u> | |
| Operating, empty | 528,600 lb. |
| Fuel | 525,000 |
| Gross | 1,250,000 |
| Payload | 140,000 |
| <u>Propulsion</u> | |
| 4 high bypass-ratio turbofans, each with 83,650 lb. static thrust | |
| <u>Performance</u> | |
| Speed | 290 kt |
| Range | 2500 n.m. |
| <u>Combat Systems</u> | |
| 2 retractable anti-aircraft gun turrets | |
| 1 105mm gun or equivalent | |
| 12 Lance-type missiles | |
| 6 Long-range anti-air missiles | |
| 1 Utility helicopter | |
| 1 Early warning radar | |
| 1 Deployable/recoverable acoustic array | |
| Crew of 30 | |

<u>Source</u>: Reference 5

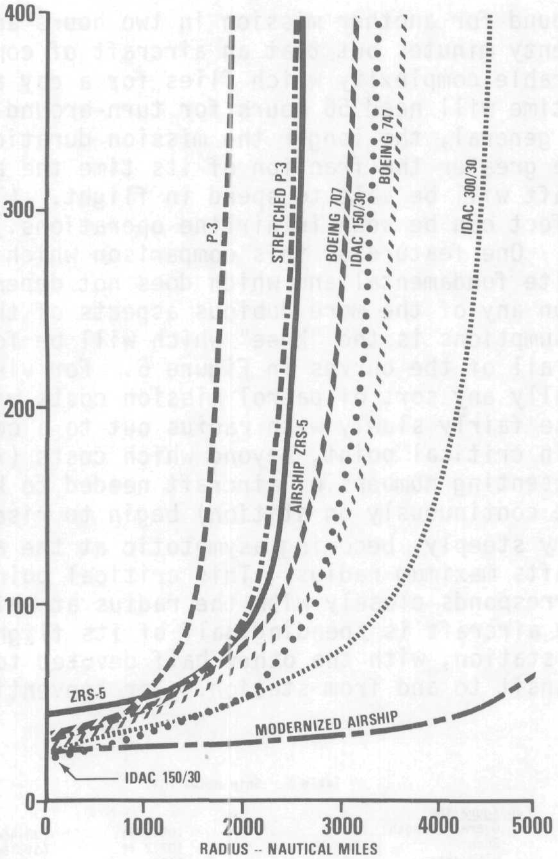


**Fig. 6 - Simplified model of cost/effectiveness for continuous patrol**

al aircraft, whose loiter fuel flow is of the same order of mignitude as their transit fuel flow, this will come at about 50% to 60% of maximum radius. For airships, however, (and probably for seaplanes as well) the critical radius for patrol efficiency will come relatively farther out, perhaps at 70% to 80% of maximum radius.

Another general truth expressed in this comparison is that advanced-technology aircraft offer real advantages in efficiency, particularly at large radii. Whether these advantages are great enough to justify the development costs is not so clear. Sharing of development costs through common use of the same airframe and engines with other military or civil users, or with other missions within the Navy, would probably be an economic necessity. And, in any event, we must bear in mind that advanced technology is an option *only* in aircraft for which we can wait a considerable period.

## ANTI-AIR WARFARE

Next after the submarine on the list of maritime threats comes the airplane. This surprises many people, despite the fact that

