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SITE SELECTION AND PRELIMINARY PLANNING CRITERIA FOR LARGE, HIGH PERFORMANCE, WATER-BASED AIRCRAFT

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SITE SELECTION AND PRELIMINARY

PLANNING CRITERIA FOR LARGE,

HIGH PERFORMANCE, WATER-BASED AIRCRAFT

by

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PREFACE

Within recent years, the Department of Defense has been constantly searching for and developing new, versatile weapon systems in order to provide the most effective defense posture possible. Within its mission, the Navy is developing new weapons which it hopes will combine the best advantages of its surface, sub-surface, and air media to form components of some of these integrated weapon systems. One of the Navy's new weapons is the water-based, high performance, long range, large seaplane which bears little resemblance to the large flying boats of the past. These new types of seaplanes were born of the necessity for a new concept of planning which, in time of war, stressed mobility and dispersion over the five-eights of the earth's surface which is water.

At the present time, 24 P6M Seamasters, the most advanced of this latest type of seaplane, are being produced for the Navy. The primary mission of the P6M is that of high performance, water-based attack aircraft which will be serviced and maintained at sea. In time of war, they will operate and strike from natural coastal and inland waterways anywhere in the world. They will be refueled from submarines or tanker seaplanes, such as the R3Y or P6M, and be maintained by specially built ship docks and tenders at sea. This whole integrated, water-based, sea serviced and maintained, highly mobile, offensive weapon system will be independent from the old, relatively slow, carrier task force or fixed-base concept of the past. This integrated system was designed to supplement the fixed land-base system which has its inherent immobility, natural

concentration, and requirement for long construction time. Normally, operations with these high performance attack seaplanes would be from sheltered waters, with only emergency operations being conducted from open seas, even though the P6M has capabilities of taking off and landing in 6-1/2-foot-sea states.

It has been said by some of the strongest proponents of this new weapons system that the major key for unlocking the true potential of these water-based weapons is proper site selection and evaluation. To the author, who is an officer in the Civil Engineer Corps of the Navy, this whole new seaplane concept and capability creates many interesting considerations and problems. Undoubtedly, some of the naval Civil Engineer Corps Officers who are concerned with site selection and planning for war plans, logistic plans, and development plans for certain new weapon systems will have need for increased knowledge along these lines.

In this thesis, I have attempted to investigate the facets that would be of primary concern to naval Civil Engineer Corps personnel. The planning considerations will range from the water basing of this type of aircraft on an operating site, consisting of some degree of natural protection from the weather and enemy observation with no facilities constructed ashore, to the other extreme of a permanent continental base. This planning, to be effective, must assure that none of the forward operating sites or advance bases contain unnecessary facilities which will intentionally or unintentionally make the attack components of this weapon system "base bound."

Other problems concerned with the more conventional aspects of permanent bases and future advances in seaplane design will be discussed.

The extreme complexity of modern weapons and their interrelated employment has made the naval Civil Engineer Corps officer of today concerned with many planning and engineering problems and areas of consideration which were not conceivable when the evolution of weapon development was relatively static a few decades ago. The planner must think and plan in new dimensions which involves a limited knowledge and appreciation of other scientific fields such as oceanography, aerology, and aerodynamics. No detailed site or preliminary planning criteria on this subject is known to exist; therefore, to become better acquainted with the rapid changes taking place in one phase of naval weapons development, I have chosen to write my thesis on site and preliminary planning considerations for large, high performance, water-based aircraft facilities.

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LIST OF SYMBOLS AND DEFINITIONS

Symbol	Units	Definition
λ	feet	average wave length.
h	feet	average significant wave height.
λ/h	-	average wave slope.
ϑ	degrees	wave slope.
θ	degrees	local slope of wave surface at point of contact.
c	feet per sec.	wave celerity.
T	seconds	average wave period.
T_n	seconds	natural period of hull.
T_e	seconds	period of wave encounter.
Λ	-	tuning ratio, T_n/T_e .
W	feet	width of wave crest.
w	lbs per ft^3	unit weight of water.
g	$feet/sec^2$	acceleration due to gravity.
L	feet	length of seaplane planing hull, not overall length of aircraft.
b	feet	max. beam of hull .
Δ	pounds	weight of loaded hull in water.
V	feet per sec.	average speed of seaplane.
V_v	" " "	vertical velocity.
V_h	" " "	horizontal velocity.
V_r	" " "	resultant velocity.
V_{re}	" " "	effective resultant velocity.
V_{ve}	" " "	effective vertical velocity.
X	degrees	angle of aircraft heading in relation to direction of oncoming wave.

Symbol	Units	Definition
τ	degrees	trim of straight portion of hull forebody.
$\Delta\tau$	degrees	change in trim angle.
γ	degrees	flight path angle.
γ_e	degrees	effective flight path angle.
$\Delta\phi$	degrees	max. change in roll angle.
ΔZ	feet	heave or rise translation of hull along vertical Z axis.
A_τ	$\Delta\tau/\vartheta$	trim parameter factor.
A_ϕ	$\Delta\phi/\vartheta$	roll parameter factor.
A_z	$\Delta Z/h$	heave parameter factor.
C_Δ	-	load coefficient, Δ/wb^3 .
C_v	-	speed coefficient $V/\sqrt{gb}$.

I. INTRODUCTION

A. Purpose

This thesis has two primary purposes. The first is to present a detailed investigation of certain important hydrodynamic, aerodynamic, physical features and operational requirements which affect site selection and related preliminary planning for large, high performance seaplanes. The second purpose is to evaluate these considerations and thereby set forth the site selection and preliminary planning criteria for this type of water-based aircraft.

B. Scope

Extensive research has revealed that no overall generalized analysis exists of how the hydrodynamic performance characteristics of these aircraft are related to all the actual basic physical factors that must be considered in site selection and preliminary planning. Nor is there any detailed planning criteria specifically for seaplanes known to exist. Therefore, by necessity, the scope of this thesis is quite broad.

The thesis is divided into seven general parts. Part I, in addition to setting forth the purpose and scope, is an introduction which briefly explains the basic characteristics of large, high performance seaplanes and gives a history of their evolution.

Part II explains the important relationship of the mission of the proposed site to the basic planning considerations of natural terrain and other physical features, safety and efficiency of operations, and the highly mobile military weapons concept explained in

the preface. A summary of a few seaplane facilities now being used by high performance type seaplanes is presented. Also, briefly, the problems and considerations of integrating permanent type seaplane facilities into regional and community master plans are discussed.

Part III contains a detailed investigation of the seaworthiness characteristics of the seaplane. The analysis of aeronautical research model studies and full scale aircraft test programs is presented so that the aircraft's basic seaworthiness performance characteristics can be defined and be related to specific wind wave, and swell parameters.

Part IV sets forth the detailed basic criteria on which site selection and related preliminary planning should be based. It evaluates each factor such as wind, tide, waves, and weather. Since the practical application of these considerations is of primary importance to the planner, the various methods of determining or evaluating the important data is briefly described where such methods are not too well known from conventional planning criteria.

Part V discusses the interrelation of each planning factor and how it affects functional and preliminary layout planning considerations.

Part VI briefly discusses the possible future developments of large, high performance seaplanes which may greatly affect future planning.

Part VII presents certain general conclusions and findings which are based on the investigations and criteria established by the writer.

Throughout this thesis the military requirements will be stressed, since the development and utilization of high performance seaplanes is at this time primarily by the military. However, it is very possible that the unique and advantageous possibilities of such aircraft for civilian

and commercial use may be developed and fully recognized in the near future. There is already some interest being aroused, both in this country and Great Britain along this line. It is considered that some of the planning criteria and considerations for the permanent continental military facility may be applicable for commercial planning. However, since these facets should be fairly evident, the author has not attempted to emphasize them.

C. Evolution of the Seaplane

It is believed that a brief review of the evolution of the development of these water borne aircraft will help provide the planner with an understanding of the basic characteristics of large, high performance seaplanes. Certain of these basic characteristics have an effect on site and preliminary planning.

In 1911 Glenn Curtiss flew the first successful float plane and in 1912 built the first flying boat. After 1912 and until 1919, a series of flying boats were designed by Curtiss which culminated in the construction of the hydrodynamically effecient NC-type flying boat. The hull of the NC-4 was 45 ft. long and had a 10-ft. beam (L/b ratio of approx. 4.5). It weighed 20,000 lbs. fully loaded and had four 400 hp engines. Its range was 1400 miles and in 1919 the NC-4 completed its first flight across the Atlantic.

From that time until World War II, efforts to construct seaplanes naturally leaned heavily on the technology and experience of the naval architect, since it must be remembered that they were constructed for and by mariners. Inasmuch as the naval architect had concerned himself very little with high speed planing phenomena, seaplane design for the most part

followed the trend of highly refined displacement ship type hulls. It was expected that these seaplanes in water would perform as well as boats; and, in fact, before World War II, they had been little more than flying "boats." A good example of this was the famed German Dornier Do X (1930) with a weight of 123,000 lbs which was a boat with wings and engines on top. Later, the famous Martin Clippers, British Empire flying boats, and others, which pioneered the first overseas airlane routes, led to the design of even larger seaplanes such as the Martin's Mars of 165,000 lbs and the British Saunders-Roe's Shetland of 125,000 lbs (Ref. 20). For these large seaplane hulls to be seaworthy, they required deep hulls with relatively inefficient large bulky frontal areas, and engines that had to be positioned high to give propellers clearance above the water. During World War II, which induced an era of great aeronautical development, the seaplane was religated to a minor role because this basic concept was not overcome.

In 1945, recognizing that a case of acute design stagnation in the hydrodynamic field was in danger of effectively eliminating the large seaplane, the Bureau of Aeronautics of the Navy, the National Advisory Committee for Aeronautics, and Convair Aircraft Corporation started an intensive coordinated research program. From the past, it was known that the short, stubby hulls of low length to beam ratio (see Fig. 8), ranging from the NC-4, L/b ratio of 4.5, to the most modern flying boats of World War II, with a L/b ratio of approximately 6, placed severe limitation on the potential load carrying ability and efficiency of planing hulls. Previous attempts to increase the fineness ratio of the hulls always met by rapid deterioration in hydrodynamic stability which resulted in violent porpoising and therefore no increase in loading. However, with new tools of investigation

that were available, the complex aerodynamic and hydrodynamic functions became better understood, and a promising relationship of increased length to beam ratios was developed which greatly improved the load carrying ability and seaworthiness of seaplane hulls (Refs. 51, 52, 53).

Rapid exploitation of this vast new area revealed that complete advanced design and construction of a large high performance seaplane was possible; therefore the Navy contracted with the Convair Company for the large R3Y seaplane transport. The R3Y has a hull coefficient of 2.58 for a normal loading, which is 300% greater than the extreme wartime overloads carried by World War II seaplanes. The hull efficiency of a seaplane is expressed in terms of a hull coefficient C_{Δ} which equals $\frac{\Delta}{wb^3}$. A direct result of this significant increase in hull efficiency was a marked reduction in hull frontal area and a proportionate reduction in aerodynamic drag. Also, with increased turboprop power plants available, a very low power loading was possible which radically increased the seaplane's performance. The power loading ratio (lbs. of aircraft per brake horsepower) of the R3Y transport is 5.6, which is less than the best fighters of World War II. The P-38 and P-51 fighters had power loadings of 6.1 and 6.2 respectively. Thus, the beginning of a new era seaplane design was started. The R3Y Tradewind only recently broke the speed record in coast-to-coast flight for transport aircraft, making a 2,400-mile flight between San Diego and Patuxent River, Maryland, averaging 403 mph.

While the R3Y has an L to b ratio of about 10 and made its initial flight in 1950, other new high performance seaplanes are being developed, such as the P6M-2 Seamaster. The Seamaster has a L to b ratio of approximately 13 and has been undergoing flight tests since May 1956.

The jet powered Seamaster is in the 600 mph class and is comparable to the B-47 in performance, and is capable of being scaled up to much greater dimensions. The Seamaster also has the capability of taking off and landing in 6-1/2-ft. waves. Table I lists the characteristics of large high performance seaplanes built or proposed.

Recent tests performed by NACA (Ref. 37) revealed some very interesting conclusions in testing seaplane models with L/b ratios of 6 through 20 in waves. It is their opinion that the present ratio of 15 is the practical upper limit at this time, but a ratio of 20 is a possible extreme. The aerodynamic drag of these hulls decreases as the L/b ratio increases, whereas the rough water hydrodynamic qualities tend to improve. Martin Co. (Ref. 5) predicts that high performance seaplanes with length to beam ratios of 20 and longer afterbodies will be designed. Martin also points out that present day high performance seaplane aerodynamic hull drags are only 4% higher than comparable land planes and the total drag need only be about 1% greater, even considering jet aircraft. Therefore, a person who is responsible for site and facility planning for large seaplanes should see that, with ever-increasing power plants, the seaplane will have a greater role in aviation.

TABLE I

Types of Large High Performance Seaplanes (Note 1)
United States Models

Characteristics	P5M-2 (Martin)	R3Y-2 (Convair)	P6M-2 (Martin)	Sea Mistress (Proposed-Ref. 25)
Wing span (ft)	118'-2"	145'-9"	100'	200' ±
Overall hull length (ft)	98'-11"	142'-6"	134'	170' ±
Hull width (ft)	10'	14'	10'	20'
Length/beam ratio	8.6	10	13.2	13 ±
Gross weight (lbs)	73,000	175,000	190,000	500,000
No. of engines	2 P (8)	4 TP (3)	4 J (4)	8 or 10 J (may be nuclear)
Total hp or lbs static thrust	7,400 hp	23,400 hp	72,000 lb-thrust	150,000 ± lb-thrust
Speed (mph)	250 M (5) or 97 L (7)	386 M	600+ M	500 - 600
Max. static draft (ft)	6' ±	8'-3"	7' ±	8'-6"
Height from keel (ft)	32'-9"	51'-5" in cradle	31'	-

British and Soviet Union Models

Characteristics	SR/45 (Saunders-Roe)	Be-6 Madge. (Beriev) (Ref. 32)	Be-8 (Beriev) (Ref. 32)	Tupolev Type (Ref. 27)
Wing span (ft)	219'-6"	100'+	100'+	? Swept Back
Overall hull length (ft)	148'	78'	Note 2	Note 2
Hull width (ft)	16'-8"	Note 2	"	"
Length/beam ratio	7.3	"	"	"
Gross weight (lbs)	315,000	60,000	60,000±	"
No. of engines	10 TP	2 P	2 J	4 J
Total hp or lbs static thrust	40,000 hp	4,000 hp	11,000 lb-thrust	23,800 hp
Speed (mph)	380 C (6)	240 M	Note 2	Note 2
Max.static draft (ft)	8'	Note 2	"	"
Height from keel (ft)	55'-9"	"	"	"

Notes:
1. All data compiled from references 18, 56, 62 unless noted.
2. Other unclassified information not available.
3. Turbo prop engine. 4. Turbojet engine 5. Max. speed.
6. Normal cruising speed. 7. Landing speed 8. Propeller engine.

II. PRELIMINARY PLANNING CONSIDERATIONS

A. Types of Seaplane Facilities

Before any site or preliminary planning may be considered for a facility, the exact mission and functions for the immediate, as well as possible future, requirements of the site must be exactly set forth and clearly defined. This seemingly elementary planning axiom is often violated and has resulted in serious consequences in some cases.

To simplify the site and preliminary planning for high performance seaplane facilities, it is considered that the planning of new facilities for virgin sites or integration into existing operating naval activities may be included into three general categories:

The strike deployment site.

The advance support base.

The permanent or semi-permanent support and training station in the continental United States.

Since the high performance seaplanes are highly specialized components in a weapon system that is designed to take full advantage of the concept of nuclear war of constant mobility and flexibility, it is believed that the requirements of these three types of facilities may be defined in the following terms:

1. Strike Deployment Site

This facility in all likelihood would consist of an area of naturally sheltered water which would provide sufficient protection from weather and enemy observation. A series of such pre-selected sites in a Norwegian fjord, a German mountain lake, a Turkish river, an Indian lagoon, or Alaskan coastal waters with no facilities constructed ashore would provide

sites sufficiently close for the aircraft to carry out their primary missions, yet with runways invulnerable to enemy bombardment. The servicing of these aircraft at these sites could be accomplished by refueling and support submarines, other logistic-tanker seaplanes such as P6M or R3Y, LSD (Landing Ship Dock) or other means. The site planner will be interested in selecting and evaluating a great number of such sites to provide the maximum flexibility that tactical or weather conditions may make necessary. It would be desirable if these sites contained the limiting terrain, weather, wind, wave, and swell parameters for safe and efficient operation; however, since these facilities would not be used very frequently, and only by experienced personnel, marginal operational conditions in all likelihood might be permitted.

2. Advance Support Base

This facility might in some circumstances consist of a relatively well sheltered water area with only the most temporary facilities constructed ashore which would supplement to a minor degree the maintenance and service normally provided by support ships, submarines, and aircraft of the integrated weapon system. The facility would provide the normal operating base for these aircraft when not deployed with fleet units at sea or operating from deployment sites. Certain aircraft inspection checks and routine echelon maintenance would be accomplished at buoys because ramps would probably not be provided. However, if the advance base is also used for other fleet requirements, more extensive facilities for the aircraft may be available. But, nothing should be done to intentionally or unintentionally make the attack components of the system "base bound." It is considered that high performance seaplanes with purely logistic support tasks to the weapons system may not operate strictly under these austere conditions. Here, again, safe and

efficient operation is highly desirable, but marginal operational conditions might be permitted depending on various factors.

3. The Permanent or Semi-permanent Support and Training Station

These facilities would probably only be constructed within the continental United States. They would be capable of providing all aircraft maintenance and overhaul that would be required. Beaching ramps and parking aprons to do this work ashore would be provided. Since this facility might be used for training operations and considerable money would be invested in permanent type shore facilities, it is considered that the limiting operating conditions should be based on those for safe and efficient operations.

B. Integration of a Permanent Facility into Regional and Community Master Plans

Permanent facilities for large seaplanes must be made a part of regional and community master plans. The 1952 report of the President's Airport Commission (Ref. 57), commonly referred to as the Doolittle Report, made the recommendation that all airport facilities, including military air facilities, should be integrated with city and regional development plans.

The permanent seaplane facility cannot be located or zoned on a segregation basis of planning, but, rather, must be integrated with the land use and community area on a performance basis. The proper control of land uses in the air corridor and land uses in the area adjacent to the facility reservation provides safeguards, both from encroachment on air operations and danger or disturbance to the community.

The development of a permanent large, high performance seaplane facility implies the use of one of the heaviest and fastest aircraft engaged in continental or intercontinental use. These faster aircraft, with higher

wing-loadings, are not so sensitive to the effect of cross wind on landing or take-off; therefore, if the sealanes are located in a reasonable sheltered water area, they should be able to take off or land in the same direction over 95% of the time. This factor will simplify some of the problems concerning integrated planning, but many others will have to be considered. Basically, the interrelation of the facility's functional requirements and the main planning factors may be set forth in the following three categories:

Water Area Considerations

Community Considerations

Other Air Facility and Air Space Considerations

1. Water Area Considerations

The full impact of the facility's requirements concerning the acquisition, restriction and control of the required water areas must be considered. Such regional activities as shipping, commercial and recreation fishing, and other requirements and their probable future growth in the general area must be taken into full account. If the facility is to be located in whole or part in navigable water, the principal Federal, State, and local laws for the protection and preservation of navigation and navigable waters must be understood and considered.

One of the requirements of Federal law concerning approval of projects in navigable waters is that an application for a permit must be submitted to the Army Corps of Engineers showing the location, extent clearances, and character of proposed facility. This information shall be delineated on maps and drawings in the form prescribed by the pamphlet, "Permit for Work in Navigable Waters," and in consultation with the District Army Engineer in charge of the locality in which the project lies.

2. Community Considerations

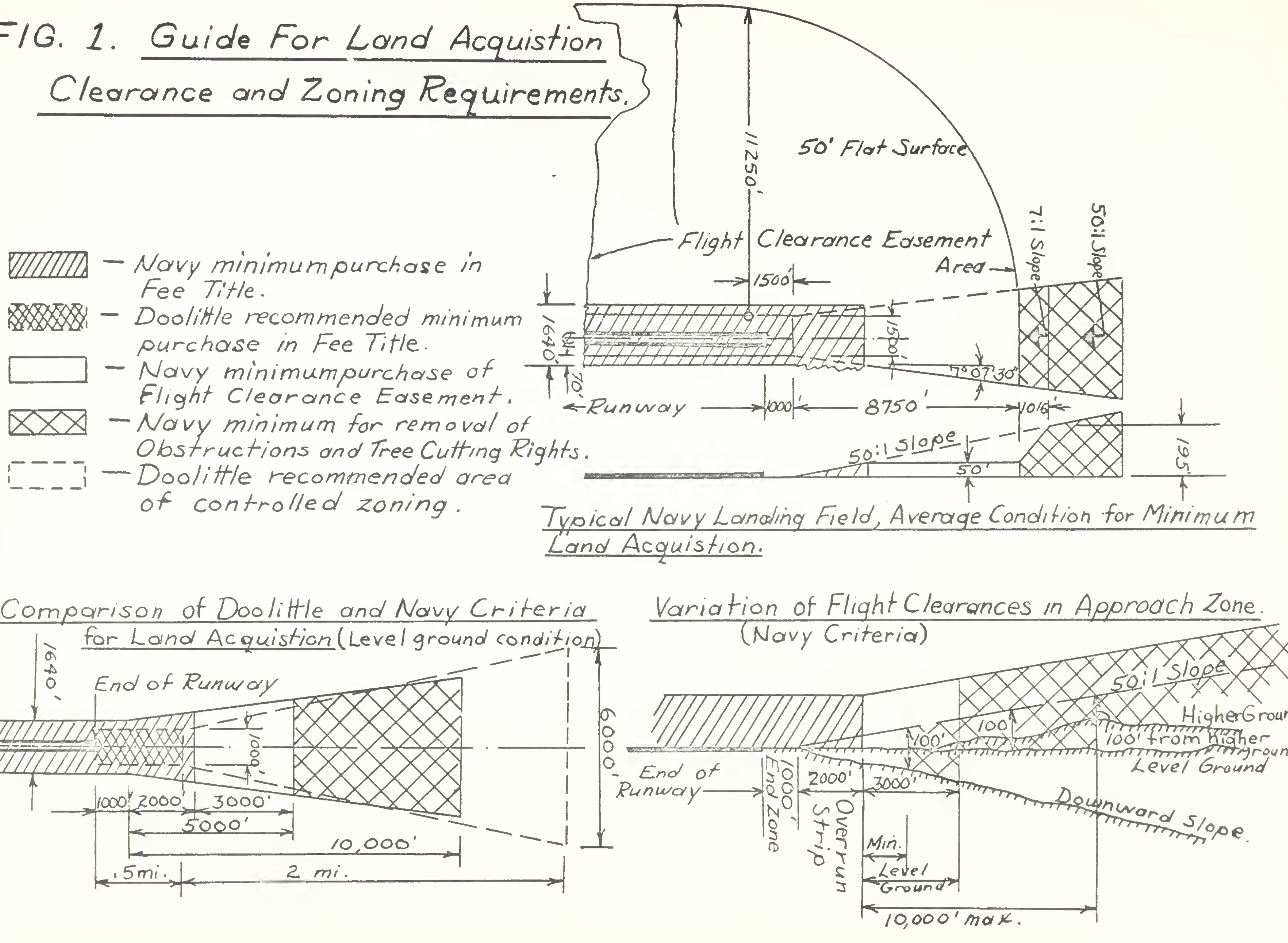
If the facility is not located in a completely remote, uninhabited area, which will rarely be the case, the single or parallel sea lane principle should be the basis of land and water uses and obstacle restrictions in the approach corridor. This is one of the basic recommendations of the Doolittle Report. The influence of the facility on land uses and land values can thus be restricted to a limited segment of the facility's periphery. As close study of references 42 and 58 will reveal, air traffic utilizing single or parallel runways will be subjected to greater controls than are now prevalent; and, in time, it will assume an even more regulated and predictable pattern. In plannin the approach zones must always be considered as embracing the full transition from runway to navigable airspace. The boundaries of this transition zone and delineation of obstructions to air navigation are shown in Fig. 2.

