HYDRODYNAMIC CHARACTERISTICS OF SEAPLANES AS AFFECTED BY HULL SHAPE PARAMETERS

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Abstract

After a period of extensive seaplane research and design work, which began well before WW II and lasted up to the mid-sixties, the seaplane concept finally lost its attractiveness. Although numerous seaplanes were still in operation worldwide, development work came almost to a complete stop. It was not until the mid-eighties that new interest in seaplanes was sparked by several activities in this field, which finally led to a cooperation agreement between Aeritalia and Dornier to design an all-new advanced technology amphibious aircraft, designated "AAA". This paper will first give an introduction to the seaplane concept and its possible benefits followed by a technical part that will deal more specifically with the shape of seaplane hulls. As can easily be visualized the shape of a hull is much more determined by hydrodynamic than by aerodynamic requirements. In order to fulfill these requirements,-which usually call for a safe and stable take-off with low resistance and spray (both in calm water and high seastate),- it is necessary to have a basic understanding of the hydrodynamic characteristics of seaplanes and how they are affected by changes in hull shape. Since no systematical theoretical treatment of the subject is available today reference will be made to model scale tests published in the literature. The most significant trends associated with hull shape will be discussed in terms of their importance on resistance, spray, longitudinal stability and impact loads.

List of Symbols

L	Length of Hull
L_f	Length of Forebody
L_a	Length of Afterbody
b	Beam Width
h_{st}	Height of Step
γ	Afterbody Keel Angle
σ	Sternpost Angle
θ	Deadrise Angle
Δ	Load on Water (=Hydrodynamic Lift)
Δ_0	Gross Load (=Weight) of Seaplane
g	Gravity Constant
w	Specific Weight of Water
R	Resistance
P	Impact Load
ϵ	Resistance to Load
τ	Trim Angle
$c_\Delta = \frac{\Delta}{wb^3}$	Beam Load Coefficient
$c_V = \frac{V}{\sqrt{gb}}$	Speed Coefficient
$K_2 = \frac{\Delta_0}{wL^2b}$	Davidson Load Coefficient
$k = \frac{\Delta_0}{wL_f^2b}$	Forebody Load Coefficient
$c_{L_h} = \frac{\sqrt{c_\Delta}}{c_V}$	Lift Coefficient

Introduction

The seaplane concept has been very attractive in the first decades of airplane history. The very long take-off and alighting distances allowed by water operation made it independent from expensive ground facilities. In addition, it was safer than land-based airplanes when flying long distances over open sea.

After the second world war more airports became available to support the growing commercial traffic, and more reliable aircraft were being built, mainly because of jet engine technology. This made the operators more sensitive to the penalties associated with seaplanes,-lower overall efficiency and higher costs- than to its advantages, practically leading to the disappearance of this type of aircraft as a means for mass transportation. The interest in military application kept the seaplane concept alive for some more time up into the sixties. Ever since that time, however, -excluding general aviation-, only very few new seaplane designs have appeared.

Recently, the preservation of the ecosystem and a more appropriate use of the earth's resources are generating new needs for special means devoted to environmental control and protection. Seaplanes, or better amphibious aircraft, have the features to provide a proper answer to new fields of activities becoming more and more important for many countries all over the world:

-Protection of the environment against the threat of forest fires and maritime pollution from oil spills;

-Relief of people involved in natural or man-caused disasters.

In addition, the technologies made available by the aeronautical progress of the last decades can make a modern amphibious aircraft also appropriate for the roles of surveillance of large sea extensions and of utility and personnel transportation in areas lacking land infrastructures.

For these reasons, Aeritalia and Dornier have started the conceptual design of an advanced amphibious aircraft, referred to as the AAA, and the development of appropriate technologies.

These activities are being performed in the frame of the European EUREKA initiative. The objective of the program is to demonstrate the feasibility of a multi-purpose amphibian having advanced payload capability and flight performance, requiring reduced logistic support, and providing high standards of comfort for the crew and passengers.

Among the various technologies being analyzed to meet the demanding requirements established for this project, great importance is being given to the hydrodynamic properties of the aircraft. The latest developments in seaplane hull design are being reviewed and consideration is given to novel configurations intended to provide high hydrodynamic efficiency, low impact loads in high seas and low spray generation. The following chapters will therefore give an overview of the basic hydrodynamics of seaplane hulls. Chapters 1 through 6 are intended to familiarize the reader with the physical background and to point out some problem areas, whereas Chapter 7 will present a more detailed discussion on the effects of hull shape parameters as they affect seaplane qualities.

Additional introductory information to the field of seaplane hydrodynamics and design may also be found in references [7], [14],[15] and [16].

1. Speed Regimes of Hull

The speed range that a seaplane passes through during the take-off run can generally be split in four phases (see Fig. 1):

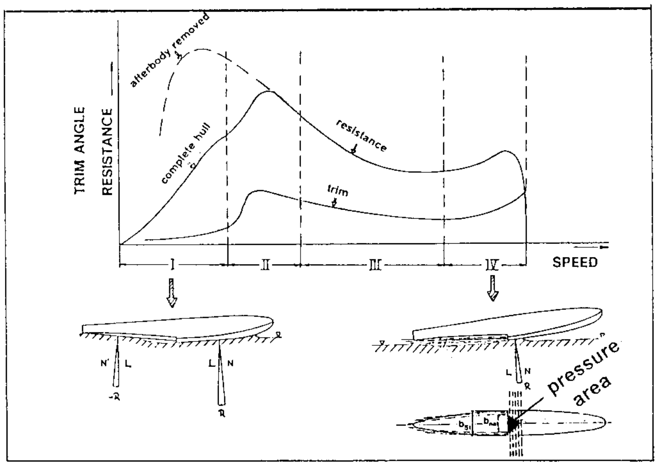


FIG.1 : SPEED REGIMES OF HULL WITH HYDRODYNAMIC RESISTANCE AND TRIM (From [12])

First Phase (Low Speed Regime): The hull behaves much like a displacement vessel moving slowly at low trim angle . Forebody and afterbody carry roughly the same load. The trough that forms behind the main step is still relatively short and allows the crest associated with it to build up under the stern pushing it up and creating a lift force with a forward component. This component accounts for a significant improvement in resistance which can easily be verified in the tank by towing the model with and without the afterbody. The increase in resistance with the afterbody removed can be very pronounced and is sketched in Fig. 1. Resistance in Phase I consists basically of friction (due to the long wetted length) and of wave drag associated with the displacement of water.