Table 7 - AEW&C Aircraft

| | Grumman E-2C* | Boeing E-3A |
|---|---|---|
| Configuration | | |
| Overall length | 57'7" | 145'6" |
| Span | 80'7" | 145'9" |
| Wing area | 700 sq.ft. | 2,892 sq.ft. |
| Weights | | |
| Operating empty (equipped) | 37,678 lb. | 172,571 lb. |
| Fuel | | 148,970 |
| Maximum gross | 59,880 | 325,000 |
| Performance | | |
| Nominal radius of action | 200 n.m. | 600 n.m. |
| Time on station | 6.1 hr. | 8.5 hr. |
| Total mission time | 9.3 hr. | 11.4 hr. |
| Typical cruise speed | 270 kt. | 430 kt. |
| Station altitude | 20-29,000 ft. | 29,000 ft. |
| Maximum speed | 322 kt. | 473 kt. @ 23,400 ft. |
| Takeoff to clear 50 ft. | 3,700 ft. | 7,670 ft. |
| Ferry range | 2,440 n.m. | 4,579 n.m. |
| Payload systems | | |
| Radar type | APS-125 | APY-1 |
| System MTBF | 30 hr. | 78 hr. |
| System availability | 90% | 95% |
| Electronic warfare equipment | Passive | None |
| Normal crew | 5 | 17 |

*Land based version with fuel in outboard wing panels.

Source: Grumman and Boeing

Soviet official texts on strategy have long presented the airplane as a close second to the submarine as an instrument of Soviet sea power (7). With the introduction of the Backfire into Soviet Naval Aviation (SNA) regiments the Russians are bringing almost all of the approaches to Europe and Japan within easy striking reach (8).

In order to reach the North Atlantic sea lanes without crossing over Europe Backfires will have to fly down through the GIUK gap--the straits between Greenland, Iceland, and the United Kingdom. Since it is only about 700 nautical miles from northern Scotland bases to Keflavik, Iceland, and another 700 nautical miles on to Sondrestrom, Greenland it would seem quite possible for fighters based at these places to intercept the transiting Backfires.

First, of course, the Backfires must be detected. Flying at high altitudes they should be visible to radars in Greenland, Iceland, and Faeroe Islands. But flight at medium altitudes or screening by jamming aircraft might prevent detection by land-based radars. Even if jamming alerted interceptors to the presence of enemy aircraft they could not expect to accomplish much without accurate vectoring.

One answer of course is an airborne early warning and control (AEW&C) aircraft. Table 7 provides data on the two AEW&C aircraft in current production, the E-2C and E-3A. There has been sharp debate about the survivability and effectiveness of the E-3A over central Europe, but this is of little immediate relevance to the mission involved here. No Soviet interceptor has anything like enough range to reach GIUK gap, engage in air combat, and return to base.

The Soviets do possess jamming aircraft which could be employed to screen Backfire raids. In order to screen against mobile AEW&C aircraft radars, however, the jammers would have to accompany the Backfires (assuming that the jammers are not powerful enough to jam the AEW&C radars at long ranges through their side lobes). The AEW&C aircraft should be able to get a fix on the jammer accurate enough to vector interceptors to it, and thus to the Backfires which it is screening.

It is possible in principle, of course, that the Soviets could outfit some Backfires with air intercept radars and air-to-air missiles in place of their anti-ship armament to attack AEW&C aircraft. It is likely that the AEW&C aircraft could evade the interceptor Backfires, which would lack interceptor control facilities, but the anti-ship Backfires might slip through in the process. Thus the AEW&C aircraft may need to have fighters close enough to chase off the interceptor Backfires.

To effectively safeguard the AEW&C aircraft the defending fighters would need to be no more than 15 minutes away. Clearly, this will mean airborne combat air patrol (CAP) aircraft in most cases. This has a serious impact on costs since, at a rough estimate, something like six fighters will be needed to support one aloft on CAP station 24 hours per day, while four fighters should be enough to permit keeping three on strip alert.

Strip-alert aircraft may also run into problems in reaching the main Backfire raids. The Backfires would normally transit at high subsonic speeds. (While the Backfires are capable of supersonic dash, the high fuel consumption involved in even a brief dash would prevent them from reaching much of the North Atlantic.) Unless very long warnings were available, strip-alert interceptors would have to fly out to intercept at supersonic speeds. 500 nautical miles is about the outside limit for supersonic intercept radius, and 350 n.m. is probably a more realistic figure for most fighters. Thus many intercepts in the GIUK gap might occur at extreme radii, and feints or operational problems might easily result in missed intercepts.

