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Use of Seaplanes and Integration within a Sea Base

by

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A study to investigate the utility of seaplanes to support an offshore military Sea Base has been undertaken by the Center For Innovation In Ship Design. The potential use and importance of seaplanes for future sea-based military missions are discussed. The research outlines the history of seaplane development, their different modes of operation and associated enabling technologies. Parametric data collected on seaplanes has been populated into a database, presented and analyzed, leading to defining initial seaplane sizing requirements. Current technology boundaries and technical issues that need further research, including those related to integrating seaplanes within a Sea Base environment have also been identified. Issues such as rough water operations, mooring and beaching have been considered, along with new methods to take advantage of existing technology to operate in high sea states. Potential seaplane design concepts are presented, with recommendations for investment in particular seaplane technologies, such as lightweight materials, spray reduction designs, and novel landing/beaching gear.

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List of Symbols

cog	center of gravity
ft	feet
angle,	degree
kts	knots
lbs	pound force
lbs/in^2	pounds per square inch
m	metres
nm	nautical miles

Abstract

A study to investigate the utility of seaplanes to support an offshore military sea base has been undertaken by the CISD. The potential use and importance of seaplanes for future sea-based military missions are discussed. The research outlines the history of seaplane development, their different modes of operation and associated enabling technologies. Parametric data collected on seaplanes has been populated into a database, presented, and analyzed, leading to definition of initial seaplane sizing requirements. Current technology boundaries and technical issues that need further research, including those related to integrating seaplanes within a Sea Base environment have also been identified. Issues such as rough water operations, mooring and beaching have been considered, along with new methods to take advantage of existing technology to operate in high sea states. Potential seaplane design concepts are presented, with recommendations for investment in particular seaplane technologies, such as lightweight materials, spray reduction designs, and novel landing/beaching gear.

1. Introduction

1.1 Introduction

A Center for Innovation in Ship Design (CISD) Innovation Cell at Naval Surface Warfare Center, Carderock Division (NSWC-CD) was tasked by the Office of Naval Research (ONR) to investigate the use of seaplanes in supporting an offshore Sea Base. In addition to defining expected capabilities of seaplanes, Sea Base interface issues were explored.

Future war-fighting concepts of operations require light, rapidly deployable and maneuverable forces. Sea Basing [Ref 1] would serve as the foundation from which these offensive and defensive forces could be projected, accelerating expeditionary deployment and employment timelines by pre-positioning vital equipment and supplies in-theatre. Furthermore, as the availability of overseas bases declines, it is compelling, both militarily and politically, to reduce the vulnerability of U.S. forces through expanded use of secure, mobile, networked Sea Bases. These forces will rely on intermediate staging bases, in or near the theatre of operations, to support troops, logistics and combat fire support.

Sea Basing is envisioned (Figure1) to have integrated combatant and auxiliary naval forces [Ref 2, 3]. New developments in amphibious assault vehicles, high-speed vessels and lighterage, and a variety of large conventional and advanced surface ships will enable the arrival and assembly of a Marine Expeditionary Brigade (MEB) sized force in a Sea Base. Strategic heavy sealift will be central to this effort. Multi-mission aircraft with the ability to conduct operations and carry sizable logistics cargos will significantly enhance Sea Base capability. Such aircraft may also be useful for other sea base missions such as organic intelligence, surveillance and reconnaissance (ISR), in-flight refueling, gun ship and anti-submarine warfare (ASW) roles. While existing land aircraft can provide many of these capabilities, large land planes do not integrate easily into the sea base. Seaplanes are an alternative to meet such requirements and may be simpler to integrate with the Sea Base.

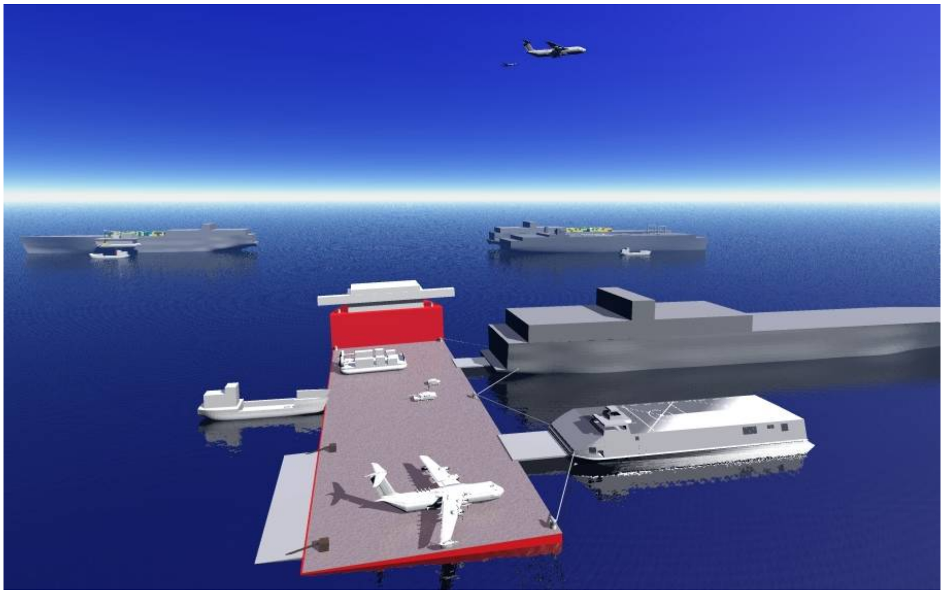

Figure 1: Sea Base vision

1.2 Scope of work

The program of work undertaken entailed addressing seaplane capability and awareness, with the aim of exploring suitable platforms to enable '*force closure*', i.e. the transfer and/or assembly of troops/equipment to and from a Sea Base. Other potential mission capabilities to be explored included in-flight refueling capability and delivery of heavy logistics from the Sea Base to the shore. The study focused on comparing both 'historical' and 'required' seaplane performance data and characteristics, whilst identifying any technology capability gaps for the 2010+ time period.

1.3 Approach

The method adopted involved initially conducting a literature search using a variety of sources including several US Navy and learned society libraries along with searches on the Internet. This enabled the collected data to be compared and made available as a single, central source of seaplane data. The data collected was assembled into a Microsoft Access database primarily to support development of parametric engineering data plots and to provide a comprehensive and searchable source of seaplane data.

Parametric engineering plots were aimed at providing insight into potential seaplane capabilities, guidance for the development of potential seaplane concepts, and consideration of seaplane/Sea Base interfacing issues. From this stage, technology requirements for the future could be addressed. A conceptual seaplane design was developed in collaboration with the Aircraft Conceptual Design group, Naval Air Systems Command, (NAVAIR), based at Patuxent River Naval Air Station. The design developed took into consideration current availability or future procurement of technologies that would provide a suitable platform to meet objectives. A summary of these findings has been provided, identifying what particular technology areas need further investigation, with recommendations for further technology development.

2. Background

2.1 What are seaplanes?

Seaplanes are similar to landplanes but have the ability to take-off, alight and operate on water. Aircraft of this type fall into three categories, as shown in Figure 2. The first type consists essentially of conventional landplanes mounted on floats (pontoons), replacing the traditional landing gear wheels. Floats are used for alighting and taking-off from water and provide buoyancy. The fuselage of the second type of seaplane is shaped like a boat (hull), which at rest and low speeds floats on the surface just like a boat - hence the term ‘flying boat’.

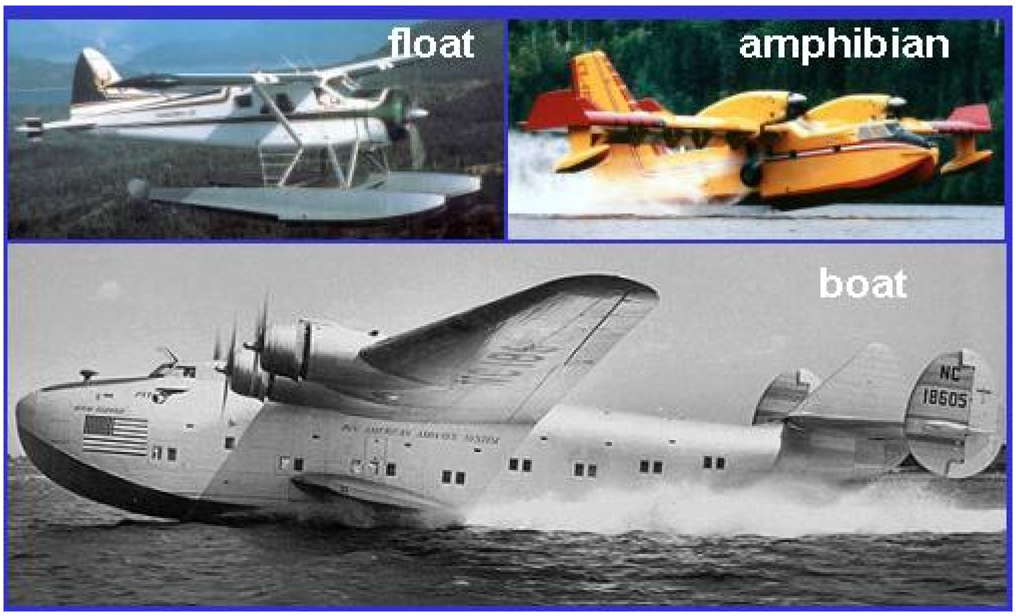

Figure 2: Types of seaplanes

The float type is common among smaller (lighter) aircraft with relatively low propulsion requirements, though conversions of large conventional landplanes, such as the Dakota DC-3, have been made in the past. Floatplanes may be equipped with either single or twin floats, however the twin float variety is common. The floats are relatively large and heavy items, add drag, and can adversely affect aircraft control.

With the flying boat, the hull serves a dual purpose of providing buoyancy in the water and volume for crew, passengers, and cargo. Flying boats tend to be larger than floatplanes, with engines mounted on or above the high wings for clearance from water and spray. Flying boats do possess small floats mounted on wingtips to aid aircraft lateral stability whilst in the water. These need be either aerodynamically faired or retractable during flight to avoid excessive drag penalties. Large flying boats in general tend to be operable in higher sea states than most floatplanes.

The final type of the seaplane is the 'amphibian', taking either floatplane or flying boat form. This particular type of seaplane has the capability to take-off and alight, both from water and land. The added capability is achieved with the landing gear being operable in water and on land airfields. This type of landing gear is usually heavy and bulky, thus penalizing the seaplane. Generally, most amphibians are of the flying boat type with sizeable payload, range and multipurpose mission role capabilities, which outweigh the weight penalty.

2.2 Alternative seaplane landing gear

Seaplanes may vary slightly through their use of different landing gear systems. Some alternatives and radical forms, shown in Figure 3, include hydroskis, hydrofoils, and air cushion landing systems.

