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(10) Frank W. Hamle

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A COMPARISON OF THE ECONOMIC COST AND MILITARY SUITABILITY OF THE HIGH PERFORMANCE SEAPLANE WITH OTHER ALTERNATIVE AIRCRAFT FOR BOMBARDMENT MISSIONS.

[redacted]

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OPERATIONS EVALUATION GROUP (formerly Operations Research Group)
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OPERATIONS EVALUATION GROUP
STUDY NO. 384

A COMPARISON OF THE ECONOMIC COST AND MILITARY SUITABILITY OF THE HIGH PERFORMANCE SEAPLANE WITH OTHER ALTERNATIVE AIRCRAFT FOR BOMBARDMENT MISSIONS

References: (a) Op04 Memorandum for the Chief of Naval Operations, Serial 00014SP40, "A Strategic Concept Based on the Use of the Seaplane as an Instrument of Logistical Economy", Top Secret, 3 March 1949. Downgraded to Secret by Ser.00747P40, 30 Nov 1949.

(b) Memorandum for Op50, "Concept of the Use of Seaplanes for Long Range Bombing Utilizing Submarines as Tankers", Secret, 22 March 1949.

(c) OEG Study No. 327, "Preliminary Study of the Military Suitability of Aircraft Carriers and Land Bases", Secret, 13 April 1948.

(d) OEG Study (Pending Publication), "Some Factors Governing the Feasibility of Very Long Range Bombing from North American Bases".

(e) USAF "Wartime Planning Factors and Data", (WPF-48), Secret, 27 August 1948.

(f) U. S. Patent 2 287 824

(g) "Must We Hide", by R. E. Lapp, Addison-Wesley, Massachusetts, 1949.

(h) Naval War College, "Logistic Planning Factors", Confidential, 1949.

(i) USF 85, Radiological Safety Manual, Confidential, 1945.

(j) Rand Quarterly Report, Secret, 1 December 1948.

(k) United States Munitions Handbook, Civilian Production Administration, Restricted, 1 May 1947.

(l) Boeing A/C Co. Technical Report No. X7-2, "An Illustrative Study of a Gapa Defense of a Typical Vulnerable Area in the Continental U. S.", Confidential, January 1949.

(m) OEG Report 51, "ASW in World War II", Confidential, 1946.

(n) Memorandum from Director, Design Research Division, BuAer, "High Performance VA Flying Boat, ADR Design No. 56", Confidential, 9 June 1947.

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(o) Op04 Memorandum, Serial 0058P04, Logistic Comparison of Seaplane vs. Land-based Aircraft Operation in Furtherance of Strategic Concepts, Secret, 25 May 1948.
(p) Air University Memorandum, "AU-4721 Water-Based Combat Aircraft", Confidential, 24 September 1947.

SUMMARY

1. Reference (a) is a logistic study comparing the relative economic effort in terms of requirements in ships, supplies and manpower to initiate and support a 100 seaplane attack unit operating at up to 2000 n. m. from enemy targets, with that required for an equivalent carrier or land-based force. It was concluded that while the economic cost for continued operation was about equal among all three alternatives, the initial cost favored the seaplane. This study examines the question further and compares five possible alternative forces of equivalent bomb delivery capabilities:

(a) The carrier task force (1500 miles from target),

(b) Overseas-based seaplanes (1500 miles from target),

(c) North American-based seaplanes (4500 miles from target),

(d) Overseas land-based bombers (1500 miles from target),

(e) North American land-based bombers (4500 miles from target).

This analysis concludes that:

(a) The cost to bomb by seaplane is about equal to the cost to bomb by carrier task force or overseas land-based aircraft (where no unusual effort is required to occupy or hold such a land base), while the cost to bomb by North American-based bombers is substantially higher than by any other alternative. Basing the seaplane in the United States and refuelling by tanker submarine does not inflate the cost to operate.

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(b) While the seaplane bomber appears to have no outstanding qualifications over the other types of bomber, neither does it have any marked weaknesses. However, the surplus power built into the seaplane for take-off pays a dividend in a substantially increased ceiling over the equivalent carrier- or land-based aircraft.

(c) The VA seaplane might be developed primarily as an auxiliary force to perform those missions which would not be suitable or economical for a carrier task group or land-based aircraft. One such important role is that of strategic reconnaissance. However, a seaplane VA force equipped for overseas operation (with ships now on hand) would be a distinctly useful one which could be quickly activated and operated in areas where adjoining terrain would not be suitable for land-base construction. Furthermore, the seaplane has an important insurance value against the chance that land- or carrier-based aviation could not perform as expected. wcw.

INTRODUCTION

2. Reference (a) is a logistic study, comparing the relative economic effort, in terms of requirements in ships, supplies and manpower, to initiate and support a seaplane attack unit with that required for an equivalent carrier or land-based force. Reference (n) proposed the development of a high-performance seaplane. Reference (o) directed study of the logistic implications of seaplane attack aircraft. Reference (p) summarizes an Air University study of water-based, or "varied-surface" aircraft and concludes that military requirements exist for aircraft capable of operating from any portion of the earth's surface. This study examines the question further.