Two other recommendations of the Doolittle Report, which are being recognized and accepted to some extent, are:

a. That the dominant runways of a facility should be protected by cleared level extensions at each end at least 1/2 mile in length and 1000 ft. wide. This area should be completely free from housing or any other form of obstruction, and such extension should be considered an integral part of the facility (see Fig. 1).

b. That there should be a fan-shaped zone beyond the 1/2 mile cleared extension at least 2 miles long and 6000 ft wide at its outer limits at each end of the dominant runway, established through effective zoning law, air easement, or land purchase. In this area the height of the buildings and also the use of land should be controlled to eliminate the erection of places of public assembly, churches, hospitals, schools, etc., and to restrict residences to the more distant locations within the zone.

FIG. 1. Guide For Land Acquistion Clearance and Zoning Requirements.



When the foregoing is carried out for seaplane facilities, the approaches should be located over water areas to the maximum extent to eliminate the need for costly land acquisition or semi-confiscatory regulations within these approach areas. If the 2-1/2 mile fan-shaped restrictive zone from the runway threshold is adhered to, it will also substantially alleviate problems of noise nuisance in the approach areas.

Noise Problem:

The noise problem should not be lightly considered as pointed out by reference 12. In a 1955 Memphis, Tennessee, meeting, the Director of the Construction and Evaluation Service of the Veterans Administration stated, "The jet plane has immeasurably increased the hazards and annoyances to residents in proximity to airports." And this should, "serve as warnings that appraisers should give very serious considerations to the effect of airports upon the desirability of adjacent housing." As a direct result of this policy, the boundaries fixed by FHA and Veteran's Administration for mortgage loans at San Diego, California, around Miramar Naval Air Station in August, 1955, were specified as a 20,000-ft. radius. The noise problem must be considered when fitting the airport into the overall community plan.

The noise problem resulting from the use of turbojet for military aircraft is a serious one, and there appears to be no easy solution. However, since this is almost a separate subject in itself, only the most brief attention can be given to it in this thesis. Turboprop aircraft does not present too much of a problem, but the turbojet with the afterburner device is the real villain. Turbojet aircraft is propelled by the thrust derived from the expulsion of extremely hot, expanding and accelerating gas from the rear of its turbine engines. The resultant noise stems mainly from two sources. At

the forward end of the engine, the air compressor spinning at very high rpm tends to produce a high-pitched whine. The greater part of the total noise appears at the rear of the engine where its high temperature, high-velocity gas jet mixes turbulently with the surrounding air.

The main efforts of industry in mechanically mitigating these noises are aimed at tuning the compressor whine out, absorbing it in the intake passages, and the adding of suppressor nozzles when no afterburners are used. Unfortunately, most high performance military aircraft require afterburner devices, and the use of suppressor in their present state of development reduces the peak performance demanded of these aircraft. Barring the obvious, but not-too-successful approach of attempting to sell the noise problem to the public as a necessity of national defense and the cost of technical progress, there are two other general approaches to the problem:

Eliminating noise in ground operations.

Eliminating noise in flight operations.

Ground operations -- (1) Disturbance can be reduced from ground engine run-ups by conducting these run-ups in area removed from nearby residential sections, as far as practicable; (2) existing airport facilities, structures, can be utilized as baffles.

Flight Operations -- The noise at take-off and in early flight which arises from turbulent mixing of hot jet stream with surrounding air causes the greatest problem. The most practical measures of interest to the site planner are:

a. Conduct approach, landing and take-off operations over water or open areas whenever possible.

b. Adopt operation procedures for the maintenance of maximum

altitude for as long as possible before landing to eliminate low, dragging power on approaches over airport neighborhoods.

c. Adopt accelerated climb-out procedures to at least 1200 ft before turning on course. An exception to this would be to take advantage of open terrain adjacent to the runway extensions. In this latter case, a turn is utilized as soon as practicable after take-off to permit the aircraft to conduct initial climb over the open areas.

References 9 and 44 contain some very recent details of the jet noise problems that were presented at the Jet Age Airport Conference in May, 1957, of which a site planner should be cognizant.

Integrated air facility and community planning may be able to meet approach and sound level zoning requirements, for instance, by having portions of the air field surrounded by landscaped buffer strips with the next contiguous area being used for manufacturing and commercial purposes. The latter area could be separated by landscaped buffer strips from the residential areas which would be the furthest distance from the facility. With this pattern, compatible land use and noise supression by distance, terrain, sound and structural attention, and reflection could be maximized.

A program of airfield zoning has been included in military planning policy to protect both investment and ability to expand. However, due in part to increased modern military aircraft requirements, this has proved difficult and has only been moderately successful. Except for obstruction zoning, it has proved financially impracticable to restrict land use in most cases. The Air Defense Command of the Air Force is now attempting to get its new fields 15 miles from the nearest large community with approach and take-off corridors 7 miles long and 4 miles wide.

The current Navy planning standards (Ref. 41) contain basic criteria for Navy policies regarding zoning, avigation easement and obstruction rights. The layout on Fig. 1 delineates the Navy's policy for the minimum land required for an average Navy landing field. In many respects, this would parallel the minimum requirements for a high performance seaplane facility with the exception that the landing course would be about 12,000 to 15,000 ft instead of 8,000 ft, and the effective width might be 3,000 ft in lieu of 1500.

Comparing the Navy minimum requirements with the Doolittle recommendations, the following is noted:

a. That the Navy minimum land programed for acquisition in fee simple is a little greater than the minimum recommended by the Doolittle report.

b. That the minimum Navy requirement for flight clearance easement requires that the Government be given the right for free and unsolicited passage for access and egress to these parcels of property for inspection, the unrestricted right to remove any or all obstructions, the tree cutting rights to continually maintain clearance to a prescribed elevation. Also included is the right to prohibit construction over the entire parcel any man-made obstruction over the prescribed elevations. It is to be noted that in no way does this ensure control or eliminate the erection of places of public assembly or restrain residence to more distant locations from the runway as strongly recommended in the Doolittle Report.

c. The Navy section out to 10,000 ft delineates that zone which includes the unrestricted right to remove any obstructions and to maintain the prescribed clearance. Also it should be noted that even beyond these three zones, out to a total distance of 60,000 ft from the end of a runway, other prescribed clearances must be maintained as set forth on page 16 of

reference 41. However, the Navy does say that when such operations are so low as to prohibit or restrict the use of land for its present or reasonably expected use, the acquisition of such land should be considered on the basis of whether it is to the advantage of the government.

It can be readily seen that the Navy minimum zoning policy falls short of the Doolittle Report minimum requirements which make it essential that well integrated local community planning be accomplished.

3. Other Air Facilities and Air Space Considerations

Another important factor in integrated regional and community planning is the proper relation of each airport with the other. A proposed site should have a traffic pattern that causes the least interference with traffic of nearby air facilities. The maximum control of large volumes of air traffic and/or varying types aircraft, such as large jet seaplanes for instance, requires the organization of air traffic without conflicts in procedure. It is necessary to avoid the intersection of traffic patterns, and this implies that air corridors be planned in parallel zones.

References 42 and 58 use the term "control zone" (see Fig. 2) to define that airspace of defined dimensions extending upwards from the surface that surround one or more airfield within which certain rules apply for the strict control and protection of air traffic. It may include the surrounding air space for 5 miles from the airfield under normal VFR (Visual Flight Rules) conditions, and 10 miles under IFR (Instrument Flight Rules) conditions, except that military jet operations require a 15-mile control area which may be greater under certain conditions. There may exist certain regional obstructions in the new proposed flight pattern or control zone which will have to be considered in addition to those already mentioned immediately adjacent to the new site.

The best basic source of information concerning avigation and obstruction requirements is the Civil Aeronautics Administration, Technical Standard Order No. N18 issued 16 April, 1950. This order outlines the procedures for determining obstructions, defines imaginary governing surfaces, and limits the heights above ground of objects in various areas near air facilities.

The requirements for military airfields have led to the establishment of a slightly different criteria for avigation and obstruction requirements. Air Force Regulation 86-3 sets forth the dimensional criteria for their airfields. U. S. Navy Bureau of Aeronautics, Instruction 11012.1A (Ref. 41) delineates this criteria for Navy and Marine Corps facilities.

For illustrative purposes, the Navy criteria has been adopted to a new high performance seaplane facility, which is being developed at Harvey Point, North Carolina as shown in Fig. 2. The proposed facility will have two sealanes oriented at 90° apart. The sealanes are planned to be 15,000 ft long and 1000 ft wide, with 1000 ft end zones. It is proposed that the facility will accommodate 24 type P5M and 12 type P6M seaplanes.

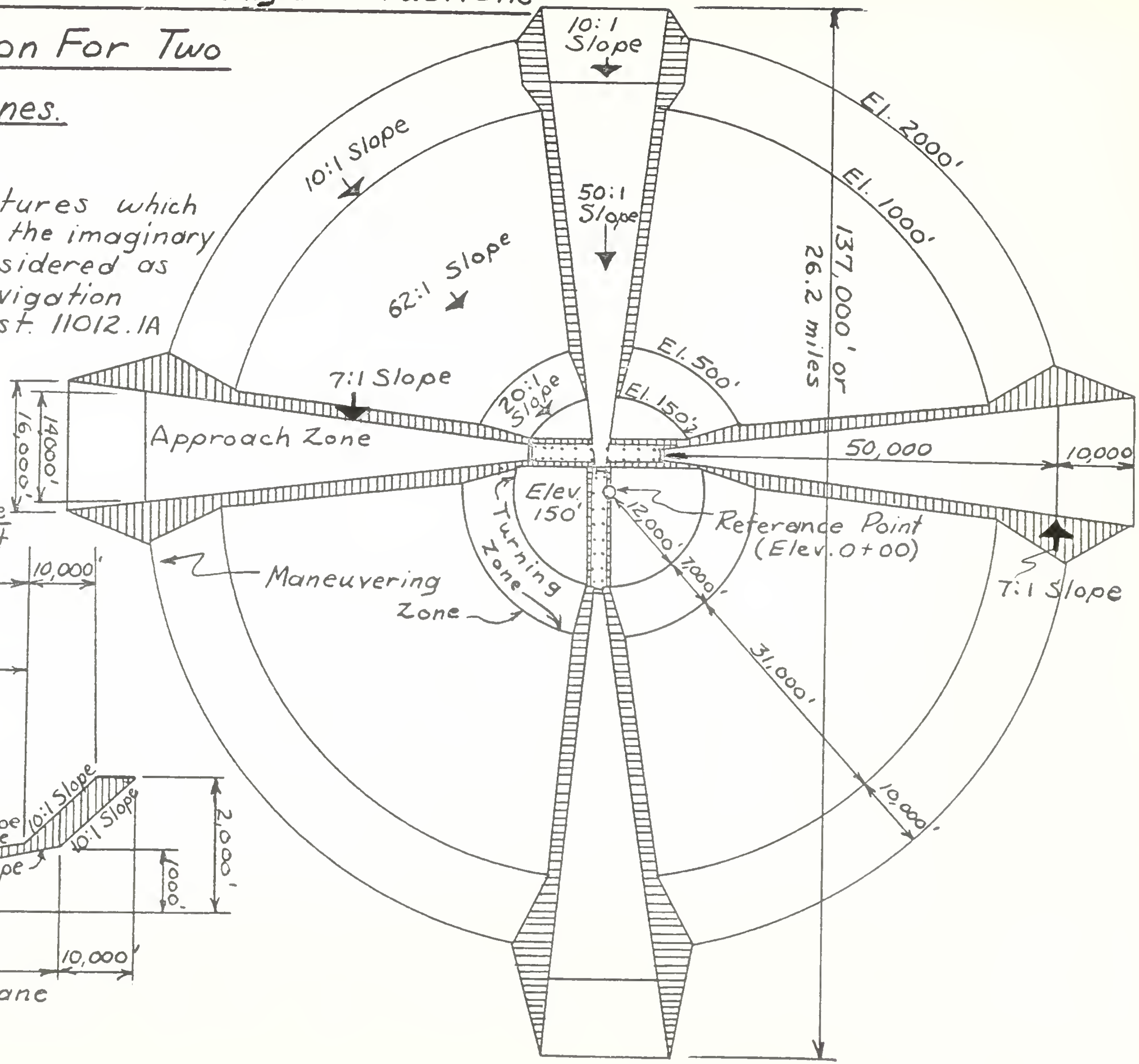
A review of Fig. 2, which delineates the parameters for obstructions to air navigation for a large seaplane training station, reveals the tremendous impact of such a facility on the surrounding region. An air space of over 540 square miles from the center of this facility, varying in height from 150 to 1000 ft from the elevation of the station, is directly affected.

To fully understand the importance of Fig. 2, the following explanation is presented:

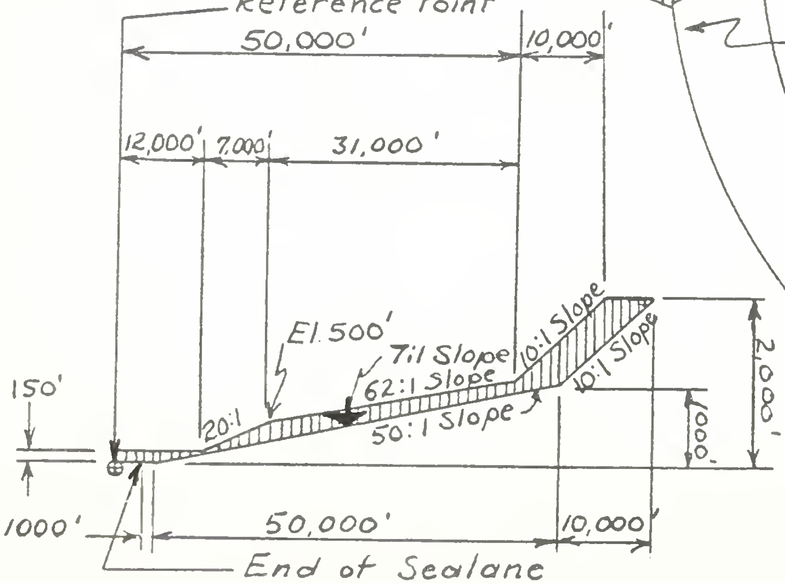
a. The airfield reference point is a point selected and marked as the approximate center of the usable landing area which is formed by adjoining runways or sealanes.

FIG. 2. Guide For Determining Obstructions To Air Navigation For Two 15,000 Ft. Sealanes.

Note:
Terrain or structures which project above any of the imaginary surfaces shall be considered as obstructions to air navigation based on Bu. Aer. Inst. 11012.1A (revised, Ref. 41)



Sectional Elev. on ℄ of Sealane



b. Man-made structures which are located further than 19,000 ft from the airfield reference point and outside of the approach zones and project above the 62:1 or 10:1 imaginary surfaces shall be subject to local aeronautical study to determine if they are hazardous to local operations including instrument procedures.

c. In addition to the above restrictions and those on Fig. 2, other man-made structures which by their nature are difficult to see (such as antenna towers) and are located within 80,000 ft of the reference point so as to be above imaginary surfaces beginning at a 12,000-ft radius from the reference point at 150 ft above air station elevation, and rising at a 50:1 slope for an additional 18,000 ft and beyond that at a 100:1 slope for an additional 50,000 ft, shall be considered as unacceptable hazards to air navigation unless a specific aeronautical study determines otherwise. Such a structure beyond the 80,000-ft radius which is in excess of the 1000 ft above the terrain will also be considered to be unacceptable hazard to air navigation unless a specific aeronautical study determines otherwise.

A new site should take into full account any air traffic restrictions that might be imposed by special requirements. Basically, there are four types of such restrictions, most of them established for military defense or training areas. They are designated:

a. Prohibited areas in which flight is banned at all times.

b. Restricted areas are usable for flight only between specified altitudes and at certain times.

c. Warning areas are basically the same as restricted areas.

d. Caution area. Flight into area is permitted although pilots must exercise extreme care when entering and flying through them.

Details of standard instrument approach procedures and air traffic control procedures form a complex problem and will not be discussed, but considerable information of value to the planner will be found in Refs. 42 and 58.

Controlled air space superimposed over other regional and community uses produces many new problems in planning which can only be solved by adequate integrated regional planning. Integrated regional air space planning can help locate aircraft holding patterns over thinly settled areas, thus reducing both the nuisance and hazard caused by circling and maneuvering under low ceilings. Also, as previously pointed out, proper planning may be able to arrange flight patterns over large bodies of water, large parks or golf courses which would minimize the noise nuisance.

In summary it is believed that the importance of timely and effective integrated community and regional planning and zoning cannot be overstressed. The safety of the community, aircraft and their operating personnel, as well as the value of the community property and the air facility may be jeopardized. The preparation of zoning plans and ordinances is a complex legal problem and should be undertaken in cooperation with competent legal counsel. Both the representatives of the local region and those of the air facility should rely on the great deal of legal information readily available through the Civil Aeronautic Administration, as well as that of their own agencies. The art of drawing legal descriptions of zones and preparation of zoning maps calls for the highest order of engineering to insure that the resulting planning and ordinances may be simple, clear, and easy to administer, and will be effective for the many years to come.

III. SEAWORTHINESS CHARACTERISTICS OF SEAPLANES

A. Definition of Seaworthiness

The term seaworthiness of a seaplane may be defined in two ways. From the hydrodynamic and structural connotation of the term, it may be defined as the ability of the aircraft to take off, land, and remain afloat in certain sea states without unacceptable levels of hydrodynamic instability and/or structural damage. From strictly a broad operational standpoint, the term may be defined as the ability of the aircraft and its crew to operate in certain sea and wave conditions which will permit the vehicle to be maintained, serviced, and berthed afloat by its crew or support components at various acceptable levels of efficiency and safety of operation. This part of the thesis will discuss the hydrodynamic and structural aspects, while the broad operational consideration will be covered in Part IV.

B. Definition of Sea and Wave Characteristics

Before a yardstick can be developed to measure the various hydrodynamic parameters of seaworthiness, an understanding of the basic characteristics of the sea and waves is essential.

A glance at a typical ocean wave record will indicate that approximation of the sea surface by a regular sine or trochocial wave train is far from being realistic. In fact, applying the methods of Fourier analysis to such a record may indicate a lack of periodicity in wave motion and present a picture of complete randomness. One may observe a surface configuration composed of waves of widely varying amplitudes -- sometimes reinforcing each other, sometimes canceling each other, some superimposed on larger waves, all traveling at different velocities and often in different directions -- the result being a confused and complex sea.

However, many studies and publications have been written about the basic characteristics of ocean waves. These efforts have done much to systematize and define the properties of sea waves and give us a better understanding of their dynamic behavior. One such excellent source (Ref. 63) has classified the waves present in the ocean into the two categories of "sea" and "swell." The waves experienced in a storm area generated by local winds of the storm are called a "sea." When waves travel out of the storm area, they change into "swell."

The salient features of "sea" waves are:

1. Individual waves have sharp angular tops.

2. The waves are short-crested. The crest line is usually only two or three wave lengths long.

3. The waves are relatively steep with the length (λ from crest to crest) being between 14 times and 24 times their height (see Fig. 3). In a shallow depth sealane or mooring area, the length to height ratio may in some cases be between 13:1 to the unstable breaking ratio of 7:1. Waves in this latter category are sometimes referred to as wind or harbor chop.

4. Small waves may be added to other larger waves. Sometimes the individual crest may seem to line up with other crests: at other times the lines of crests may seem to intersect at angles of 20° to 30° to each other. The short crested feature is caused by intersecting wave systems. High waves follow low waves in a completely erratic manner. There is great variability in the periods. The "average wave length" is not equal to the classical 5.12 times the square of the "average period."

"Swell" is characterized by these features (see Fig. 4):

1. Swell waves are low with rounded tops, and the steepness or slope ratio of the length to height may be between 25:1 to 100:1. However,

some Pacific Ocean ground swells have length-to-height ratios greater than 100:1. They may have heights ranging 3 to 4 ft and lengths from 500 to 1300 ft. When this ratio is greater than 100, the shape of the wave is nearly sinusoidal, and not trochodial.

2. Swell characteristics differ greatly in different parts of the world; for example, while off the West Coast of the United States, swells vary in length between 100 to 1300 ft and in height from 3 to 12 ft, with a celerity of 15 to 50 knots; and off the East Coast of the United States swell lengths vary from 150 to 600 ft, are not therefore as high, and have a celerity of 15 to 30 knots (Ref. 63).

3. Swells following one another are nearly the same height.

4. The crest lines are usually six to seven times the wave length.

5. Groups of five to eight swell waves follow each other followed by relative calm of approximately 20 seconds duration.

6. Swells in the group gradually increase in amplitude toward the middle of the group.

7. While the expression $\lambda = 5.12\ T^2$ is not true for the chaotic, irregular, unpredictable wind wave, the swell is predictable in the short range sense, as can be seen from the foregoing. Therefore, the classical formula is nearly true for swell conditions. Reference 43 considers that frequently the formula is accurate to within 10 to 15% for swells, with the average wave length generally less than set forth in the formula. In other words, the variance in "average wave length" and "average period" is not completely irregular.

Other features of "sea" and "swell" effects:

1. There may be some local choppy waves superimposed on a swell, but the presence of the swell can be recognized by the relatively long crest lines.

2. Trains of long waves will travel faster than trains of short waves and pass through and under them.

3. At moments when one wave is passing through another during overtaking it is in coincidence with the wave overtaken. The momentary resultant wave will be equal to the sum of the heights of the waves in the coincidence, and when crests of one train fill the troughs of others the sea smooths for that moment. Some of the more experienced seaplane pilots have the ability to select these dead or relatively calm areas and land where, a few miles away, a tremendous 15-ft sea would forbid any experienced pilot or seaplanes from landing (Ref. 21).

4. The oceanographer's definition of significant wave height, i.e., the mean of the highest 1/3 of waves observed, must be qualified with the knowledge that 1/10 of the waves present will be half again as high, and one in a hundred may be twice as high, and there will also exist relatively smooth areas.

5. The moving sea will impose forces on the seaplane causing heave, roll, pitch, yaw, and slam. Compared to the "sea" wave of the same height, the energy ($MV^2/2$) of the swell is potentially very dangerous in this regard to the seaplane because of its celerity, which can be up to 50 knots, and its greater mass of water. A large seaplane hull can plow through a relatively small, steep "sea" wave without danger or damage; while, if it hit a very fast, flat, long swell of the same height with its wide breadth of water, serious damage could occur.

There remains another basic consideration concerning the understanding and analysis of waves with which a site planner must be familiar. This is the transformation effect of deep water waves as they pass into shallower water. By definition, a deep water wave is located in water whose depth is greater than $\lambda/2$. Waves in depth of water less than $\lambda/2$ but greater than $\lambda/25$ are referred to as transitional waves, or more commonly as shallow water waves. The classic description of wave behavior in shallow water states that, as the depth of water becomes equal to $\lambda/2$, the wave begins to "feel" the bottom and is retarded. This effect is called refraction; and, generally, the following can be considered to happen: The wave length and celerity decrease, the height tends to increase, while the period is assumed to be fairly constant The theory and relationships of the transformation of waves in shallow water are reviewed in refs. 26 and 48.