If the situation is marginal in the North Atlantic it is hopeless in the North Pacific. There is a 3000 n.m. gap between northern Japan and our bases in the Aleutians, through which the Backfires could pour to ravage trans-Pacific shipping. With present land-based fighters one would have to resort not only to CAP but to air refueling to close this gap, at enormous cost.

One plausible answer is higher performance special purpose interceptors, as exemplified by the Lockheed YF-12A of the 1960s (Figure 7). With less need for agility and low-level speed it is possible for such interceptors to have relatively high supersonic lift/drag ratios and low structural weight fractions (9, 10, 11), resulting in substantially increased radius at supersonic speeds. It is clear from consideration of supersonic transport technology (11) that supersonic intercept radii adequate to give good coverage of ocean areas are technically feasible.

There is another way in which land-based aircraft might play a part in combating the Backfire and like threats: combine the functions of detection and anti-air missile (AAM) launch in a single transport-type offensive anti-air (TOAA) aircraft. The concept is

Fig. 7 - Photograph of YF-12A

that TOAA aircraft, flying in data-linked pairs, would patrol in areas such as the GIUK gap and the approaches to Soviet bases on the Kamchatka Penisula. Upon detecting a Backfire raid with their AEW radars they would attack with long-range AAMs. By operating in pairs they would be able to provide mutual tactical support, triangulate on jammers, and synchronously "blink" their radars to disrupt enemy countermeasures without losing information.

The fundamental principles which underlie the attractiveness of such a scheme are: (a) if standing airborne patrols must be maintained then it will be more economical to do so with aircraft optimized for high efficiency, and (b) a highly efficient aircraft can afford to carry heavy and powerful sensors and weapons to offset its own deficiencies in speed and acceleration.

Other uses for TOAA aircraft also suggest themselves. For one thing they could be stationed as escort or screening forces for convoys or naval surface forces which lack their own fighters and AEW&C aircraft. Less obviously, they might also perform similar functions for carriers. By relieving the carrier of the need to conduct constant air operations for its own defense this would permit it to increase its speed of advance (particularly if the wind is blowing in the direction the carrier needs to go) and would reduce its detectability, while enabling it to concentrate far more of its capability in striking power rather than self protection.

In general the aircraft discussed under the ASW section should all be well suited to the TOAA role, although TOAA payload weights would probably run to the higher end of the spectrum in an effort to gain a substantial detection and weapon range advantage over interceptor Backfires and other potential threats. While no TOAA aircraft exist today it would not be difficult to concoct one with modifed versions of existing systems. The feasibility of such a "quick and dirty" TOAA versions of the stretched P-3 and of the Lockheed C-130 Hercules transport aircraft have been studied, and the results are shown in Table 8 and Figures 8 and 9.

The large rotodomes of radars such as the APY-1 and APS-125 impose a drag penalty, but this is probably quite avoidable for any but very near-term TOAA aircraft. Full conformal radar arrays clearly seem to be the ultimate answer. In the shorter term fixed fuselage-mounted fore-and-aft planar arrays should be acceptable, since TOAA aircraft do not have the same need for full $360^{\circ}$ isotropic radar coverage that AEW&C aircraft have.

In principle, airships could also be used as TOAA aircraft. Their lack of speed, large radar cross section (at least for rigid types),