Second Phase (Hump Speed Regime): This phase is characterized by a sudden increase in trim angle and a decrease in draft. It constitutes the transition between the 'displacement range' and the true 'planing range' and goes along with a pronounced maximum in resistance and trim. The increase in trim is brought about by a significant extension of the wake which allows the forebody forces (acting in front of the c.g.) to lower the tail and push the bow up. At the same time the drag reducing effect of the stern (see Phase I) diminishes and finally disappears. The hump is roughly found at speeds from 30 to 50% take-off speed.

Third Phase (Planing Regime): The trough of the forebody now extends beyond the stern and the center of pressure on the forebody moves aft towards the c.g. (which lies at a certain percentage of beam width in front of the step). As soon as it passes the c.g. the nose-up moment will be turned into a nose-down moment, trim will come down and the tail will start to clear the water. The hull is now carried by dynamic lift forces on the forebody alone. Since resistance in this phase is largely pressure drag,-at least at moderate and high trim angles-,resistance will reduce, as speed increases, in a similar manner as trim.

Fourth Phase (Take-Off Speed Regime): Just before take-off the pilot usually increases the trim angle to utilize the full lift potential of the wing. At this stage the pressure area in front of the step is confined to a small triangular region around the keel causing a large amount of spray to be thrown against the bottom of the afterbody which creates additional resistance. This increment leads to a distinct second hump before take-off and needs careful consideration if the aircraft is low on power.

2. Resistance

Besides hull geometry resistance mainly depends on load, speed and trim angle. To illustrate some typical effects Fig. 2 has a set of resistance curves taken from old German tank test data [1].

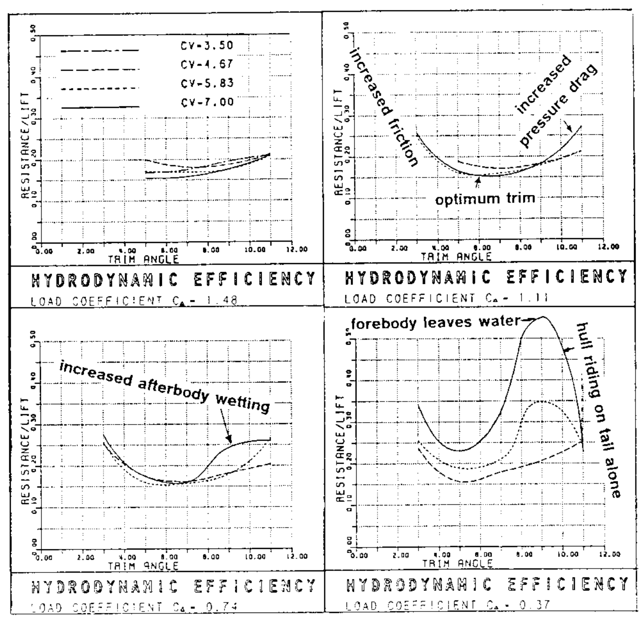


FIG.2 : EFFECT OF LOAD AND SPEED ON RESISTANCE (From [1])

The plots show resistance to load over speed in the planing range. It can be seen that all curves have a minimum around 5 to 7 degrees. If the seaplane can stay within this range during the take-off run hydrodynamic efficiency will be best. The increase in resistance towards the lower end of trim angles is a consequence of the increased wetted length which creates more frictional drag. At higher trims the wetted length becomes smaller and the pressure drag goes up until, -at high angles-, the hull will ride on the tail alone. This causes a significant drop in resistance as can be seen at the high speed, light load conditions at high trim (corresponding to conditions just before take-off). The bump like shape in the resistance curves at light loads and high speeds is due to the small pressure area which causes the aforementioned increased afterbody wetting. It is also seen from Fig. 2 that the ratio of resistance to lift (where lift is equal to load) does not vary very much with speed at high and moderate loads. At light loads, however, this is no longer the case. The reason again is afterbody wetting.

3. Moments

In the low speed regime up to the hump hydrodynamic moments govern the behaviour of the seaplane while aerodynamic moments are small. However, once the hull has reached the planing range controllability of the aircraft will improve significantly because aerodynamic moments are going up and hydrodynamic moments are going down. A set of typical moment curves from [1] is found in Fig. 3. At low trim angles all moments in the planing range ($c_v \geq 4.67$) will curve up progressively because the center of pressure quickly moves forward with decreasing trim. On the other end, at high trim, the curves will drop down as soon as the afterbody dips into the water creating a nose-down moment. With decreasing load and increasing speed the center of pressure approaches the step and the moments become small.

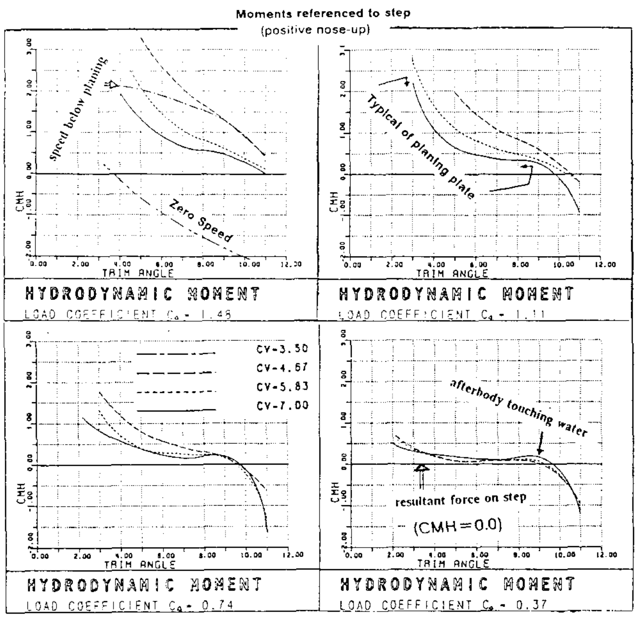


FIG.3 : EFFECT OF LOAD AND SPEED ON MOMENTS (From [1])

4. Porpoising

Porpoising is a coupled oscillation of heave and trim which can occur anywhere at speeds from around the hump up to take-off. It appears at certain trim angles, speeds and loads and can be destructive to the plane if it builds up to large amplitudes. By definition, porpoising starts when trim oscillations of ± 1 degree occur. By connecting such points on a trim vs. speed plot it is possible to draw two lines called the upper limit and the lower limit (Fig. 4). If the seaplane design is good there is a safe range of trim over the whole speed range allowing the plane to take off without passing through either one of these limits.