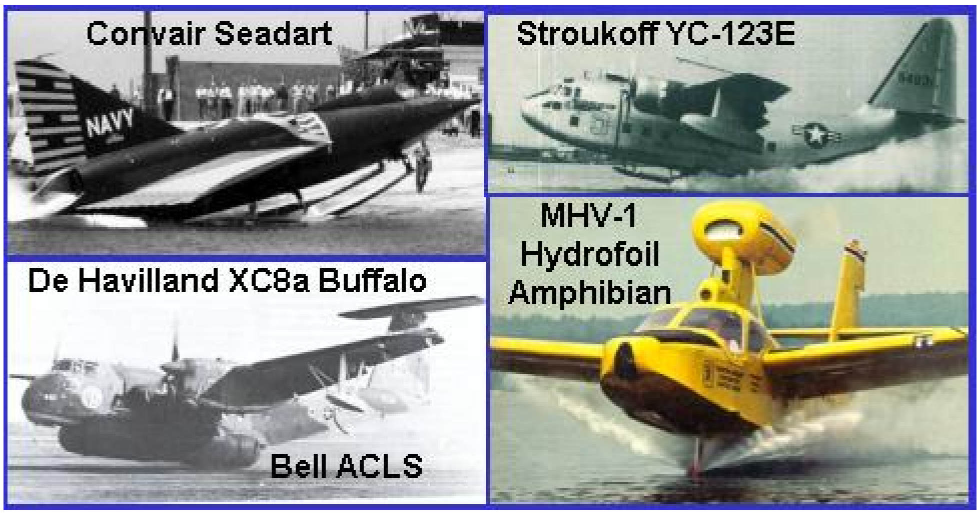

Figure 3: Alternative forms of seaplane landing gear

The 'hydroski' is aimed at reducing drag and improving motions during take-off and landing. Ski height is selected to suit aircraft speed and sea state. Hydroskis are good at reducing and absorbing landing loads. The skis, usually fitted with small beaching wheels, are fully retractable (either pantograph or linear retraction) to minimize overall in-flight aircraft drag and allow the seaplane to taxi onto land from water. The disadvantage of using such skis is that they can generate high hydrodynamic drag at low speed before the aircraft planes, which in-turn may require more installed power. Hence this can be detrimental with low powered turbo-prop aircraft designed for low cruising speeds and unable to afford surplus installed power to cope with the additional drag during take-off. Hydroskis are more ideally suited for high powered aircraft such as the Convair SeaDart. Such aircraft generally require high take-off and landing speeds. For example, the supersonic SeaDart takes off at 130 knots. The high power required for supersonic flight resulted in an excess of power at low speeds to overcome the higher drag of the skis. The lower accelerations for the ski-equipped aircraft resulted in a lighter structure and lower gross weight, despite the additional ski weight and associated mechanisms.

The 'hydrofoil' is essentially a small water-wing completely immersed until lift-off, capable of efficiently generating large lift. The use of a hydrofoil mechanism provides an ideal opportunity to use relatively small surfaces to lift the hull beyond the hump speed, then be retracted, leaving the aircraft to plane on the hull surface. The hydrofoil risks developing cavitation at high operating speeds. Historically, cavitation has occurred unpredictably when the suction over the upper surface was too intense, causing immediate loss of lift and longitudinal stability. Hydrofoils increase waterborne draft and are structurally vulnerable to potential damage from loose surface debris.

The ‘Air Cushion Landing System’ (ACLS) was demonstrated [Ref 4] by the Bell Aerospace Co. employing an inflated air-bag located under the aircraft fuselage. This ‘skirt’ is used to contain an air cushion to support the aircraft. The system is similar to that used by a hovercraft. The prototype system contained cleverly designed features to control the aircraft while taxiing, provide braking forces, retract and stow the system in flight, and passively support the aircraft for parking or skirt maintenance. A source of pressurized air is needed for the skirt and cushion. Bell demonstrated this type of landing gear system on a De Havilland XC8a Buffalo, as shown in Figure 3. Besides providing buoyancy on the water it allows alighting, take-off, and taxiing from both water and land, hence a fully amphibious aircraft. However issues concerning controlled ground directional movement of the aircraft, in-flight storage, deployment and energy source for inflating/deflating the air cushion still need to be resolved.

2.3 Utilization of seaplanes

Seaplanes have been utilized in a variety of military and commercial roles. Military usage has been substantial including fighters, large bomber/patrol aircraft, and troop/cargo transport aircraft. Commercial usage has varied from large aircraft for trans-oceanic passenger and cargo transport, use as water bombers to support fire fighting on large inaccessible forests, through to smaller craft for recreational/inter-island commuting purposes. Seaplanes of more recent times have been adopted for multi-purpose roles such as fire fighting in large inaccessible forests and ocean search and rescue.

2.4 Historical perspective of seaplanes

The popularity and apparent demise of the seaplane as an important element of aviation can be traced to a combination of operational, performance, and economic characteristics.

The early beginnings of seaplane development can be traced back to the initial flight attempts of Samuel Langley and the more successful Wright brothers’ *Flyer* aircraft. However, alternative forms of seaplanes were being conceptualized well before by various people including designs generated by Leonardo da Vinci, Alexander Graham Bell’s AEA Co., and glider designs by Voisin. Initial successful developments involved producing lightweight aircraft, carrying only man and machine (see Figure 4), as exemplified by the Curtis ‘Hydro’ aircraft - the first true seaplane. The advent of World War I fuelled the urgent need for naval aviation supremacy, hence providing justification for developing seaplanes to meet various roles such as small fighter aircraft. Post World War I efforts explored the use of much larger aircraft for bomber/patrol purposes and long distance (transatlantic) passenger flights, see Figure 5. Seaplanes were also used for racing (Schneider Trophy), a popular pastime between the wars and passenger transportation by converting conventional land planes.

In the years prior to World War II, airports capable of handling large, long-range aircraft were limited or non-existent in most parts of the world. However, most areas of the world of interest to commerce were located near bodies of water such as lakes, rivers, harbors, and other types of marine facilities. Islands, such as the Hawaiian archipelago, were obviously well suited for seaplane operations. These

Figure 4: Initial development of seaplanes

Figure 5: Early uses of seaplanes

natural resources required little development, providing an almost unlimited number of worldwide facilities for the operation of large, long-range seaplanes. Both military and commercial air operations made extensive use of these natural resources.

Commercial airlines operated both passenger and freight service with flying boats. The military employed these aircraft for transport, reconnaissance, anti-ship/submarine patrol, and search and rescue roles. The flying boat offered long distance, over-water flights with the prospect of a safe landing in the event of an engine failure, a very real possibility with the relatively unreliable engines available in the early days of aviation. While the chances of a flying boat surviving a landing in rough seas on the open ocean are of course problematical, numerous instances of such incidents were recorded. Perhaps this advantage was more psychological than real.

The flying boat seemed for many years to have an important and permanent place in the aeronautical world. However, it possessed certain inherent disadvantages in its dual capacity for operation on water and in air. The aerodynamic drag of the flying boat hull-fuselage was considerably higher than that of the conventional landplane fuselage. Hence the cruising speeds and aerodynamic cruising efficiency tended to be lower than that of comparable landplanes. The economic potential of flying boats slowly became limited in comparison with the fast developing landplanes. Furthermore, the ever-present danger of colliding with submerged objects, subsequent hull rupture and possible sinking, and the difficulties in transferring passengers to and from a moored flying boat, posed ever-present operational problems.

During, and particularly, after World War II many parts of the world saw the development of a large number of airfields equipped with long, hard-surface runways and basic amenities for passengers. Large, fast, highly efficient landplanes suitable for carrying passengers emerged from the war era. These aircraft were equipped with more reliable engines and had the ability to operate in a variety of weather conditions. These factors spelled the gradual decline of the flying boat as a viable means for economical transportation of passengers and freight over long distances. Commercial airlines using flying boats on long, over-water routes soon followed suit by terminating these types of aircraft operations and eventually the seaplanes themselves. A few of the smaller flying boats of World War II vintage are still used primarily for leisure or inter-island commuter type operations or by enthusiasts.

Seaplanes had been operated for over 50 years in the US Navy. Thousands of seaplanes were commissioned into operation during and after the two world wars. Several different makes and types of seaplanes with varying mission roles were utilized, as detailed in the following table.

Seaplane	Quantity
PBY Catalina	3,281
PBY2 Coronado	217
PBM Mariner	1,366
P5M Marlin	284
HU-16 Albatross	464
JMR Mars	6
R3Y Tradewind	11

Table 1; Seaplane manufacture for US Navy

One popular type, the Martin PBY Catalina, saw over 2,000 aircraft being produced for the US Navy and 1,200 for non-military purposes. Figure 6 shows the production rate of the Martin Catalina during World War II. For many years after the war, both the U.S. Navy and Coast Guard continued to use flying boats for reconnaissance, antisubmarine patrol, or search and rescue missions. Steady growth in seaplane speed, range, and payload capabilities accompanied this experience. Examples of US Navy aircraft from this era, as well as notable seaplanes from other nations are shown chronologically in Figure 7. However long distance (turboprop) landplanes and helicopters gradually assumed these duties replacing the flying boat. Currently no seaplanes exist within the US Navy or Coast Guard inventories, apart from those permanently on loan to museums.

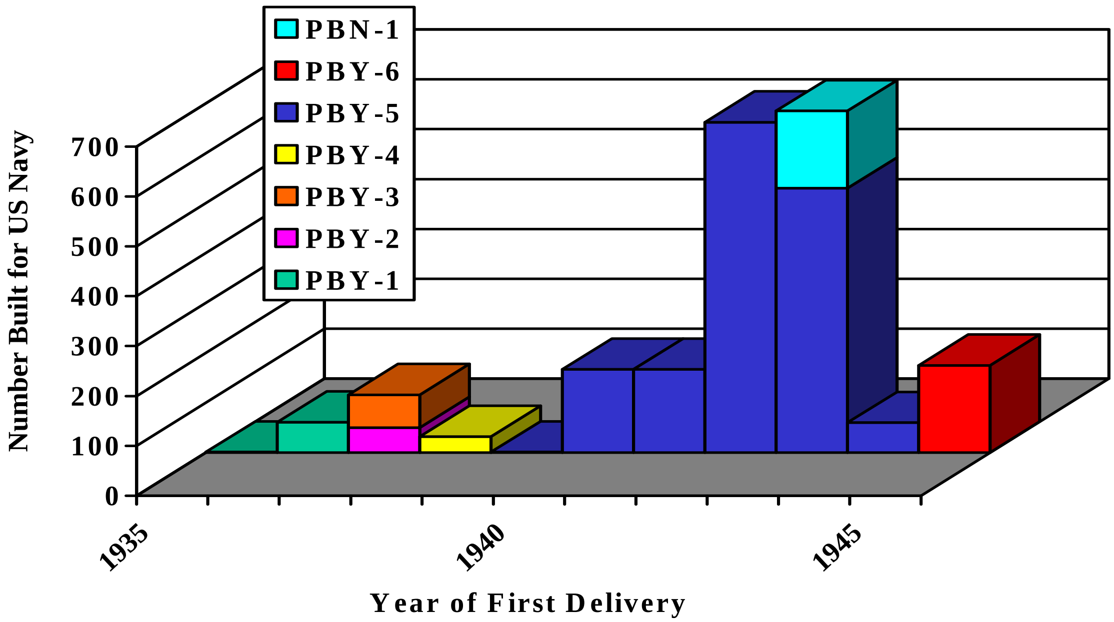

Figure 6: Consolidated Catalina production

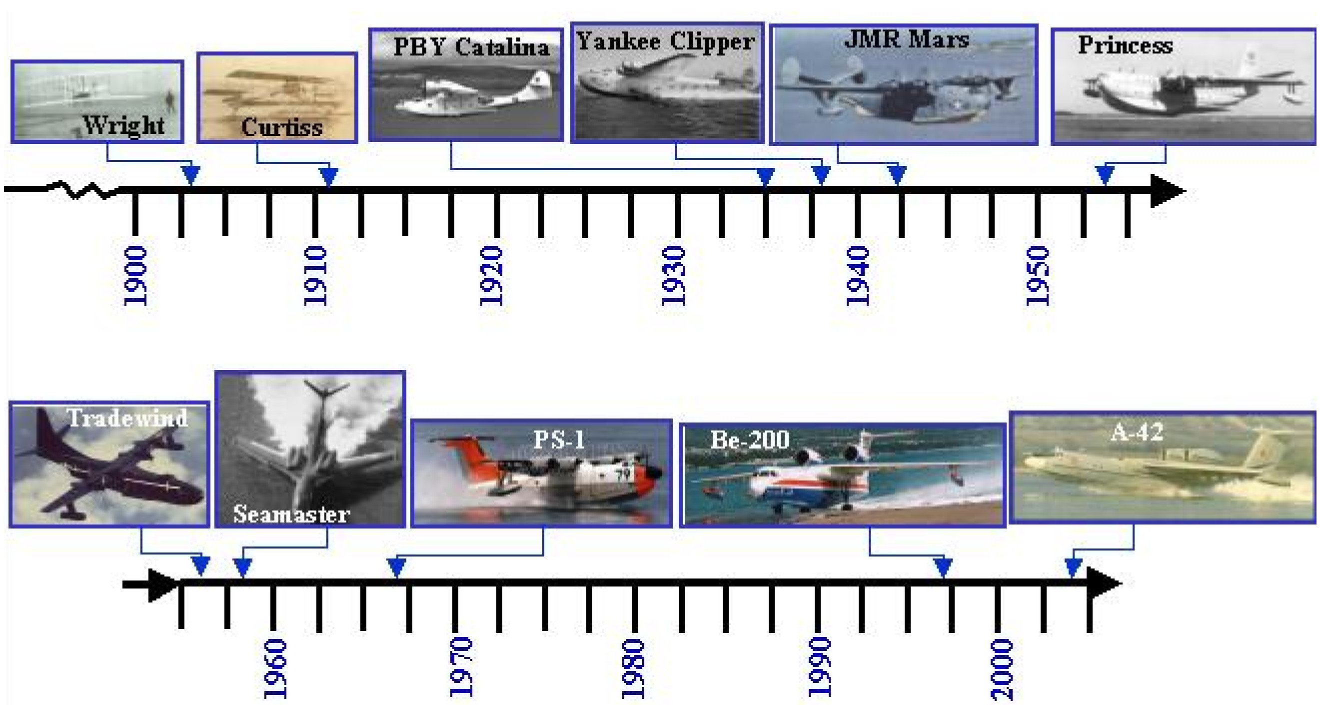

Figure 7: Evolution of Sea Base capable seaplanes

A few seaplane projects were launched after World War II for military purposes, but proved to be either abortive or suffered from reduced funding. Several efforts by British and US manufacturers concentrated on a number of factors:-