As explained previously, the classical formulas for deep water waves are:

$$\lambda = \frac{gT^2}{2\pi} \quad \text{or} \quad c = \frac{gT}{2\pi}$$

For transitional waves the expression becomes:

$$\lambda = \frac{gT^2}{2\pi} \tanh \frac{2\pi d}{\lambda} \quad \text{or} \quad c = \frac{gT}{2\pi} \tanh \frac{2\pi d}{\lambda}$$

where d is the depth.

The various methods used to project deep water wave conditions to inshore localities at a proposed site will be explained in Part IV-B-3.

C. Seaworthiness Parameters

In order to evaluate the seaworthiness characteristics of the seaplan in various sea states, certain measureable variables or factors must be established which will represent the critical motions of the aircraft. Fig. 6 delineates the basic critical motions of the hydrodynamic behavior of a seaplan

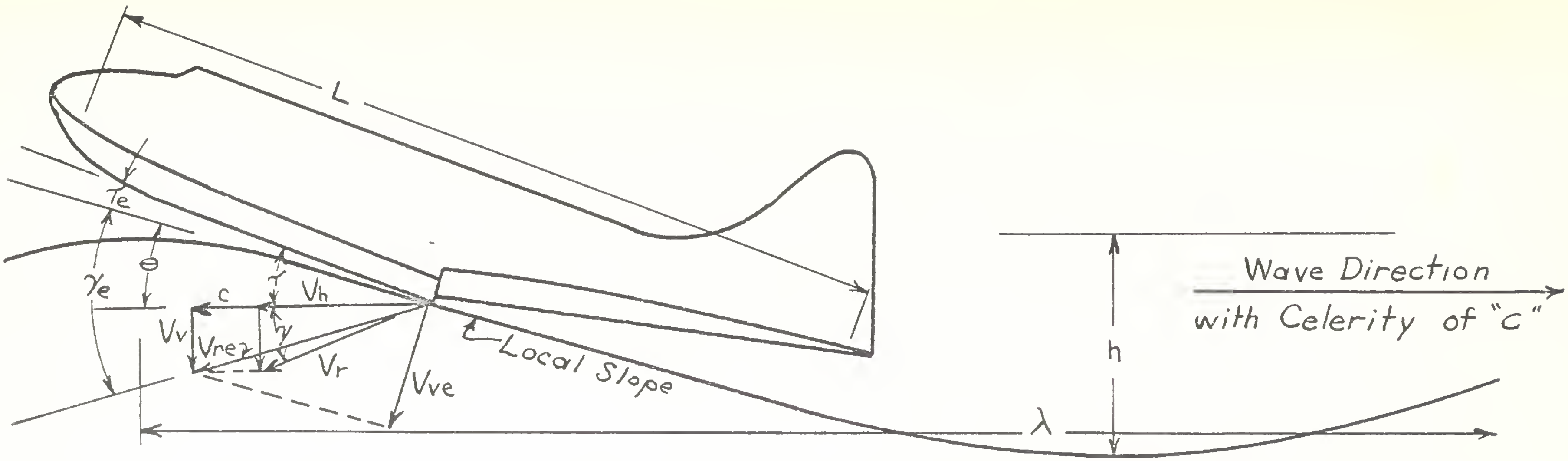
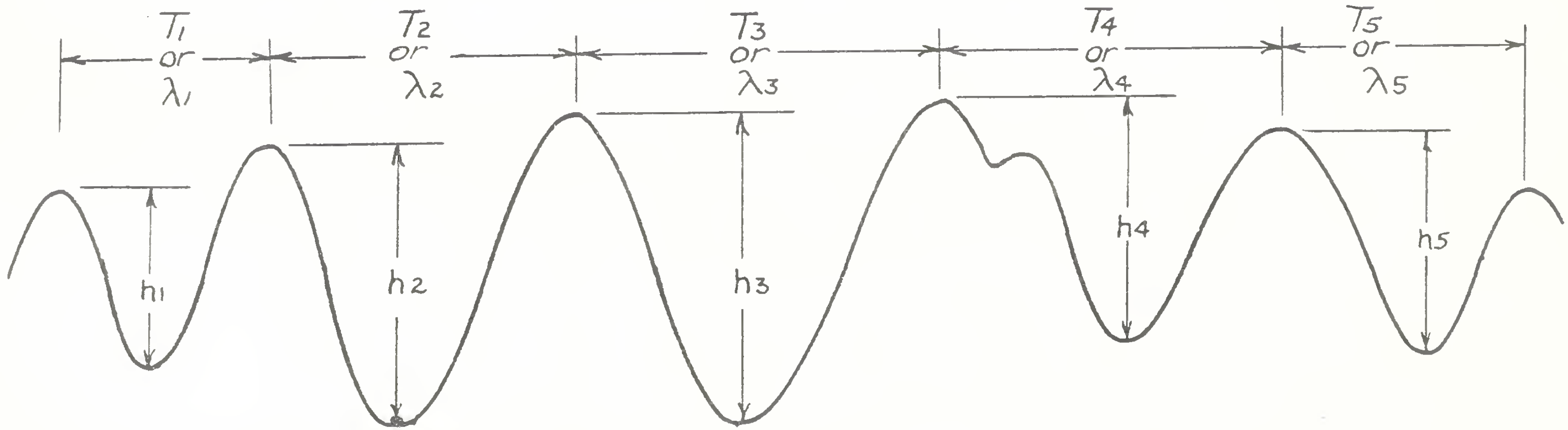


FIG. 3. Relation of Geometric and Effective Contact Parameters on Wave.
(After J. B. Parkinson, Ref. 37.)



$\lambda_1, T_1 < \lambda_2, T_2 < \lambda_3, T_3 > \lambda_4, T_4 > \lambda_5, T_5$ and $h_1 < h_2 < h_3 > h_4 > h_5$. Therefore, reference to λ, T, or h of a "sea" wave or "swell" must be considered to be average values.

FIG. 4. Typical Swell Characteristics

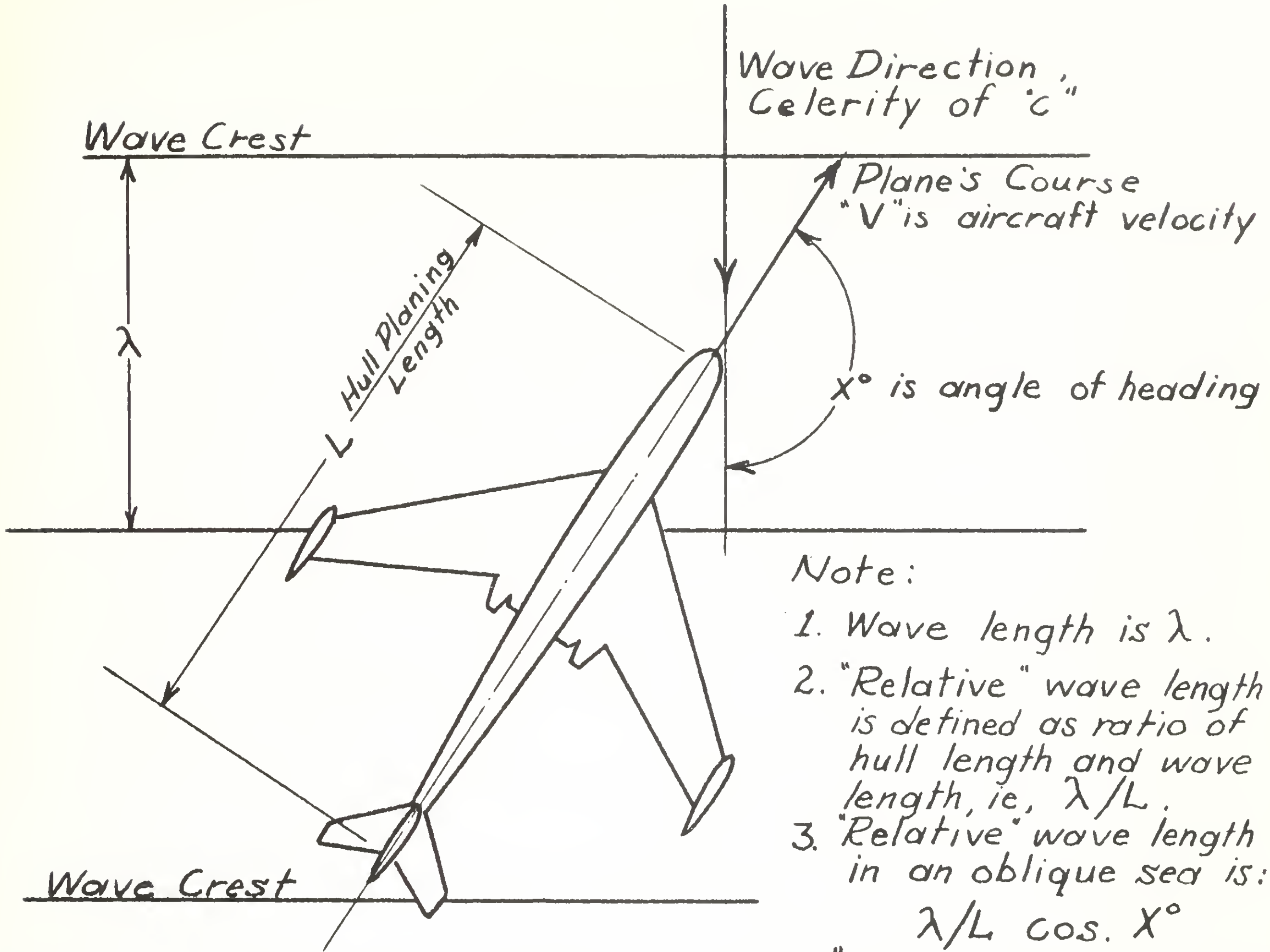


FIG. 5. Relationship of Wave Length to "Relative" Wave Length

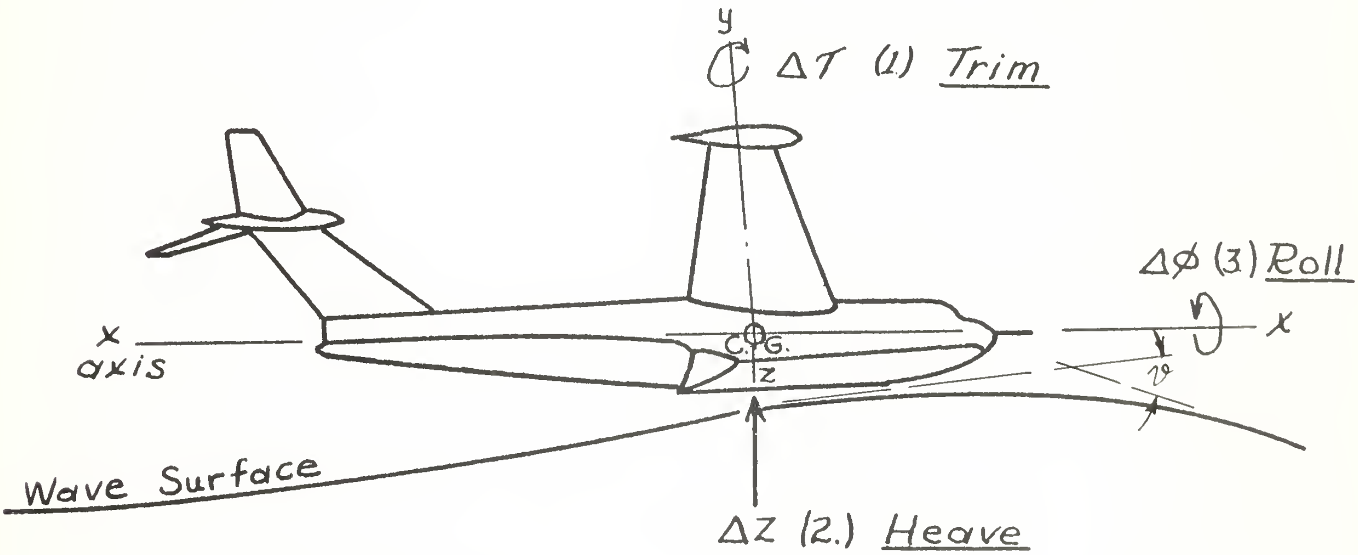


FIG. 6. The Three Critical Motions of Hydrodynamic Behavior

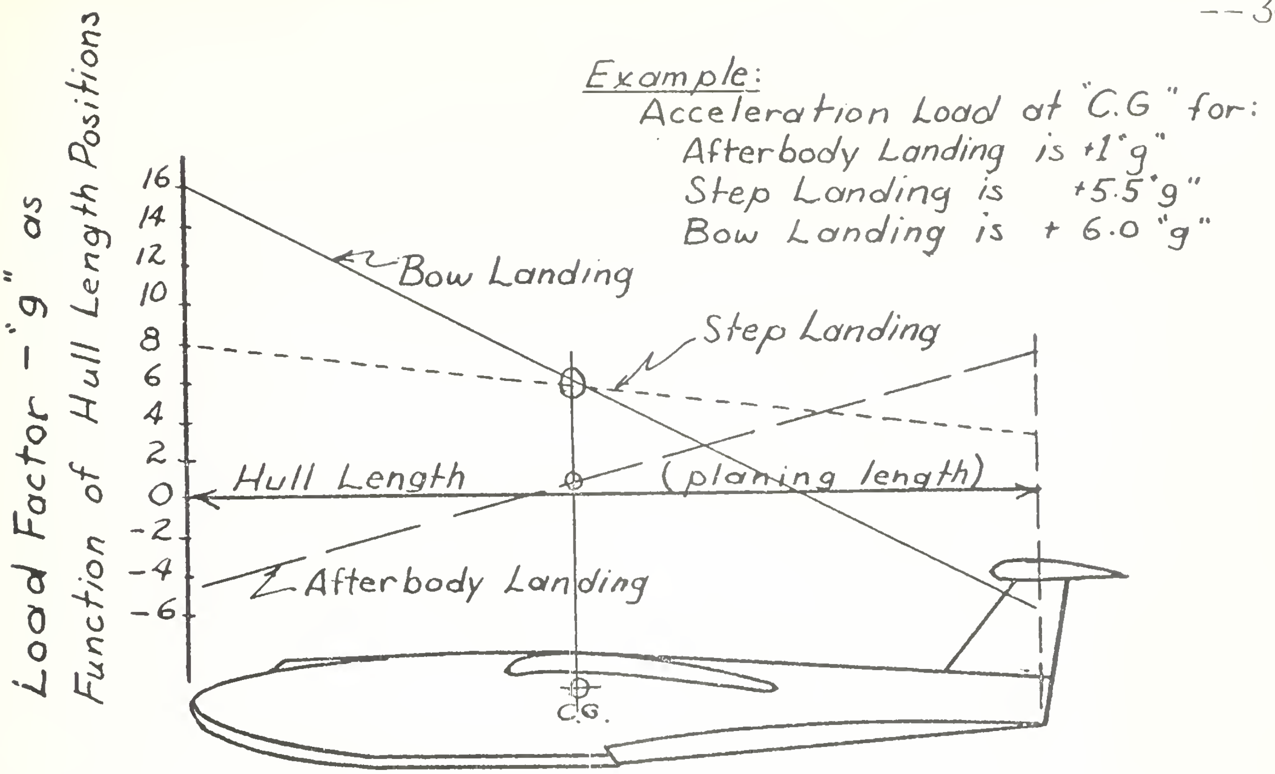


FIG. 7. Effective Load Factor Due Vertical and Pitching Accelerations on Hull Type Seaplane. (After Ref. 33)

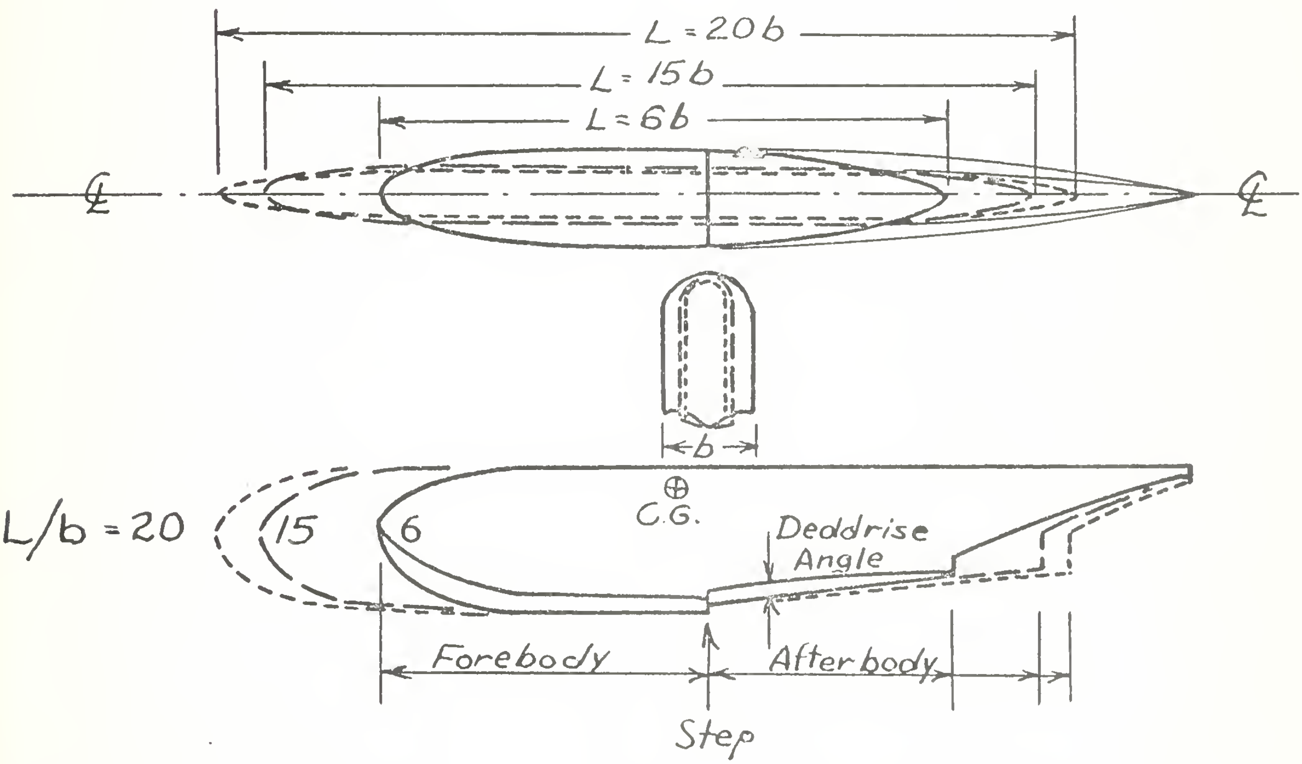


FIG. 8. Series of Hulls of Various Length-Beam Ratios. (After Fig. 7, Ref. 37)

If the motions exceed certain limits, hydrodynamic instability or structural damage to the aircraft should be expected. It is believed that the factors or variables can be related to the four following seaworthiness parameters:

1. Trim parameter.

Trim is commonly referred to as pitching motion in ship terminology and is one of the most important since it produces angular acceleration which can result in relatively high load factors on the extreme ends of the seaplane hull. Fig. 7 shows the relative range of load factors that can be expected on a large, high performance seaplane when landing in various angles to a wave surface. This pitching motion can also result in considerable discomfort to the crew. In accordance with Fig. 6, the trim parameter may be expressed in change of trim angle $\Delta\tau$, in degrees around the Y axis, or as the dimensionless amplitude parameter of $A_\tau = \Delta\tau / \gamma$ Of course, it may also be expressed in an effect which it causes; that is, angular acceleration in terms of radians/sec./sec.

2. Heave parameter.

Heave refers to the vertical translation of the hull along the Z axis which runs through the center of gravity of the aircraft. This motion is a resultant of the oscillatory motion of the wave and the forward motion of the aircraft. In accordance with Fig. 6, it may be expressed in terms of ΔZ in feet, or as the dimensionless amplitude parameter $A_z = \Delta Z/h$, where "h" is the wave height. Heave may also be referred to in terms of vertical acceleration in "g's," ft/sec./sec., or as shown in Fig. 3 as Vve which is the effective vertical velocity in feet per second. Since it is common practice to design aircraft structures in terms of so many "g's," which may be correlated to so many psi of hull loading by various methods (Ref. 53), vertical

acceleration has become a commonly accepted way to measure the effect of heave motion.

3. Roll parameter.

In accordance with Fig. 6 roll may be referred to in terms of the change of roll angle $\Delta \phi$ in degrees around the x axis or by the dimensionless amplitude parameter $A_\phi = \Delta \phi / \nu$. This motion will be primarily caused by the heaving of the wing tip floats which will be a function of the distance between the tips.

4. Tuning ratio parameter.

The occurrence of a peak value of this motion is analogous to resonance in a vibrating system, and may be referred to as synchronism. The critical range should occur when the frequency of wave encounter is equal to the natural frequency of the hull. Thus it may be expressed in terms of the ratio of T_n/T_e, where T_n is the natural period of the hull in seconds and T_e the period of wave encounter in seconds.

The hydrodynamic behavior of the seaplane in the following portions of this part of the thesis will be expressed in some combination of the foregoing motion parameters.

D. Approach Used for Seaworthiness Investigations

As stated previously, unfortunately there is not available any generalized over-all analysis of the hydrodynamic behavior of a seaplane in various wave conditions which can readily aid the site planner or serve the primary purposes of this thesis. In fact, at the expense of reality, much of the aeronautical design of these aircraft from the standpoint of hydrodynamic analysis is done by model tests in towing tanks and by small dynamically powered and controlled models. The models are subjected to an idealized wave

system consisting of regular sine or trochoidal components. Hull impact loads are determined from pressure equations containing empirical coefficients relating the load to hull geometry and to operational requirements of the aircraft, reflective to some sort of sea state which has been shown to hold for similar designs. Therefore, due to the present relatively limited state of art and science in this field, it has been necessary for the writer to investigate some of the basic aeronautical research studies on model test analysis and a few full scale testing programs in order to determine the basic generalized hydrodynamic behavior characteristics of seaplanes in various wave conditions. Unfortunately much of the detailed hydrodynamic performance data for certain existing high performance seaplanes is classified security information; therefore, the writer was not able to utilize this data for this thesis. However, certain generalized conclusions based on unclassified information, which can satisfactorily fulfill the site planner's broad requirements, have been established by the writer.

References 8, 10, 37, 38, 39, 43, and 46 contain some of the best unclassified model tests analysis on hydrodynamic characteristics that the writer was able to locate. Four of these studies will be analyzed in the following sections of the thesis. Also applicable portions of references 13, 15 and 22, which contain results of limited full scale seaworthiness testing programs, will be presented.

E. Model Study Analysis

The following model analyses are based on deep water type waves:

1. First Test Analysis (Ref. 10)

This testing program made an investigation of the take-off and landing behavior of seaplane hulls having length-beam ratio of 6 and 15. The gross

weight of the design model was 75,000 lbs. The models had the same relative depth and position of step, maximum depth of hull, and ratio of forebody to afterbody length; yet the model with the L to b ratio of 15 had a minimum aerodynamic drag of 29% less than the L to b model of 6. Landings of the powered dynamic models were made in rough water corresponding to full-size waves of various sizes up to approximately 500 ft in length and 6 ft in height. The waves were approximately trochoidal and all testing made into the direction of the oncoming wave. Everything possible was done to duplicate actual landing and take-off procedures with this type of model and testing equipment. The models were free to trim about a pivot located at the center of gravity of the model, and were free to move vertically, but were restrained in roll and yaw. The speed for landing behavior was slightly above flying speed, and the usual landing trim was used. The speeds ranged all the way to take-off speeds. The roll and tuning ratio parameters were not investigated.