Upper limit porpoising is mainly associated with afterbody geometry whereas lower limit porpoising depends mainly on the forebody lines in front of the main step. Exceeding the porpoising limits can cause the motion to be come very violent within a very small range of trim. The severity associated with it usually goes up with speed.

Some comprehensive test data on porpoising can be found in [3] and [17].

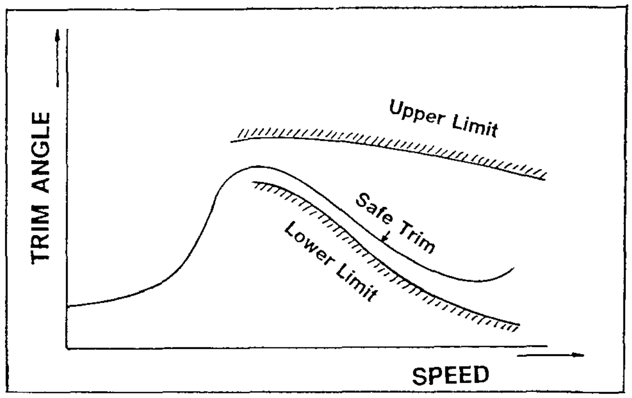


FIG.4 : PORPOISING LIMITS

5. Spray

As soon as the hull leaves the low speed displacement range it starts to develop spray. Spray is mainly produced by the forebody and can affect various parts of the airplane, such as propellers, engines, flaps or elevator. Basically, two different types of spray occur on a seaplane hull:

1. Velocity Spray
2. Blister Spray

Velocity spray is developed along the intersecting line of the forebody and the water surface and is shot out sideways at high velocity and low angle (Fig. 5). Looking from the side it appears forward of the intersection point of the chine line and the water (called the spray root). Velocity spray usually causes no problems for

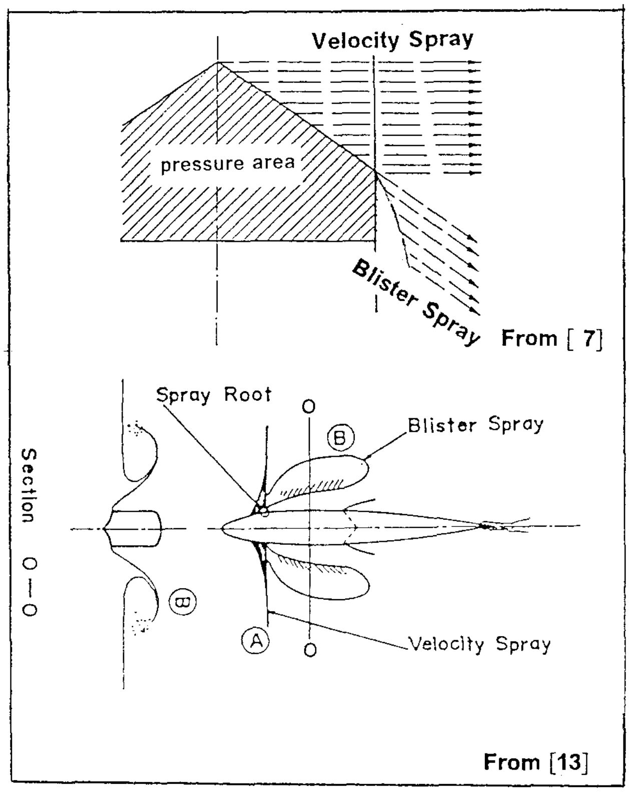


FIG.5 : TYPICAL SHAPE OF SPRAY

seaplanes. It can easily be diverted away from the plane by a small amount of chine flare. Much more important than 'velocity spray' is 'blister spray' which originates along the chines of the forebody at an angle somewhat tilted against the direction of motion (see Fig. 5). It can rise up high and reach the wing, the tail or other parts of the airplane. The name 'blister spray' describes its shape which has the form of a blister containing an air filled space. This shape in its pure form, however, is usually observed only on scale models, not on full scale seaplanes. This is because, at large scales, the blister quickly disintegrates into a cloud of mist obstructing the observer's view.

6. Impact Loads

Impact loads on seaplane hulls are strongly affected by sea state. In calm water the pilot has comparitively good control over the touch-down phase and can bring the plane down gently without significant impact forces. In larger waves, however, the random wave patterns create a large bandwidth of forces and moments on the hull which make it difficult for the pilot to keep control. The plane's behaviour therefore is of a statistical nature with high loads and attitudes occuring under unfavorable conditions of forward speed, sink speed, wave slope and trim angle. The landing technique which has been investigated experimentally in [18] is therefore of great importance.

To a certain degree impact loads can also be influenced by proper shaping of the hull.

7. Hull Shape Parameters

Seaplane hulls may differ widely in shape but yet, the similarities are good enough,-due to hydrodynamic and aerodynamic design requirements-, to allow to compare them by using certain geometrical shape parameters. This finally makes it possible to compare different hulls of different sizes by a set of usually non-dimensional parameters. The basic ones that affect seaplane hydrodynamic qualities most are listed below and pictured in Fig. 6:

-Length/Beam Ratio
-Forebody/Afterbody Length Ratio
-Deadrise at Step
-Forebody Warping
-Step Height/Beam Ratio
-Chine Flare
-Afterbody Keel Angle
-Afterbody Deadrise and Warping