While it is generally accepted that unescorted bomber aircraft risk intolerable combat losses unless such bombers can cruise at speeds near those of the attacking interceptors, the penalty in range incurred in achieving such speed is a serious one. At present, this range limitation on high performance aircraft can be obviated in one of the following ways:

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(a) Refuelling North American land-based bombers in flight.
(b) Operating land-based bombers from overseas bases close to targets.
(c) Operating bombers from carriers close to targets.

It has been suggested (references (a) and (b)), however, that high performance seaplanes operating from either advanced mobile bases or North American bases (and refuelled enroute by tanker submarines (SSO's)) might prove to be the best solution and the cheapest, in terms of economic effort, to maintain. This study is written to examine such a proposal in further detail.

3. Although it is not intended to evaluate the usefulness or practicality of any given bombing campaign, a bombing role is assumed, to provide a common basis for comparing the relative economic effort required for the alternative forces.

4. For the purposes of this paper, the size of each bomber force will be taken as that equivalent in bombing potential to three land-based medium bomber groups, each with forty aircraft, against a target 1,500 nautical miles distant. While this does not necessarily mean that this size of force is a proper one, it is shown in Appendix A that it is of not unreasonable composition. Moreover, the equivalent force can be reduced or multiplied without seriously altering the reasoning on which the conclusions of this study are based; except for the fact that combat losses tend to remain independent of the number of aircraft in a mission. Such equivalent forces, however, could deliver 5000 tons of conventional bombs per month, or perhaps 300 atom bombs per year (over the radius assumed), and at a combat loss rate of, say, six percent per mission.

5. The bomber aircraft are assumed to possess the characteristics cited in Table I, providing forces comparable to those given in reference (a); thus the logistic data developed there can be used directly.

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TABLE I

Aircraft Characteristics

(Prepared by BuAer's Design Research Division)

	Seaplane	Land- or Carrier- Based	Tanker
Gross Weight (lbs.)	125,000	80,000	310,000
Empty Weight (lbs.)	58,000	35,000	135,000
Combat Radius (naut. mi.)	1,700	1,700	3,000
Cruise Mach No.	0.85	0.85	.36
Maximum Mach No.	0.88	0.88	.60
Bomb load at combat radius (lbs.)	6,000	6,000	----

COMPARATIVE COST TO OPERATE

6. First, without questioning accomplishment, it is useful to inquire into the economic cost of bombing by each of the five alternative forces. The result of such an inquiry does not by itself prove the superiority of one bombing system over any other, but it may remain a major factor in a decision to develop any untried weapon whose firm contribution cannot be clearly anticipated. Although the following accounting is made in terms of World War II dollars and experience, in the words of reference (c), "(such a) procedure is justified by the lack of a peacetime economic situation even remotely resembling the total economic mobilization obtaining during the war".

7. Results of a cost analysis are presented in Figure 1 and Table II, and the basis of such cost accounting is outlined in Appendix A.

8. The useful life of a base over which its initial cost must be amortized is an important factor in comparing costs. This useful life may be terminated by enemy action, end of hostilities, old age, or merely by being left too far behind the front to be of further value. Since this useful life of a task force or base cannot be readily estimated except in specific cases, the total costs are presented in Figure 1 as a function of base life. Also, since aircraft combat attrition will vary with conditions, costs in Figure 1 are indicated between combat loss limits of five and ten aircraft per strike. From the data developed in reference (d), average losses of at least five appear reasonable.