The results of the maximum vertical and angular acceleration load factors for this testing program are shown in Figs. 9 and 10. It will be observed that the maximum hull loads for both models and for all wave heights occurred between wave lengths of 100 and 255 ft. Or expressing the wave length in terms of hull lengths, with the L to b model of 6 having an L of 64.6 ft and the L to b model of 15 with an L of 81.6 ft, we can say that the critical range of waves was roughly between 1.6 and 4 hull lengths for both models. If we ignore the less important 2-ft height waves and the L to b model of 6, which is not regarded as a high performance seaplane hull, we have a critical wave length range of 169 to 255 ft, or a critical "relative" wave length range of 1.96 to 3.1.

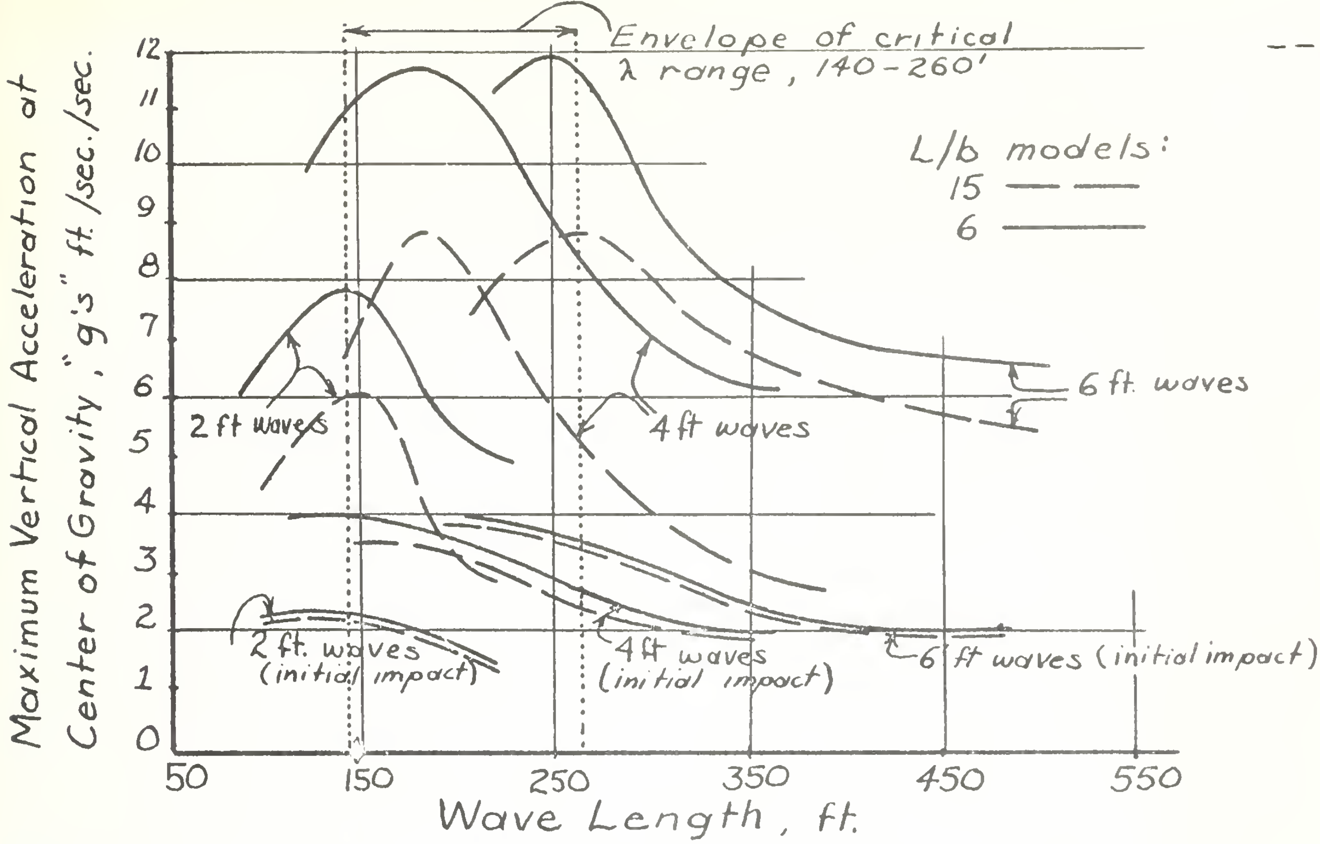


FIG. 9. Max. Load Factors For Various Wave Lengths and Heights For Landings.

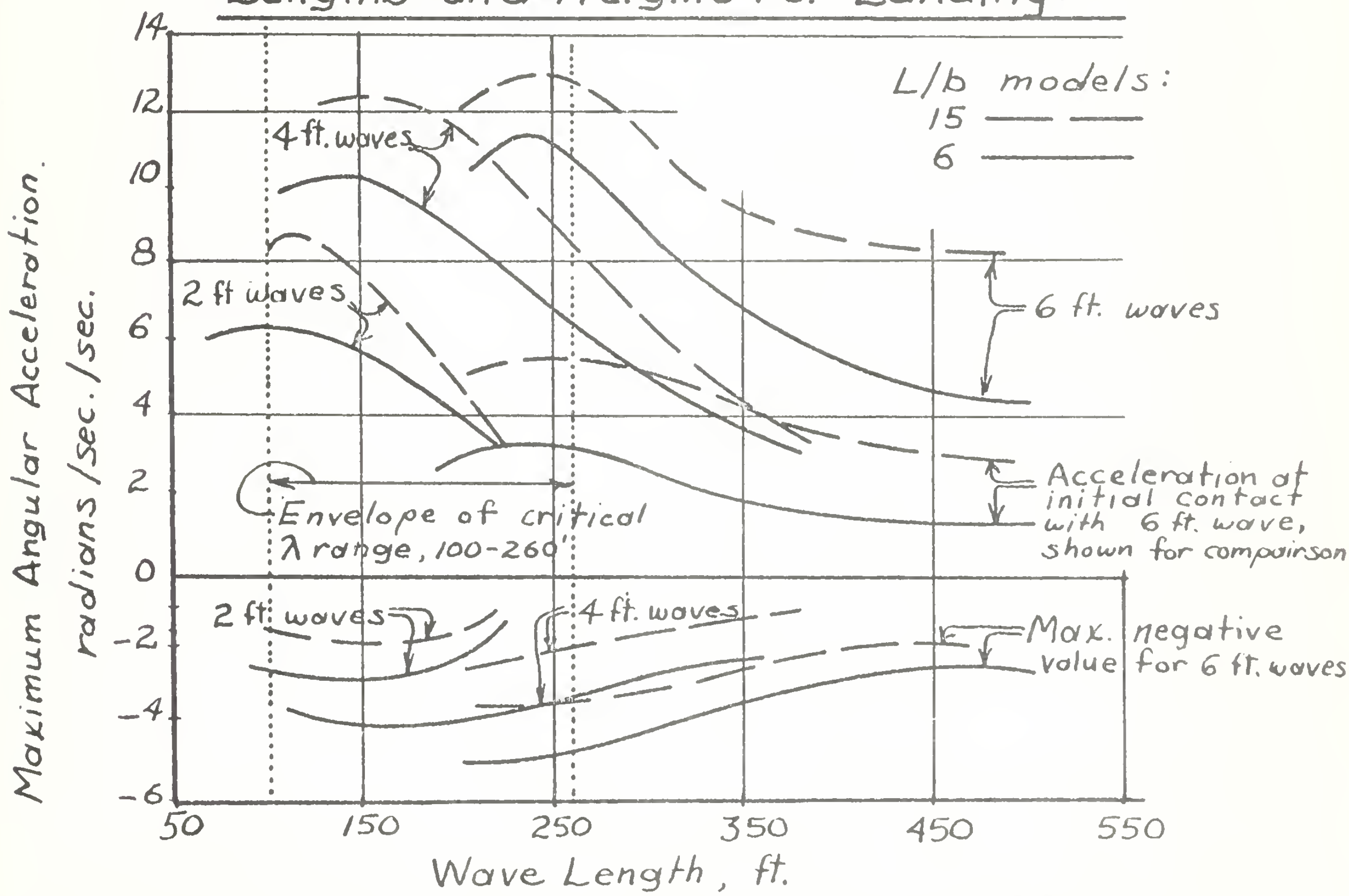


FIG. 10. Max. Angular Acceleration For Various Wave Lengths and Heights For Landings.

The results of the trim and heave parameters for landing can be summarized as follows:

a. Trim. (expressed in degrees) For the 15 L/b model for all waves (2, 4, 6 ft), the critical wave length range was between 200 and 240 ft, while for the 6 L/b model, the range was 150 to 210 ft and the 15 L/b model had approximately a 25% less maximum trim magnitude than the 6 L/b model.

b. Heave. (expressed in feet) For the 15 L/b model for all waves, the critical wave length range was between 210 and 280 ft. For the 6 L/b model, the range for 2 and 6 ft waves was 200 to 240 ft with the maximum magnitude being about the same for both models.

The test results for taxiing and take-off behavior can be summarized as follows:

a. For the 6 L/b model in wave lengths between 150 and 200 ft for 4-and 6-ft wave heights, some trim and heave instability was exhibited near take-off speed. However, the impact accelerations were also much less than for landing.

b. For the 15 L/b model, no dangerous oscillations in trim or heave were encountered for 2-and 4-ft waves. (6-ft waves could not be tested.) Take-off hull loads were much less than in landing.

It can be seen from the foregoing that all the factors evaulated had their maximum critical values in the following range of "relative" wave lengths (see Fig. 5 for definition of "relative" wave length):

a. L/b model of 6 (low performance seaplane hull)

Factors Measured	"Relative" Wave Length
(1) Vertical and angular accelerations	1.6 - 4.0
(2) Trim	3.1 - 3.7
(3) Heave	3.1 - 3.7

b. L/b model of 15

Factors Measured	"Relative" Wave Length
(1) Vertical and angular accelerations	1.96 - 3.1
(2) Trim	2.45 - 2.94
(3) Heave	2.57 - 2.94

Applicable general conclusions from the first test are as follows:

a. The 15 L/b hull experienced considerably less maximum vertical acceleration and trim magnitudes than the 6 L/b model, while the angular acceleration and heave factors were about the same.

b. Landings imposed greater hull loadings than take-offs, and the initial impact, on the average, was never greater than subsequent contacts.

c. For the high performance type hull the measured parameters revealed a critical "relative" wave length range of approximately 2 to 3 with an average of 2.68.

2. Second Test Analysis

Additional interesting conclusions and relationships are evident from the test program described by reference 37. The testing technique was basically the same as that described in the first test analysis except, in this case, models with L/b ratios of 6, 15, and 20 were investigated (see Fig. 8). Three L/b models of 6, 15, and 20 have hull lengths of 63.6, 81.6, and 89.5 ft respectively. When the critical wave lengths were analyzed in terms of "relative" wave lengths for the magnitudes of maximum trim, heave, vertical and angular acceleration, the following was determined:

TABLE II

Maximum Values of Measured Factors Related to the Critical "Relative" Wave Lengths

Hull Types	Trim λ/L	Heave λ/L	Angular Accel. λ/L	Vertical Accel. λ/L
L/b 6	2.86	3.09	2.24	2.78
L/b 15	2.63	3.0	1.77	2.2
L/b 20	2.62	3.08	1.67	2.01

It is evident from the above table and the first test analysis that there is a rather constant relationship between the critical seaworthiness parameters of a seaplane and the "relative" wave length. It should be emphasized that this critical "relative" wave length does not have a definite specific universal relationship to the hull length alone. Any exact figure for any specific hull must consider all the different hull configuration factors such as the ratio of forebody to afterbody, the specific V bottom dead rise angle, the configuration of step connecting the forebody to the afterbody of the hull as shown in Fig. 8. But for site planning purposes, where wave or swell conditions are never known with any exact degree of accuracy, the over-all range of values shown in the table can be considered generally valid.

Another important finding concerning the three types of hulls tested is that the size and aerodynamic drag of the hull decreases as the length-beam ratio increases, while the smooth water hydrodynamic qualities remain more or less comparable throughout the series. These tank investigations have demonstrated the significant improvement in the rough water qualities exhibited by the higher L/b ratio hulls. An analysis of this effect for the various types of hulls going into a 4-ft wave system is presented in the following table:

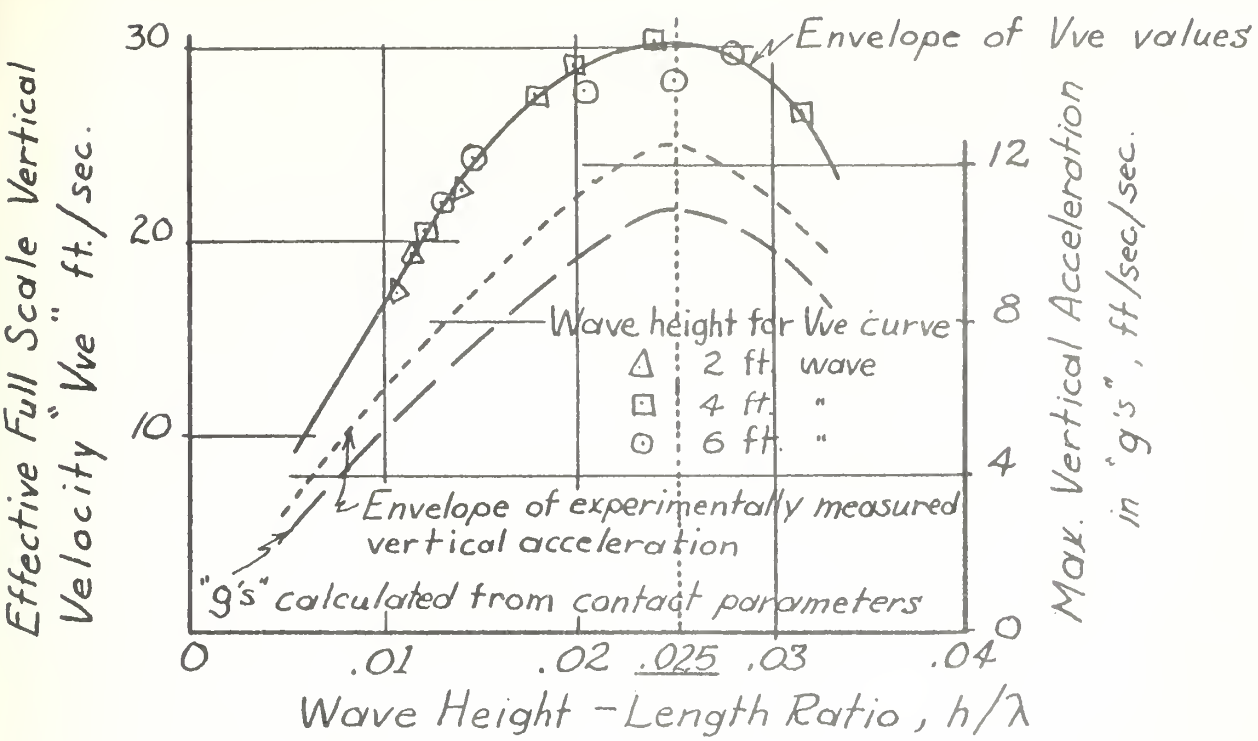
TABLE III

Percent Reduction in Measured Magnitudes
Based on 6 L/b Hull Type as Base

	Measured Factors for 4-ft Wave Analysis			
Hull Type	Trim	Heave	Angular Accel.	Vertical Accel.
L/b 6	24° max.	22 ft max.	10.5 "g's" rad/sec²	11.5 "g's" ft/sec²
L/b 15	16.5% less	9% less	19% more	21.8% less
L/b 20	21% less	36.4% less	19% more	52.2% less

Another factor which appears to be of importance for site planning purposes is the relationship between the important factors of the effective velocity and the vertical acceleration of the seaplane hull at the point of impact and the wave slope. This is delineated in Fig. 11 for the L/b models of 6 and 15 in various wave heights of 2, 4, and 6 ft. According to the basic theorical theory presented in reference 29, the maximum normal impact load of a prismatic forebody is a function of the trim, flight-path angle, and the vertical velocity at contact with a smooth still water surface, as well as the V-bottom deadrise hull angle and the hull weight. However, reference 28, by the use of certain simplifying assumptions which have been determined to be within the accuracy of experimental data, has applied this theory to rough water conditions by redefining the original theorical contact angles relative to the local wave slope and by taking into account the velocity increments due to wave motion.

The simplified contact parameters of this relationship are delineated in Fig. 3 by referring the angle θ which is the local slope of the wave surface at contact; and τ , the trim angle of the straight portion of the forebody; and γ , the flight-path angle; and the resultant velocity V_r to the



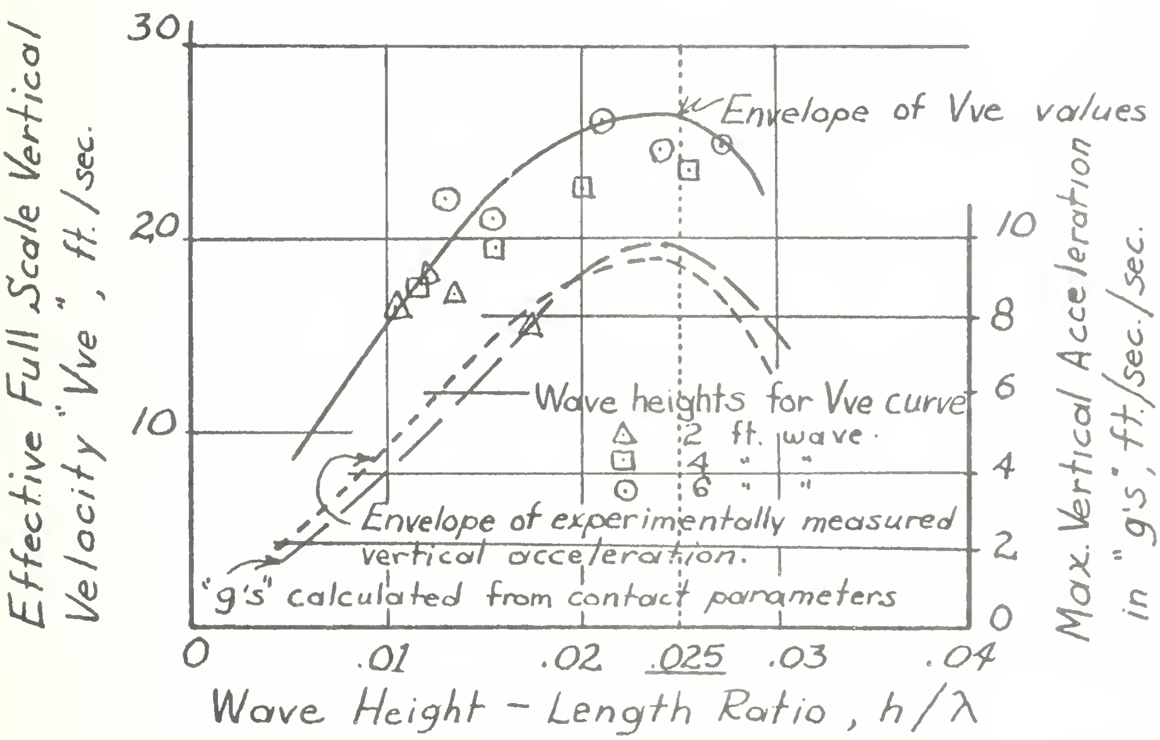


FIG. 11. Relationship Between Vertical Velocity Vertical Acceleration at C.G. of Hull to Wave Slope. (Based on data from Ref. 37)

horizontal. Then, by considering the wave a body of water in horizontal translation at velocity of c (celerity) and adding this to the horizontal component of the aircraft speed V_h, the effective resultant velocity Vre is determined. From the figure, the effective contact parameters determining the water load are as follows:

$$\tau_e = \tau - \theta \quad \text{and}$$

$$Vve = Vv \cos \theta + (V_h + c) \sin \theta \quad \text{and}$$

$$\gamma_e = \theta + \text{arc tan} \frac{Vv}{V_h + c}$$

Since the angles are small the actual normal load on the aircraft is approximately equal to the vertical load measured on the model. The assumption of small angles is considered quite valid since for a swell V_h will range from 3 to 6 times the celerity and the effective trim τ_e is usually between 0 to 4°.

The wave celerity and slopes at contact were not directly measured, but it was assumed that the maximum impacts occurred on the maximum slopes of the tank waves and that these waves were trochoidal. The slope is then

$$\theta = \text{arc tan} \frac{\pi h}{\lambda} \quad \text{and the celerity}$$

$$c = \sqrt{\frac{g\lambda}{2\pi}}$$

With these simplified relationships established, the experimental test data was related to Vve and h/λ and plotted as shown in Fig. 11. When the vertical accelerations of the hull are calculated from the effective factors of Vve, τ_e, θ, and c, and compared with the measured vertical accelerations in Fig. 11, there is reasonably close agreement; therefore, the simplifying assumptions appear justified. However, more important is the fact that

the values for all the curves for both models peak at approximately the average wave slope of .025 or as sometimes expressed a slope of 40:1. According to the Douglas scale of swell characteristics, the average critical wave for these tests with this slope and heights from 2 to 6 ft could be classified as a low, short swell (Ref. 7). For aircraft with longer hulls such as the P6M (134 ft) or the R3Y, with an average critical "relative" wave length of approximately 2.2, the critical wave with this slope would be classified as a low, almost average swell; or if the height is 6 ft or higher, a moderate, average swell according to the Douglas swell scale.

It appears that this relationship of critical wave slope of $h/\lambda = .025$ will provide the planner another important tool for site selection evaluation.

A study of figure 3 reveals another interesting facet when considering the landing motion of a seaplane in a swell. Although the swell surface usually moves with considerable velocity (15 to 40 knots), actual translation of the water is negligible. Therefore, when an aircraft bounces off the swell while heading into it, it is not thrown off the water by the vertical motion of the swell, but is hydroplaned off the rising slope due to the total speed of $V_h + c$ involved.

The take-off resistance in waves for these models was investigated. It was found, even with the increase in thrust afforded by present developments in power plants, take-off in rough water is going to be a problem. The resistance becomes greater in rough water because of the added energy in the motions previously explained, and the increased wetting of parts of the airplane that remain dry in smooth water operation. In fact, with 6-ft waves, the resistance near take-off speed became very great since the model could no

longer ride over the crests and the aerodynamic components were heavily wetted. This part of the test program illustrated the need for jet-assisted take-off for open sea operations in swells and defines a problem that can become more severe in the future for the closely coupled jet propelled seaplane.

Applicable general conclusions from the second test are as follows:

a. That, for all three hull types, there was a fairly constant relationship between the critical motions of the seaplane and the "relative" wave lengths, which ranged from approximately 1.7 to 3.1. The 6 L/b hull had a 2.74 average; the 15 L/b model, a 2.4 average; and the 20 L/b hull, a 2.34 average -- which compare closely with the first model test analysis average of 2.68.

b. That the trend toward higher performance type hulls (increased L/b ratio) greatly improves the seaworthiness characteristics of the aircraft in rough water.

c. That a relatively simplified analysis of a seaplane's impact on a wave has been established which permits a better understanding of the critical hydrodynamic loadings on the hull. It has also been shown in other testing programs that this analysis is also generally valid for the critical second or third impact or bounce.

d. There appears to be a critical average wave slope of approximately 40:1 which produces the maximum heave and hull loadings on all types of L/b hulls. For large seaplanes this wave is a low or moderate, average swell.