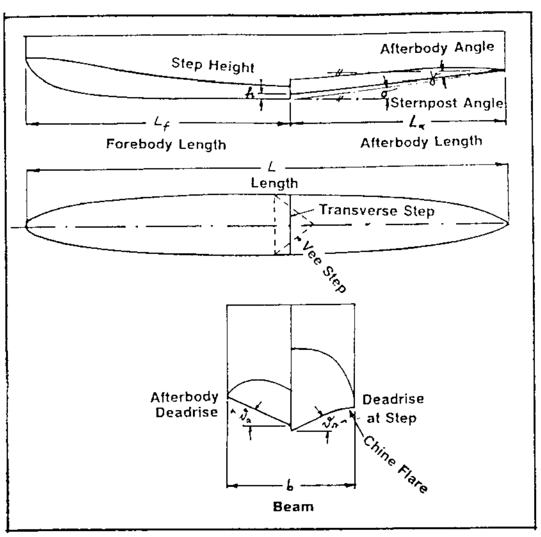


FIG.6 : HULL SHAPE PARAMETERS

These parameters will be discussed with respect to resistance, porpoising, spray and impact loads, as appropriate. The results presented herein are mostly based on model scale tests published in the literature The compilation is by no means complete and is supposed to highlight only some relationships that have been discovered during the course of many years of seaplane research. Due to the complexity of hull shapes, their wide variety and the interaction of different parameters geometrical modifications on one hull may not always show the same hydrodynamic effects on another. However, there are some well established trends that the designer can rely on.

Analyzing the existing test results in the manner presented here is sometimes difficult because it is not always possible to change just one parameter while keeping all the others constant. These difficulties will be pointed out where they occur.

7.1 Length/Beam Ratio

Before WW II seaplanes usually had length/beam ratios from around 4 to 6. During and after the war, however, intensive research was carried out to determine the possible advantages of long and slender hulls. Many reports were published on this subject and several planes, such as the Martin 'Marlin', the Martin 'Seamaster', the BV 222, the Beriev Be 10 or the Shin Meiwa US-1, were actually built and flown. It was found that, with the same resistance and spray characteristics, a slender hull would offer benefits in terms of aerodynamic drag and structural weight. The question arose under what conditions resistance and spray would be similar if L/b was varied. Davidson first found that best collapsing of data was achieved when the coefficient

$$K_2 = \frac{\Delta_0}{wL^2 b}$$

was held constant. This led to the conclusion that a slender hull could carry more weight with the same resistance and spray than a short and wider hull or, alternatively, would have less resistance at the same weight. However, comparing different length/beam ratios for a certain design requires a careful look at all implications. Table I (Fig. 7) was therefore prepared to illustrate the effects involved with varying L/b:

Starting out in Fig. 7 from a design hull with a length of 20m and a beam width of 3.33m, three variations may be considered which each lead to a higher L/b. For these variations the following simplified assumptions can be made:

1. Beam width is related to cross sectional area and hence aerodynamic drag of the hull.
2. The product beam x length is a measure of volume (assuming a constant height) and hence structural weight.
3. The denominator of the Davidson coefficient,i.e. $L^2 \times b$ is a measure of resistance and spray.

It is therefore assumed without specifying the following relationships in more detail that generally

-aerodynamic drag goes up with beam width
-structural weight goes down with length x beam
-resistance and spray go down when $L^2 \times b$ goes up

The arrows in Table I indicate in which direction these characteristics go when L/b is changed. It is evident from the table that varying L/b to larger values does not necessarily yield a better design in terms of both weight and performance, but it does indicate that a potential for improvement is there. It is up to the designer to establish priorities and constraints and to evaluate the potential benefits when making his choice of L/b. Some examples of model scale resistance tests with varying length/beam ratio are presented in Fig. 8. They are all based on constant beam and varying length, corresponding therefore to Variation 1 in Table I.

The effect of L/b on porpoising is not so straightforward because it is not the L/b ratio as such that is responsible for stability but other parameters that may come along with a change in L/b. It can easily be visualized that lengthening the hull may not have any

TABLE I

Principal Effects of L/B Variations (Weight of Hull = const.) on

- Aerodynamic Drag
- Structural Weight
- Resistance and Spray

Parameter	represented by	Baseline conf.	Variation 1	Variation 2	Variation 3
Beam width	b	$b = 3.33m$	$b_1 = 3.33m$	$b_2 = 2.22m$	$b_3 = 2.22m$
Length	L	$L = 20.0m$	$L_1 = 30.0m$	$L_2 = 20.0m$	$L_3 = 30.0m$
Slenderness	L/b	$L/b = 6.0$	↑ $L_1/b_1 = 9.0$	↑ $L_2/b_2 = 9.0$	↑ $L_3/b_3 = 13.5$
Cross Sectional Area (Aerodynamic drag)	b	$b/b = 1.0$	– $b_1/b = 1.0$	↓ $b_2/b = 0.67$	↓ $b_3/b = 0.67$
Volume (Structural weight)	$b \times L$	$\frac{b \times L}{b \times L} = 1.0$	↑ $\frac{b_1 \times L_1}{b \times L} = 1.5$	↓ $\frac{b_2 \times L_2}{b \times L} = 0.67$	– $\frac{b_3 \times L_3}{b \times L} = 1.0$
Length^2 × Beam (Resistance and Spray)	$b \times L^2$	$\frac{b \times L^2}{b \times L^2} = 1.0$	↓ $\frac{b_1 \times L_1^2}{b \times L^2} = 2.25$	↑ $\frac{b_2 \times L_2^2}{b \times L^2} = 0.67$	↓ $\frac{b_3 \times L_3^2}{b \times L^2} = 1.50$