- *Speed* - employing jet engines instead of propeller/piston driven engines, allowing good acceleration times in water and air.
- *Range* - reduced aircraft weights through lighter materials, improved aerodynamic fuselage designs.
- *Multipurpose role* – various mission role capabilities to at least match or exceed their landplane counterparts.

The Saunders-Roe (SARO) Princess (passenger transport), SARO SR-A1 (military jet), Convair SeaDart (supersonic flight) and Martin P6M SeaMaster (anti-submarine warfare/mine warfare) demonstrated (see Figure 8) that jet-engine and turbo-prop aircraft seaplanes could be effective in a variety of roles. However, after successfully flight-testing the Princess aircraft, the customer decided to become a land plane only airline, with this magnificent aircraft subsequently scrapped. U.S. Navy interest in combat seaplane development reduced mainly [Ref 5] for budgetary reasons and because nuclear submarine and aircraft carrier programs had taken greater priority.

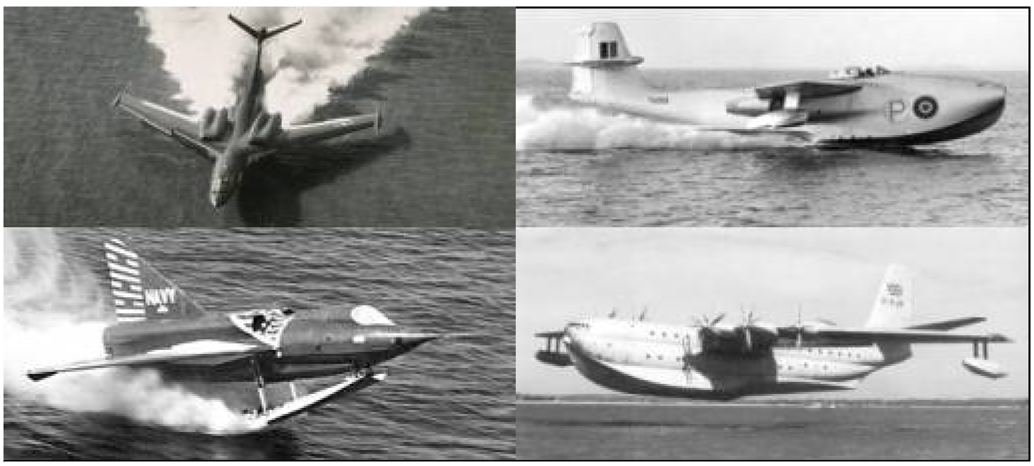

Figure 8: Experimental trials of using jet engines on seaplanes

The turboprop-powered Convair R3Y Tradewind shown in Figure 9, illustrated that sleek aerodynamic hull designs, with relatively high speeds and bow nose un/loading capability were practical as cargo transport seaplanes. The late 1960's witnessed the successful pursuit of more commercial and multipurpose applications including fire-fighting (Canadair CL-214), and search and rescue (Shin Meiwa US-1A) roles (Figure 10). Recently developed smaller seaplanes targeted the low-volume passenger transportation market, essentially for short island and inland waterway transfers as well as leisure/enthusiast activities. However the level of technology improvements in these newly designed aircraft have not been hugely significant, but only incremental to the previous generation of similar seaplane aircraft.

Figure 9: Convair Tradewind aircraft

Figure 10: Seaplane firefighting and search and rescue roles

The Russian manufacturer Beriev produces a range of large multipurpose seaplanes , such as the Be-200 and A-40 aircraft, with much improved performance. In addition, the Shin Meiwa company in Japan retains production capability for the US-1a, an aircraft with exceptional rough water capabilities. U.S. seaplane activities are limited to a proposal to convert

Lockheed Martin C-130 aircraft to float planes and a number of notional concepts for very large transports.

3. Rough Water Operations

3.1 Rough water operations

Reliable rough water operations are crucial during take-off, landing, taxiing, cargo un/loading and aircraft survival. The issue of taxiing can be addressed with considerations to engine power and efficient aircraft control, whilst (non-operational) survival is partly discussed through the use of appropriate mooring systems. The main area requiring further investigation is that of take-off and landing performance. Investigation of the issue is hindered by the scarcity of good, rough water performance data.

Although the required operability is undefined, it is observed from Figure 11, that about 90% of all waves are in seastate 4 or lower (i.e. below 8ft in height). Seastate 5 encompasses about 95% of all waves likely to be encountered. The aim for the seaplane was therefore to have full operational capability in seastate 4, with limited operation in seastate 5. This is reflected in the notional seaplane design criteria.

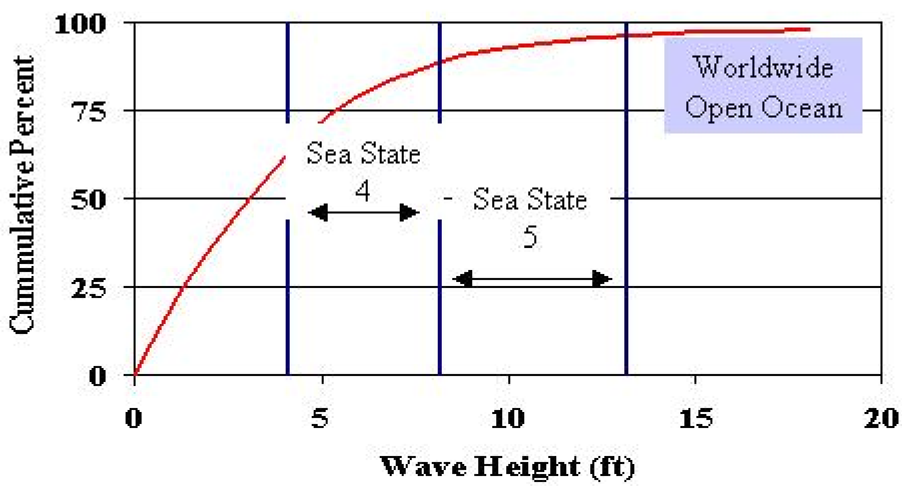

Figure 11: Rough water operation - worldwide ocean

In the early 1950's, proposals to use the Short Solent-class (82,000lb) flying boat in a military capacity were put forward. However no quantified evidence existed for operating in the open sea, possibly under adverse seastate conditions. Hence subsequent sea trials were performed where sea conditions covered ocean swells from 50 to 170 ft in length, and 1 to 5 ft in height. Although the trials were aimed at assessing the characteristics of a specific seaplane, the tests provided an opportunity for studying their behavior in sea swells. Figure 12 shows an example of a particular trial [Ref 6] resulting in an aborted

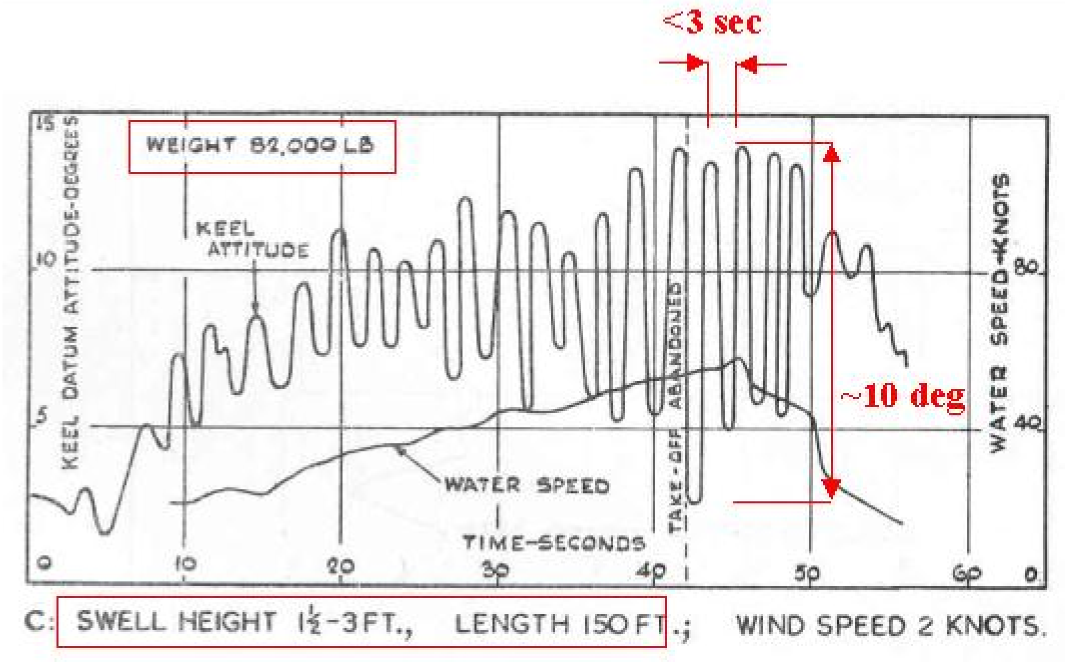

Figure 12: Effect of swell on pitching motion

take-off. The graph shows the plot of keel datum attitude (loosely defined as aircraft pitch) against time. It is observed that the aircraft reaches a point at which violent porpoising is experienced, with amplitudes of around 5º. The consequences of such violent motions are hugely critical, with likelihood of the aircraft pitching up, stalling and then ploughing uncontrollably into the sea or ploughing into on-coming waves. In either case, considerable damage to the aircraft would be likely.

The trials concluded that, violent porpoising may occur on a normally stable hull, if operated in ocean swells of length greater than the aircraft length. It was also noticed that aircraft stability was unaffected by swell heights of greater than 1ft. The porpoising motion was found to be relatively insensitive to aircraft weight, but increased the required take-off acceleration. Possessing lower aircraft weight assisted in reducing the extent of the unstable operating region.

The following options to deal with such loss in aircraft stability were recommended:-

- Shifting the critical period by variation of the hull form.
- Accelerating through the hump region has considerable effect on the acceptable amount of porpoising. A minimum acceleration of 0.1g recommended.
- Using Jet Assisted Take-Off (JATO), with the pitching motion of a swell used as a ‘ramp’, similar to the take-off ramps on aircraft carriers. JATOs are one-time rocket canisters fired to add lift.
- Use active motion control systems to compensate for wave-pitching effects.

One particular aircraft that has achieved seastate 5 operation is the Japanese Shin Meiwa US-1A. This is primarily used for the search and rescue role, with a maximum take-off weight near 100,000lbs. Figure 13 (Ref. 7) shows actual rescues performed, in a variety of sea conditions, some occurring in seastate 5.