3. Third Test Analysis (Ref. 46).

This test program was much different from the other two, since it investigated the seaworthiness of two models having L/b ratios of 8 and 12, being towed in oblique simple wave fronts. This test was much more realistic than the other two test analyses in some respects, because it investigated L/b ratios in the range of those which are actually being used on the P5M, R3Y, and P6M type hulls. Also, often the course of the seaplane is at some angle to the wave train, since it is impossible or undesirable to take off and land head on into a train of uniform waves. All experiments were made by the models in the pre-hump speed range, the maximum speed being 40% of take-off speed. Therefore, no landing impact or take-off studies were made.

The three motions of heaving, pitching, rolling, as well as the critical tuning ratio were observed. In previous tests the roll and tuning ratio were observed. In previous tests the roll and tuning ratio parameters were not investigated. The models were tested on headings of $x = 0^\circ$, 45°, 90°, 135°, and 180° (see Fig. 5 for the relationship of headings and wave direction). It should be noted that in an oblique sea, the "relative" wave length is more realistically expressed $\frac{\lambda}{L \cos x}$ which will be referred to as "relative" wave length. All the results shown in Figure 12 and Table IV have been corrected for the obliquity of the wave front and are thus only identified by the various values of "relative" wave length.

Figure 12 contains polar diagrams illustrating the effect of heading on the amplitude parameters of trim, heaving, and rolling in terms of the "relative" wave length. The lines drawn here for both models are envelope values and represent probable maximum values at any particular heading and "relative" wave length.

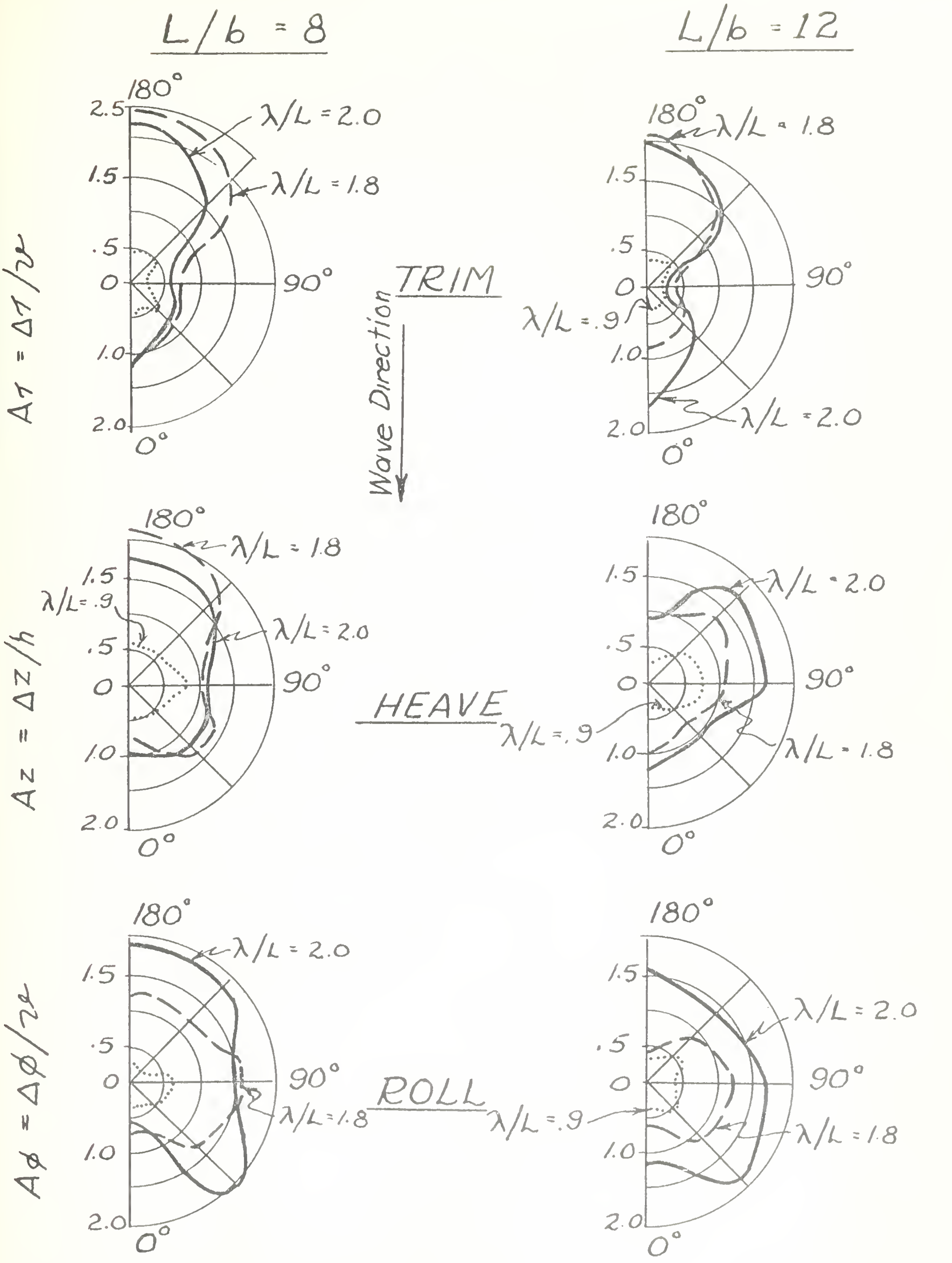


FIG. 12. Amplitude Parameters As A Function Of Heading. (After Schulz, E.F., Ref. 46)

The headings on which maximum and minimum amplitude parameters were observed are:

Motion:	Minimum	Maximum
Pitching	90°, 0°	180°, 135°
Heaving	0°	135°, 180°
Rolling	0°	45°, 90°

The foregoing hydrodynamic considerations alone would indicate landing and taking off or maneuvering should be parallel to the predominant or primary critical swell system, or with this wave system in order to reduce the probability of high impact loads. However, if the wind and sea are running in the same direction, this means landing and taking off either cross-wind or downwind, which may be inadvisable operationally under certain conditions. From purely aerodynamic considerations, the pilot would choose landing and taking off into the wind to gain every possible advantage from decreased water speed. These hydrodynamic vs. aerodynamic considerations will be discussed in detail in the later analysis of actual landing and take-off studies.

Detailed analysis of the seaworthiness parameters as a function of the tuning ratio and speed was made, and the main findings applicable to this thesis are summarized in Table IV. As defined in C3 earlier, the tuning ratio is the natural period of the hull, T_n in seconds, to the period of wave encounter T_e in seconds. The critical range of synchronism occurs when the ratio T_n/T_e is unity. The speed function is expressed in terms of a speed coefficient, C_V , which equals $V/\sqrt{gb}$. The most unfavorable conditions for these relationships are shown in Table IV in terms of "relative" wave length. In the evaluation of the speeds and headings which produced synchronism, it was observed that one or two wave encounters were required before reasonably

TABLE IV

Critical "Relative" Wave Length Values for the Three Parameters of Trim, Heave, and Roll as a Function of Tuning Ratio and Speed

	Critical "Relative" Wave Lengths for:					
	Trim $A_{\tau} = \Delta\tau/2\vartheta$		Heave $A_Z = \Delta Z/h$		Roll $A_{\phi} = \Delta\phi/2\vartheta$	
Testing Function:	L/b=8	L/b=12	L/b=8	L/b=12	L/b=8	L/b=12
(a) Tuning Ratio Λ	2.2	1.8	2.2	2.0	2.5	2.0
(b) C_v Speed Coefficients for range of 0 to 40% of take-off speed	2.2	2.0	2.2	2.0	2.2	2.0

steady oscillations are experienced. During take-off, it was shown that if the pilot could accelerate rapidly through the region of synchronism by using such special assistance as JATO, the extreme motion might be somewhat alleviated. During landing, rapid deceleration may be employed at the judicious moment by using reverse thrust and thus reduce synchronism. Also synchronism was reduced by traveling with the waves ($x = 0^{\circ}$) or parallel to the wave crests ($x = 90^{\circ}$).

From a study of Fig. 12 and Table IV it is evident that waves having a "relative" wave-hull length ratio between 1.5 and 2.2 ($1.5 < \frac{\lambda}{L \cos x} < 2.2$) produced the maximum values for all seaworthiness parameters. The amplitude parameters of all motions increase as the wave length increases to a value of approximately 2.2. As the "relative" wave length is further increased, the amplitude parameters are reduced. Note that this finding was in close general agreement with the higher L/b ratio hulls in Table III for the second test analysis.

While traveling parallel with the wave crests, where $\frac{\lambda}{L \cos x} = \infty$, it was found that the tip floats on a seaplane having a span approximately

equal to the wave length λ, may be forced under when the hull is in the trough on this heading.

In summary, the following main general conclusions for this test are:

a. That operations in swells having "relative" wave lengths between 1.5 and 2.2 considering all possible headings should be avoided if possible.

b. Based on hydrodynamic considerations, i.e., not taking into account the wind factor, it appears that the most favorable orientation of all traffic in swells and larger sea waves is with the wave or parallel to the wave crests.

4. Fourth Test Analysis

Reference 8 contains the results of a test program somewhat similar to the tests described by references 10 and 37. Three different seaplane model hulls with L/b ratios of 5.94, 6.65, and 8.9 were tested in rough water landings representing, for full-size aircraft, waves of various sizes up to about 600 ft in length and 6 ft in height. The types of waves ranged from a short chop to the equivalent of a long ground swell. The following magnitudes or factors were measured:

a. Vertical acceleration and trim at initial impact.

b. Maximum vertical acceleration at any impact.

c. Maximum change in trim and heave, at any time during landing run.

The applicable general conclusions are as follows:

a. Wherever there were a sufficient number of landings to determine an actual trend for all three models, the critical "relative" wave length ranged from 1.5 to 2.2 for all.

b. The critical wave steepness that produced the maximum unfavorable motion ranged from .0245 to .036 with the average very close to .028 which compares very well with the .025 for the second test analysis.

F. Full Scale Test Programs

1. First Full Scale Test Analysis

In 1944 and 1945, the U. S. Coast Guard carried out one of the most extensive full scale testing programs, concerning the problem of landing a seaplane in deep water waves, that have been performed to date. The test report (Ref. 22) is based upon the results obtained during 54 landings and take-offs under continuously varying conditions. The landings and take-offs were made heading into the swell, traveling with the swell, and parallel to the swell. They were made under different wind conditions, and they were made with local seas present on top of the swells. Continuous and careful records were obtained by experienced personnel in order to make it possible to decide what actually happened during each take-off or landing. Motion pictures of each landing and take-off and accelerometer records were taken at various points in the aircraft.

It is considered that this report is extremely valuable because of the clear insight on the performance and seaworthiness of a seaplane in varying sea states. These tests also provide a rough yardstick on which to base the operational capabilities and site limitations of the larger, high performance seaplanes. The PBM-3, aircraft used in the test, had a gross weight of 44,000 lbs, over-all length of 77 ft, and a L/b ratio of about 6. It is considered that the fact this L/b ratio is much lower than those of high performance aircraft will not make any appreciable difference in the general conclusions that will be determined from this test, because it has been shown in previous test analyses that certain factors such as angle of heading, critical wave slope, and critical range of "relative" wave length are generally the same for all L/b ratios.

TABLE V. Analysis of MacDiarmid's Report of Open Sea Landing Tests for PBM-3C Seaplane

Sea and Swell Height	Approx. Wave Length and Period (in seconds)	Approx. Wind and Swell Direction	Wind Velocity & Wave Celerity (Knots)	No. of Landings and Landing Approach Relative to Swell (see Fig. 5)	Average Vertical Acceleration at C.G. in "g's"	Average Maximum Acceleration on Hull in "g's"
3' Swell	850' - 13s	Both West	Swell 39 Wind 5	2 at 90°	1.6	2.5
"	"	"	"	1 at 0°	1.8	2.7
"	"	"	"	1 at 180°	2.5	2.9
"	510' - 10s	"	Swell 30 Wind 5	1 at 90°	1.9	2.4
"	"	"	"	1 at 180°	3.3	4.6
4' Swell	NW 180' - 6s W 500' - 10s	One Swell and Wind West, Other Swell NW	NW Swell 18 W Swell 30 Wind 7	2 at 90°	3.1	5.0 and 6.3
"	"	"	"	1 at 0°	3.2	6.3
"	"	"	"	1 at 180°	4.2	-
5' Sea and Swell	850' - 13s	Both West	Swell 39 Wind 15	2 at 90°	3.2	5.4
6' Swell	125' - 5s	Wind West, Swell WNW	Swell 15 Wind 7	2 at 90°	2.1	3.6
"	"	"	"	1 at 0°	2.4	3.8
6' Sea and Swell	500' - 10s	Both West	Swell 20 Wind 5	2 at 90°	2.5	4.4
"	"	"	"	1 at 180°	-	5.6

(TABLE V. Cont'd.)

Sea and Swell Height	Approx. Wave Length and Period (in seconds)	Approx. Wind and Swell Direction	Wind Velocity & Wave Celerity (Knots)	No. of Landings and Landing Approach Relative to Swell (see Fig. 5)	Average Vertical Acceleration at C.G. in "g's"	Average Maximum Acceleration on Hull in "g's"
8' Sea and Swell	320' - 8s	Wind West, Swell WNW	Swell 24 Wind 20	1 at 90°	3.2	4.9
8' Swell	-	Both West	Swell 20 Wind 5	2 at 90°	4.5	-
10' Swells 2 Systems	NW 320' - 8s W 1280' - 16s	Wind West 6' Swell NW 4' Swell W	Wind 5 NW Swell 25 W Swell 48	1 at 90°	1.7	4.0
"	"	"	"	1 at 180°	5.7	6.7*
8' to 11' Sea: 5' to 8' Local Sea on 3' Swell	500' - 10s for primary swell	All West	Wind 15 Sea 25 Swell 30	2 at 90°	3.7	7.1
"	"	"	"	1 at 0°	5.1	9.1*
10' to 12' Sea: 8' to 10' Sea and Swell with 2' Wind Chop	320' - 8s for primary swell	Wind NNW Swell NW	Wind 16 Swell 24	1 at 90°	6.0	9.3**
7' to 12' Sea: 7' Sea Added to undetermined Swell	Primary swell system 160 mi. from site: $\lambda = 1175'$, $T=15s$ $c = 45$, $h = 5'$	Wind W Sea W Swell W	Wind 4 Sea 19 Swell ?	1 at 90°	2.2	5.8
"	"	"	"	1 at 0°	5.7	11.2*

Notes: *Some limited damage did occur. **MacDiarmid considered this sea condition to be nearly the practical limit for this aircraft.

The author has prepared Table V which contains the most complete information for 28 of the 54 landings for the purposes of the thesis. Data concerning the take-offs is not set forth because in almost every case the landings were the most critical factor. This is also borne out by results of model tests shown on Figures 8 and 9. The most important findings for MacDiarmid's test are listed below. It should be noted that the first three findings compare with the previous model test analyses.

a. In every case, landing parallel to the swell crests produced the minimum vertical acceleration load on the hull.

b. Landing with the swell in every instance was more favorable than landing into the swell regardless of the wind conditions experienced in the testing program.

c. Landing into the swell produced the worst loading conditions.

d. In these tests one of MacDiarmid's main conclusions concerning the wind was that landing or taking off in 90° cross winds less than 20 knots was no great problem in the various sea states experienced. And taking a compromise course between higher cross winds and the primary swell system proved successful.

e. Also, it was found that, in the majority of the landings, the maximum acceleration loading occurred in the bow.

For illustration of the important difference of landing into the swell vs. landing with the swell, consider the plane landing on a sea surface which is actually composed of one simple harmonic progressive wave as shown by the relationship of velocity and wave considerations delineated in Fig. 3. Assuming this swell is sinusoidal with a period of 10 seconds and is moving with a celerity of 30 knots, the seaplane has a stalling speed of 65 knots and it

is landing into the swell; it encounters the waves as if they are standing still, and the plane is travelling at 95 knots against the wave. A simple computation then shows that the plane passes from one crest to the next in 3.2 seconds, which gives the pilot very little chance to react to the responses of the plane in the wave. Conversely, when the plane is travelling with the waves at the same stalling speed of 65 knots, its relative motion to the crests is 35 knots. The plane then encounters a wave every 11.7 seconds which reduces the hull impacts and loadings and gives the pilot much more time to react properly. It is also apparent that a take-off into the fast swell will cause the plane to strike successive swells so fast that the effect is pounding rather than planing.

Another interesting finding determined by these tests is the number of landing bounces which the plane made for each type of landing. Of 22 landings made parallel to the swell, the average number of bounces was 2.3 impacts. For the 10 landings with the swell, the average number of bounces was 2.4. For the 7 landings into the swell, the average was 3.3 contacts. Of course, it is not too accurate to compare these results because the swells were not the same height in each case. But the data does appear to show that landing parallel to the swell is the least bumpy, while landing into the swell is the most bumpy. MacDiarmid also found that, in most instances, the second or third bounce created the greatest hull loadings. This is also borne out by Figs. 9 and 10 which show that the initial landing impacts are generally one third to one half the maximum impact vertical accelerations loadings in "g's."

Almost all of MacDiarmid's testing was done primarily in swell conditions; therefore, not much is known about the limiting conditions of a local

sea. Reference 40 offers some interesting opinions about this. This reference considers that landing in a swell with a significant height of 5 or 6 ft would be quite different from landing in a sea with exactly the same significant height. The swell spectra is composed of a narrow band of frequencies and the average period is quite high. This means, first of all, that the slopes of the sea surface are not great. Secondly, it means that, if an area of the sea surface is found over which the waves are relatively low, the properties of the swell make it possible to guarantee, with some degree of assurance, that the swell will remain low during the time it takes to land. A locally generated "sea" of the same significant height produced by local winds would cover a much wider frequency band. The average period and average wave length would be much lower, and since the waves have the same significant height, this means the slopes of the sea surface would be much steeper. In addition, due to the great irregularlity of the "sea" waves, there would be no guarantee that, if a relatively flat area of the sea surface was found, it would stay low the next few seconds. Consequently, to land a seaplane in a "sea" is far more dangerous than to land in a swell of the same significant height. It probably should be recommended that landing in a sea spectrum (this does not include harbor or wind chop) should be restricted to significant height which is much lower than swells. The above comments would also apply for take-offs in a "sea." It is considered that MacDiarmid's rules and procedures for landing in swells would follow with minor modifications for landing in a "sea," except that the pilot should expect much bumpier, more irregular conditions, and the whole operation would be more hazardous.

A frequent condition which is encountered as shown by some of MacDiarmid's tests consists of a swell with a 3-to 5-ft significant height occurring simultaneously with a local "sea" of 3-to 5-ft significant height.

The "sea" is less dangerous than the underlying swell in these conditions, and yet the sea pattern may completely mask the swell from the pilot or other observers unless great care is taken to detect it. In fact, this is the condition which contributed to the last damaged down swell landing listed last on Table V.

Another condition can occur where there are cross swells, that is, two different systems arriving from different storms at a distance, with a local sea on top of them; for example, the two landings MacDiarmid made on a 10-ft swell system as shown on Table V. This produces very hazardous landing and take-off conditions because of the simultaneous presence of three different wave systems. However, it is interesting to note that MacDiarmid was able to detect the best landing pattern in the test landing and by landing parallel to the general swell effect the vertical acceleration for the combined 10-ft wave was 1.7 "g's" which was generally less than landing into a 3-ft swell.

MacDiarmid, in his tests, demonstrated that the use of jet or rocket power to assist in making a quick take-off is one of the most important contributions to safe seaplane operations in rough water ever made. JATO (jet assisted take-off) improved the control of the aircraft and was recommended for take-off's being made in rough water.

In summary, the main general conclusions that can be determined from this test program are as follows for sea and swell running in the same direction:

a. In every case the landing maneuver is more critical from the seaworthiness standpoint than take-off.

b. Landing impact hull loadings were the least when made parallel to the swell, slightly greater when with the swell, and the most unfavorable when made into the swell. The second or third bounce creates the maximum loading.

c. When the wind is less than 20 knots, landing or taking off in any direction to the wind is not too important. When it is over 20 knots, for the type of aircraft tested, it became more of a controlling factor.

2. British Full Scale Test Programs

References 13 and 15 contain certain limited information concerning the seaworthiness evaluation of two British seaplane testing programs. The findings for both were about the same; therefore, only the results pertaining to reference 15, which was the major aircraft, will be related.

Reference 15 contains the results for the four-engined Solent Mark 3 seaplane (over-all length 89.6 ft, planing length 70.9 ft, L/b ratio 6.6, take-off weights 72,000 to 84,000 lbs, take-off speed 85 knots, landing speed 90-95 knots, 6800 total hp). Both the Sunderland Mark 5 (Ref. 13) and the Solent Mark 3 seaplanes were designed for a maximum center of gravity acceleration of approximately 3.5 g. The main findings and conclusions of these tests of interest for site planning considerations are:

a. Take-offs at 82,000 lbs, into winds of 20 knots, gusting to 27 knots, and a 4-ft wind chop (distance between crests of 40 ft) proved to be satisfactory.

b. On take-offs or landings, the maximum cross wind for proper stability of this aircraft appeared to be 15 knots.

c. Violent porpoising (pitching and heave motions) may occur on a normally stable hull of this type, if operated into ocean swells of greater than a 1.3 "relative" wave length and heights greater than 1-1/2 ft. Example: Take-off into 2-ft swell, length 30-50 ft produced no instability. Take-off into 2-ft swell approximately 90 ft long ("relative" wave length of 1.3) produced violent porpoising, but take-off was made. Take-offs into a series of

1-1/2 to 3-ft swells, 150 ft long ("relative" wave length of 2.1) had to be abandoned. Take-off parallel to 3- to 4-ft swells, 150 ft long, produced no instability. Another example was landing into swells. Landing into a 14-knot wind and a 4- to 5-ft swell, 100 to 150 ft long ("relative" wave length range of 1.4 to 2.1), produced violent pitching and heave which caused some minor damage to the aircraft. During take-off into the same swells and wind, no excessive motions occurred. Subsequent landings parallel to 3- to 4-ft swells were made without any instability or excessive motion.

G. Determination of the Hydrodynamic Characteristics which Affect Planning Considerations

It is considered that the investigations of the previous model and full scale test programs have been sufficiently developed, at this point, to serve as a basis for the basic site planning criteria which depends on the hydrodynamic performance of the aircraft. This portion of Part III will set forth what the writer believes these important and critical planning considerations should be and on what they are based. The writer has developed Table VI as a convenient method to present the generalized hydrodynamic performance data in terms of the important planning considerations.

The table was developed in the following way: First, the sea states were divided into the five separate categories shown. The testing programs definitely pointed out that operations in swells of "relative" wave lengths, ranging between 1.5 to 2.5, are especially critical for all types of hulls and, therefore, must be considered separately from other conditions. The Solent Mark 3 analysis showed that wind or harbor chop was still another category, while MacDiarmid's report, the third test analysis and other tests showed that orientation of heading, and the basic differences between wind

waves and swells required other bases of consideration.

Because of the different missions that may be assigned to seaplane facilities, which permit different levels of efficiency and safety in operations and calculated risk of structural damage, the three operational categories are established. Also, since it was shown in the testing programs that landings are always more critical than take-offs, each operation is further subdivided.