FIG.7 : PRINCIPAL EFFECTS OF L/B VARIATIONS

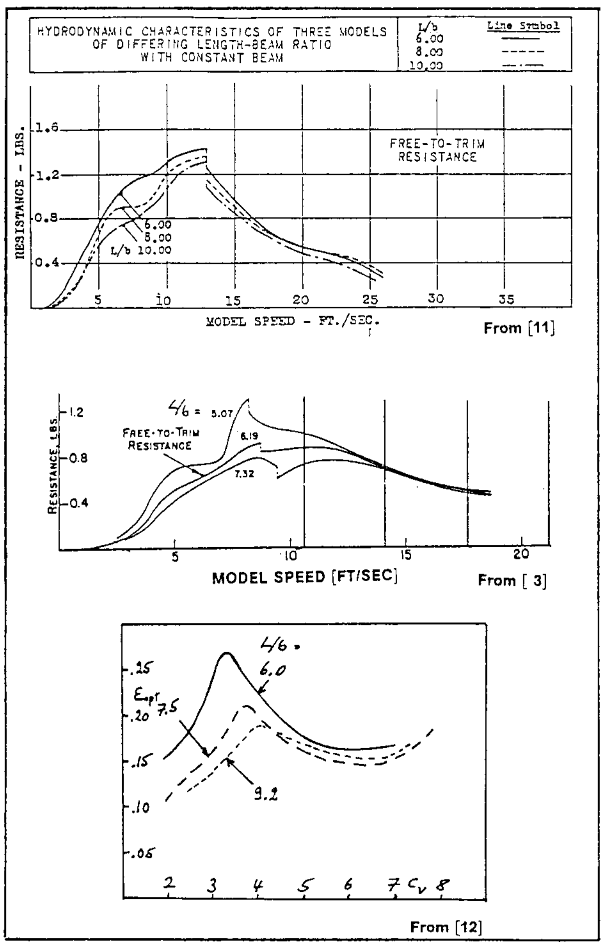


FIG.8 : EFFECT OF LENGTH/BEAM RATIO ON RESISTANCE

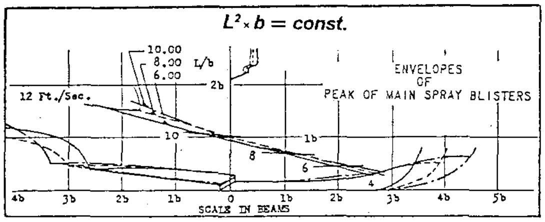
effect on porpoising if the added length at some condition is not in touch with the water at all. For instance, at high speeds the afterbody is completely out of the water. Adding length to it, therefore, cannot have any effect. Likewise, lengthening the forebody will be useless if the submerged part of the forebody goes unaffected by the change. There is, however, a relationship which is closely related to L/b and which has a significant effect on porpoising. It is the dynamic lift coefficient

$$c_{L_h} = \frac{\sqrt{c_\Delta}}{c_V}$$

which depends on beam width (but not on L/b). Following Table I an increase in L/b may very well go along with a reduced beam so that the effect of altering c_{L_h} along with L/b will show up as an L/b effect. Indeed, a significant rise of the lower limit may be observed if L/b is increased by reducing b. Another effect is the reduction in sternpost angle that usually goes along with a lengthening of the afterbody and causes the upper porpoising limit to become lower (the stern gets in touch with the water at a smaller trim angle).

The effect of L/b on spray is very similar to that on resistance. If it is assumed that spray also depends on the Davidson coefficient then similar spray behaviour can be expected for hulls having equal K_2 's. This has indeed been verified in tests. An example is given in Fig.9.

There is some evidence that impact loads in waves may go down when L/b is increased. Measurements were reported in [2] which indicate a substantial reduction (25%) in vertical accelerations when increasing L/b from 6 to 15. It was also found, however, that angular accelerations will go up at the same time. Hence,it is not possible to make a conclusive statement on L/b benefits on impact loads.



LOADING COEFFICIENTS

L/b	6.00	8.00	10.00
C_{Δ_0}	0.72	1.28	2.00
$K_{3/2}$	0.049	0.057	0.063
K_2 (Constant)	0.020	0.020	0.020

FIG.9 : EFFECT OF LENGTH/BEAM RATIO ON SPRAY (From [11])

7.2 Length of Forebody and Afterbody

A seaplane hull can usually be divided in two parts, namely the forebody, extending from the bow to the main step, and the afterbody, extending from the step to the stern. Looking at the effects of forebody or afterbody in this context makes only sense if L/b is kept constant. This investigation therefore amounts to determining the effects of varying step location on a hull with constant length/beam ratio. It will be assumed that the pivot point,-or center of gravity-, remains fixed relative to the step to eliminate inherent changes in trim. By evaluating the data presented in [3] it was possible to determine the effect of step location on resistance for nearly constant L/b. Fig. 10 shows the results. The influence apparently is small.

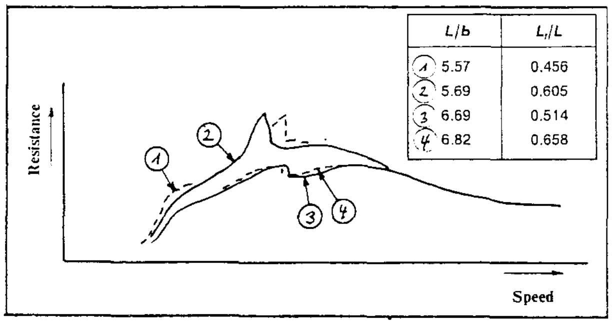


FIG.10: EFFECT OF STEP LOCATION ON RESISTANCE AT NEARLY CONSTANT L/B (From [3])

The effect of step location on porpoising will be most visible on the upper limit because moving the step aft, for example, will increase the sternpost angle which, in turn, will raise the trim angle at which the stern touches the water. Therefore, the upper limit will go up somewhat. The lower limit should not be affected at higher speeds (where the afterbody is out of the water) provided that the forebody hull lines do not change. Again, as was the case with L/b, it is difficult and maybe not meaningful to implement a pure shift in the step location without affecting any of the other hull shape parameters. The investigation as to the effects of L/b and L_f/L, ,-although very prominent and most visible parameters on a hull-, is therefore somewhat academic.

As far as spray is concerned it was found in [4] that low speed spray can be related to a forebody load factor defined by

$$k = \frac{\Delta_0}{w L_f^2 b}$$

If beam loading c_Δ and L/b are assumed constant it is possible to relate this factor to the spray generation associated with different step locations. Accepting k now as the driving coefficient for spray generation it becomes clear that in the case of varying L/b (with constant step location) it is really k and not K_2 that determines spray intensity. It is only that, with constant step location, K_2 and k vary in the same manner with L/b. Fig 11 shows an example how spray height varies with step location for different loadings.

Only one indication as to the effect of step location on impact loads has been found in the literature [5]. It shows a significant drop with increasing afterbody length (Fig. 12). Unfortunately, no further details on the test conditions were given which makes it difficult to comment on the results. One possible explanation could be the reduced sternpost angle which makes the hull run at lower mean trim thereby reducing the loads.