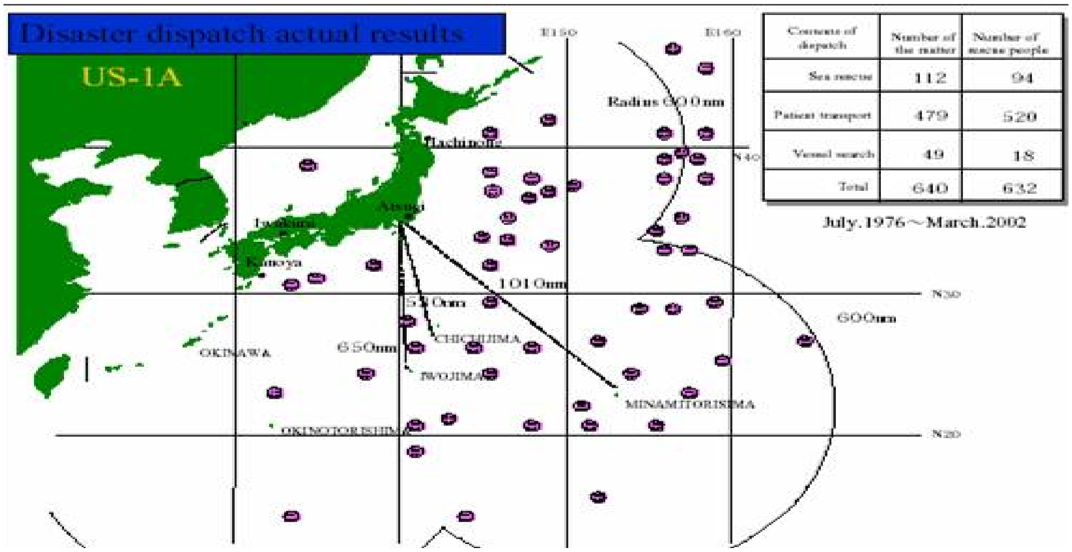

Figure 13: Shin Meiwa US-1A search and rescue operations

The US-1A aircraft was delivered in 1967 and is still in operation today. Though the technology is slightly out-dated, the aircraft has some defining technologies that aid high sea state operations. The aircraft has a slender hull to shift the critical hump period to occur at lower speeds. With the ability to accelerate quickly through these periods, the problematic issue of porpoising is alleviated. The US-1A also possesses active and passive water spray suppression systems on the aircraft hull to protect propellers and above water structures in high seas. Spray is essentially caused by peak pressure developing in the area where the fuselage planning-bottom enters the water. Spray occurs [Ref 8] in two forms; *ribbon (or velocity)* spray and *blister* spray that is far more damaging. Spray creates many problems such as ingress of water into turrets, portholes and engine air intakes, all leading to severe corrosion and inefficiency if corrective (and expensive) maintenance is not performed. Spray also increases water resistance and causes gradual impact load damage to engine propellers and tail surfaces. Spray can be suppressed by deflection and its effects are ameliorated by aeration to reduce solidity mass. Turbo-prop engines require spray separators, using plenum chambers between the air intake and engine. Hollow-grinding the fuselage fore body with an inverted gutter (spray dam) and increasing the fore body fineness (length/beam) also help reduce spray formation as featured with US-1A aircraft.
Short Take-Off and Landing (STOL) technology in the form of blown flaps, rudder, and elevator allows the Shin Meiwa to exploit short-term occurrences of benign conditions in high seas to land of take-off quickly. The aircraft's low stall speed allows it to loiter until a small calm patch in the ocean waves is found, and then land extremely quickly using the STOL technology.

Figure 14 shows a plot of wave height against wave length, from information [Ref 7] provided by Shin Meiwa. The appropriate seastate 4 and 5 bands have been indicated. The breaking waves line is a theoretical rule of thumb indicating the steepest wave possible without encountering wave-breaking. The right shaded area illustrates the estimates by Shin Meiwa of the operating region of conventional flying boats. This shows that flying boats can generally operate through sea state 3 with limited operations in higher seas for waves of 550ft and longer. The slope of these longer waves is sufficiently

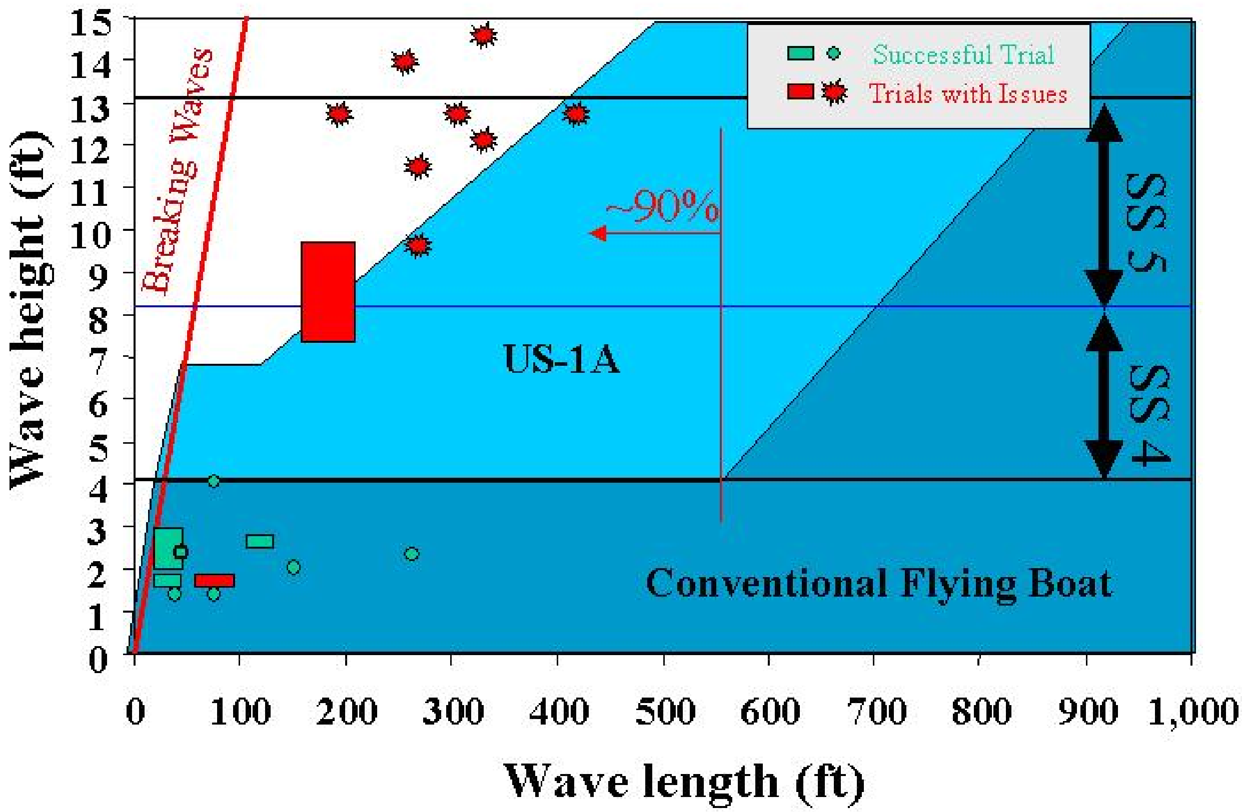

Figure 14: Shin Meiwa US-1A operating limits

low that the aircraft can profile the waves without exciting severe motions. However, 90% of the waves encountered during a year in the north Pacific are below 550ft in length.

There have been many successful seaplane operations in seas up to sea state 3 and more limited experience in higher seas. However, operations in the higher seas were often associated with negative consequences such as aborted take-offs, damage to the aircraft, and loss of aircraft in some instances. It is to be noted that even in seastate 3 there were some operations with similar issues. These were probably due to the aircraft achieving critical wave length, leading to violent porpoising as discussed earlier. The left shaded area is what Shin Meiwa claim to be the operating region for the US-1A aircraft. This area encompasses must of seastate 4 and some of seastate 5. With appropriate upgraded technology, a full state sea 4 operation is expected to be feasible.

Rapid take-off and landing is important for high seastate performance. An awareness of the sea surface and weather is critical for these maneuvers to be performed effectively and safely. Exploiting benign patches of water is also important, using STOL technology to aid this. Another important issue that contributes to rough water performance is the (engine) power-to-weight (aircraft) ratio. Figure 15 shows the power to weight ratio of some popular seaplanes listed in approximate chronological order. The Convair Tradewind was designed to operate in seastate 4 conditions, along with Shin Meiwa US-1A and Beriev A-42PE. All of

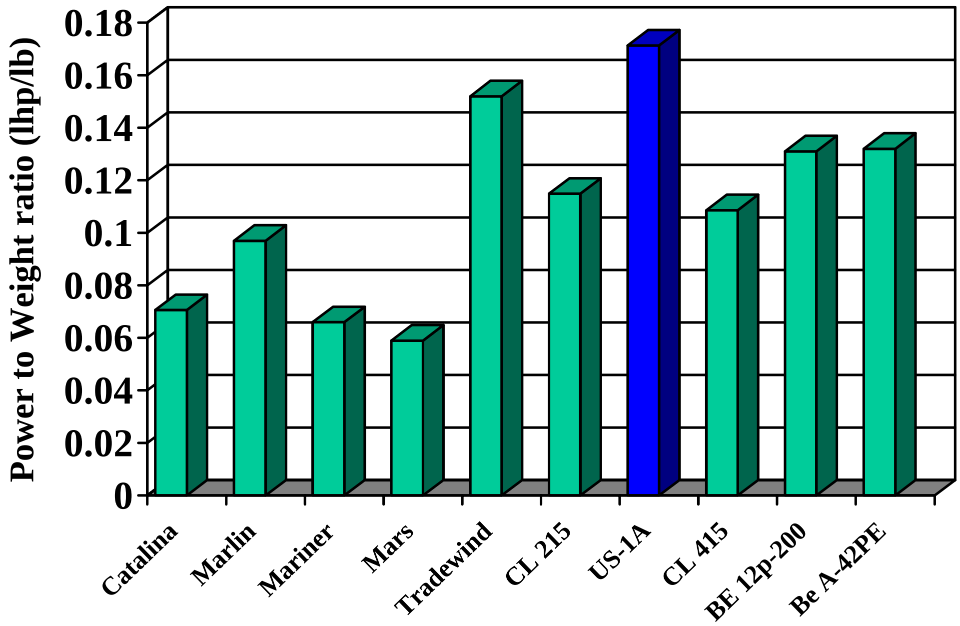

Figure 15: Comparison of aircraft power-to-weight ratio

these aircraft have a high power to weight ratio. High power-to-weight ratio enables high acceleration to allow the aircraft to accelerate through the critical hump period faster and get airborne quickly. This helps mitigate porpoising. High power-to-weight ratio also implies the ability of the aircraft to maneuver in the water quickly, with relatively good directional control.

4. Seaplane Integration with Sea Base

4.1 Seaplane/Sea Base integration

Capabilities required of a Sea Base to support seaplane operations were investigated. Emphasis was placed upon the Sea Base-seaplane interaction and not seaplane requirements. The following issues were considered:

- *Mooring*, handling aircraft at low speeds in water and berthing,
- *Unloading/loading*, transfer of personnel and cargo,
- *Surface traffic control*, control of aircraft during taxiing, take-off and landing, and other surface vessels maneuvering in the vicinity,
- *Refueling*, refueling the seaplane in the sea base,

- *Maintenance*, environmental protection (wash), servicing, and repair,
- *Mission reconfiguration*, transformation to other mission roles,
- *Aircraft safety equipment*, aircraft design features and equipment for crew,
- *Anchorage*,
- *Docking/undocking*, the use of reversible thrusters or turntables,
- *Terminal facilities*, messing areas, logistic stowage/handling and cargo protection.

This list is not exhaustive, but provides a reasonable indication of pertinent issues for successful seaplane/sea-base integration.