The next step was to specify the significant wave or swell height for each of the foregoing parameters. For swells this was done, based on the following considerations:

a. It has been conclusively established that the greater the L/b ratio, the more measurably improved are the seaworthiness characteristics and the greater the reduction in hull loadings. Therefore, for a large high performance hull the greater the hydrodynamic capabilities, and the larger and heavier the aircraft, the smaller the waves become, relatively speaking.

b. The aircraft used in the relatively recent British tests (Refs.13 and 15) were designed to withstand maximum vertical accelerations of 3.5 "g's," and it might be assumed that MacDiarmid's PBM-3 was also capable of approximately the same loadings. It is also understood from the Martin Company (Ref. 24) that the P5M is designed to withstand an approximate 5 g loading at its center of gravity. Therefore, it is believed safe to assume that the high performance type seaplane would be designed to withstand at least similar loadings. Thus, it has been arbitrarily assumed, for safe and efficient operation, that the maximum g loading would be 3.0 g; for marginal operations, 4 g; and for dangerous and/or inefficient operation, 5 g.

TABLE VI

Generalized Performance Data for Seaplane Operations*

	Significant Wave Heights (ft) for:					
	Safe and efficient operation		Marginal operation		Dangerous and/ or inefficient operation	
Sea Conditions:	Landing	Take-off	Landing	Take-off	Landing	Take-off**
(1) Harbor or wind chop	4.5	4.5	6	7	Unlimited***	
(2) Swell--						
(a) Into swell Between critical λ/L of 1.5 to 2.5	2.0	2	2.5	3	2.5-4	3-5
(b) Outside critical λ/L range	2.5	3	3.5	4	3.5-5	4-6
(3) Swell. With or parallel to swell	4.0	4.5	6	7	6-8	7-10
(4) "Sea." Into wind waves	2.5	3	3	3.3	3-4	3.3-4.8
(5) "Sea." With or parallel to wind waves	3.5	4	4.8	6	4.8-6.6	6-8.2

*The values given in this table are considered valid for aircraft operating at normal gross weight.

**These take-offs are based on the aircraft using JATO.

***According to reference 63 wind chop never gets larger than 6 to 7 ft.

c. Therefore, using the previous testing programs as yardsticks and taking into consideration all of the foregoing facets, the relative equivalent swell heights were established. Table V was particularly valuable in this regard since, in many cases, direct correlation was possible between the 3 g, 4 g, and 5 g limits and the average values of the vertical accelerations at the center of gravity given in the table.

To specify wave heights for "sea" or wind waves, a slightly different approach was considered necessary. Because of the irregularity and unpredictable nature of this type of wave, and the very serious effect this can have on seaplane operations, as brought out in the MacDiarmid's test analysis and ref. 40, an additional factor of safety is required. The writer considered that the best way to do this was as follows: The wave heights in the second and third columns of lines 4 and 5 of Table VI were not based on the significant wave height -- that is, the average of the one-third higher heights of a given wave group. The height was based on the wave height which would not be exceeded 95 percent of the time in any particular wave group. For example, if the significant wind wave height is 4 ft, by using the method proposed by R. R. Putz (Ref. 48) it can be determined that the wave from this group of waves that will not be exceeded 95 percent of the time will be 5 ft. This 5-ft wave will then be considered to be the equivalent of a 5-ft swell for comparative evaluation with the results of the various testing programs; however, the significant "sea" wave height of 4 ft would be listed in the table to make all the values be listed as significant heights.

It should also be noted that no separate category for critical "relative" wave length range of 1.5 to 2.5 is used in Table VI for wind waves. The reason for this is that the average maximum steepness of a wind wave is approximately 17:1; therefore, between heights of 6 to 8 ft the wind wave cannot be in that critical range.

When the wave height is made up of a swell system and local wind wave component, it is believed that, if the average wind wave height is equal to or larger than the average swell height, the smaller appropriate limiting values in Table VI for wind wave should be used. If the average swell wave

height is much larger than wind wave component, conversely, the appropriate swell values may be safe enough.

Other conclusions or analyses that could be made concerning the orientation of sealanes, and problems concerning taxiing in rough water and wind, will not be brought out at this time but, rather, incorporated into Part IV.

IV. SITE SELECTION CRITERIA

The establishment of proper site selection criteria is dependent on two basic factors. The mission and functions of the proposed site as defined in Part II, and the various physical, meteorological, geographic, and oceanographic components of the site. Unless these two basic considerations are in consonance with one another, proper planning cannot be effectively accomplished.

This section will delineate the various physical factors that must be considered to meet certain operational requirements. Air space considerations will not be covered since it is set forth in Part II,B. The limiting parameters for each factor will be set forth, but interrelation of each factor to another will be discussed in Part V.

A. Summary of Existing Facilities and Planning

A brief summary of certain permanent or semi-permanent seaplane facilities now serving large and/or high performance seaplanes will be presented to serve as a basis of comparison to the criteria that will be established. The analysis of the facilities was developed from reference 60 and includes those facilities which were capable of serving the R3Y and the P5M type aircraft. The pertinent data is as follows:

1. Sealanes. All have at least two sealanes, with about half even having three. NAS Quonset Point has a 6000-ft diameter circle. The average sealane is 12,000 ft long and 1000 ft wide.

2. Minimum Depth of Water in Sealanes. Based on MLW, the minimum depth of NAS Norfolk is 8 ft with 2.3-ft tidal range, NAS Quonset is 8 ft with 3.8-ft tidal range, NAS Patuxent is 10 ft with 1.2-ft tidal range; with all others having greater effective depths.

3. Minimum Ramp Depth. The minimum depth of water at the toe of the ramp for the P5M aircraft is 12 ft at NAS Quonset, NS Bermuda has 10 ft depth with 2.6-ft tidal range, and NAS Norfolk has 10 ft depth.

4. Maximum Current. The maximum currents at these activities are 3.5 knots at CGAS Brooklyn and 3 knots at NAS Quonset.

5. Minimum Anchorage Depth. Minimum depths of 8 ft exist at NAS Quonset, NAS Patuxent, and NAS Norfolk.

When considering facilities being planned for high performance seaplanes, we should review the plans for the proposed NAAF at Harvey Point, North Carolina, which is being built to support 24 type P5M and 12 type P6M aircraft, as well as other seaplanes. The Harvey Point operating facilities will consist of the following main features: two sealanes 15,000 ft long by 1000 ft wide, oriented 90° apart. Present minimum depth of water in sealanes is 10 ft at MLW with a mean tidal range of 6 in, and it is planned to eventually dredge depth to 12 ft. The mooring area will be 12 ft deep with a 14-ft depth at toe of ramps. The mooring area is connected to the sealanes by an 11,000-ft taxi channel of a 12-ft depth.

Another source which is worthy of review is a study (Ref. 17) being conducted by the Office of Naval Research to determine the potential of water sites in the United States in order to establish suitable transcontinental seaplane routes for large, high performance aircraft being built and proposed. The study has revealed that a considerable potential exists in the form of coastal bays, sounds, rivers, natural and man-made lakes. Included in this latter term are reservoirs used for conservation, flood control, irrigation, navigation, power production, industrial, recreation, and other purposes. Even the cost of constructing an artificial sealane landing site to meet the basic criteria was investigated. It is contemplated that when the report is

completed, two transcontinental routes for large, high performance seaplanes will be selected.

The basic criteria being used in this report for the preliminary evaluation of these water sites are based on the following:

1. Main Landing Site. The minimum water area should be 4 miles by one half mile. This area would be capable of providing a single sealane 15,000 ft long by 1000 ft wide with 1000 ft clearance on each side and at either end. The remaining 4000 ft is an additional allowance for clearing shore obstructions such as trees and hills at the ends of the sealane. The minimum water depth within a desirable operating area is 13 ft. The approach zones must be free of any interference from the surrounding terrain rising above the 50:1 glide angle originating at the ends of the sealane.

2. Emergency Operating Site. The minimum water area is 3-1/2 miles by one half mile, which is capable of providing one sealane 12,000 ft long by 1000 ft wide, with 1000 ft clearance all around. The water depth and approach clearances are the same as for the main landing site.

It is expected that the final report for this study will be completed within the near future.

B. Site Selection and Evaluation Criteria

It is considered that the site selection and evaluation criteria can be divided into 12 general categories, which covers all the various basic physical planning considerations. Within each of these 12 categories the criteria will be further subdivided so as to be in consonance with the generalized operational requirements dictated by the mission and function of the three types of seaplane sites defined in Part II. The 12 basic planning categories are set forth as follows:

1. Minimum Water and Land Area Requirements

a. Deployment Site: The minimum length of sealane will vary for each model of aircraft depending on its weight and thrust weight ratio. Considering all models in use or planned, it is believed the minimum operational water area should be 3-1/2 by 1/2 miles providing adverse obstruction, wind, and swell conditions do not dictate the requirement for a larger area. This area is capable of providing a single sealane 12,000 by 1000 ft with 1000 ft clearance all around. However, it is desired to point out that highly variable wind and swell patterns over certain acceptable limits, which will be set forth in later categories, may require other sealanes so oriented that the minimum area may have to be considerably larger than the minimum of 1.75 square miles. An example of how adverse wind and swell can greatly affect take-off length was recently related in reference 55. In this case, a P5M attempted to take off on what was considered to be the most favorable sealane in a shifting wind and confused sea and a 5-ft swell condition, with the use of JATO. After a 12,000-ft take-off run, with JATO expended, the pilot had to abort the take-off. The main point here is, if a facility is to have all weather capabilities the sealanes must have sufficient length to normally provide safe and efficient high gross weight take-offs. For the present type of high performance seaplanes, it is considered the minimum length of sealane for a deployment site should be 12,000 ft even though, under good wind and surface conditions, take-offs can be made in 5000 ft or less without JATO. For safe and efficient operations, it is believed, the minimum length of sealane should be 15,000 ft to provide all weather capabilities. No land area would normally be required.

b. Advance Support Site: Minimum water area requirement should be 4 miles by 1/2 mile, providing obstruction, wind and swell conditions permit.

This area allows a single sealane 15,000 ft long by 1000 ft wide, with 1000 ft clearance on either side and 3000 ft at each end. If two sealanes are required, considerably more area would be required. A mooring area should be provided which will permit a minimum spacing of 800 ft between mooring buoys and, also, the area should be large enough to accommodate support ships. Land requirements should be the smallest practicable considering present as well as future missions of the site. Since almost all maintenance and servicing will be done at the buoy or aboard LSD's or tenders, little land area should be required.

c. Permanent Base: Water area should be same as above. Considerable more land area will be required since most maintenance would be done ashore; and the normal shore establishment training, administration, support, housing, and supply areas would be required. A parking apron should be provided in addition to mooring area. A minimum of 8000 square yards for each P6M aircraft, 5400 square yards for P5M type and about 10,000 square yards for a R3Y type would be highly desirable.

2. Depth of Water and Tide Conditions

There are 3 ways in which the maximum draft of a seaplane may exceed its normal specified draft. When a seaplane lands and the power is cut rather quickly at some point on the runout, the hull experiences a sudden settling in the water. If no waves are present, this condition will create the maximum draft for the hull. If waves are present, the hull will also experience plunging motions which can be of a considerable magnitude in critical "relative" swell lengths. The third consideration is landing or taxiing with partially filled hull compartments. Where no waves are present, it is believed that the draft requirements for dynamic settling and flooded compartments should be at least 1-1/2 ft greater than the specified normal draft. Where waves and the

possibility of critical swells can be expected, it is believed the maximum draft should be 2 to 3 ft greater than the aircraft's normal specified draft in order to take into account all of the contributing effects (Ref. 24). The tidal history of each site must be studied so the proper bottom depth in relation to the fixed datum is sufficient to meet all operating requirements. The extreme low and high tide records are needed, not only to determine depths in the operating area, but for the planning of any facilities in the mooring or support areas. Accordingly, a history of the variations in river or lake sites must be studied. Based on P5M, P6M, and R3Y type aircraft, it is considered the minimum water depths should be as follows, providing the mean tidal range or non ocean variation is no more than one-half foot:

a. Deployment Site: Sealane and taxi channel operating area 10.5 ft, mooring area 12 ft.

b. Advance Support Site: Operating and mooring areas 12 ft.

c. Permanent Base: Operating and mooring areas 13 ft. If a ramp is required, the depth in a limited area in front of the ramp should be at least 14 ft. The beaching vehicle used with the P6M requires approximately a 14-ft depth.

If tidal or water level variations are in excess of the one-half foot range, this variation must be added to the foregoing depths. Of course, if support ships are required in the operating or mooring area, additional depth will be required. The draft of an LSD which may be used for seaplane support is 19 ft maximum and, allowing an additional 3 ft for proper controllability of the ship, a total minimum depth of 22 ft may be required.

3. Waves Considerations

Wave considerations for preliminary site evaluation must be based on the efficiency and safety of all the various types of operations that are to be conducted in the site area. Table VI sets forth the wave parameters for the aircraft landing and take-off operations that will be conducted in the sea-lanes for safe and efficient operations, and for marginal levels of operation. Similarly, performance data for all the various operations in mooring and beaching areas must also be fully considered. Table VII was developed by the author as a guide for preliminary site evaluation.

Some of the data in Table VII was taken from reference 14 which was prepared by A. H. Glenn, a firm of consulting oceanographers working with oil companies on the Gulf Coast. Glenn's work is the only known study of this type; however, unfortunately, it does not differentiate between the various factors of wave periods, wave direction, wind conditions, currents, or experience of personnel involved. The author obtained the data for the various operations involving seaplanes from consultation with naval seaplane pilots, Martin Company (Refs. 23 and 24), and references 55 and 61. Since wave heights for Glenn's data appeared too low for harbor or wind chop, and he did not separate wind waves from swells, the author attempted to evaluate these facets. It should also be pointed out that some operations could be carried out in increased wave heights beyond the marginal state, but these operations must be regarded as dangerous and/or inefficient operations.

If the landing and mooring areas are in an area of wave exposure, it is evident from Tables VI and VII that the limiting conditions will be those based on the capabilities of the small craft and equipment needed to service and support the aircraft. It appears that the most critical operation

TABLE VII

Generalized Performance Data for Seaplane Support Operations

Type of Operation:	Significant Wave Heights (ft) for: Safe, Efficient Operations — Wind Waves	Safe, Efficient Operations — Swells	Marginal Operations — Wind Waves	Marginal Operations — Swells
1. Deep Sea Tug				
a. Handling oil & water barge	0-2(a)	0-2(a)	2-4(a)	2-4(a)
b. Towing oil & water barge	0-4(a)	0-4(a)	4-6(a)	4-6(a)
2. Aircraft Service Boats 24 to 50 ft in length				
a Underway at cruising speed	0-2(a)	0-3(c)	2-4(a)	3-5(c)
b. Loading of personnel or equip. at aircraft	0-2(c)	0-2.5(c)	2-3(b)	2.5-3.5(c)
c. Performing maint. inspections or work on seaplane at bouy	0-1 or 1.5 Wind Chop(c)	0-1.5(b)	1-2(b)	1.5-3.0(b)
3. Service and Crash Boats 60 to 100 ft in length				
a. Underway at crusing speed	0-7(c)	0-8(a)	7-12(c)	8-15(a)
b. Loading of personnel or equip. at aircraft	0-2(c)	0-3(c)	2-3(c)	3-4(c)
c. Buoy laying	0-2 or 2.5 Wind Chop(a)	0-2.5(c)	2-3(a)	2.5-3.5(c)
4. Seaplane fueling at buoy	0-2(c)	0-2(c)	2-3(b)	2-3(b)
5. Keeping Seaplane moored at buoy	0-3 or 4 Wind Chop(c)	0-4(b)	3-6(b)	4-7(c)
6. Marriage of cradle to seaplane	0-1.5(c)	0-1.5(c)	1.5-3(b)	1.5-3.0(b)
7. Drydocking aboard ship	0-1.0(b)	0-1.0(b)	1.0-1.5(b)	1.0-1.5(b)

Notes: (a) This denotes data was based on ref. 14.
(b) Generalized opinions expressed by the Martin Co.
(c) Generalized opinions of writer and other naval officers where no other information was available.

is the performance of the various hourly inspection checks and maintenance on the aircraft from small boats or from the aircraft while it is secured to the buoy. While this limiting conditions in some cases might be as low as 1 to 2 ft for a permanent or advance support base, it is considered that the limiting wave height for support operations from fleet components at a deployment site would be about 3 ft. The transfer of heavy ordinance items from small craft to the aircraft becomes difficult in any type of wave action.

Once all operational and performance limitations are determined in terms of significant wave heights, the next step is the determination of the wave exposure at the site. In specifying wave exposure, information is needed relating the period or length, height, direction of approach, and frequency of occurrence of all waves which reach the inshore areas (say, the 8 fathom contour) of the site. Strictly speaking, such statistical data would encompass a spectrum of waves, but for practical purposes, this can usually be reduced to two or three principal directions of approach on the basis of frequency of occurrence and significant magnitude of wave height. It may also be expected that each direction of approach will be associated with a particular off shore storm generating area, hence with a fairly narrow range of wave periods. Reference 4 reviews the methods in which this information may be so categorized. Since wave prediction, forecasting, and hindcasting is a specialized field of science in itself, it will not be discussed in detail, but the evaluation of these methods will be briefly summarized.

Basically, there are three ways in which the deep water wave (depth greater than $\lambda/2$) spectrum that will affect the proposed site can be determined. The three main methods are as follows:

a. Hindcasting Methods (see Ref. 48). This technique is the most general method for obtaining wave exposure data since synoptic weather charts

required for this method are generally available for large areas of the world. This method is fairly accurate and is being improved and systematized, but it requires skilled professional personnel to accomplish the work.

b. Climatic Methods (Ref. 7). This general technique is not so accurate since it does not provide as much specific information on wave height, period, and direction as does the hindcasting method; but it can be done about 25 times faster by sub-professional personnel. The Navy Hydrographic Office has developed a method based on meteorological principles which can give a synoptic wave chart for large areas of the ocean. Another somewhat similar method that could be used for determining the probable deep water wave exposure in an area is that developed by W. J. Pierson, Jr. at New York University. Both the Navy Hydrographic Office and the Pierson forecasting methods are described in reference 40.

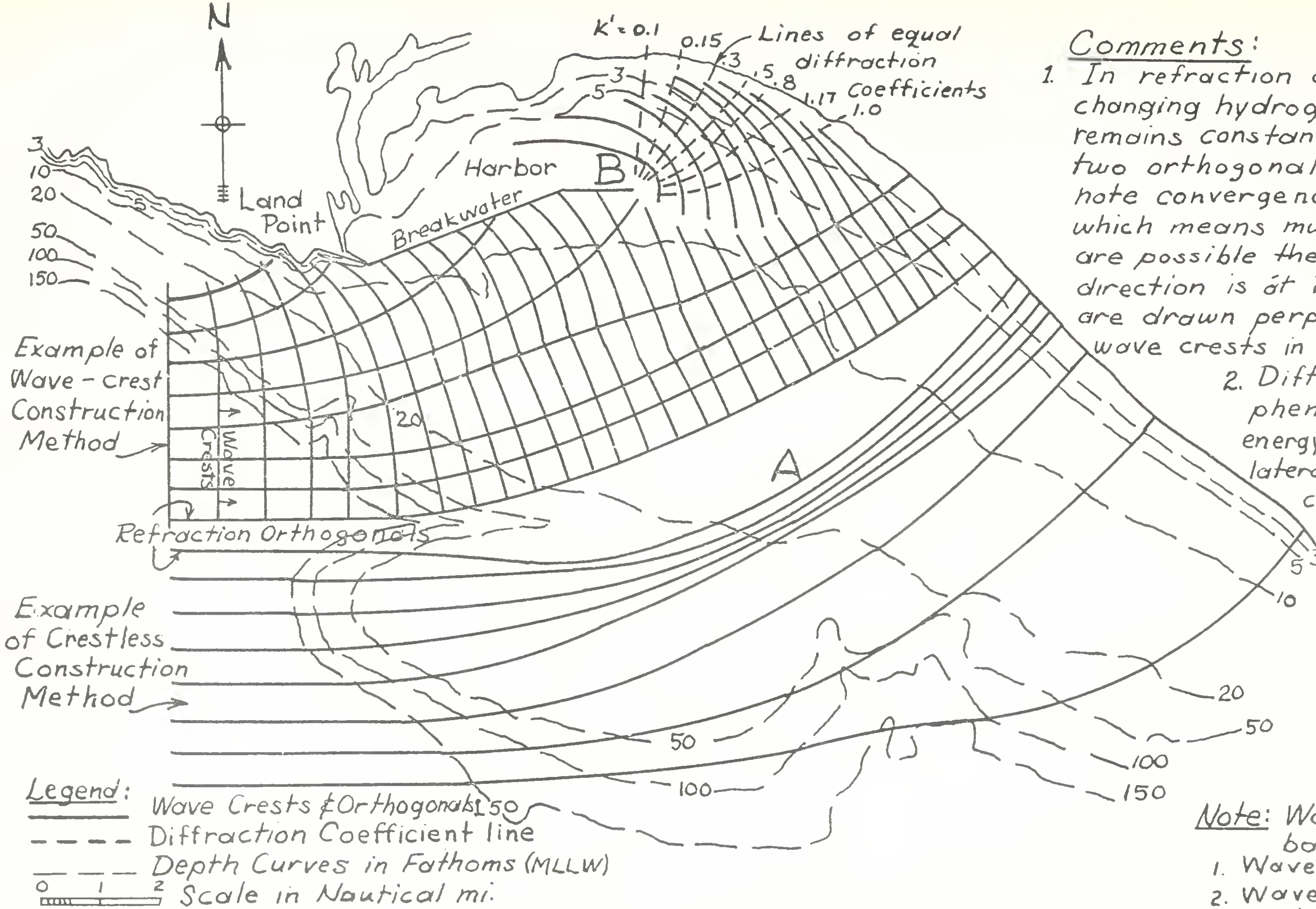
c. Observational Methods. Readily available sources of ocean wave information are the Sea and Swell Atlases published by the Navy Hydrographic Office. These atlases, providing world-wide coverage on a monthly basis, have been compiled from visual observations of sea and swell recorded aboard merchant and naval vessels. Also on file are British and Japanese sea and swell atlases dating back to 1904. In addition to the published atlases, there exists a large amount of observations of sea conditions for coastal points throughout the world in manuscript form. In some parts of the world, systematic wave observations, by instruments or individuals, have been carried on for a sufficiently long time to establish an accurate statistical measure of deep water wave exposure for the region. References 16 and 50 are two examples of this.

In many instances, the important components of the seaplane facility, the sealanes and mooring area, will be located in water depths between $\lambda/2$ and

$\lambda/25$. However, in most cases the basic wave data pertaining to any proposed site will be in terms of deep water type waves and swells. Therefore, a method must be used which will project the off-shore deep water condition to the inshore localities of the site, taking into account all the basic shoaling changes in the wave characteristics explained in Part III,B. This could be particularly important where long swells may be retracted so their heights tend to increase and the lengths may be reduced to the critical "relative" wave length range of 1.5 to 2.5 in certain areas under consideration. Or that certain primary swell or wave systems may reinforce one another in particular areas so as to create very dangerous surface conditions during crtain periods of the year. The techniques of projecting waves to an inshore site involves chiefly refraction analysis, although diffraction by outlying islands or headlands must be considered. A proper refraction-diffraction analysis, based on fairly accurate regional deep water waves particulars, should be able to provide the required wave direction and average significant height, and average wave length and period, for the sealane and mooring areas of the site.

This data, together with the seaworthiness parameters of Part III,G and Table VII, will permit comparative evaluation with other sites, orientation of sealanes and air traffic patterns, taxi lanes, efficient location of mooring, refueling area, and beaching ramps. The various methods for making wave refraction and diffraction diagrams are well covered in references 40, 48, 19, and 11, and should give no particular problems in their applications so they will only be discussed very briefly. See Fig. 13 for an example of the combined effect of refraction and diffraction.