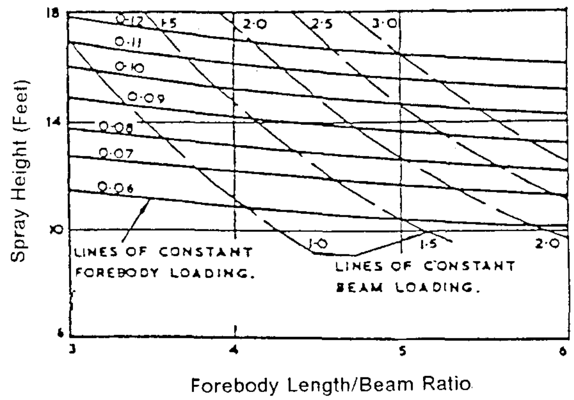


FIG.11: EFFECT OF FOREBODY LENGTH/BEAM RATIO, FOREBODY LOADING AND BEAM LOADING ON SPRAY HEIGHT (From [5])

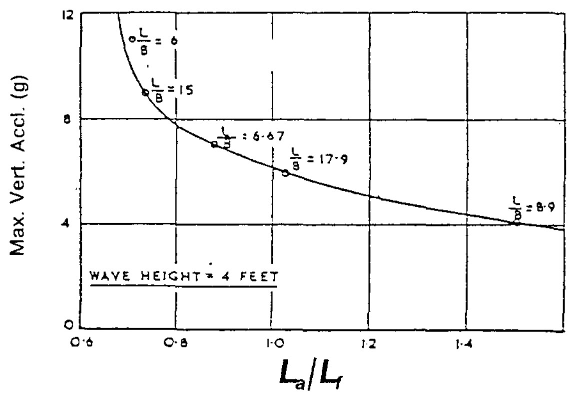


FIG.12: EFFECT OF STEP LOCATION ON MAXIMUM VERTICAL LANDING ACCELERATIONS (From [5])

7.3 Deadrise Angle at Step

Increasing the deadrise angle at the step means making the hull bottom a less efficient planing device. The hull will ride more deeply in the water and experience more frictional drag Fig 13 shows some examples taken from test data on plates and complete hulls. As can be expected the effect is most pronounced in the planing range.

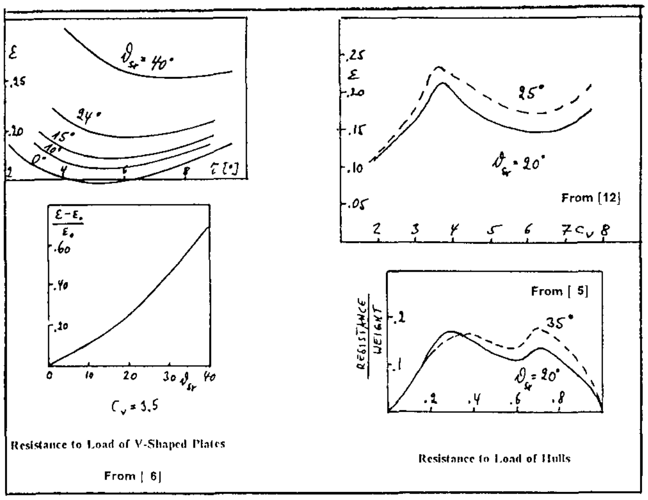


FIG.13: EFFECT OF DEADRISE ANGLE AT STEP ON RESISTANCE

Porpoising can also be affected by deadrise angle as shown in Fig.14 . In this case, apparently, there is an optimum around 20 degrees. Since deadrise angle at the step is not the only parameter that affects porpoising these results are not necessarily representative of other configurations. In any case, the effect may be pronounced.

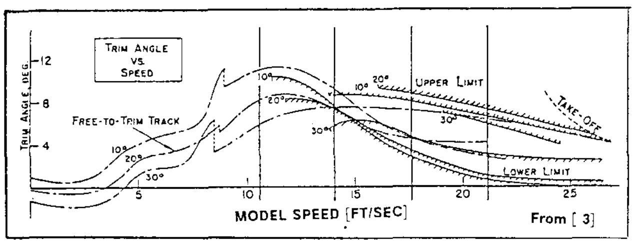


FIG.14: EFFECT OF DEADRISE ANGLE AT STEP ON PORPOISING (From [3])

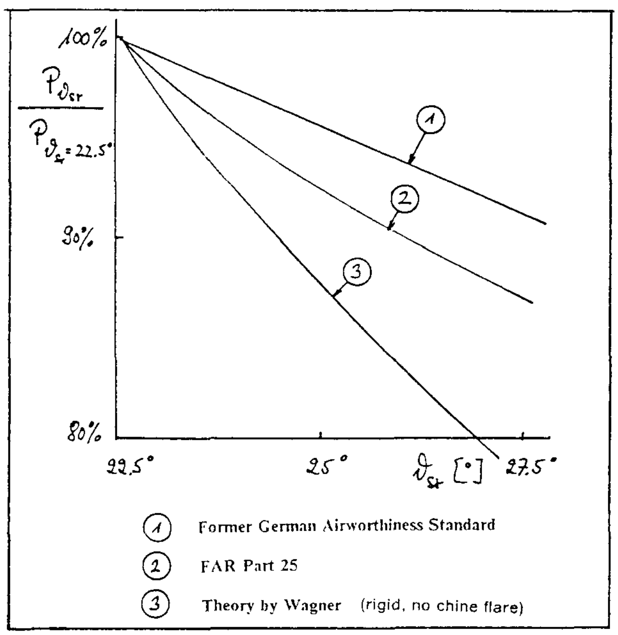


FIG.15: EFFECT OF DEADRISE ANGLE AT STEP ON IMPACT LOADS

Spray generation is reported in [6] to first increase with deadrise angle and then drop off again. The maximum was found to lie somewhere between 24 and 40 degrees. This effect is explainable in that at high deadrise angles lift is generated more and more by buoyancy forces rather than dynamic lift forces which reduces pressure gradients and hence spray formation.

Perhaps the most pronounced effect of deadrise angle is on impact loads. It can easily be visualized that impact forces must go down with increasing deadrise which has long been established by both theory and experiment. Fig. 15 shows as an example current and former airworthiness standards and a theory developed by Wagner [8]. The theoretical approach shows some deviation from the other two curves, possibly because it assumes a completely rigid body and no chine flare.