4.2 Mooring

In the past, there has been a tendency to remove seaplanes from the water when not in use. It is easier, less time consuming and economical to keep the seaplane in the water where and when possible. This also means the time to deploy the seaplane (i.e. take flight) at short notice is much quicker. Hence the issue of mooring the seaplane whilst not in use needs to be addressed.

There is perhaps a misconception that seaplanes could be moored to a buoy (Figure 16) in low sea states to avoid damage at higher conditions. This was true in the past when seaplanes were rigidly moored to buoys. High ‘snap loads’ that occurred in high winds often caused severe damage to the aircraft. However, British manufacturers introduced the ‘anti–snatch’ system (Figure 17) to overcome this problem. Attached to the buoy was a sinker chain (with its own anchor), acting as a damper to minimize the pull of the mooring chain on the seaplane anchor. A restoring force is provided as a smooth function of displacement, when an abrupt high impact load is exerted on the seaplane. This means the aircraft is not suddenly ‘snatched’, avoiding damage. In the past, four Sunderland seaplanes withstood wind gusts of 100kts without damage, whilst there was much damage to those on shore. This method allows the possibility of leaving the seaplanes at sea, as opposed to being removed during non-operational periods. The use of buoys can provide an adequate method for mooring large or small seaplanes when water depth is not excessive. The buoy may also be exploited further by providing a means for surface

Figure 16: Mooring to buoys

refueling the seaplane through adapting a system similar to the Offshore Petroleum Discharge System (OPDS) as shown in Figures 18.

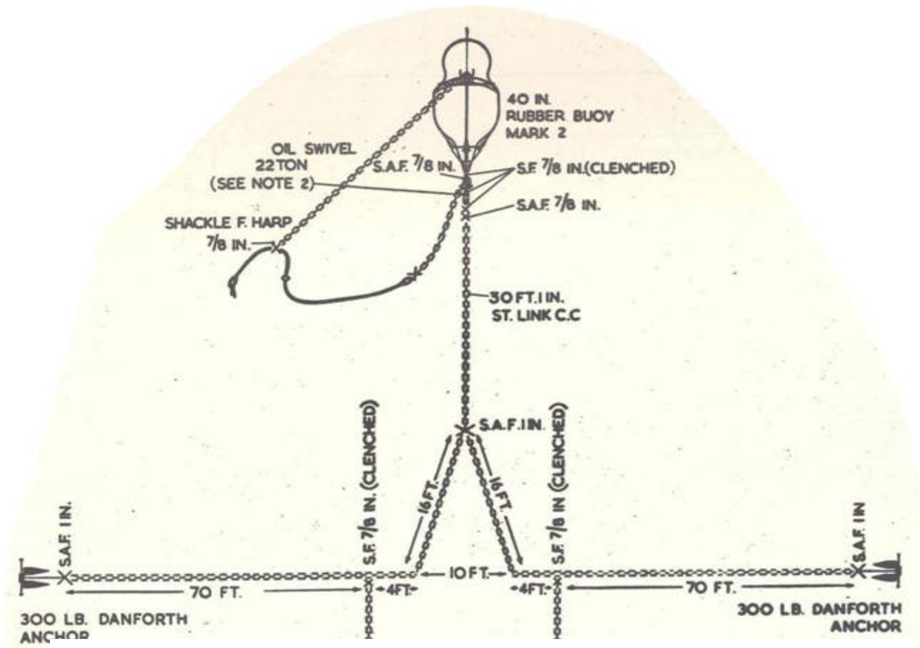

Figure 17: Schematic of British anti-snatch system

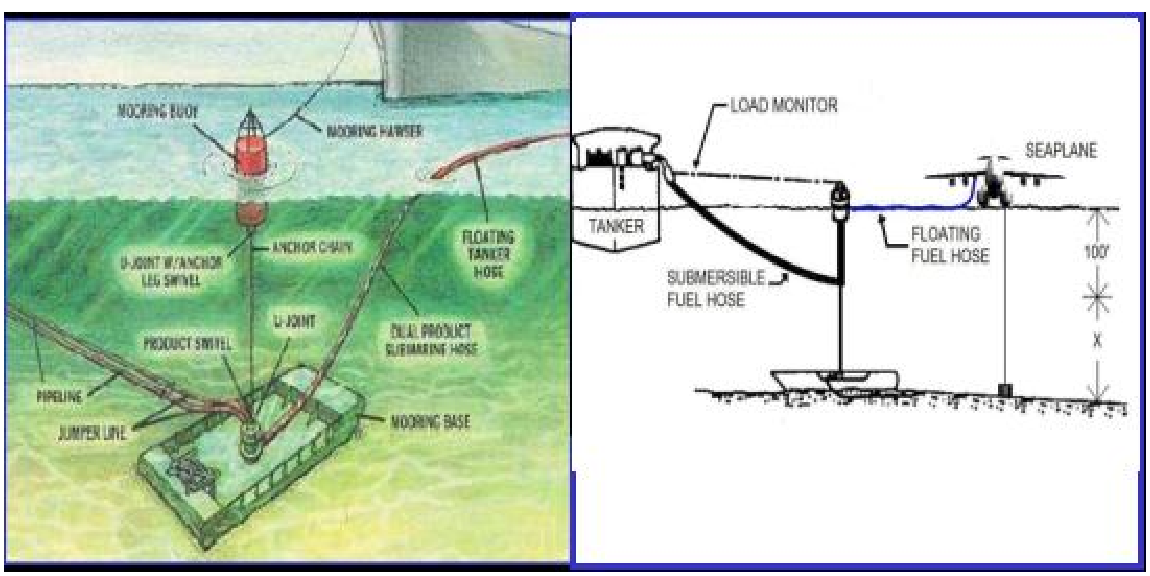

Figure 18: Off-shore Petroleum Discharge System (OPDS)

4.3 Docking

Docking aircraft out of the water is more appropriate for operations such as transfer of payload and personnel, heavy maintenance, reconfiguration of the aircraft, and to provide safe haven during high seastates or other adverse weather conditions.

The transfer of payload at sea is one of the biggest issues facing any Sea Base. A conceptual method of transferring payload at sea is demonstrated in Figure 19 using the Intermediate Transfer Station (ITS) concept (Ref 9) proposed by a previous CISD innovation cell. This concept is based upon utilizing a heavy lift ship (HLS) to provide a large platform deck area for improved cargo transfer between roll on/roll off vessels and lighters. The size of this deck area is large - an example being the Dockwise Blue Marlin with a platform deck area of approximately 600ft x 200ft. The ITS concept involves ballasting the ship down to the lower deck and then applying an appropriate list (about 2º for a Blue Marlin size ship) angle. This creates both a low side and a high side. The low side allows lighters such as LCACs and LCUs to interface with the HLS while larger ships dock on the high side. In general, the ITS benefits the Sea Base by reducing the torque on the ramps during cargo transfer in high sea states, providing a sheltered lee for the lighters, and allowing for multiple lighters to receive the cargo simultaneously.

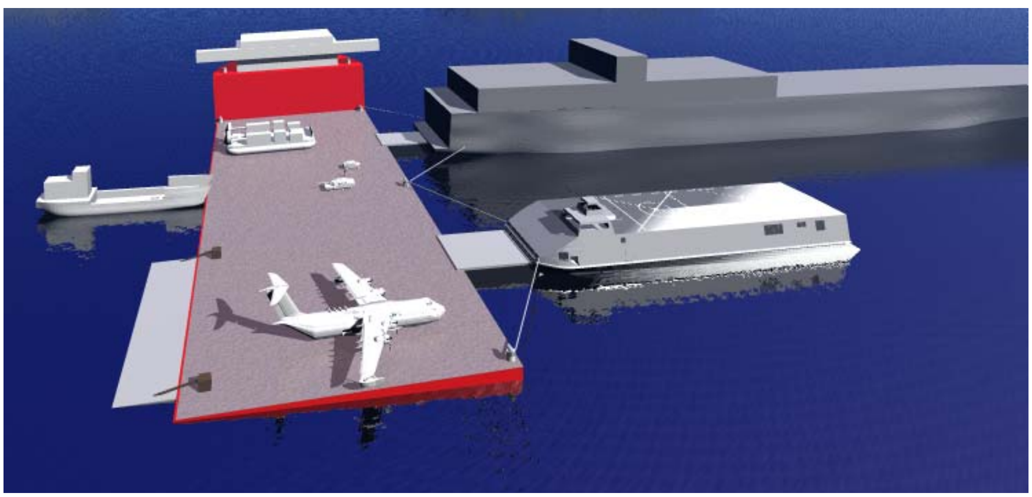

Figure 19: Docking onto ITS

This concept can be extended to support seaplane operations from the low side of the HLS. The HLS becomes a floating seaplane ramp to allow seaplanes to come onboard. Payload can be conveniently transferred between the seaplane and the HLS securely attached to a dry deck. Seaplane operations may be enhanced by fitting affixed, retractable, and/or extendable ramps to the HLS to allow the seaplane on to the platform deck. Other features such as a crash barrier on the ITS may be necessary. As an alternative method to taxiing the seaplane up the ramp, the seaplane could be winched onto the deck using systems similar to those used with earlier seaplanes.

These ideas have focused primarily on using the ITS to dock the seaplane. Other concepts (Figure 20) not involving the ITS include the use of a cradle, especially if the seaplane does not possess appropriate beaching gear. In the past, cradles have provided an adequate method for docking the seaplane to a surface vessel. The downside of this method is that the aircraft requires the cradle to dock, thus reducing its ability to be self-sufficient, unless it carries it’s own cradle.

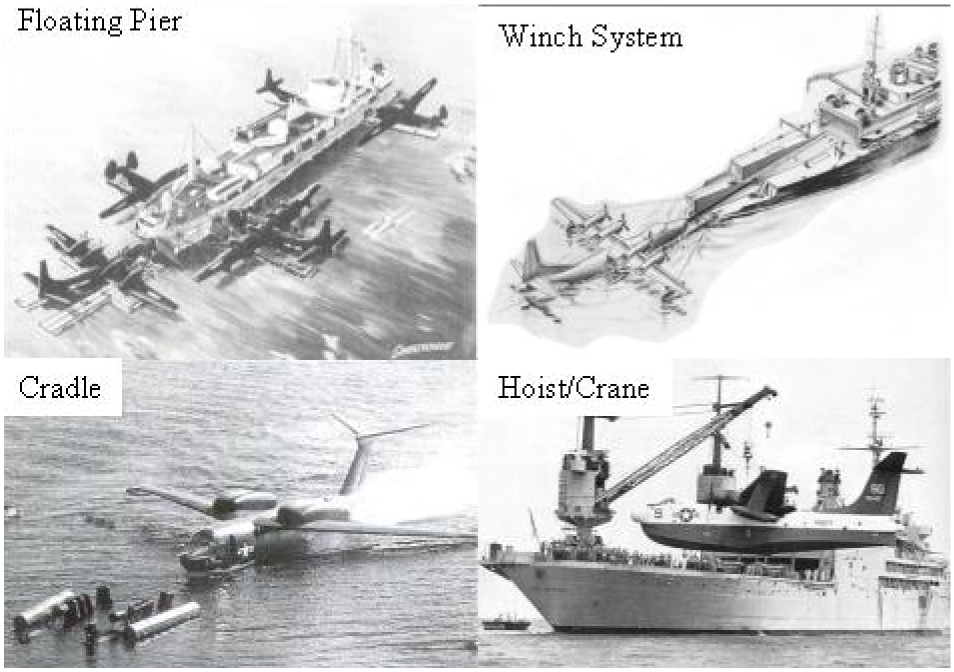

Figure 20: Alternative methods for docking seaplanes

Floating piers, marine railways, hoists, cranes, elevators and U-Docks are all ideas that have been explored in the past. Although these methods are feasible and have been used in the past, there is no existing operational equipment available.

One very successful idea from the past, negating the need for a dedicated ship, was the use of a loading boom. This system was anchored to the side of a ship, and attached to the seaplane, restraining the aircraft both in yaw and lateral separation from the ship. A boom could be attached to the seaplane allowing the transfer of passengers from the seaplane. The boom could also permit the transfer of fuel and other supply lines.