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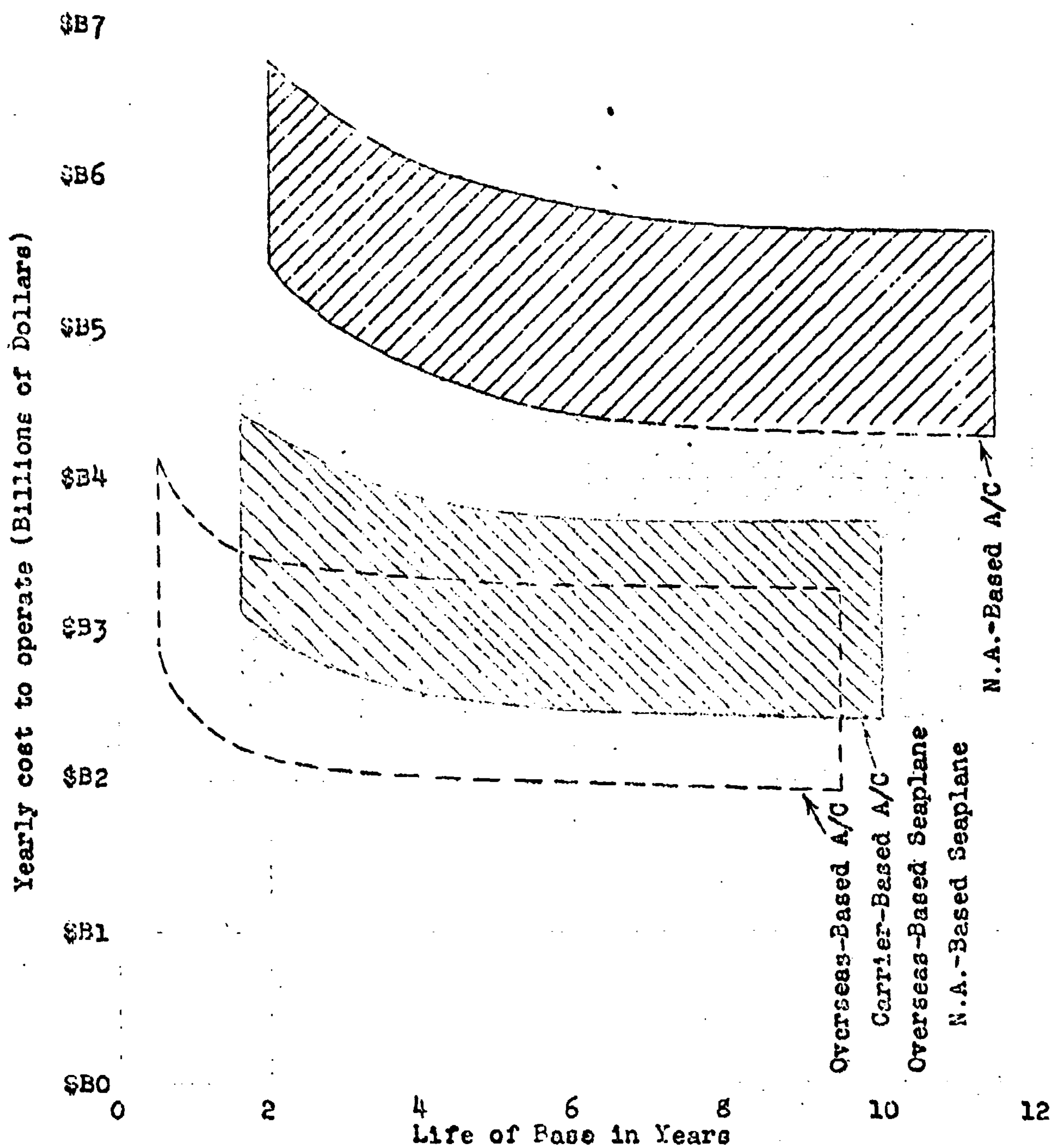

FIG. 1 COST TO OPERATE ALTERNATIVE BOMBARDMENT FORCES (Upper and lower limits of cost are for combat losses of 5 or 10 A/C per strike, respectively)

9. To indicate more clearly the make-up of these total costs, a breakdown for a sample base life is given in Table II. Although base costs are amortized here over five years, this period is an arbitrary one, chosen simply as an illustration. It will be noted, also, that an average 20 month life is assumed for ships of the replenishment or supply forces, both in Figure 1 and Table II. This is based on peak shipping losses on the North Atlantic Trade Convoy route of 5% per crossing during March 1943 (reference (m)).

TABLE II

Yearly Cost to Operate the Five Alternative Forces Described in Text (In Millions of Dollars)

	Seaplane A/C		Carrier-Based A/C	Land-Based A/C	
	Over-Seas-Based	N.A.-Based		Over-Seas-Based	N.A.-Based
Base Amortization (5 yr. life)	110	160	300	95	565
Base Operation	135	45	180	125	180
Logistic Force Amortization (20 mo. life)	180	165	440	235	-
Logistic Force Operation	70	50	135	85	-
A/C Operation	80	120	55	55	710
A/C Replacement	1315	1270	815	815	1680
Flight Crew Training	565	630	565	565	1380
Total Yearly Cost	2455	2440	2490	1975	4515
Craft operated:					
Bombers	120	255	120	120	255
Defensive VF	240		240	240	
Tankers		45 SSO's			625 B-36's

10. Clearly, no exact comparison can be made among the various alternatives of Figure 1 without some knowledge or estimate of base life. Some factors bearing on selection of base life are as follows:

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(a) We have taken, as an outside estimate, that an intensive enemy effort might cause a loss rate among ships of carrier or seaplane bases of as much as five percent per month — about ten times that encountered in Pacific operations during World War II, despite Kamikaze attacks. This rate of loss would correspond to a base life of some 1 2/3 years.

(b) North American bases may be relatively immune to enemy attack (except perhaps those near the Chutoski Peninsula) and thus would probably have a useful life at least as long as the duration of a possible war.

(c) Included in the base accounting costs of the North American-based seaplane aircraft, however, are the S[illegible]O's whose initial cost is taken to be $360 million, about half the total base cost.

(d) The overseas land base might have a useful life considerably less than a year since any one location can become unsuitable or untenable. While it is true that such a base might be useful for other air activity, the cost of the initial shipping to activate the base must still be amortized over just that period of time it contains its bomber groups.

(e) Base life of a land installation under constant attack could be measured by the ratio of initial cost to the yearly cost for repair of combat damage.

(f) Not included in this accounting is the cost to seize and defend the ground on which to construct a land base.

(g) The cost of economic or military aid to any nation in exchange for the right to establish or maintain bases of any nature is not included. When such costs exist, as they frequently do, they are tremendous and may easily dwarf the costs developed in this study.

11. From the cost comparisons of Figure 1 and Table II, the following will be noted:

(a) In general, the overseas land-based bomber force seems to be somewhat cheaper than any other alternative, but the North American land-based force is substantially the most expensive.*

(b) If aircraft combat attrition is held to around five per mission, the seaplane, either based overseas or in North America, is about equivalent in operating cost to carrier aircraft.