Table 8 - Two TOAA Aircraft Concepts

| | Lockheed Stretched P-3 (AAW) | Lockheed C-130 (AAW) |
|---|---|---|
| **Configuration** | | |
| Overall length | 123'4" | 99'5" |
| Span | 110' | 132'7" |
| Wing area | 1,450 sq.ft. | 1,745 sq.ft. |
| **Weights** | | |
| Operating, empty | 84,004 lb. | 88,601 lb. |
| Fuel | 73,578 | 73,984 |
| Gross | 163,450 | 175,056 |
| AAW Payload | 25,638 | 27,248 |
| **Propulsion** | | |
| 4 Detroit Diesel Allison 501-M69 turboprop engines | | |
| **Performance** (missiles retained). | | |
| Maximum speed | 364 kt | 310 kt |
| Loiter altitude | 17,000 ft. (avg) | 20-25,000 ft. |
| Radius of action* | | |
| Zero time on station | 2,100 n.m. | 2,200 n.m. |
| 4 hr. time on station | 1,550 | 1,690 |
| 8 hr. time on station | 1,000 | 1,180 |
| **Combat systems** | | |
| AEW radar | APS-125 | APS-125 |
| Missile fire control | AWG-9 | AWG-9 |
| Missiles | 6 folding-fin AIM-54 PHOENIX | 10 AIM-54 PHOENIX |
| Crew | 12 | 12 |
| **Other MODS to Basic A/C** | As for stretched P-3 | Refaired aft fuselage; extended landing gear fairings; 1000 gal. fuselage fuel |

*With reserves equal to 10% of initial fuel plus fuel for 20 minutes at sea level, 5% increased fuel flow, and four-engine loiter.

Source: Lockheed feasibility-level conceptual design studies.