4.4 Interaction with Sea Base environment

Management and control of air and surface traffic at a land airfield is very important and an extremely busy task. Within the Sea Base environment, there will be various surface vehicles such as LCACs, LCUs, tugboats and heavy lift ships maneuvering as well as other air traffic such as helicopters. With the addition of seaplanes, operational and safety issues similar to those found at land airfields will be encountered. Both air and surface traffic control, similar to that at military airbases, is required. In addition landing areas, taxiways and parking zones need to be identified to permit various military flying operations, including night flying. This could be accomplished in a traditional fashion using buoys, beacons, etc. or by creating a 'virtual airfield' using modern Head Up Display (HUD) technology to mark out the airstrips from the seaplane cockpit. However, if the virtual airfield approach is used, information needs to be communicated to all traffic in the area.

The US Federal Aviation Authority (FAA) has produced guidelines [Ref 10] for the setup of a civilian seaplane base. Although aimed more at small seaports, the same principles can be applied in context to the sea base environment.

Other operational issues will include controlling pollution (fuel transfer will be taking place at sea), preventing intruders, maintenance of landing strip markers, sea condition sensors, crash and rescue services and removal of floating debris to prevent collision damage.

4.5 Beaching

The ability to beach seaplanes greatly enhances operations such as transfer of cargo and personnel, aircraft maintenance, weather protection, and refueling. Beaching seaplanes is not new. Systems using beaching wheels and attachable cradles were developed and used during the seaplane historical era. Beaching would also facilitate secondary missions such as medevac, humanitarian relief, or civilian rescues. However, affixed or portable ramps may be required at the shore to allow safe and easy beaching. These ramps could be as simple as piecing together wooden planks.

The Convair Tradewind aircraft, dubbed the 'flying LST', demonstrated beaching (Figure 9) without ramps on shore. While the demonstration was successful, problems encountered prevented the technique from being implemented. With the stern remaining in water, the aircraft was subject to a variety of motions due to the waves and wind. An alternative is to remove the seaplane completely from the water. This may be achieved using the air cushion landing system mentioned earlier.

Beaching is not easy and there still remain many concerns. Not all beaches are the same – some beaches are short, rugged and with non-ideal gradients. Hence the capability of the beaching concepts mentioned above need to be investigated further, with improvements applied using new technology.

5. Seaplane Conceptual Design

5.1 Primary design considerations

The design considerations addressed for the seaplane concept stemmed from the main objectives set out for the study which entailed:

- Enabling 'Force Closure' – to transfer or assemble troops/equipment at the Sea Base.
- Logistics delivery – to transport, load/unload a range of payload sizes and weights.
- In-flight refueling -. to provide multi-point aerial refueling capability for combat aircraft.

Secondary objectives included para-drop of equipment, cargo, or troops.

5.2 Design requirements

A set of requirements was established to guide development of a notional seaplane concept. Some of the drivers that have been identified are detailed as follows:-

- Payload – 30 short tons (60,000lbs), with the ability to carry a sufficient number of troops (180) to move coherent units, transport several 20 ft TEU ISO containers, or transport various light Army/Marine vehicles.
- Speed – sufficient to allow in-flight refueling of fighter jet aircraft.
- Range – 2,000nm total range allowing primarily intra-theatre operations (deliver logistics to and from the Sea Base), and be capable of inter-theater ferry flights from CONUS (continental US) to an intermediate support base (ISB).
- Sea keeping – ensure the seaplane is fully operable through seastate 4 with limited operations in seastate 5.
- Fully amphibious capability (alighting and take-off on water and land) and be capable of beaching to the shore.

5.3 Characterization of seaplanes

A literature search was conducted using a variety of sources, including several US Navy inter-departmental libraries, learned societies, and external organizations such as historical centers/museums as well as Internet searches.

The technical and descriptive data collected on seaplanes was populated into a Microsoft Access database. Information was obtained for over 240 seaplanes with gross weights of 60,000 pounds or more. The database was used to store the large amount of numerical data and facilitate its export into Microsoft Excel format for subsequent (graphical) analysis. The database allows users to individually tailor field searches of the data, with filters to discard unwanted search results. Individual seaplane images linked to their appropriate record fields are also available. Although the database was initially aimed to document the data collected, it forms a suitable knowledge base store for future seaplane data miners.

5.4 Parametric study

A parametric analysis of the seaplane data was performed to allow an understanding and characterization of both historic and current seaplane capabilities. The study also provided a vehicle to address science and technology requirements needed to develop a seaplane that could meet future requirements.

The parametric study focused on a set of notional requirements for a seaplane of potential interest to support sea base operations. Mission characteristics included a 2,000 mile range, 60,000 pound payload, and a 300^+ knot cruise speed.

The graph in Figure 21 shows plots of aircraft length, wing span and [gross weight-empty weight] against gross take-off weight from the seaplane data collected. Several land planes have been included as reference points. The plots of both length and wing span generally show linear trends with increasing

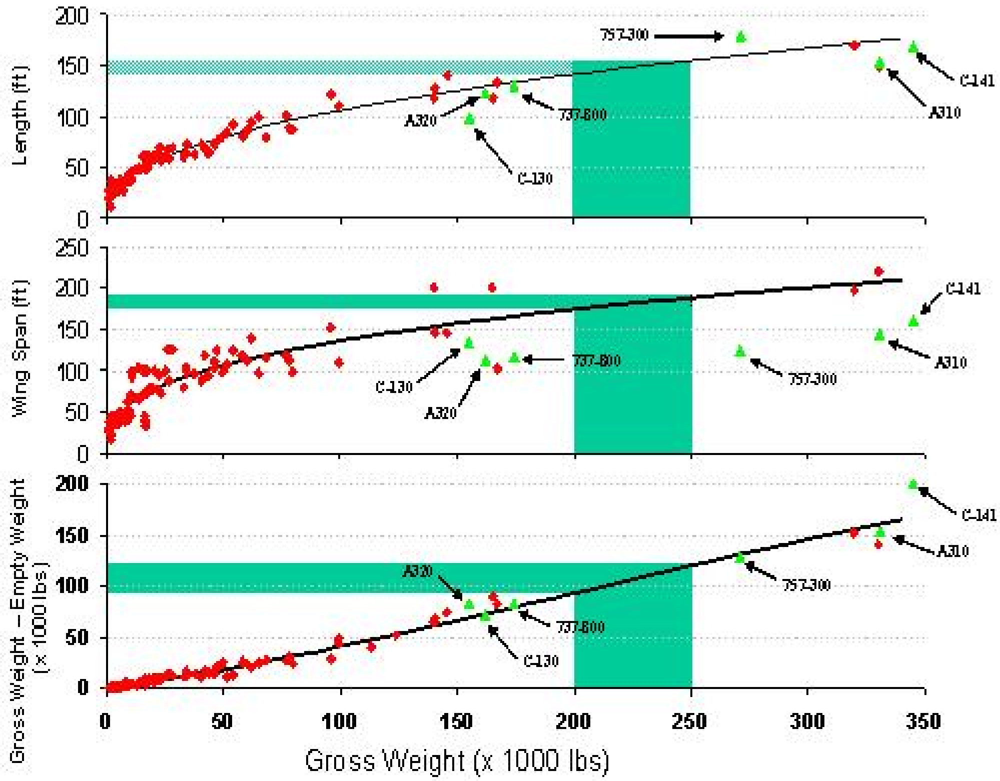

Figure 21: Aircraft length, weight, and wing span

aircraft gross weight. This is expected, as lift (function of weight) is proportional to wing area, and the percent increase of wing area is proportional to the percent increase of wing span squared. The term [gross weight - empty weight] essentially equates to the weight of payload+fuel, with passengers included as payload. As the payload is increased, the required fuel increases, hence the gross take-off weight also increases linearly as seen in the graph.

The plots provide the opportunity to examine requirements for payload+fuel, but in-turn also allows an estimation of the gross take-off weight to be made. Corresponding estimations for aircraft length and wingspan can also be obtained for a particular gross take-off weight. It should be noted that these plots are based on historical data, largely intended to produce approximate initial figures for the early design phase. They do not take account of any improved/future technologies or individual aircraft requirements.

5.5 Range-payload

Plots of range versus payload are very important for conducting long distance operations. Each aircraft has a maximum allowable weight for payload, fuel, and the sum of payload plus fuel. It is the decision of the aircraft operator on how best to optimize this make up. The aircraft can carry maximum fuel, and minimum payload, to adhere as the ferry or maximum range of the aircraft. If the payload is increased, the quantity of fuel that can be carried will have to be reduced. With less fuel available, the aircraft range will be lower. Fuel tank volumes and utilization of external fuel tanks will also affect these figures.

Although large amounts of seaplane data were collected, little data existed to allow appropriate range – payload graphs. However, data existed for the Convair Tradewind (types R3Y-1 and R3Y-2), the SARD Princess and the Martin Mars (JRM-2), as shown in Figure 22. The Lockheed Martin C-130J is included as reference, noting that the C-130J is a land based cargo plane, with substantial technology investment over the years.

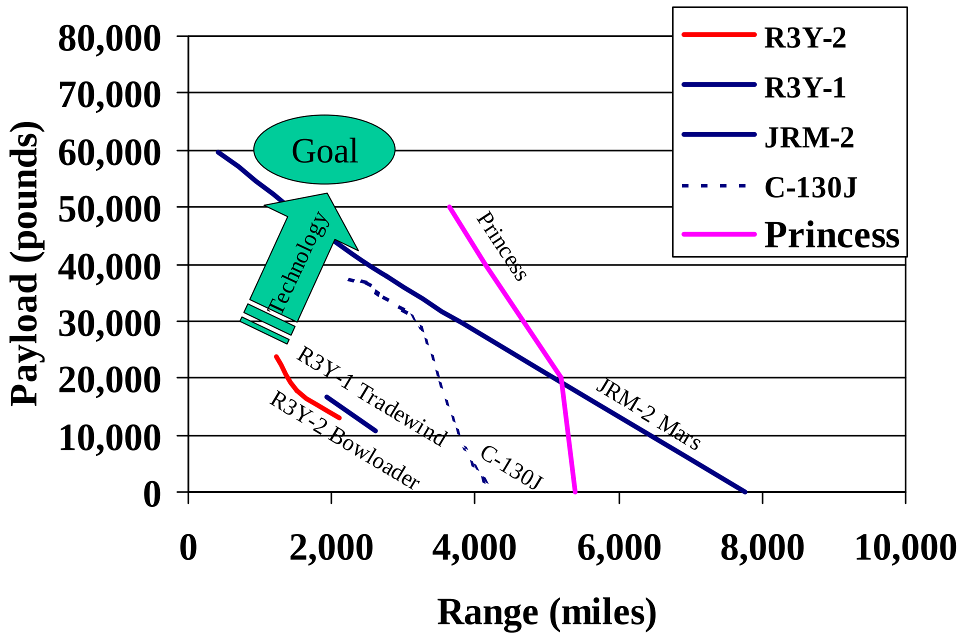

Figure 22: Payload -Range parametric data

The parametric plots illustrate the characteristics expected for a seaplane with a range of approximately 2,000nm and payload of 60,000lbs. The desired region of payload/range highlighted in Figure 22 currently exists outside of the boundary for the data collected. However, application of appropriate current or future technologies (analogous with C-130 developments), should allow this gap to be bridged.

5.6 Empty weight fraction

An important part of initial aircraft design process involves estimating the aircraft empty weight fraction, i.e. the ratio of empty weight to full load gross weight (W_{empty}/W_0). Historical sources suggest that the empty weight fractions of seaplanes were generally greater than those for land based cargo planes. Besides the seaplane contributing to extra volume/weight through the hull and strengthened landing gear, there have not been major investments in seaplane design since the 1950s. Even modern seaplanes are built around pre-1950s technology or have been modified from conventional land planes. Alternatively for land based cargo aircraft, such as the Lockheed Martin C-130, investment has continued over the years and, through successful research, improved technologies have allowed for a lighter and more efficient aircraft. Hence, a historical comparison of all (past and current) land based cargo planes with seaplanes is unworkable. Instead, the approach required to adopt is that of investigating how technology advances have improved land planes and extrapolate these advances to seaplanes. For instance the impact of advanced technology on the empty weight fraction for cargo planes transposed directly towards seaplanes would vastly improve the seaplane performance characteristics, extending the range and fuel efficiency.