(c) The conclusion that seaplanes can operate from North American bases at costs comparable to those of other alternatives may be unexpected. Moreover, the seaplane carries a weight penalty over the equivalent land-based aircraft of about 55%, and there is reason to believe that during development this might be reduced. Since aircraft procurement, base, and operation cost as well as fuel requirements are just about proportional to aircraft empty weight, any reduction in this weight penalty should assure a reduction in the cost to bomb.

12. Further factors of some importance affecting this cost analysis are as follows:

(a) About two-thirds of the roughly half a billion dollars for operation and amortization of the carrier task force is chargeable directly to the surface supporting vessels. If less surface ASW and AA defense were required, some saving would accrue by omitting a portion of these.

(b) It has been tacitly assumed that the North American land-based bombers operate from the Eastern United States. If the bases were located in Northern Alaska, a stiff logistic problem would arise with a cost comparable to that for the overseas forces.

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* If B-36 aircraft were used to drop an equivalent bomb <u>tonnage</u>, the cost-to-operate would drop about 13% because of the great load-carrying capacity of this aircraft, but would still be considerably higher than any other alternative. This lower cost for B-36's is based on a requirement of only 1/3 as many missions per month as smaller craft, thus reducing the number of diverse targets which can be attacked. For an equal number of missions for, say, A-bomb delivery, the B-36 cost would, in general, be twice as high as the cost for the VA used in this paper.

(c) Reference (e) suggests that in Arctic regions the sortie rate of land-based aircraft will be about 55% of the rate in temperate zones.

(d) The assumption has been made that the seaplane sortie rate is equivalent to the land or carrier-based rate, since the additional effort for hull maintenance is not expected to be a limiting factor for an average activity of about ten sorties per month.

COMPARATIVE ABILITY TO OPERATE

13. Thus far the discussion has rested on the assumption that each force is equally capable of accomplishing a given mission and the ability of the enemy to compromise this mission is independent of the type of force employed. It remains, then, to suggest distinctive operational features of each of the five alternatives:

(a) Land bombers based in the North American continent, while expensive to operate, may have the important advantage of being potentially capable of reaching a large portion of the world with less logistical preparation, and therefore less delay after the commencing of hostilities, than for other alternatives.

(b) In-flight refuelling of North American land-based bombers may not be practical for large or sustained operations.

(c) Seaplanes based in North America may be more feasibly refuelled once the machinery for overseas refuelling has been provided. While reference (b) envisages submarine tankers (SSO's) for this task, it has been suggested (reference (f)) that the SSO's would not need to make physical contact with the seaplane but could instead leave plastic aviation gasoline containers floating beneath the surface. These containers attached to a marking buoy would then operate by compressed gas. Since such containers could be left in many likely refuelling areas, the operation would be enormously simplified. The SSO could minimize the likelihood of its being surprised on the surface by exercising considerable choice in timing, and if several SSO's were necessary, each could operate singly. Although these aviation gasoline containers might normally be difficult to locate, each could be equipped with a radar beacon. A refuelling technique such as this would allow seaplane sorties to any point in the world at a relatively low cost to operate, although again large sustained strikes may not be practical.

(d) While over equivalent striking radii the land-based bomber force costs perhaps only 80% as much to operate as the equivalent carrier force, the latter may tend to level this cost by choosing an aircraft launching site as close as is prudent to the target, thus enabling a higher sortie rate. Land-based aircraft have no such discretion and indeed will be essentially limited to just those targets within range of the base.

(e) Freedom of choice by carrier forces forces the enemy to dilute his air defense over all the perimeters of his country, an action which tends to reduce the number of interceptors which can attack a strike.

(f) For floating bases there may be less danger of base attrition seriously interrupting bombing efforts since additional ships can be quickly added to the force as replacements for sunk or damaged vessels.

(g) Seaplane bases possess a limited mobility and the ability to recover rapidly from severe battle damage; also, the advantage that its aircraft are seldom confronted with the lack of an airstrip on which to alight.

(h) Normally seaplanes would be based near land to assure quiet seas and immunity from submarines. (Actually it is intended that the seaplane be operable in seas up to six foot wave height corresponding to a sea state of about 4, or 85% availability in the Pacific). In many such localities, the terrain would be quite unsuitable for nearby land bases or the time necessary to construct a land base would be prohibitive.

(i) An outstandingly advantageous use of the fuel cell refuelled seaplane may lie in the mission of strategic reconnaissance. This vital function is now entrusted to single, large, very long-range, low performance aircraft. No safety is afforded by a large number per raid, and vulnerability appears to be critically or prohibitively high. The high-altitude, high performance seaplane may well be justified for this mission alone.