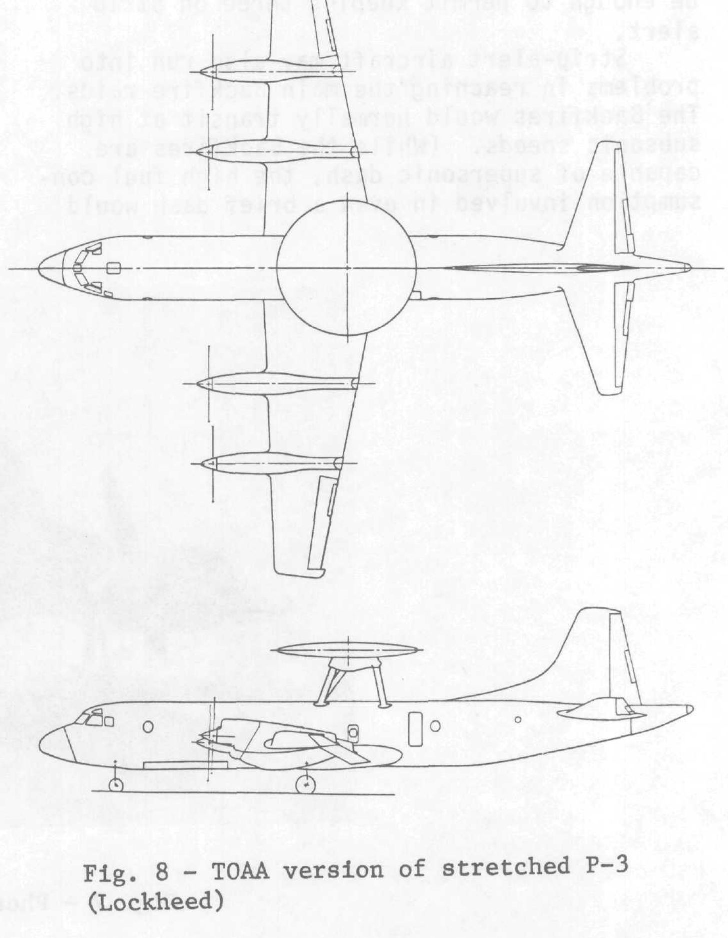

**Fig. 8 - TOAA version of stretched P-3 (Lockheed)**

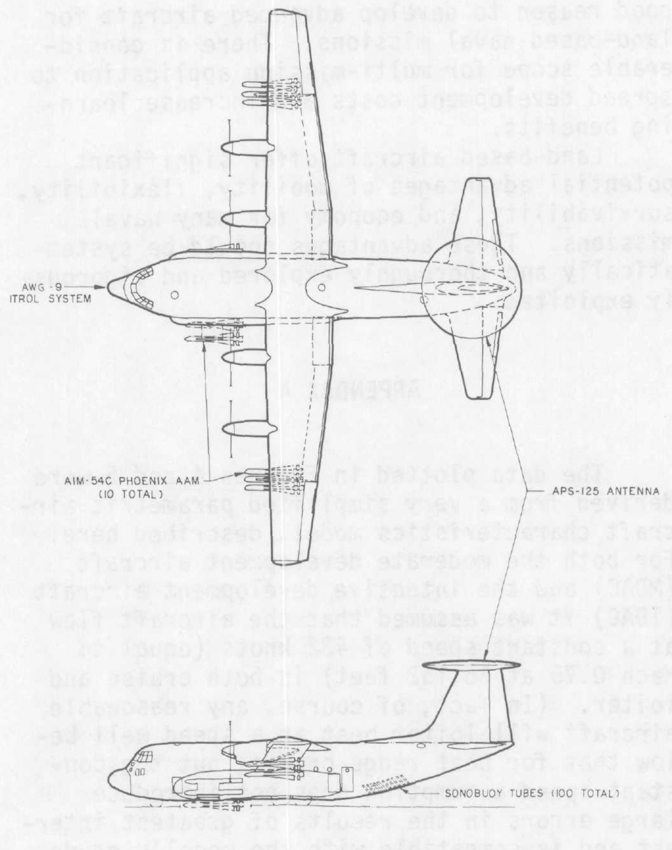


Fig. 9 - TOAA version of C-130 (Lockheed)

and particularly their lack of altitude capability would all be serious handicaps, however.

ANTI-SHIP WARFARE

Official Soviet military thought has long relegated surface ships to subsidiary and supporting roles in major war, and the Joint Chiefs of Staff assessment is that a combination of geographical factors and allied air power would greatly restrict employment of Soviet surface units in a major war in any event (12). Nevertheless, the Soviet surface fleet is too large and well armed for complacency; in a surprise onslaught, or near its homeland, it could do great damage.

Land-based aircraft play a major role in our anti-ship forces today and in the immediate future. The P-3, with its APS-115 radar and electronic intercept equipment, is a mainstay of our surface surveillance capabilities. Many land-based aircraft are capable of attacking surface ships.

The advent of sea-based aircraft in the Soviet Navy does change things somewhat, however. While the Yak-36 Forger carried by the Kiev is 20 years out of date in terms of fighter performance it would still be enough to endanger surveillance aircraft such as the P-3 and E-2, and could make weapon delivery more hazardous.

One answer to these problems is simply to increase the standoff both for surveillance and weapons release. Radar detection of surface ships at 200 nautical miles or more presents no real technical problems and visual identification could probably be dispensed with, in most shooting-war situations. And missile ranges can certainly be increased to 200 n.m., or even more, if there is a need. Other approaches are certainly also possible.

STRIKE

It may at first seem that strike against land targets, even when carried out by Navy aircraft, is not a naval mission in the strict sense. There may be some justice to this view in the case of the sort of strike warfare which our carriers prosecuted in Korea and Vietnam but there are also truly naval objectives on land--ports, dockyards, naval airfields, and the like--and strikes against these targets are surely a legitimate naval mission. Moreover, bases are vital in naval warfare and we might need to conduct strikes against non-naval facilities on land incident to seizure of a base for naval needs.

The problem with strike warfare has always been that aircraft with good efficiency for long-range cruise are too vulnerable and aircraft with good survivability are too short-ranged. The gradual increase in tactical aircraft ranges and the widespread application (at least in the U.S.) of flight refueling have certainly extended the reach of land-based tactical air strike forces but coverage of many potentially-important naval targets remains limited. Aircraft such as the B-52 offer virtually unrestricted coverage but have limitations in their ability to deliver precision attacks against heavily defended targets without fighter support.

Of course long-range missiles can permit standoff great enough to safeguard even the softest of aircraft. It is still difficult, however, to envision a guidance and control concept which would permit effective and economical attack against a wide variety of targets with launch-and-leave missiles.