The graph in Figure 23 shows a plot of empty weight fraction against full load gross weight. Three trend lines are shown; Pre-1950 seaplanes, Pre-1950 land-based cargo planes and 1950-1990 land-based cargo planes. It is observed that both seaplanes and cargo planes have similar trend lines for pre-1950 aircraft. This can be attributed to the similar technology levels available at that time for both types of aircraft. Since the 1950's there has been about a 20% reduction in the empty weight fraction of land-based cargo planes. This is due to the increased use of lighter materials and less material through modern structural analysis techniques, as well as lightweight, fuel efficient engines. It is reasonable to assume that if similar levels of technology were applied to seaplanes, the empty weight fraction could also be reduced by a similar amount. Further reductions might well result from the availability of future technology currently on the science horizon.

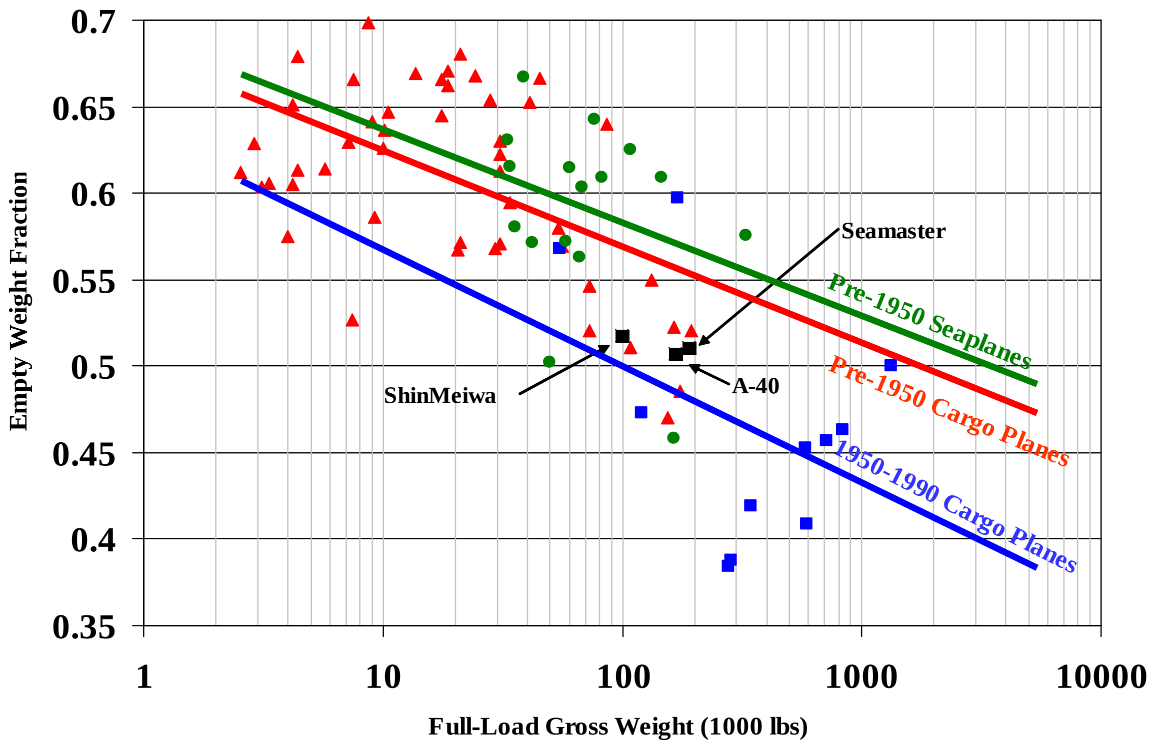

Figure 23: Empty weight fraction

5.7 Seaplane initial sizing

Results from the parametric studies allowed an initial sizing of the seaplane conceptual design. The process [Ref 11] involved taking into consideration that the gross maximum take-off weight is a sum of the passenger, payload, fuel and empty weights. Rearranging the equation provides both the fuel weight fraction (W_{fuel}/W_0) and empty weight fraction (W_{empty}/W_0) as a function of maximum takeoff weight (W_0). An iterative process must be used to solve the following equation;

$$W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$$

$$W_0 = \frac{W_{crew} + W_{payload}}{1 - \left(\frac{W_{fuel}}{W_0}\right) - \left(\frac{W_{empty}}{W_0}\right)}$$

The empty weight fraction was estimated using the results from the parametric studies as previously discussed. The fuel weight fraction is a function of many aircraft parameters. Fuel is burnt at all stages of flight including taxiing, hence the overall aircraft weight will continually reduce. To estimate the fuel fraction, a simple mission profile must be assumed such as that shown in Figure 24. The profile must take into account a failed landing, and have enough fuel for any diversions, to either avoid adverse weather conditions or other salient reasons. Assumptions about the aircraft characteristics, such as maximum lift-to-drag ratio (L/D_{max}) and lift coefficient (C_L) during cruise, along with a combination of endurance and Breguet range equation, enable a fuel fraction to be estimated. The equation can then be solved for various payload and range values. Example values being; W_0=160,000lbs, payload=60,000lbs, empty weight=76,000lbs, fuel weight=52,000lbs.

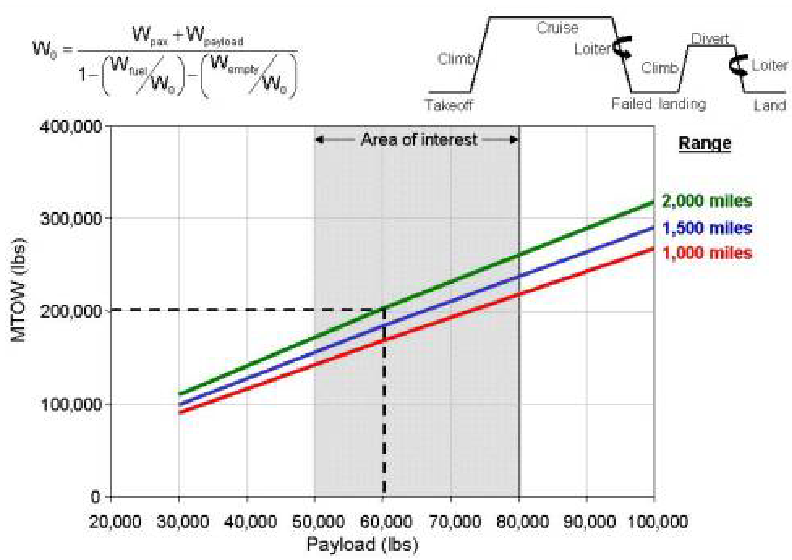

Figure 24: Seaplane initial sizing

$W_{payload}$	60,000
W_{fuel}/W_0	0.324
W_{empty}/W_0	0.46
W_0 (guess)	283,000
W_0 (calculated)	277,420

Table 2; Empty weight fraction estimation results

This procedure essentially leads to obtaining a plot of maximum take-off weight (MTOW) against payload as shown in Figure 24. The graph allows approximate values to be used for initially sizing the aircraft. Several iterations are needed, along with more complex analysis to reach final design figures.

5.8 Seaplane conceptual design

The conceptual design generated shows (Figure 25) a boat-type seaplane, with high mounted wings carrying six turbo-prop engines. The aircraft geometrical dimensions are listed in the table below, with comparisons to other aircraft. The aircraft has been designed to be fully amphibious, hence alight and take-off from water and land, with appropriate undercarriage design and fuselage strengthening.

	Shin Meiwa US-1A	C-130J	Seaplane Design Concept	C-17	C- 5
MTOW (lbs)	94,800	155,000	260,000	585,000	840,000
Payload (lbs)	30,000	34,000	60,000	170,900	270,000
Empty weight (lbs)	56,200	79,291	127,000	278,000	337,935
Length / Height (ft)	110 / 33	98 / 39	144 / 47	174 / 55	247 / 65
Wing span, b, (ft)	109	132.6	163	171	223
Wing Area, S (ft^2)	1,460	1,745	2,650	3,800	6,200
Range, (nm) (with payload)	2,300	1,600	2,000	4,741	6,320
Cruise Speed, (kts)	230	362	368	450	450

Table 3; Comparison of seaplane concept with other aircraft

5.8.1 Hull design

The seaplane bottom hull configuration is similar to the Russian Albatross (A-40) aircraft. The hull shape uses a slight 'double chine' design type to take advantage of various hydrodynamic and structural advantages. Studies [Ref 12] of different hull shapes have shown this type reduces both water spray and hydrodynamic resistance, whilst allowing larger beam loadings. Other features of this design also entail reduced impact accelerations on landing and good structural (tension) loading capability. The planing length has been suitably positioned to avoid large moments being introduced during loading and unloading. A fairing has been used to merge the hull step to reduce drag penalties during flight and allow suitable water flow separation. In-flight drag has been reduced by equipping the seaplane with retractable wing tip floats.

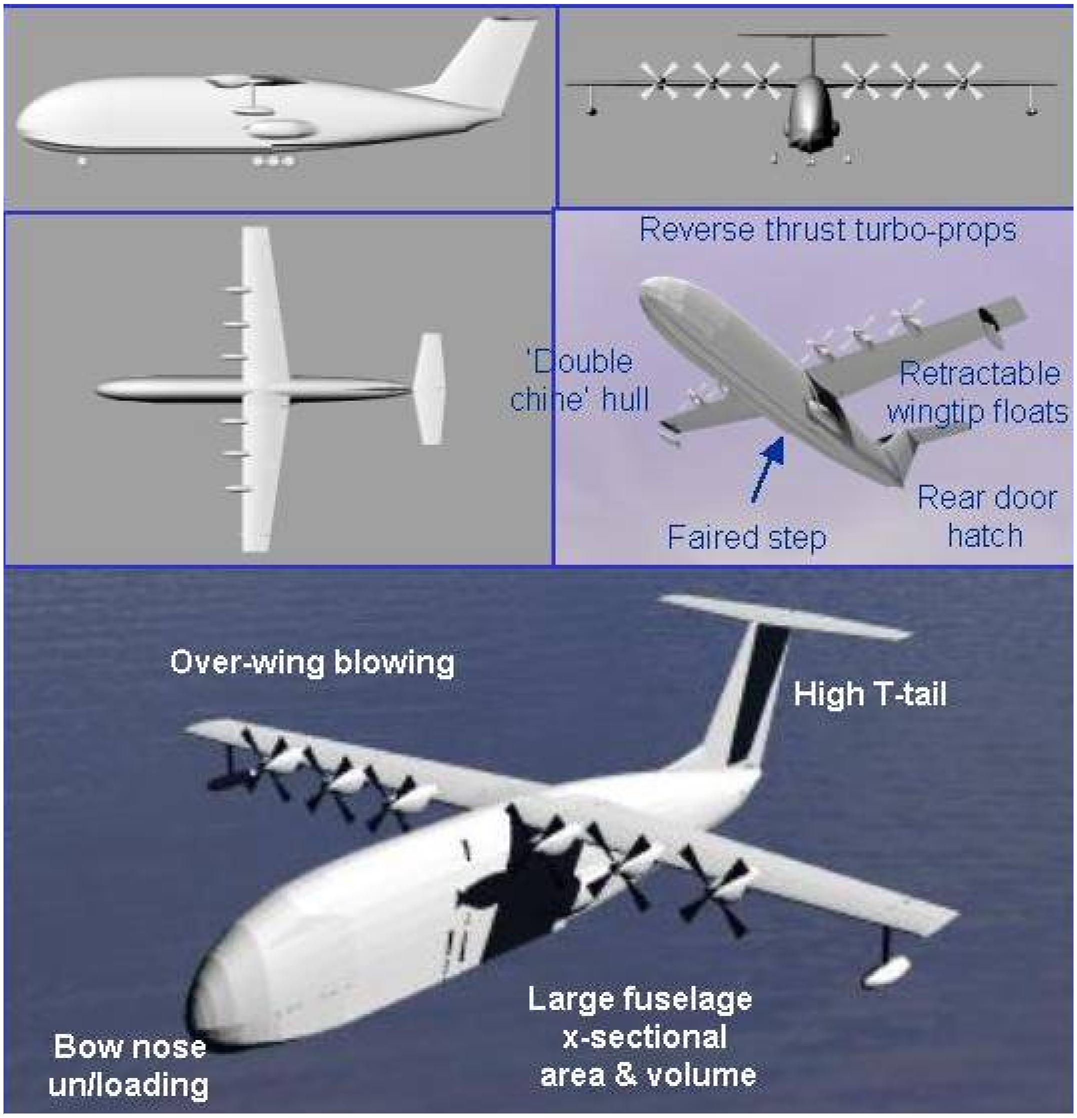

Figure 25: Features of the seaplane design concept

5.8.2 Wing design and loading

The wings are mounted high on the aircraft fuselage keeping the propellers and engines away from water or spray. The wing design entails the use of high lift devices - triple slotted flaps, with Krueger flaps for the leading edge. The wing loading characteristics for the seaplane design has been based upon landplanes with a similar wing loading of circa 98lbs/in^2. An Aspect Ratio of 10 has been maintained during the design.