7.4 Forebody Warping

Warping in this context means change of deadrise along the forebody, usually expressed in degrees per beam. Forebody warping is not the only but probably the most important parameter to describe forebody lines. For reasons of porpoising the warping ahead of the main step should be constant (=linear increase in angle) to create straight buttock lines on the planing part of the bottom. Fig. 16 shows that, if warping is increased, the lower porpoising limit can be lowered considerably. This may not widen the distance from a certain trim track to the limit since the trim comes down also, but it may allow the hull to plane more efficiently in terms of resistance (optimum trim). On the other hand, overall resistance will go up somewhat due to the aforementioned increase in wetted area (see Fig. 17). Forebody warping is therefore an important parameter in hull design that requires careful consideration.

Spray is reported in [9] to reduce somewhat with increased warping, and impact loads may also be expected to reduce because of the increase in mean deadrise angle along the impacting forebody area.

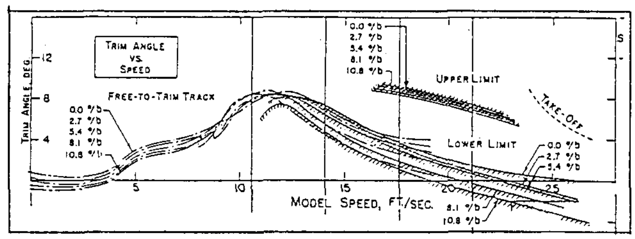


FIG.16: EFFECT OF FOREBODY WARPING ON PORPOISING (From [3])

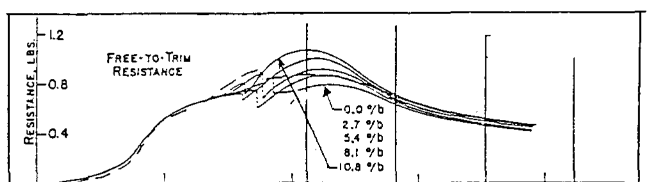


FIG.17: EFFECT OF FOREBODY WARPING ON RESISTANCE (From [3])

7.5 Step Height/Beam Ratio

The main step is an easy means to allow the hull to transit efficiently from the displacement range to the planing range. The flow is forced to break clear behind the step giving room to an air filled cavity which prevents unfavorable suction forces that could keep the hull from leaving the water. The main task of the step is therefore to provide adequate ventilation to the bottom side of the hull without compromising aerodynamic drag too much. The most simple step shape is the transverse step which has been investigated with all kinds of step heights ranging from 0 to 17% of beam width. Other step shapes have also been looked at, such as the vee-step for example (Fig. 6) with the aim of reducing aerodynamic drag while maintaining hydrodynamic qualities. However, the bulk of test data is for transverse steps.

Fig.18 illustrates the basic effects of step height on resistance. It can be seen that at low speeds resistance tends to go up with height because the afterbody, set here at constant angle, will move upwards and reduce the favorable pushing force associated with the crest under the stern (see chapter 1) at high speeds. Conversely, increased wetting can cause higher resistance on the after body with low step height. It is therefore desirable to have a small step height at low speed and a large step height at high speed. In reality, of course, step height will be a constant value which must be optimized in model tests.

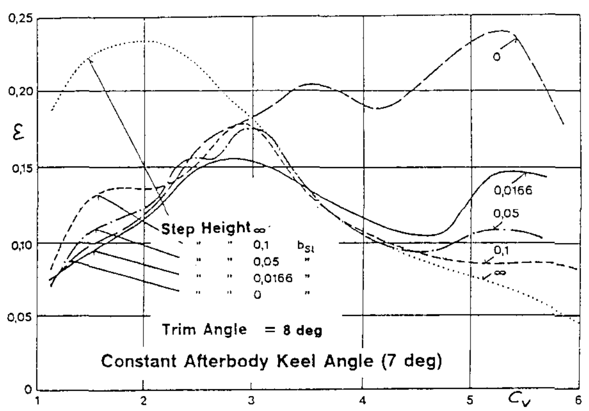


FIG.18: EFFECT OF STEP HEIGHT ON RESISTANCE (From [12])

It should be noted here that the effect of step height cannot really be decoupled from the afterbody keel angle . It is perhaps physically more reasonable to hold the sternpost at its original location and vary the afterbody angle with step height. The effects can be quite different under these assumptions. Here again, it becomes clear that the effects of hull shape parameters on hydrodynamics cannot be looked at in an isolated manner.

Porpoising is also affected by step height because inadequate ventilation can cause unsteady forces to develop on the bottom of the hull. Most pronounced is a phenomenon called 'skipping' which occurs at high speeds around the upper porpoising limit. It can usually be reduced by increasing step height[10]. The effect on porpoising limits again depend on the assumption whether the afterbody angle or the sternpost angle is held constant. Because the results are significantly different Fig. 19 shows both cases. As can be seen the change in upper limit porpoising is actually due to the changes in sternpost location.

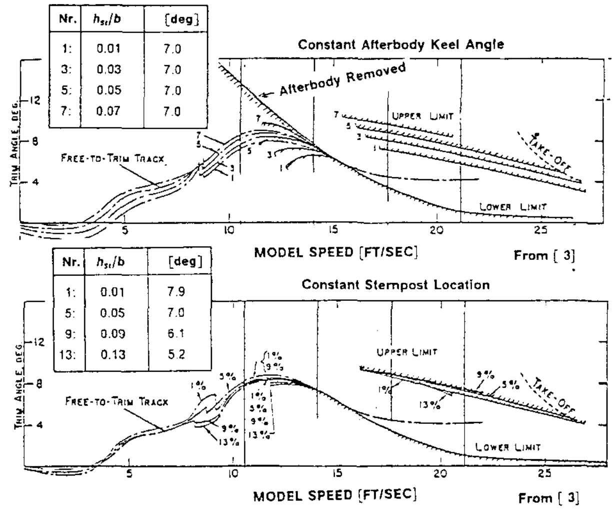


FIG.19: EFFECT OF STEP HEIGHT ON PORPOISING (From [3])

Spray formation and impact loads cannot directly be related to step height. However, other parameters changing with step height may have some effect.