One interesting and unique possibility is the use of large, efficient aircraft to carry small tactical aircraft to and from the scene of engagement. Boeing and the Air Force have studied 747s carrying "micro-fighters" and larger aircraft are, of course, feasible. Previous experiments have shown that it is possible to launch and recover aircraft in flight, although many practical questions have yet to be worked out. Whether and under what circumstances this might prove superior to flight refueling as a means of bringing tactical aircraft to distant targets is not entirely clear.

BASING

Historically, lack of suitable bases has been a major deterrent to wider employment of land-based aircraft for naval missions. Aircraft ranges have increased greatly but it remains important to have bases within 1000 to 1500 nautical miles of important operating areas, as can be seen from Figure 6. So far as sea-lane protection is concerned our present basing situation is reasonably satisfactory, as can be seen from Figures 2 and 3 (except, of course, for the lack of adequate interceptor bases in the North Pacific). Since these bases are, for the most part, either in U.S. territory or in the territory of nations who would be depending upon us to aid in their own defense it is reasonable to feel fairly sanguine about the availability of these bases in a major maritime war.

Nevertheless, it is certainly possible that there could be circumstances which would deprive us of the use of one or another important base. It is in just such circumstances, of course, that the longer range offered by advanced aircraft would be of greatest value. Figure 10, taken from reference 13, gives an idea of the coverage which could be provided by aircraft of various radii operating exclusively from bases in U.S. territory.

There is still another virtue to range as it affects basing: with long-range aircraft one needs fewer primary operating bases. This is a significant economy, and could help to reduce the need for stationing American squadrons in allied territory in peacetime.

CONCLUSION

If there were a naval war tomorrow, land-based aircraft would play a major role on both sides. The technological means exist to increase this role, and it may well be militarily and economically attractive to do so.

Much can be done with adaptations of existing types of aircraft, but there may be

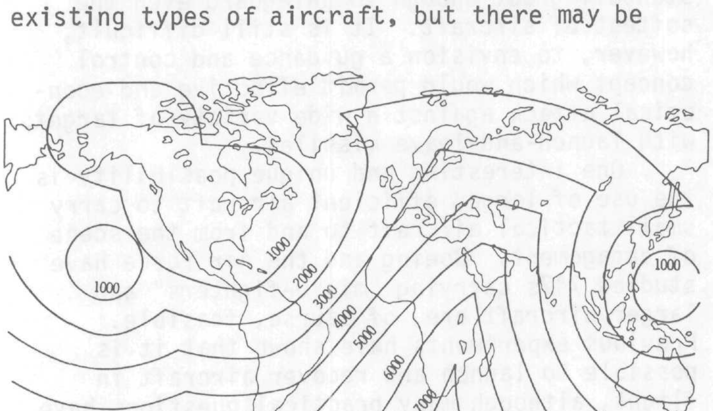


**Fig. 10 - Coverage versus radius from bases in U.S. territory (Rand)**

good reason to develop advanced aircraft for land-based naval missions. There is considerable scope for multi-mission application to spread development costs and increase learning benefits.

Land-based aircraft offer significant potential advantages of mobility, flexibility, survivability, and economy for many naval missions. These advantages should be systematically and thoroughly explored and vigorously exploited.

APPENDIX A

The data plotted in Figures 4 and 5 were derived from a very simplified parametric aircraft characteristics model, described here. For both the moderate development aircraft (MDAC) and the intensive development aircraft (IDAC) it was assumed that the aircraft flew at a constant speed of 432 knots (equal to Mach 0.75 at 36,152 feet) in both cruise and loiter. (In fact, of course, any reasonable aircraft will loiter best at a speed well below that for best range cruise, but the constant speed assumption does not introduce large errors in the results of greatest interest and is compatible with the model's crude level of detail.)