5.8.3 Over-wing blowing

The seaplane has over-wing blowing to increase the STOL characteristics of the aircraft. This technique uses the air stream behind the propellers along with wing lifting surfaces to control and maximize the 'boundary layer', thus substantially increasing the lift contribution by the wings. This technique coupled with a very high angle of attack, low aircraft stall speed and high power is used to maintain steep angles of climb and descent.

5.8.4 Tail plane

The seaplane has been designed with a large vertical tail to provide sufficient effectiveness and directional control whilst water taxiing in cross winds and assist lateral stability during flight. The design also features highly mounted horizontal tail-planes to avoid water spray during take-off, and be clear of any impinging propeller jet-stream flow thus allowing good control effectiveness. These large tail-planes (stabilizers) provide good effectiveness during take-off and sufficient control forces to counteract large center of gravity variations due to cargo placement. A retractable rudder is also featured on the tail of the hull at the water line.

5.8.5 Payload and range

The design allows a maximum payload of 60,000lbs to be stored in the aircraft fuselage. This capacity allows several US military vehicles (Stryker, HMMVV) and self-mobile 20 ft TEU ISO-containers to be transported over a maximum range of 2,000nm. The transportation of 180 troops is also feasible, including allowance for personal (110lbs) equipment. A rear door and lowering ramp to allow the para-drop of small to medium size logistics and special forces vehicles (11m RHIB) is also included.

5.8.6 Power-to-weight ratio

Seaplanes with high power and rapid response would allow the aircraft to exploit benign patches of water during take-off and landing and provide responsive surface control during taxiing. Hence the 'power-to-weight' ratio of the seaplane was maximized using current engines to enable this feature. Though the power-to-weight ratio is low compared to those of the Be-12, US-1A, and Tradewind aircraft, future engine designs should enhance power-to-weight ratios.

5.8.7 Landing gear system

A conventional landing gear has been adopted, which is retractable into slender faired 'blisters' located on either side of the aircraft fuselage. The landing gear has been suitably designed to allow amphibious capability. The nose wheel is retractable into the hull, with appropriate levels of water sealing. The landing gear has been designed with low turnover and tilt angles of 60º and 8º respectively to prevent the aircraft tipping over. It is proposed that an air cushion landing system (ACLS) could be applied to the aircraft to aid beaching onto the shore or ITS, once suitable technology enhancements to the ACLS have been developed.

5.9 Time to deploy

To investigate the mission profile further, the initial seaplane design was compared to a High Speed Vessel (HSV) in transporting troops from the Intermediate Support Base (ISB) out to the Sea Base, as shown in the schematic, Figure 26. A simple model was created using Microsoft Excel, simulating the various processes which would occur when troops arrive at the ISB, in readiness for transportation to the Sea Base. This included transport to the seaplane, take-off, cruise, alighting, etc, with times estimated for each of these processes. The model allowed the ability to vary the number of vehicles and the distance from the ISB to the Sea Base, calculating the time to transport 13,000 troops with personal equipment. Saturation levels were also taken into account, i.e. there are only a finite number of seaplanes or HSVs that a Sea Base could support at any instant. It was assumed that the Sea Base could only support two vehicles docked at any one instant.

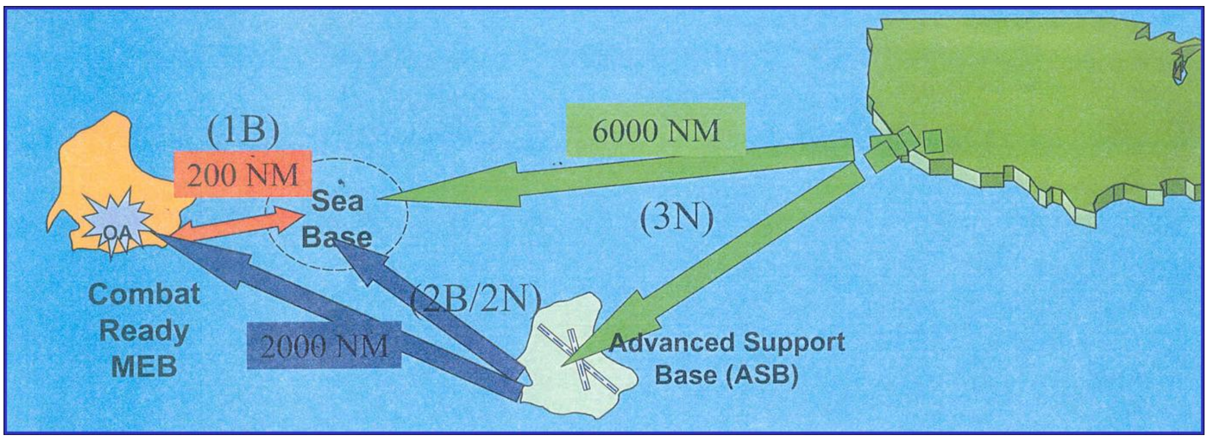

Figure 26: Schematic showing transfer to the ISB and Sea Base

Figure 27 shows the results from these calculations. As an example, to transfer 13,000 troops to a Sea Base 1,000nm away in 65hrs (circa 3 days), either 10 seaplanes or 33 HSVs could be used. However, if there were a limit to the number of vehicles available, the graph can be read alternatively to obtain the number of hours each vehicle would take. Although increasing the number of seaplanes would decrease the time taken, it is observed that the process saturates at approximately 27 aircraft. Adding more aircraft does not reduce the transfer time because the process is limited by the time to dock at the Sea Base, offload troops, and undock. The HSV saturates at a much higher level due to the lower cruise speed of the vehicle. There is also a cross over point at short distances where transfer by HSV would be quicker than using seaplanes.

In general, the number of vehicles available will be limited, with seaplane transfer being
much quicker in most cases, though saturation is more of an issue for the seaplane than it is for the HSV.

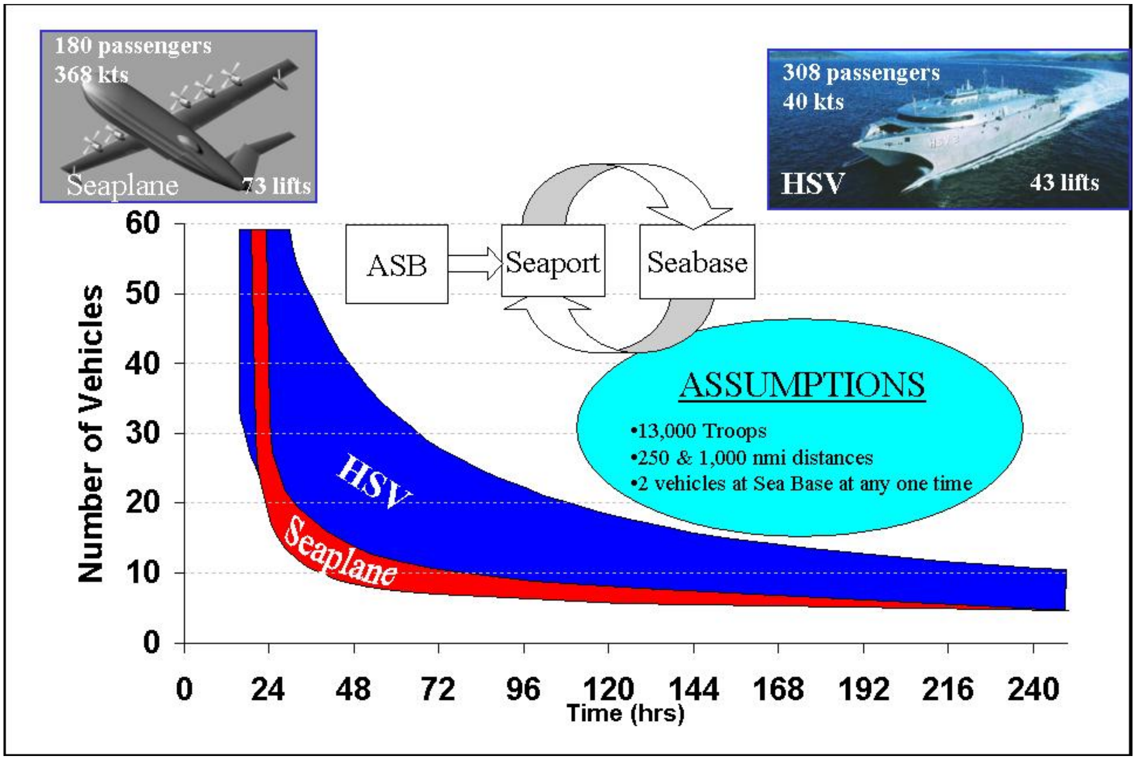

Figure 27: Seaplane/HSV deployment time

6. Conclusions

It is evident from the study that seaplanes have a potential role in supporting seabasing through rapid and strategic deployment of troops, equipment, and logistic support. Seaplanes would certainly enhance Sea Base capability, providing a useful resource to achieve force closure, heavy lift logistic sustainment from the Sea Base to shore, and in-flight refueling. However, for the seaplane to achieve its full potential, advanced technologies, compared to those that already exist on current seaplanes, will be required.

Low cost, high impact research needs to be conducted into several areas. These include the development of advanced hull designs to optimize aero-/hydro-dynamic performance, reduce spray, reduce structural loads, and improve fatigue characteristics. The application of suitable composite materials would minimize weight and prevent corrosion, whilst maintaining strength. A similar strategy could also be employed for engines where possible. Non-conventional landing systems such as the air cushion landing system could provide a viable method for docking and beaching the aircraft, besides landing and take-off from both hard surface runways and water. Resolving issues with directional control and air cushion deployment would be the initial steps to investigate. Active motion control systems, such as water thrusters, control surfaces, or surface dampers could be employed to avoid/minimize seaplane porpoising. Advances in high-lift devices could be exploited towards increasing the STOL properties to reduce take-off and landing distances.

All weather sea surface monitoring and prediction systems would provide seaplane operators the valuable information to locate benign patches of water and anticipate adverse seastate conditions. Such systems would also allow around the clock operations.

The integration of seaplanes within a Sea Base raises several issues, particularly with the transfer of personnel and cargo between the seaplane and the Sea Base. Several methods of dealing with sea base interface issues have been identified. These include mooring using buoys with 'anti-snatch' systems, options for surface refueling using the OPDS method, and docking/beaching onto the ITS or shore using beaching gear.

Full scale experimentation with existing seaplanes and potential Sea Base assets to evaluate and measure the level of capability enhancement seaplanes would bring to a Sea Base are desirable. Such experimentation would provide a measure of the utility of seaplanes and prescriptive guidance for engineering technology and human training requirements.

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