(j) There is one less obvious advantage of the seaplane. It was noted above that the all up weight is about 55% over that of a land- or carrier-based aircraft of equivalent performance. One reason for this increased weight arises from the need for greater take-off power. Bu Aer's Design Research Division has stated that once airborne, however, this added power pays a dividend in increased cruising altitude of 6000 or 7000 feet on the average during the flight to target with an altitude over target of 50,000 feet instead of 40,000. Although it is difficult to assess qualitatively the advantage of this performance, certainly it may result in some saving in the cost-to-operate by reducing combat attrition through air interception. For example, survival of just one additional aircraft per mission reduces the yearly operating cost by $0.4 billion. Moreover, this higher ceiling imposes on the enemy the requirement to build more costly interceptors — such factors as these may be more important in hampering the enemy's war production than bombing itself.

(k) Although it has been assumed that speed alone protects these aircraft over enemy territory, the advantages of fighter escorts must not be overlooked. A most important result of the World War II European bombing campaign was the attrition of the German air force by the offensive tactics of escort fighters accompanying the AAF bombers. Moreover, if escorts could even reduce combat losses by two or three VA per mission, their cost to operate would be justified by the dollars saved in aircraft and crew replacement. No practical way yet suggests itself for providing fighter escorts from North American bases.

(l) The relative rate of aviation gasoline consumption is indicated in Table III and includes the fuel consumed in air and ASW defense of the overseas bases. Fuel for support and base ships is also shown though this item is less critical. As would be expected, the North American-based aircraft burn several times the aviation gasoline of the three overseas forces.

TABLE III

Relative Rate of Fuel Consumption per Unit Weight of Bombs on Target

Force		Aviation Gasoline	Ships' Fuel (In 10 millions of gals/mo.)	Total
Overseas:	Land-based	1	1	2
	Carrier-based	1	8	9
	Seaplane	1 ½	3/4	2 ¼
U.S.	Land-based	8 ½	--	8 ½
	Seaplane	4	1	5

CONCLUSIONS

14. Conclusions which bear on the desirability of developing a high performance jet VA seaplane are as follows:

(a) Costs to procure and operate should be comparable to carrier-based or overseas land-based aircraft, and substantially cheaper than North American-based bombers.

(b) Such aircraft appear to be suitable for missions which would be uneconomical for carrier-based and unsuitable for North American land-based aircraft. Strategic reconnaissance is an example.

(c) The performance, and consequent ability to operate in the face of opposition, would be superior to that of very long-range land-based bombers.

(d) The seaplane, through use of submarine or fuel-cell refuelling, provides a method for very long-range, high performance missions at lower cost than air refuelling, which may be feasible when air refuelling is not.

(e) Availability of a developed, high performance seaplane would provide insurance against presently unforseeable circumstances under which land-based or carrier-based aircraft might be unable to operate as now expected.

15. Conclusions bearing on the desirability of planning for overseas floating seaplane bases from which to operate high-performance attack seaplanes are as follows:

(a) The cost for establishment and maintenance of such bases should be comparable to costs for equivalent land bases, and in some cases may be substantially less.

(b) Overseas seaplane bases could be activated quickly, with ships now on hand, and could be located in areas where nearby terrain is unsuitable for land-base construction.

(c) Such bases, with mobility which is limited compared to carrier forces, but far greater than that of land bases, can better utilize areas relatively free from enemy opposition and force dispersal of enemy strength.

(d) Such bases can provide fighter escort to attack aircraft, when such escort could not be provided from North American bases.

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APPENDIX A

Basis of Cost Analysis

A. Aircraft Planning Factors

1. The full strength complement of each overseas air force was set at 120 aircraft and the average sortie was taken to be of 1,500 nautical miles radius plus 3,000 additional miles for the U.S.-based bombers. Using the planning factors given in references (d) and (e) as bases, it was assumed that:

(a) Two-thirds of the complement, or 80 aircraft, would participate in each mission.
(b) Aborts would amount to 5% of the strike plus 5% for each 1,000 nautical miles to target.
(c) All overseas-based bombers would average 9.7 sorties per month, and all U.S.-based bombers would average 5.5. (This attributes to jet aircraft the same sortie rate experienced by reciprocating engine aircraft during World War II.) The sortie rate for tanker aircraft (B-36's) would be 4.5 per month.
(d) Combat attrition per mission would be at least five but not more than 15 aircraft per 1,000 enemy aircraft on the ground. (For planning purposes, the figure of five per mission was used.) Sixty percent of the combat losses would occur after "bombs away".

2. Using those factors, the efficiency of delivery from overseas bases was computed to be:

$$(0.875 - 2/80) \text{ or } 0.85$$

and the tonnage delivered per month would be

(Efficiency)x(No. of A/C)x(Missions/month)x(Bomb Load), or,

$$\left[(0.875)(80) - (2)\right] \quad (9.7)\ (3/2)(5), = 5000 \text{ tons},$$

since each aircraft can carry about five tons of bombs over the radii assumed here. (Actually, the seaplane could carry correspondingly greater loads for lesser radii). For the same bomb tonnage and the same number of missions per month from N.A. bases, the required number of aircraft, N, can be determined from the expression

$$5000 = \left[(0.725)(N)(K) - 2\right] \quad (9.7)(3/2)(5).$$

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K, the fraction of A/C participating in each strike, is (5.5)/(9.7)(3/2) and therefore N is equal to 255. Moreover, two B-36 tankers are required for each sortie with in-flight refuelling, setting a total requirement of

(255)(5.5)(2)/(4.5) = 625 B-36's.