For the MDAC the use of a current or near-current (e.g., JT10D or CFM56) high-bypass ratio turbofan engine is assumed. The IDAC, as indicated in the text, is assumed to use advanced turboprop engines turning advanced, highly-loaded high-speed props or "prop-fans" (14, 15). Other technological aspects are as described in the text.

Air range has been calculated from one of two alternate forms of Brequet's range equation, depending on propulsion type:

$$R = \left(\frac{V}{TSFC}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W}{We + mWf}\right) \qquad \text{(A-1)}$$

$$R = 325.9\left(\frac{\eta}{PSFC}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W}{We + mWf}\right) \qquad \text{(A-2)}$$

where,

R = Air range (no wind) in nautical miles
V = Speed = 432 knots
$\eta$ = Prop aircraft propulsive efficiency
TSFC = Thrust specific fuel consumption for jet aircraft
PSFC = Power specific fuel consumption for prop aircraft
L/D = Lift/drag ratio
W = Takeoff gross weight
We = Empty weight, fully equipped
Wf = Weight of fuel at takeoff
m = Fraction of fuel retained as reserve = 0.12

Radii are calculated from the following equation:

$$r(h) = (R - hV)/2 \quad \text{(A-3)}$$

where,

$r(h)$ = Radius with h hours spent on station

The basic weight equation employed is,

$$W = W_e + W_f \quad \text{(A-4)}$$

$$= W_u + W_p + W_f$$

where,

$W_u$ = Unequipped empty weight

$W_p$ = Payload weight

Here, as throughout the payload is taken as including all mission avionics (but not basic flight avionics equivalent to airline standard), armament (but not weapons bay structure), mission stores, crew, and effects.

Figure A-1 presents the weight data used, while Table A-1 shows the other input data assumed.

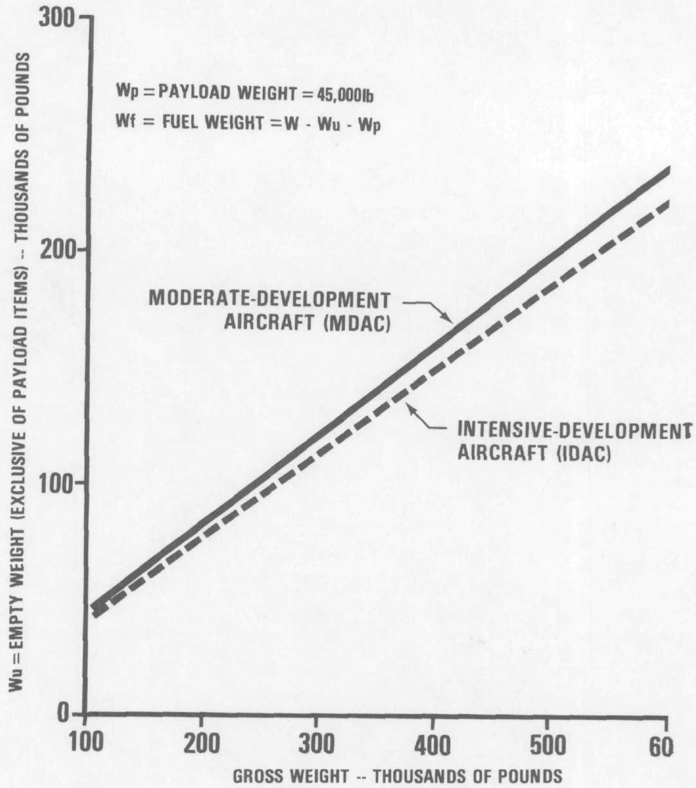


Fig. A-1 - Weight assumptions

Table A-1 - Input Assumptions

| | Moderate-Development Aircraft (MDAC) | Intensive-Development Aircraft (IDAC) |
|---|---|---|
| TSFC | 0.667 lb./lb-h. | - |
| PSFC | - | 0.330 lb./SHP-hr. |
| $\eta$ | - | 0.82 |
| L/D | 18 | 20 |

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