The two basic methods of constructing refraction diagrams are:



Comments:

1. In refraction of waves over changing hydrography, the energy remains constant between any two orthogonal lines. Therefore; note convergence in area "A", which means much higher waves are possible there when wave direction is at 270°. Orthogonals are drawn perpendicular to wave crests in wave-crest method.
2. Diffraction is that phenomenon whereby energy is transferred laterally along a wave crest. See area "B" on plan. Example, along K' = .3 line, wave heigths are .3 of their values outside the breakwater.

Note: Wave Refraction based on following:

1. Wave direction - 270°
2. Wave period — 15 sec.
3. Crest interval — 4 waves

FIG. 13. Example of Combined Refraction and Diffraction Effect.

a. Wave-crest method, as described in references 19 and 48. The advantages of this method are (1) the diagram can be drawn without contour lines over the base hydrography, and it shows the successive position of the wave crest; (2) the principles are easily understood and operator skill is quickly attained. A disadvantage is that it is hard to properly scale the diagram in areas of very shallow water and rugged bottom terrain.

b. Crestless method as described in reference 19. The advantages are that the scaling is much more flexible and it provides better basic wave information. The main disadvantage is that principles and procedures are more difficult to understand, and the operator must exercise better judgment and be closely supervised.

Regardless of which method is used, a detailed, fairly large-scale map of the bottom topography is essential. In the crestless method, bottom contouring is required, while in the wave-crest construction only the average depths are used as determined by inspection of soundings.

Diffraction is the phenomenon in which the propagation of water waves continues into a sheltered region formed by a breakwater or similar barrier that interrupts part of an otherwise regular wave train. The basic method used for this analysis is the Penney and Price solution which is described in references 11 and 61.

Another tool that should not be overlooked by the site planner is aerial photography of the wave patterns of the proposed site. It is of great value, not only in most preliminary site selection evaluations, but as a supplementary check to the detailed refraction-diffraction analyses. In nearly all cases, the conformity of properly constructed diagrams to the actual photographed wave pattern have been proven to be sufficiently close to dispel

any doubts regarding the accuracy of the diagrams (Ref. 11). Reference 40 contains some good examples of the uses of photography for these general purposes.

From the analysis of refraction-diffraction diagrams and/or aerial photography, there is one factor that affects the wave exposure at a site more than any other. This factor is the regional and local site's natural topography, and to a limited extent artificial protective features. The importance of natural protective features of any proposed seaplane site cannot be too strongly emphasized if the full potential and mobile concept of high performance seaplanes is to be fully utilized. Aside from the unusual occurrence of a completely protected artificial or natural harbor in the form of a deeply indented bay, much less spectacular but more frequently occurring topographic features as offshore islands or reefs, submarine canyons or prominent hadlands may afford considerable wave protection.

Islands and headlands operate by diffraction to produce a zone or "shadow" in their lea of considerable reduced wave disturbance. Since such wave barriers are very large in terms of wave lengths, the analysis of Penney and Price may be applied to determine the extent of the shadow and wave height reduction within the shadow. A good example of such natural protective features are the off-shore channel islands of Southern California which exert an important modifying effect on the wave system of the adjacent shore areas.

Submarine canyons may have an important refractive effect on approaching wave trains, their relative greater depths producing orthogonal divergence with resulting wave height attentuation along the canyon axis. A submarine ridge has the opposite effect of a canyon, the ridge producing orthogonal convergence with resulting increased wave heights.

Off-shore reefs or shoals can afford considerable protection to an area. For example, at Guam, the Calalan Bank, before the breakwater was built, was in -30 to 40 ft below MLLW. When large, long swells passed over it into the deep extensive harbor (120 ft below MLLW) it distorted the waves in the lea of the bank so these wave lengths were about one-quarter of the original wave lengths. The average wave height was reduced about 50%, and the wave energy, which is proportional to $w\lambda h^2$, was reduced about 75% (Ref. 30).

Determination of harbor chop: There is no exact analytical method available to determine this type wave height because of the great number of unknown variables entering the problem. However, according to reference 1, experience has shown that the following empirical formula proposed by Stevenson may be used with reasonable confidence in estimating the harbor or wind chop in a harbor-like area:

$$h = 1.5\sqrt{F} + 2.5 - \sqrt[4]{F}$$

where F is the fetch in nautical miles.

The cost of just one aircraft accident at an operating site may well amount into the hundreds of thousands of dollars. The efficiency and capabilities of a proper operating site in wartime may be beyond the assignment of a dollar value. It has been estimated by reference 7 that the cost of a preliminary survey of wave conditions based on tabulated sea and swell data is less than $100 per location. A more detailed study using hindcasting and the preparation of wave refraction diagrams will probably range between $2000 and $4000. With values such as these, adequate planning of wave exposure by the methods previously mentioned provides an enticing way to save money.

4. Topographic Conditions

In addition to the appraisal of the topographic features which affect wave exposure discussed in the preceding section, all natural or man-made obstructions for a distance of at least 15 miles from the site should be accurately determined. The subject of avigational obstructions is covered in detail in Part II,B; therefore, it will not be further discussed here.

Another important factor is the accurate determination of the elevation of the operating site. Since all sealane lengths are established on the basis of operations at mean sea level, the sealane must be lengthened if the elevation is higher. Reference 41 specifies that the length shall be increased in the amount of 1.1% per 100 ft of altitude above mean sea-level.

An analysis of the shape of the terrain in relationship to the site is also important because of the serious effect it can have on local and regional wind conditions. This consideration will be discussed in the next section.

A very desirable feature at a deployment or an advance support site is a calm, sandy beach where the seaplane can be carefully beached to perform hull repairs in extreme emergencies.

5. Wind Considerations

The most important surface wind information is the prevailing directions and velocity and the maximum wind of 5-min duration. The data should be based on as many years' observations as possible. The most desirable method to represent the wind data characteristics of a site is by the wind rose technique as shown in reference 41. This wind rose delineates the percentage of time that winds of a certain direction and velocity can be expected to occur.

If no wind rose exists for the desired site, but there are some for the surrounding region, a composite rose of sufficient accuracy may be established from an evaluation of these if the intervening terrain is level or slightly rolling. If the intervening terrain is mountainous, a composite rose may be established by weighted averages, providing an accurate topographic map is used. However, the rose should only be used as a guide pending sufficient local verification.

Reference 41 has established the Navy criteria that all airfields should provide 95% over-all wind coverage with limiting cross-wind components of 10.4 knots for training stations and 15 knots for fields operating tricycle gear aircraft. Seaplanes are not specifically mentioned in this reference; however, it is interesting to note that a 10.4-knot limiting cross wind component was established for Harvey Point which will be used for training purposes. Based on this, other references, and pilot opinion, it is considered that the following should be established as the limiting cross-wind components for high performance seaplanes:

	Landing	Take-off*
Training Facilities (Ref. 41)	10.4 knots	10.4 knots
Operational Facilities (Refs. 3 and 36)	20 "	15 "
Marginal operational conditions (Ref. 23)	25 "	20 "

*without JATO

In many areas of the world, there are regional winds of great intensity which are peculiar to that region and are of such a varying frequency, duration, and magnitude, that their effects must be considered in any preliminary considerations of site planning. In many cases, these storms are from a

much different direction than the prevailing winds. These winds are generally well known to the mariners and aviators who operate in these local areas, and they frequently refer to such publications as the U. S. Hydrographic Office's Sailing Directions, or the British Admiralty's Pilot publication for specific data. A person responsible for site selection should not only consult such data, but should make detailed inquiries of local sources of information. Following are a few examples of these unique wind phenomena , which, acting over unprotected water area, or funneling over or around a particular adjoining land form, could make seaplane operations extremely dangerous or impractical for excessive lengths of time.

The Alaskan "williwaw" (Ref. 49) occurs among the outlying islands and coast which are caused by the wind passing through the cliffs and mountains in such a manner as to give rise to gusts or brief squalls of extreme violence. Velocities of over 100 knots have been recorded. They are especially dangerous because they often succeed one another from very different directions, although tending to follow the downward slopes of the adjoining land forms. Their frequency depends on the local site, and their duration may be from a few seconds to 5 minutes.

French Mediterranean "Mistral" are caused by anti-cyclonic conditions over northern Spain, southern France and the low antecedent pressures in the western Mediterraneans. On the average, 11 of these storms will occur in a year with winds over 40 knots and occur most frequently during the winter (Ref. 45). They may last for a period of from 3 to 5 days or longer.

Other examples of such land-wind storms which affect the adjoining water areas are: Argentine "Pumpero," North African "Sirocio" and California "Santana."

In addition to the foregoing unique regional wind phenomena, there are situations where local land masses and winds can cause serious effects. For instance, a large conical mountain located near an existing seaplane site divides the prevailing wind in such a manner as to produce a confused and unpredictable wind pattern in the operating area. Recently a P5M, taking off with JATO assistance at the site, crashed because the pilot couldn't predict the wind force in relation to the 5-ft swells in the area (Ref. 3).

6. Current Conditions

River or tidal currents in excess of 6 knots in the sealanes will not normally cause any difficulties for landings and take-offs (Ref. 47). However, currents in excess of 3 to 4 knots, where taxiing operations are conducted, are undesirable. In some cases, undesirable currents may be offset to some extent by advantageous winds. In the mooring area, the currents should not exceed 3 knots, while at a permanent base where self-propelled or aircraft-propelled beaching cradles are used, the currents should not exceed 2 knots.

Rivers provide a great potential for seaplane operations; however, they have certain inherent hazards which must be considered. Water traffic, shifting bottom conditions, possibility of floods, and floating debris cannot be overlooked. Floating debris moved by currents into the operating areas have been one of the greatest causes of seaplane accidents (Ref. 55). Evaluation of a site must consider its vulnerability to floating debris that can enter the operating areas during periods of low visibilities or at night. No operating solution to this problem has yet been found.

For the combined effect of wind and current on small boat and seaplane operations in the mooring area, see Part V,C.

7. Foundation Conditions

The type of bottom in the mooring area is of special importance in connection with its ability to hold anchors. Bottoms of rock or hard gravel are poor for holding, as are deep mud and silt. Clay or soft coral have good holding resistance, while sand and loose gravel are usually the best types of bottom material. Bodies of water which contain old stumps or logs on the bottom cause anchors and lines to foul, and over a period of time can create a hazard if these submerged objects rise to the surface and remain partially or totally submerged.

The holding power of anchors in material other than firm sand should be determined by approved tests (Ref. 31), preferably conducted at the site where the anchors are to be placed. When test data is not available, however, the holding power of steel anchors in different bottoms may be estimated by Table VIII:

TABLE VIII*

Holding Power of Steel Anchors in Various Soils

Type of bottom:	Ratio of holding power of bottom compared to firm sand (Approximate)
Well-compacted sand	1.0
Stiff, dense clay (plastic)	1.5
Sticky clay of medium density (cohesive)	.67
Soft mud (fluid), loose, coarse sand, gravel	.33
Hard bottom (rock, shale, boulders)	.25

*(after Ref. 31, p. 59)

The criteria used at Harvey Point for the P6M is that the anchor mooring must be designed to keep the aircraft secured in 100 mph winds and 6-ft waves. It is believed that this should be the minimum criteria for all sites. A standard class E free-swinging riser-type mooring assembly with sinkers, which has a holding power of 50,000 lbs based on sand (Ref. 31) is to be used. Three 9000-lb stockless anchors, or three 4000-lb LWT anchors, can be used with this mooring assembly. At Harvey Point, special fueling buoys are being installed in the mooring area for refueling aircraft. A flexible submarine fuel line will run from shore to the buoys. Each buoy will be secured with three 6000-lb stockless anchors. Providing the currents are 3 knots or less, these mooring and fueling buoys should be able to accommodate the P5M and P6M aircraft in almost all locations.

Foundation conditions must also be accurately determined for design of conventional shore and support structures, especially at permanent bases.

8. Ice Cover

Accurate ice cover information for a proposed site is essential. Unfortunately, there is no simple method to obtain this data in most cases. The average dates of the first freeze and last thaw and maximum thickness of ice should be determined. In some areas of the United States and other countries, these data are represented in isopleth form on maps; but the data can only be used as a general guide, at best. Average frost and temperature charts of an area do not provide sufficient information. The history of each site must be separately studied from the best local information available, because of the highly erratic nature of ice cover distribution. Variation from expected average conditions may be caused by salinity, great water depth, or the temperature of the water supply. For example, some mountain lakes and

salt lakes seldom freeze, although the air temperature may be well below freezing for long periods of time. Minor ice cover along the shore line should not handicap a site if the operating and mooring areas are ice free. Permanent and advance support sites should be free of ice all year, but a deployment site could have ice cover, providing accurate information as to ice-free conditions are known.

9. Temperature Data

It is considered that mean maximum and minimum, as well as extreme, air temperature over a period of years should be determined. The mean sea temperature is also useful for many purposes.

The standard sealane length is normally based on mean sea-level elevation and standard sea-level temperature of 59°F. Therefore, after the standard runway has been corrected for altitude, it should be further increased by .66% for each degree fahrenheit that the mean daily temperature for the hottest month of the year (average over a period of years) exceeds 59°F (Ref. 41).

In colder climates, air temperature can be very critical. For instance, a water site may be relatively free of surface ice the year around; yet the air temperature can be so low that seaplane operations may not be possible for abnormal lengths of time. During take-off, when considerable spray is generated and aerosoled into the freezing air, it can readily weight certain surfaces of the aircraft with a thin layer of ice so the aircraft cannot become airborne. Also, under certain conditions, a few fractions of an inch of frost or frozen snow on a moored aircraft may prevent the aerodynamic surfaces from functioning properly until these surfaces are swept down and cleared. This might be rather critical on a large aircraft moored at a buoy when time and readiness are important factors.

10. Precipitation

The distribution and intensity should be determined in order to aid in the planning of shore facilities where required. These data are also important where water levels in lakes or rivers are dependent on precipitation in the region. Abnormal precipitation which includes snow can also affect visibilities and reduce VFR capabilities.

11. Weather Storms

The frequency, intensity and duration of thunderstorms, typhoons, and other storm occurrences, in addition to the windstorms mentioned above in item 5 (Wind Considerations), should be determined. Many of these are of a seasonal nature and affect flying condition and reduce VFR capabilities of the site. Typhoons in the region could seriously affect wave exposure to a normally well-sheltered water area. Abnormal wind pressures could result in especially designed structures, mooring, and essential auxiliary seaplane equipment.

12. Fog and Reduced Visibilities

A special study of all the factors which affect the average percentage contact flying weather, VFR conditions, should be made. In this country, United States Weather Bureau publications "Local Climatological Data" and "Classified Flying Weather" are a good source of such information.

This information is important for comparative evaluations with other sites and for determining the avigational aids and lighting systems that should be used depending on the mission of the site. One of the unique all-weather advantages of a seaplane is that a few radar reflective buoys can be used to bring the aircraft down to the predetermined water level in zero-zero weather. Water-based aircraft do not require the precise positioning that a land jet

aircraft does on a runway. Normally, the landing of a land-based jet, both laterally and along the runway length, requires the most elaborate flying aids known to aeronautical sciences.

V. FUNCTIONAL AND PRELIMINARY LAYOUT PLANNING

In Part IV, the limiting parameters for each separate important planning element are set forth. In this part, the interrelation of these factors will be presented. While it is not the purpose of this thesis to discuss the various facility components such as lighting, operation towers, hangers, parking aprons, etc., reference will be made only to certain special features that have important affect on preliminary planning.

A. Orientation of Sealanes

The minimum size of a sealane should be as set forth in IV,B,1 for the three types of basic sites. For sites with no ocean-type waves, the orientation of the sealanes should be similar to that for a land-based aircraft with the wind and physical obstructions being the two main factors of consideration.

For a site with ocean waves or swells, the orientation of the primary swell systems, wind, and physical obstructions are the primary factors of consideration. Providing obstructions are not a major problem, the following generalizations concerning orientation are set forth. These generalizations are primarily based on MacDiarmid's test program, subsequent testing by the Navy, and reference 46.

With a uniform sea (swell and sea in the same approximate direction) and wind less than 20 knots:

1. For landing or take-off, the best heading is parallel to the crest, regardless of the wind direction. Either the crest or the trough of the swell may be used, because the previously held fears of serious danger of dragging a wing float or sliding down the face of a swell were not supported by these tests.

2. The second best choice for landing or take-off is down swell.

3. Landing or taking off into swell and wind is a poor third choice unless the wind is much faster than the swell. Heading should be such as to bring wind as much ahead as possible without driving directly into the swell.

When the primary swell system and wind waves from the higher prevailing winds are not in the same direction, the wind is less than 20 knots:

1. If the significant heights of the swells are equal to, or greater than, the wind wave height, the best orientation appears to be parallel to the swell crests as described for the foregoing uniform sea condition. This would be particularly true if the "relative" swell lengths are within 1.5 to 2.5 range.

2. If the wind wave height is considerably greater than the swells system, the same preference of maneuvering should be given to the limiting wind wave pattern as for the uniform sea in the foregoing paragraph.

With two primary cross swell systems of approximately the same height and wind less than 20 knots: This is very hard to evaluate in general, but a compromising oblique heading so as not to head into either swell would be best, if possible.

High wind chop only ($\lambda < 50$ ft, $h < 4.5$ ft) with wind in excess of 25 knots: In this case, the wind would be the limiting factor and landings and take-offs should be made into the wind.

As can be seen from the foregoing, many factors affect the orientation of the sealane and only a special study of all the factors within the parameters mentioned can provide the most effective and safe sealane orientation.

If one sealane orientation is not capable of fulfilling the terrain,

obstruction , local development , wind direction, and wave and swell considerations in consonance with the proper level of safety and efficiency based on the activity's mission, two sealanes will be required (Ref. 41).

Another factor which has become increasingly important with large high speed seaplanes is boat traffic within the operating areas. Uncontrolled traffic cannot be tolerated because aircraft may be moving down a sealane at 140 knots on step or just airborne, and cannot safely abort or maneuver around an obstruction approximately 3/4 of a mile in front of it (Ref. 23). It is considered that for safe and efficient operation of high performance aircraft, no surface traffic should be permitted in the sealane areas, just as none is allowed for landplane runways. These seaplanes have all-weather capabilities and will be using the sealanes in periods of rough weather and reduced visibility. Under these conditions, it is impossible to regulate any type of boat traffic in the operating area even with the use of radar. For the permanent base or advance support site, where frequent operations will be conducted, a specific, well-delineated operating area should be set aside solely for the use of high performance aircraft. No boat traffic should be permitted except under emergency conditions as long as the seaplane facility is in an operational status. It is believed that the condition in which a flying "boat" was considered a boat and was expected to share the free navigational rights of a water area with other boats can no longer be accepted. Many flying "boat" pilots, who shared San Diego harbor and others like it under these conditions in the past, regarded it as strictly marginal type operations, if not dangerous and inefficient.

B. Orientation of Taxi Lanes

Taxiing is difficult in areas exposed to waves and swells and it is more of a water problem than a wind problem. In some swell conditions, steering is difficult regardless of wind forces. If the surface is regular, but the wind is strong, the wind is the major problem. It is often difficult to get the aircraft headed downwind because of weathercocking (tendency to run into the wind). In some cases, when the wind gets above 35 knots, it may even be impossible to turn the aircraft and taxi down wind. The high freeboard draft ratio allows the aircraft to drift considerably off course whenever a strong wind component is working on the broad fuselage and tail surfaces. Because of these problems, the P6M and P5M have hydroflaps installed which greatly improve their water handling qualities. Depending on the wind and forward taxiing speed, each aircraft has separate turning radii; however, average turning radius for planning purposes may be considered to vary between 3 to 5 times the length of the aircraft.

Because of all these varied conditions which may exist at any site, only the following generalizations pertaining to the layout and orientation of taxi-channels can be made:

1. The distance should be as short as possible between the sealane and mooring area, and it should be relatively free of surface traffic. In general, if the taxi channel does not have wave exposure more severe than found in the sealane, the distance is not dependent upon the high performance aircraft's ability to taxi, but rather upon the mission requirements for fuel and taxiing time. Based on opinions of Martin Co. (Ref. 24), it is believed that a maximum taxiing distance of 3 miles might be acceptable where fuel and time factors are critical. This might be increased to 6 miles maximum where these considerations are not too important.

2. The desirable maximum width of channel depends on local conditions; however, minimum width should never be less than four times the maximum wing span of the aircraft.

3. There should not be any turns in the course of the channel, if possible, because of night or all-weather operational difficulties.

4. The critical "relative" swell lengths of 1.5 to 2.5 should be avoided if possible. Reference 46 points out that even at normal taxiing speeds, trim, heave, and roll parameters were much larger in this range, regardless of heading.

5. The maximum wave heights in the taxi channel should not generally exceed those prescribed as the limit for the seaplane.

C. Location of Mooring Areas

It is possible for the sealanes to be in a relatively exposed position to wind and waves; however, the mooring area should be in a much better protected location. Under adverse weather conditions, the aircraft, by using special ~~alternaturely~~ alternately planned sealanes or JATO, need only be in a landing or take-off area a few minutes, but the aircraft in the mooring areas are required to be there the majority of their useful life. As pointed out in Part IV, wind, wave, swell and current conditions must be considerably less than in the sealane areas. While in the mooring area, the Martin Co. believes that the following conditions are the maximum conditions that can be permitted: (1) For small boat (up to 40 ft) tie-up to a seaplane, maximum conditions are 3-ft waves, 4-knot current and 25-to 40-knot wind; (2) for a seaplane mooring to fueling buoy maximum conditions are 3-ft waves, a 3-knot current or a 20-knot wind. While the mooring area must be generally much better sheltered, it must be relatively close to the sealanes; therefore, the best advantages of the

local terrain must be fully considered. If the most desirable location of a major mooring area for maintenance and servicing functions is beyond the allowable taxiing distance, consideration should be given to the installation of ready operational buoys in an area adjacent to the sealanes.

Based on a minimum spacing of 800 ft between mooring buoys, it is considered that the minimum mooring area for 10 buoys should be about 250 acres. This will provide flexibility in spacing and provision for traffic lanes.

D. Functional Relationship of Areas

While the orientation of the various primary components of the operational areas is essential, it is also very important that the over-all relationships of all functional use areas of a large base be considered during preliminary planning. The interrelation of the operations, maintenance, supply, housing, medical, administration, fuel and ordinance areas must be considered on the basis of efficiency, safety, noise interference and future expansion.

Efficiency and safety for performing the mission and function of the activity will be of the first importance whether the site is permanent, advance support, or a deployment site. At a large base site, the operational, maintenance and supply functions should be somewhat physically contiguous for proper flow of work. The fuel and ordinance storage facilities should be safely separated from populated areas, yet relatively short routes or media of transportation of product must be used.

Noise interference to the housing, medical and administrative functional areas will require a study of construction, topographic and distance factors. Reference 41 sets forth the limiting noise levels for various functional areas and can be used as a guide in preliminary planning. At the

present time, the maximum noise problem arising from seaplane operations is caused by the P6M aircraft. During taxiing and engine run-up, in which the aircraft uses its afterburners, Martin Co. has recommended the following noise restrictions: No personnel shall be within a danger area 50 ft forward or 100 ft to the side or aft of the aircraft unless in a soundproof building. Both ear plugs and ear muffs shall be worn outside the danger area but within a 500-ft radius. Either ear plugs or ear muffs shall be worn outside a 500-ft radius but within a 1000-ft radius of the aircraft. No special personnel protection is required outside a 1000-ft radius of the aircraft.