B. Force Composition

1. Except where noted below, the force requirements given in reference (a) were used directly with no change. For logistic support, it was presumed that each ship had a turn-around time of two months. Details of the force composition are given below:

(a) Fast Carrier Task Force: The carrier task force would consist of two task groups, each with

2 CVB (for VA),
1 CV (for air defense),
1 CVL (for ASW defense),
4 CA, 4 CL (AA), and
18 DD.

This was similar to the task force proposed in reference (a) and the replenishment force requirements given there were re-checked for the task force above by means of reference (h). The cost to operate each was about equal. Buaer's Ships Installation Division advised that if suitable catapults were installed on the CVB, 31 to 32 VA aircraft could be spotted aboard each, thus assuring a total striking force of 120. Without the improved catapult, only about 12 could be accommodated since the full flight deck would be required for take-off.

(b) Overseas Land Base: All requirements were taken directly from reference (a).

(c) Overseas Seaplane Base: All requirements were taken directly from reference (a). Seaplanes for air and ASW defense were assumed, but the use of carriers for this defense would not alter the cost to operate appreciably.

(d) N.A. Land Base: Requirements are given in Appendix B. No air or ASW defense was included.

(e) N.A. Seaplane Base: In addition to the aircraft requirements given in Appendix A, it was computed that 45 SSO's would be needed, each carrying 150,000 gallons of aviation gasoline. To allow time for travelling to and from a replenishment point, the assumption was made that each submarine could refuel a seaplane strike four times per month. The necessary logistic support force was determined from reference (h). No air or ASW defense for the U.S. base of submarine refuelling force was included.

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APPENDIX B

Relative Risk to Base

1. While attention has been given previously to the relative risk to base expressed as differences in base life, this factor may be examined in somewhat more detail. Although the carrier task force exposes a substantially greater investment to the enemy than does a land base, - and one which can be irretrievably lost - the effect of this has been considered in the cost-to-operate, and it is useful here to examine only the relative ease with which a determined enemy might by aggressive attack render the alternative forces impotent.

2. With conventional weapons the experiences of World War II suggest that both the carrier and land base can absorb large amounts of punishment without serious loss of effectiveness. A seaplane base should be equally difficult to neutralize given similar defenses. In the open sea, however, such a base would be subject to serious risk from submarines.

3. Weapons of mass destruction, on the other hand, pose a different problem though not necessarily a serious one. An enemy may find more worthwhile targets than air bases of <u>any</u> type on which to expend such weapons. It is interesting, however, to consider the effect of, say, one atom bomb dropped on each of these three bases alerted to attack.

While A.E.C. Restricted Data cannot be used in a paper of this nature, references (g) and (i) contain information from which rough estimates may be drawn. An atom bomb apparently has characteristics generally as follows:

(a) Air burst: Severe damage will occur up to ½ mile from the burst center. Beyond one mile the possibility of damage or dangerous radiation is negligible. Under six feet of solid earth one can survive even directly beneath the burst. Except for the radioactive cloud (which drifts away) no dangerous radioactivity will persist.

(b) Water burst: In waters as deep as 175 feet, or perhaps less, a base surge will be developed carrying lethal radioactivity about one or two miles downwind. Again structural damage would be restricted to about a mile. However, in water, say, 40 feet deep no surge could be created. At Bikini the lagoon waters were safe within a wee[k] been suggested that in some cases no radioactive residue may remain at all.

(c) Ground burst: The radius of damage would be substantially decreased but the immediate area would remain dangerously radioactive.

4. Since the normal distance between the major ships of a carrier task group is a mile or greater, one atom bomb over the force would on the average affect only one ship; and since the enemy bombardier must be conceded some discretion in the choice of targets, one of the eight carriers in the force would probably be knocked out per bomb delivered. It is possible, of course, that a bomb dropped between two ships might damage more than one but, on the average, only one would be affected.

5. A seaplane base, on the other hand, moored in shallow waters would be less vulnerable to a water burst bomb, but in any case would no doubt suffer about the same proportionate amount of damage, even though no single ship would be as important as a major task force ship.

6. The vulnerability of a land air base to atom bombing is open to question. There seems to be no reason why, on suitable terrain, a land base should not be dispersed sufficiently so that no greater proportion be destroyed by atom bomb attack than in a floating base. On the other hand, floating bases possess duplication of runways and control facilities, similar duplication of which would raise the cost of the land base. Without such duplication, damage to even a small fraction of a land base would, if in a vital spot, neutralize the entire base for a period much longer than that required to replace a floating base component. Of course the useful life of a land base, exclusive of its supply line, is unaffected by enemy submarine activity.

7. Up to this point the discussion has considered equal levels of attack, but clearly the relative risk to base will also be a function of the expected density of this attack. First with the exception of bases near the Chutoski Peninsula, North American land bases are relatively immune from air attack. However, an advanced undefended base for refuelling of aircraft does not enjoy such immunity. In this sense it appears that the North American-based, refuelling seaplane accrues rather great risk from attack by enemy fighters or bombers which may trail aircraft to a refuelling rendezvous. Indeed it is quite likely that large numbers of such aircraft on frequent missions would be quite vulnerable during refuelling.