Future expansion capabilities of any or all the functional areas should be considered to provide for orderly expansions should there be a change in the existing mission of the site or a major change in the characteristics of the aircraft.

E. Support Facility Considerations

1. Beaching Facilities and Handling Gear

This support element is an important consideration in preliminary planning.

At a permanent base, major repair on the hull or basic aircraft structure will usually be performed; therefore, concrete ramps and parking aprons should be provided. The advance support site in peacetime might perform first and second echelon maintenance, but during active combat this type of activity would normally only perform first echelon maintenance; and beaching would be accomplished for only emergency repair or concealment.

Other factors which must be taken into consideration are: (1) Handling time. The methods used in the past have been quite time consuming because the aircraft many times had to be towed to the beaching gear and then undergo elaborate beaching procedures. (2) Manpower. It is desirable to provide a system

in which the minimum number of men are involved in the beaching operation to eliminate confusion and delays. (3) Meteorological. In cold or foul weather the health and comfort of beaching personnel must be considered. If a ramp is required, it is recommended that the beaching site be so chosen so the ramp slopes down and away from the prevailing wind. This would allow beaching in the lea of the slope.

A review of all the various types of beaching, docking and handling gear or facilities that have been or are being used can be categorized as land support or water borne types.

The land supported types include: (1) The ramp utilizing various methods of cable attachments (Ref. 54). (2) The graving dock (Ref. 2). (3) Hoisting systems (Ref. 54).

The water borne types include: (1) Floating berthing docks (Ref. 54). (2) Floating dry docks may consist of Navy pontoon cells, or variations of the LSD system (Ref. 59). (3) Floating hoist. The P5M-2 has two built in hoist fittings on the hull-top center line at the wing for hoisting the aircraft aboard a tender or LSD. (4) Floating wheel units (Ref. 54). The P5M uses this method now. It consists of two main wheels and a tail wheel dolly, which fit into sockets on the hull or wings. Each unit is provided with water-tight tanks for floatation. A beaching crew wades out to the positioned aircraft and makes connection with wheel units. Then the plane is pulled up the ramp with a tractor. This operation usually requires 6 men and under the most favorable conditions requires ten minutes. In unfavorable weather, more manpower and much more time is required. And, since the gear and aircraft are free floating, with no means of damping their relative motion, hull damage can easily result. This system has become obsolete for aircraft

larger than the P5M. (5) Floating cradle. This includes those other than are brought up ramp with tractor, cables, or tracks. This type of cradle is self-propelled or propelled by the supported aircraft as in the case of the P6M. The type used for the P6M is the most advanced to date. This vehicle has four dual wheels, with a maximum wheel load of 50,000 lbs. This huge, self-propelled, floating vehicle can position itself to the aircraft and, when married, an automatic locking device secures aircraft to the cradle. The aircraft then, with its jet engines, provides movement of whole unit up the gently sloping ramp (10:1 slope). It has its own centering devices. The cradle vehicle can operate in a 25-knot crosswind and a 2-knot cross current. This present type of vehicle could only be used where a special ramp is available as would be provided by a permanent base; however, various other methods are being studied to adopt such a vehicle in an advance base type terrain. The cradle system could eliminate an extensive cable and buoy system which could be detected by enemy reconnaisance. The cradle will have its own operators and thereby relieve the pilot of some of the beaching responsibilities The R3Y cradle is a mobile self-propelled cradle equipped with 4 large outboard motors at each corner. It weighs 25,000 lbs, is of aluminum construction and can be disassembled and airlifted inside the aircraft. It has 8 large wheels with power steering and braking. With its motors and a 4-man crew, it can maneuver to aircraft and marry. The aircraft taxis up and down ramp under its own power similar to the P6M (Ref. 6).

All of the foregoing systems have many obvious disadvantages, particularly for advance base use. It is obvious that wave height and length will also place restrictions on beaching operations. Establishing physical contact between the aircraft and any type of gear in rough water endangers both units.

Experienced personnel have expressed their views as to the maximum amount of vertical rise and fall of an aircraft which beaching gear can accommodate at time of contact. These opinions vary from several inches to several feet. The Martin Co. states (Ref. 24) that the P6M beaching vehicle is designed to marry in sea conditions up to a 3-ft wave of relatively short wave length (160 ft average). At the present time, the best beaching methods appear to be as follows: (1) Permanent base. The P6M or R3Y type cradles and ramp. (2) Advance base. The LSD system or advance base type floating dock. However, a self-propelled cradle type vehicle would eliminate many of the problems of the base planner if it could be made to operate on advance base type terrain of mud, sand, and gravel.

Based on the beaching ramps planned for the NAAF at Harvey Point, it is considered that a ramp for high performance seaplanes should meet the following requirements: A minimum of one ramp for each squadron of 12 planes to be supported. The ramp should be 100 ft wide, with the maximum slope 10:1. Because of the 50,000-lb cradle wheel load and petroleum spillage, the ramps should be of concrete. The toe of the ramp should be located so as to provide 20 ft of water at that point with a minimum of 14 ft at all times. Winch pads at the top of the ramp and lighting are desirable.

2. Small Boat and Barge Facilities

Since the basic concept is to keep the large seaplanes in the water as much of the time as possible, a certain number of supporting small craft or boats will be required to perform the following functions: Transfer personnel and supplies to and from aircraft by boat. To provide picket, crash and rescue and other safety operations. To aid in aircraft refueling and line handling in the mooring and beaching ramp areas. Also to permit the necessary hourly

maintenance checks to be performed at buoy by the crew.

In order to meet the above requirements at a permanent base, which might support approximately 25 seaplanes of the P5M and P6M type, it is considered that approximately the following small craft would be required:

4 - 7-ft line handling boats	1 - 63-ft crash boat
1 - 24-ft personnel boat	1 - 50-ft motor launch
1 - 33-ft re-arming scow	1 - 45-ft picket boat
1 - 45-ft crash boat	1 - 104-ft YSD

The berthing or operation of these craft would not require a water depth of over 8 ft; therefore, no special dredging of water depth restrictions would be imposed by their use since this depth is less than required for the aircraft. However, a limited size boat house with covered or uncovered berthing slips would be required to house and perform repairs and maintenance function on the craft. The boat house and small craft slips and basin would require much better wind and storm wave protection than would the aircraft they serve. If this protection cannot be made available from the natural terrain, a small, simple, artificial breakwater may be required to provide immediate protection to the berthing slips.

If it is determined that oil barge unloading facilities are the most economical method of delivering the huge quantities of fuel that are required, the following facilities may have to be provided: A small pier located out of the seaplane operating or mooring area. The depth of water in barge channel, turning basin, and along side pier should be able to accommodate at least one barge which may be approximately 200 ft long and 36 ft wide, 11 ft high with a minimum draft of 8 to 10 ft when loaded. These barges will probably be attended by tugs. Since the current trend is toward the use of barges of larger capacities and draft, and to provide for the squat of the tugs, the

total depth of water should be about 12 ft without consideration for any tidal range.

Advance support sites. In consonance with the basic concepts of maintaining and supporting these large seaplanes afloat, the shore based facilities will probably be much less than for the permanent site; therefore, even greater provision should be made for supporting small craft and boats. Also sufficient protected water depth somewhere in the immediate area to accommodate a LSD will be required if a floating dry dock or beaching ramps are not necessary or available. The fuel barge unloading requirements might be replaced by small fleet tankers requiring a greater depth.

3. Fueling Requirements

The facilities required to provide the large quantities of aircraft fuel necessary for an activity must be considered during site selection. The method by which fuel is transported, handled, and stored at the site can affect a great number of the site considerations such as water depth, size of area, and wave exposure, to name a few. Flexible storage and dispersing systems should be provided to handle sufficient jet fuel and aviation gasoline to support the aircraft using the activity. A permanent or large advance support base should have the capabilities of delivering two grades of jet fuel and one grade of aviation gasoline.

The average fuel consumptionsfor the current types of seaplanes in terms of gallons per hour of operational flight time are listed in Table IX.

The station fuel capacity for each type of fuel must be based on the operational flight time on each aircraft which is determined by the mission of the aircraft and activity, type of aircraft, and climatic conditions.

Once the fuel type and usage requirements are known, a feasibility and economic study should be made which includes the following factors: The

TABLE IX*

Aircraft Fuel Consumption, Average Hourly Rate

Type:	Average hourly rate in gallons	Type or grade of fuel
P6M, 4-engine jet	2000	JP-4
P5M, 2-engine prop	490	115/145
R3Y, 4-engine prop-jet	1700	100/130
UF/PBM, 2-engine prop	250	115/145

*(after Ref. 41, p. 20)

method of delivery (pipeline, water, rail, truck), frequency of deliveries, required quality control procedures, and possible delays in receipt of supplies.

The refueling facilities should be provided in such a manner so a certain minimum number of aircraft per hour can be refueled day or night. To do this, certain of the following type of facilities would probably be required depending on type of site:

a. Fuel mooring buoys, see Part IV,B,7.

b. Pile-mounted refuleing platform in the mooring area.

c. Some high-speed refueling stations on the parking apron.

d. In certain cases, refueling from a ship or a barge direct to the aircraft may even be practicable.

VI. FUTURE DEVELOPMENTS

A. Nuclear Powered Aircraft

A great deal of work has been done in the field of nuclear propulsion for aircraft in the United States, chiefly by projects set up by the Atomic Energy Commission and the U. S. Air Force. The U. S. Navy has been very active, too, but it has concentrated its main effort on nuclear propulsion for submarines and other sea-going vessels. However, the Navy considers that the large high performance seaplane has such a good potential for nuclear propulsion that it is pushing this phase. The Navy has awarded contracts for the development of nuclear aircraft powerplants to the Allison Division, Curtiss-Wright Corporation, and the General Electric Company for testing in seaplanes to be built by the Convair Division and the Martin Company (Ref. 62). It will be noted from Table I that later models for the Sea Mistress, which is a scaled up model of the P6M Sea Master, may be powered by nuclear propulsion.

It should also be noted that in England, the Hawker Giddeley Power Company Ltd. and the Rolls-Royce Ltd. are developing nuclear aircraft power plants. Also, three large, subsonic, Sanders-Roe Princess seaplanes are available for flight testing these powerplants (Ref. 62). The Navy has proposed (Ref. 35) that the first nuclear-powered aircraft should be a seaplane for the following reasons:

1. The weight of an aircraft capable of carrying atomic powerplant will require extremely long runways for take-off and landings. If the aircraft is water-based, the runways would be already available.

2. If flown over and landed in the water, it would be safer to test.

3. That if an existing airframe such as the R3Y or P6M is adapted for a nuclear powerplant, a low powered, subsonic aircraft could be built much sooner. Such a seaplane, with practically unlimited range, could immediately perform valuable anti-submarine, radar early-warning, and other tasks, as well as provide invaluable experience for the designing of an atomic-powered high-speed attack plane for the Air Force and Navy.

The task of engineering a workable atomic engine for an aircraft is emphasized by the fact that the power loading (lbs of vehicle weight per hp) of the atomic submarine is more than 150 and that of a sonic bomber must approach 4. Lightweight shielding and engine components are therefore mandatory in such an aircraft.

B. Hydrofoil and Hydro-skis

Very promising solutions to some of the water-based problems of the high performance seaplanes are the investigations on hydrofoils and hydro-skis. By reference 34 Grumman Aircraft Corporation pointed out that the hydrofoil is capable of great reductions in landing impact loads, improvement of stability during the transition from flight speeds to water control velocities, and greatly enhances take-off characteristics. Grumman, using the Steven's Institute of Technology test tanks, has tested a hydrofoil model in conditions approximating sea state 5 (waves 10 to 12 ft high). The ordinary hull model produced impact accelerations of 3.7 g's at impact points and 13.5 g's at pilot position, while the hydrofoil reduced these to a 1 g hull load and a 2.5-g acceleration at pilot station. Similar gains were obtained in take-off tests with the hydrofoil requiring less power to lift the hull clear and lower drag yielded shorter take-off run. Hydrofoils are adaptable to large or small seaplanes.

VII. CONCLUSIONS

Within the last few years, the tremendous advancements in aerodynamic and hydrodynamic design have started the development of new types of high performance seaplanes that approach the performance, and in certain ways may exceed the capabilities, of land-based aircraft. The key to unlocking the true potential of the water-based aircraft, particularly for military uses, is site selection and evaluation. However, unfortunately, it is not known how to evaluate much of the data needed for proper site selection. An attempt to survey briefly the limited existing knowledge and basic factors of consideration and thereby establish site planning criteria, is the purpose of this thesis.

The general findings and conclusions of this effort are set forth briefly as follows:

1. The clear understanding of the exact mission and functions of the site will define the acceptable limits of efficiency and safety of operations. These considerations are probably themost important factors in selection and evaluation of any site.

2. There is a certain "relative" wave length range of 1.5 to 2.5 times the aircraft's planing hull length, and a certain wave slope of approximately 40:1 which is very critical in many different ways for the operation of all large high performance seaplanes.

3. In general, the hydrodynamic performance of the seaplane is primarily a wave problem when winds are less than 25 knots.

4. In the present state of development, the support components required for the highly flexible operations of these aircraft are far behind the potential capabilities of the aircraft. In most cases the operational limitations of the support components and facilities are the determining factor in site selection and evaluation.

5. Based on all these foregoing considerations, the broad planning criteria set forth in parts III,G; IV, and V of the thesis have been developed by the writer.

6. The present state of practical knowledge in the field of oceanography pertaining to actual wave surface configurations found in what might be regarded as a normal seaway is extremely limited. Much work remains to be done, for instance, in the area of statistical representations of wave slopes to actual sea states to aid in the proper design of the aircraft and site selection. However, some progress is just now beginning to be achieved, in part, by means of the mathematical tools of modern statistical theory corroborated by actual observations with specially developed wave measuring instruments.

7. It appears that, in order to develop the full potential of large high performance seaplanes, the present concepts maintained by some that large seaplanes must be frequently beached must be abandoned. It is believed that in a relatively short time large seaplanes will be dry docked like a ship only once a year or every two years and never brought out of the water between these docking periods. It is believed that marine growth on the hull can be eliminated as a problem.

8. It is becoming increasingly important that military seaplane facilities, supporting extensive operations of high performance aircraft, should be located as far away from restricted airspace and nearby communities as economically possible. It is believed that the location of major faciliti should never be less than 15 miles from a major community. Even at this distance the integration of the facility's requirements must be in consonance with local community and regional master plans.

9. Based on military considerations, the ready access to unrestricted airspace within the U. S. is becoming highly critical. Available airspace for all-weather instrument capabilities is becoming more valuable in certain respects than real estate, Regional airspace requirements can easily be the main planning factor in many areas of the U. S.

PART VIII

Bibliography

In this bibliography the following abbreviations are used: NACA - National Advisory Committee for Aeronautics; ASCE - American Society of Civil Engineers.

1. Abbett, R. W., Harbor Engineering, American Civil Engineering Practice, Vol. II, p. 21-14, 1956.

2. Aeronautical Engineering Review, July 1947.

3. Approach, The Naval Aviation Safety Review, Vol. 1, No. 7, p. 14, 1956.

4. Arthur, R. S., Wave Forecasting and Hindcasting, Proceedings of the First Conference on Coastal Engineering, Chapter 8, 1951.

5. Aviation Age, p. 50, June 1955.

6. Aviation Week, Vol, 62, p. 32, 28 Feb. 1955.

7. Bates, C. C., Fleming, R. H., The Engineering Application of Sea and Swell Data, Proceedings of the First Conference on Coastal Engineering, Chapter 9, 1951.

8. Benson, J. M., Havens, R. F., Woodward, D. R., Landing Characteristics in Waves of Three Dynamic Models of Flying Boats, NACA Technical Note 2508, January 1952.

9. Buck, D. A., Civil Jet Noise, Journal of the Air Transport Division, Proceedings of the ASCE, Paper 1469, December 1957.

10. Carter, A. W., Effect of Hull Length-Beam Ratio on the Hydrodynamic Characteristics of Flying Boats in Waves, NACA, Technical Note 1782, January 1949.

11. Dunham, J. W., Refraction and Diffraction Diagrams, Proceedings of the First Conference on Coastal Engineering, Chapter 4, 1951.

12. Fisher, Leigh, Airport and City Planning, Proceedings of ASCE, Paper No. 1109, November 1956.

13. Friswell, J. K., Parker, R., Full Scale Measurements of Impact Loads on a Large Flying Boat (Sunderland Mk. 5), Aeronautical Research Council Current Papers (British) CP No. 342, 1957.

14. Glenn, A. H., Progress Report on Solution of Wave, Tide, Current, and Hurricane Problems in Coastal Operations, Oil and Gas Journal, Vol. 49, pp. 174-177, 1950.

15. Hamilton, J. A., Gigg, R. V., The Full Scale Hydrodynamic Performance of a Large Four-engined Flying Boat at Overload in Calm Water and Swell, Aeronautical Research Council Reports and Memoranda (British) R&M No. 2898, 1956.

16. Harney, L. A., Saur, J. F. T. Jr., Robinson, A. R., A Statistical Study of Wave Conditions at Four Open-Sea Localities in the North Pacific Ocean, NACA, Technical Note No. 1493, January 1949.

17. Interim Report Transcontinental Seaplane Route Study, U. S. Navy Office of Naval Research Contract Nonr. 2258 (00) 15 March 1957.

18. Jane's All the Worlds Aircraft, 1956-57 edition.

19. Johnson, J. W., O'Brien, M. P., Isaacs, J. D., Graphical Construction of Wave Refraction Diagrams, Navy Hydrographic Office Publ. No. 605, 1948.

20. Knowles, Henry, The Future of the Flying Boat, The Journal of the Royal Aeronautical Society, pp. 322-354, May 1952.

21. MacDiarmid, D. B., Some Thoughts on True Sea Basing Aircraft, Proceedings of the National Aviation Meeting, p. 11, August 1957.

22. MacDiarmid, D. B., Report of Open Sea Landing Tests and Study, U. S. Coast Guard reprint, December 1957.

23. Martin Co. letter to Lt. Cdr. N. J. Magneson, U. S. N., 16 October 1957.

24. Martin Co. letter to Lt. Cdr. N. J. Magneson, U. S. N., 20 Feb. 1958.

25. Martin Proposes New Logistics Plan, p. 29, Aviation Week, 2 Sept. 1957.

26. Mason, M. A., The Transformation of Waves in Shallow Water, Proceedings of the First Conference on Coastal Engineering, Chapter 3, 1951.

27. Military Review, Vol. 34, No. 8, p. 69, November 1954.

28. Miller, R. W., Hydrodynamic Impact Loads in Rough Water for a Prismatic Float Having an Angle of Dead Rise of 30^{o}, NACA Technical Note 1776, 1948.

29. Milwitzky, B, A Generalized Theorical and Experimental Investigation of the Motions and Hydrodynamic Loads Experienced by V-Bottom Seaplanes During Step-Landing Impacts, NACA, Technical Note 1516, 1948.

30. Model Studies of Apra Harbor, Guam, M. I., California Institute of Technology Hydrodynamics Laboratory Report No. N-63, 1949.

31. Mooring Guide, Volumes 1 and 2, U. S. Navy, Bureau of Yards and Docks Technical Publication, NAVDOCKS TP-Pw-2, March 1954.

32. Naval Aviation News, p. 30, November 1956.

33. Navy Aims at Low Power Atom Seaplane, Aviation Week, p. 30, 15 April 1957.

34. Navy Indicates Need for True Seaplane, Aviation Week, p. 32, 12 August 1957

35. Navy Proposes Atomic Seaplane as First Nuclear Aircraft, New York Times, p. 1, 2 January 1958.

36. Open Sea Seaplane Operations, U. S. Navy Aviation Safety Activity Report NASA-A64-P1-953, August 1953.

37. Parkinson, J. B., NACA Model Investigations of Seaplanes in Waves, Proceedings of the First Conference on Ships and Waves, Chapter 31, October 1954.

38. Parkinson, J. B., Appreciation and Determination of the Hydrodynamic Qualities of Seaplanes, NACA, Technical Note 1290, May 1947.

39. Pierson, W. J., St. Denis, M., On Some Recent Developments in the Theory of Ship Motions, Proceedings of the First Conference on Ships and Waves, Chapter 12, October 1954.

40. Pierson, W. J., Practical Methods for Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics, Technical Report 1, New York University to Bureau of Aeronautics, Contract No. N189s86743, July 1953.

41. Planning Standards for U. S. Naval and Marine Corps Air Station Facilities, Bu. Aer. Instruction 11012.1A, 18 July 1957.

42. Proceedures for the Control of Air Traffic, U. S. Army, Navy, Air Force, Coast Guard, Civil Aeronautics Administration Manual, Third Edition, 15 Sept. 1957.

43. Ridland, D. M., Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings Hydrodynamic Stability, Aeronautical Research Council Current Papers (British) C.P. 237, 1956.

44. Rosendal, C. E., The Jet Age Airport and its Neighbors, Journal of the Air Transport Division, Proceedings of the ASCE, Paper No. 1481, December 1957.

45. Sailing Directions, The Mediterranian, Vol. II, U. S. Navy Hydrographic Publ. No. 152, pp. 16-18, 1951.

46. Schulz, E. F., Model Tests to Predict the Seaworthiness of Seaplane Hulls, Colorado A & M College report to Bureau of Aeronautics, Contract no. NOas54-908c, January 1957.

47. Seaplane Facilities, U. S. Dept. of Commerce, Civil Aeronautics Administration Booklet, May 1950.

48. Shore Protection Planning and Design, Beach Erosion Board, Office of the Chief of Engineers, Technical Report No. 4, Chapter I, June 1954.

49. South-East Alaska Pilot, p. 21, Hydrographic Dept., British Admiralty, 194?

50. Statistical Study of Wave Conditions in the North Atlantic Ocean, Mediterranian Sea, Indian Ocean, U. S. Navy Hydrographic Office Publ., Misc. No. 15208.

51. Stout, E. G., A Review of High-Speed Hydrodynamic Development, Proceedings of the Third Anglo-American Aeronautical Conference, The Royal Aeronautical Society, p. 231, 1951.

52. Stout E. G., High Speed Water-Based Aircraft, Aircraft Engineering, pp. 43-50, February 1953.

53. Stout, E. G., Bases Unlimited, Aeronautical Engineering Review, pp. 42-55, June 1955.

54. Survey of Existing Beaching Equipment and Conclusions Pertaining to the Development of a Beaching Cradle for Large Flying Boats, Edo. Corp. Reports Nos. 2702, 2713, to Bureau of Aeronautics, December 1948.

55. Summary of P5M-1, -2 Aircraft Accidents, 1 July 1952 to 30 June 1957, U. S. Naval Aviation Safety Center, December 1957.

56. The Aircraft Year Book for 1957, The Aircraft Industry Assoc. of America, 1957.

57. The Airport and Its Neighbors, The Report of the President's Airport Commission, 16 May 1952.

58. United States Manual of Criteria for Standard Instrument Approach Procedures, U. S. Army, Navy, Air Force, Coast Guard, Civil Aeronautics Administration Manual, third edition, 1 Sept. 1956.

59. United States Naval Institute Proceedings, Vol. 83, No. 5, p. 571, May 1957.

60. United States Navy Seaplane Pilot's Handbook, North Atlantic, U. S. Navy Hydrographic Office Publ. No. 306, 7 November 1957 (Revised).

61. Wave Protection Aspects of Harbor Design, California Institute of Technology Report No. E-11 to Bureau of Yards and Docks, Contract NOg-12561, August 1952.

62. Wilkinson, P. H., Aircraft Engines of the World, 1957.

63. Wind Waves at Sea Breakers and Surf, U. S. Navy Hydrographic Office Publ. No. 602, 1947.