This possibility seems to set a practical limit to the number of seaplanes which can participate, as well as prohibiting frequent raids which an enemy could anticipate and prepare for.

8. On the other hand, overseas bases whether afloat or ashore must expect continuing attack at all times. However, the density of air attack will probably be much greater against permanently located bases, for the enemy can construct his attack bases where they will be most effective. Even a mobile seaplane base may suffer this disadvantage to some extent since the requirements for a base location in navigable yet sheltered waters allows the enemy to anticipate probable locations. Here a carrier base enjoys a considerable advantage since it can choose its current operating area to minimize retaliatory air attack and, thus, the overall risk to base will be at least as low as to land base.

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APPENDIX C

Cost Accounting

1. The cost factors used to develop the cost-to-operate data presented in this study are outlined below:

(a) Ship Cost: All ship costs were taken from unpublished BuShip's data (Code 279) and include AA where appropriate.

(b) Land Base Cost: Initial cost of land bases less cost of shipping to build base and AA guns was computed at the rate of $30 per empty-weight-pound of aircraft complement. This figure was based on the price cited in reference (j) converted to World War II dollars. Cost of AA guns was taken from references (k) and (l).

(c) Aircraft cost: Aircraft cost was taken to be $20 and $25 per empty-weight-pound of aircraft for reciprocating engine and jet aircraft, respectively. Reference (c) suggested $20 per pound for World War II aircraft, and jet aircraft cost about 25% more.

(d) Ship Operation: Ship operation costs per year were taken from reference (c). These, less depreciation but including repair and modification costs, are:

(1) $550 per year per standard displacement ton for DD's and DE's.
(2) $200 per year per standard displacement ton for all other combat vessels, and
(3) $100 per year per gross ton for auxiliaries.

(e) Land Base Operation: Land base operation was computed at the rate of $2 per year per empty-weight-pound of aircraft complement (reference (c)).

(f) Aircraft Operation: Aircraft operation costs were taken at the rate of $8 per year per empty-weight-pound of aircraft complement (reference (c)).

(g) Personnel Cost: Salaries and material for additional personnel were taken at the rate of $2400 per man per year (reference (c)).

2. Using the data given above the yearly cost to operate can then be computed as outlined below:

(a) Logistic Supply Forces: The cost to operate each supply force and the yearly depreciation (replacement cost) are shown in Table III. Depreciation is based on 10% losses per month at sea which, with a turn around time of two months, amounts to six months at sea per year, or 60% replacement each year. The initial lift for the overseas land-based force is computed on a two months of operation basis.

TABLE III

Yearly Replacement and Operating Cost for Replenishment Forces (in Millions of Dollars)

	Initial Ship Cost	Replacement Ship Cost	Operating Cost
Carrier-Based A/C:			
Auxiliaries	$ 360	$ 220	$ 75
Escort	$ 360	$ 220	$ 60
Total Cost		$ 440	$135
N.A.-Based Seaplanes:			
M/V to support SSO	$ 130	$ 80	$ 25
Escort	$ 140	$ 85	$ 25
Total Cost		$ 165	$ 50
Overseas-Based Seaplane:			
M/V	$ 155	$ 95	$ 45
Escort	$ 140	$ 85	$ 25
Total Cost		$ 180	$ 70
Overseas Land-Based A/C:			
Total for Initial Lift at 2 months operation	$1400	$ 140	$ 50
Support: M/V	$ 210	$ 125	$ 55
Support: Escort	$ 180	$ 110	$ 30
Support: Total Cost		$ 235	$ 85

(b) Base or Ship Cost: The initial cost of the base and/or ships is found and this cost then amortized over the life of the base. The cost of AA defense of the overseas land base was computed from reference (k) by taking the cost of AA guns equivalent in size and number to those of the carrier task force and adding the cost of a director system as given in reference (1).

(1) Carrier Task Force:

4 CVBs	$ M 340
2 CVs	$ M 130
2 CVLs	$ M 50
Supporting Ships (8 CAs, 8 CL(AA)s, 36 DDs)	$ M 960
Total Cost	$ 1480 Million

(2) NA-Based Seaplane: (Assuming cost of base is the same as an equivalent sized land base.)

Seaplane base for 15 million empty wt. pounds of A/C @ $30/lb.	$ M 450
Cost of 45 SSOs @ $ M 8 each	$ M 360
Total Cost	$ 810 million

(3) Overseas-Based Seaplane:

Cost of Base Ships	$ M 130
Cost of Base Defense Ships	$ M 270
Cost of Air Defense Ships	$ M 140
Total Cost	$ 540 million

(4) North American Land-Based A/C:

Cost of Base for 9 million empty wt. pounds of bomber A/C @ $30/lb.	$ M 270
Cost of Base for 85 million empty wt. pounds of tanker A/C @ $30/lb.	$ M2550
Total Cost	$ 2820 million

(5) Overseas Land-Based A/C:

Cost of Base for 4.2 million empty wt. pounds of bomber A/C @ $30/lbs.	$ M 126
Cost of Base for 2.8 million empty wt. pounds of defensive A/C @ $30/lb.	$ M 84
Cost of AA guns ($M50 for Guns, $M15 for director)	$ M 65
Cost of Initial lift (Table III)	$ M 190
Total Cost	$ 465 million

(c) Base Operation: In addition to base operating cost, the cost of operating one third additional base ships is included to provide replacement for overhaul and repair.

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(1) Carrier Task Force:

Cost of operating 4 CVBs per year @ $200/ton	$ M 36
Cost of operating 2 CVs and 2 CVLs per year @ $200/ton	$ M 15
Cost of operating supporting ships per year @ $200/ton	$ M 85
Total	$ M 136
For Replacement	$ M 45
Total Cost	$ 181 million

(2) NA-Based Seaplane:

Cost of operating base for 15 million empty wt. pounds of A/C @ $2/lb.	$ M 30
Cost of operating 45 SSOs @ $200/ton	$ M 15
Total Cost	$ 45 million

(3) Overseas-Based Seaplane:

Cost of operating Base Ships	$ M 100
For Replacement	$ M 33
Total Cost	$ 133 million

(4) NA-Based A/C:

Cost of operating base for 4.2 million empty wt. pounds of bomber A/C @ $2/lb.	$ M 8.4
Cost of operating base for 85 million empty wt. pounds of tanker A/C @ $2/lb.	$ M 170.0
Total Cost	$ 178 million

(5) Overseas Land-Based A/C:

Cost of operating base for 7.0 million empty wt. pounds of defensive and bomber A/C @ $2/lb.	$ M 14
Cost of 45,000 additional army troops estimated in reference (a) for defense and services @ $2400 per year per man	$ M 110
Total Cost	$ 124 million

(d) A/C Operation:

Cost of Operating @ $81 empty wt. pounds of A/C

7.0 million lbs. of carrier A/C	$ M 55

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15.0 million lbs. of NA-based seaplanes	$ M 120
9.8 million lbs. of overseas-based séaplanes	$ M 78
89.0 million lbs. of NA-based A/C	$ M 710
7.0 million lbs. of overseas-based A/C	$ M 55

(e) A/C Replacement: At five A/C losses per mission for bomber A/C, 1% per mission for tanker A/C (0.8 per mission), and 1½ year life for all other A/C, Table IV gives the yearly A/C replacement cost.

TABLE IV

Yearly A/C Replacement Cost (Millions of Dollars)

	Missions per year	Wt.of A/C (lbs.)	Millions of lbs. replaced	Replacement Cost
Carrier A/C:				
VA	175	35,000	30.5	$ 770
Defensive A/C	--	---	1.85	$ 46
Total Cost				$ 816
NA-based Seaplane:				
VA	210	58,000	61	$1270
Total Cost				$1270
Overseas-based Seaplane:				
VA	175	58,000	51	$1270
Defensive A/C	--	---	1.85	$ 46
Total Cost				$1316
NA-based bomber:				
Bomber	210	35,000	37	$ 770
Tanker	420	135,000	45	$ 910
Total Cost				$1680
Overseas-based bomber:				
Bomber	175	35,000	30.5	$ 770
Defensive A/C	--	----	1.85	$ 46
Total Cost				$ 816

(f) Flight Crew Training: While flight crew training costs do not cover the full cost of rear echelon activity which should be charged to the operation they certainly account for by far the greater amount. The cost of this training per crew can be approximated by taking from reference (c) the empty wt. pound of A/C required to train 1200 flight crews per year. This wt. in millions of pounds is: for the B-36, 55; for the bomber, 17; and for the fighter A/C, 4. Then with a yearly cost of $22 per per empty wt. pound ($12 for A/C replacement plus $8 for A/C operation and $2 for Base Operation) this amounts to:

$1.0 million per crew for the B-36,
$0.3 million per crew for the bomber, and
$0.075 million per crew for the fighter A/C.

If the bomber pilots are allowed a 50% survival probability, crew replacement rate must be, at 5 losses per mission, 10 per mission. Similarly, the B-36 tanker with 0.8 loss per mission is 1.8 per mission. The crews for the 2.8 million empty wt. pounds of air and ASW defense overseas are replaced at the rate of two fighter crews per 10,000 empty wt. pounds per year. This latter assumption is an adequate one since it allows a new crew every six months per fighter. The cost is relatively small anyway. Table V summarizes the total cost for all five forces.

TABLE V

Cost of Flight Crew Training
(In Millions of Dollars per Year)

	Missions Per Year	Replacement per Mission	Crews Required	Cost Per Crew	Cost
Carrier-Based A/C:					
VA	175	10	1750	0.3	$ 525
Defensive A/C	--	--	560	0.075	42
Total Cost					$ 567
NA-based Seaplane:					
VA	210	10	2100	0.3	$ 630
Total Cost					$ 630
Overseas-Based Seaplane:					
VA	175	10	1750	0.3	$ 525
Defensive A/C	--	--	560	0.075	42
Total Cost					$ 567
NA Land-Based Bomber:					
Bomber	210	10	2100	0.3	$ 630
Tanker	420	1.8	750	1.0	750
Total Cost					$1380
Overseas Land-Based Bomber:					
Bomber	175	10	1750	0.3	$ 525
Defensive A/C	--	--	560	0.075	42
Total Cost					$ 567