7.6 Chine Flare

Most all seaplanes exhibit some sort of chine flare. Its main purpose is to divert the velocity spray away from the hull in a horizontal direction. If the flare deflects the water too much down as in Fig. 20c) it may rebounce from the surface which is undesirable. Type b) in Fig.20 is therefore commonly employed. Since chine flare is almost mandatory in terms of spray suppression not many tests have been carried out to evaluate the changes in hydrodynamic behaviour associated with it. In [9] it is reported that resistance is not much affected. On porpoising some effect may be there due to the change in deadrise from keel to chine. As far as impact loads are concerned it is obvious that flare will reduce the mean dead rise angle and hence increase loads by a certain amount.

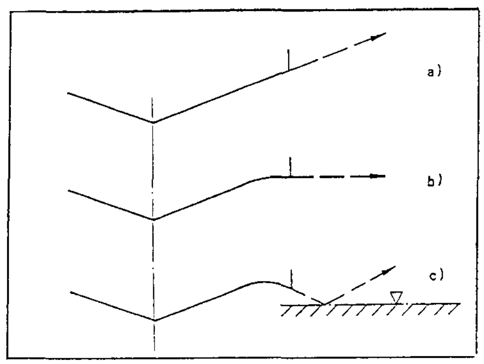


FIG.20: CHINE FORMS

7.7 Afterbody Keel Angle/Sternpost Angle

In this context afterbody keel angle (at constant step height) and sternpost angle can be used likewise to describe the physically more meaningful vertical location of the stern relative to the water surface.

Fig.21 shows that a pronounced effect on hump resistance exists. The reason is simply the change in trim that goes along with a change in sternpost height. The higher the sternpost is located the more up-trim is required to bring the stern down on the water to balance the forebody forces.

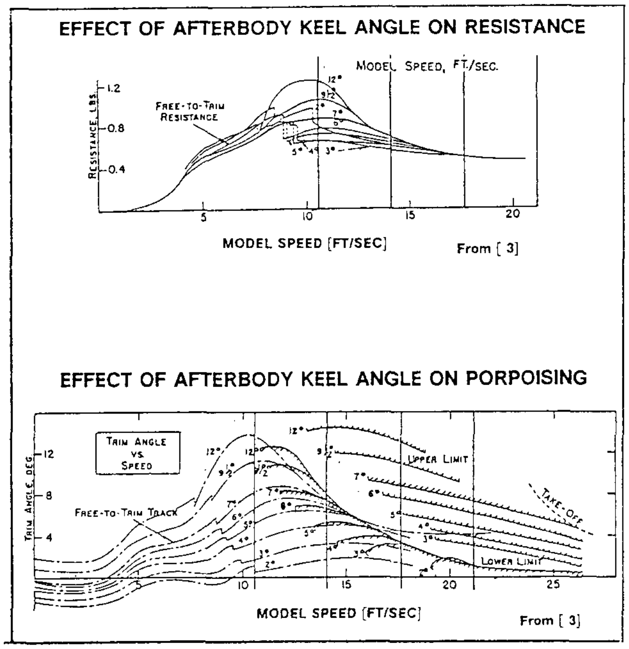


FIG.21: EFFECT OF AFTERBODY KEEL ANGLE ON RESISTANCE AND PORPOISING (From [3])

Porpoising is equally affected. Since upper limit porpoising is started by the interaction of the stern with the water the upper limit will move up if sternpost height increases. Lower limit porpoising, on the other hand, is damped by the stern. Therefore, the lower limit will move up too with sternpost location.

Spray formation will probably be larger for higher afterbody angles because of the higher trim and the higher pressures on the bottom of the hull.

The effect on impact loads is difficult to predict. It can be argued, perhaps, that a small afterbody angle will tend to keep the mean trim lower in waves thereby reducing the impact forces.

7.8 Afterbody Deadrise and Warping

The effects of deadrise and warping of the afterbody are not as pronounced as those of the forebody. However, it was found in [3] and [9] that warping will increase resistance which is due to the larger wetted area. At higher speeds the afterbody will lift out of the water and the effect will disappear.

Porpoising is affected only at the upper limit. Following results from [3] (Fig.22) a trend seems to exist towards increasing upper limits with increasing deadrise indicating that a certain amount of force and hence draft is required on the afterbody for porpoising to take effect.

Spray is not thought to be affected but impact loads may be inasmuch as the afterbody gets in touch with the waves. Considering the fact that forebody deadrise has a significant effect on impact loads it appears plausible that afterbody deadrise will work in a similar way.

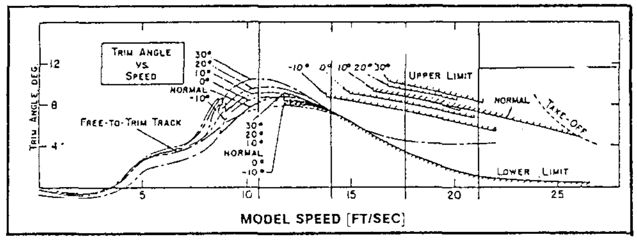


FIG.22: EFFECT OF AFTERBODY WARPING ON PORPOISING (From [3])

8. Theoretical Tools

Up until today seaplane design has primarily relied on model scale tests and experience from former projects. Theoretical methods have been rather limited in use. One reason is that seaplane development came almost to a complete halt in the mid sixties stopping also most development work on analytical tools. The other reason is the complexity of the flow: A hull is usually not a simple geometrical shape and it passes through different speed regimes with different types of flow. Particularly the interference effects between forebody and afterbody can prove difficult to predict.

Since it is hard to visualize that any analytical method could provide complete flow field calculations with reliable accuracy in the forseeable future, the most effective way to proceed will be to further develop mathematical or semi-empirical methods to a degree that allow useful predictions at least in certain parts of the flow regime. Some methods already exist ([8],[19],[20],[21]). It is promising also, that a lot of progress has been made in the past in the field of naval architecture which could perhaps be put to use in seaplane design as well.

Summary

After about 20 years of absence of seaplane design work a new interest in this field seems to surface now. It has led to a cooperation agreement between Dornier and Aeritalia with the aim of designing a new advanced-technology amphibious aircraft. A review of the existing experience in this field has been carried out to form the basis for the design of a hull with good hydrodynamic qualities and performance. Among other things, this requires a profound knowledge of how the hydrodynamic characteristics of a hull are related to hull geometry. It was found that the complex geometrical shape of a seaplane hull can be broken into a certain number of shape parameters which allow for a quick look comparison of different hulls. The parameters can be chosen in various ways depending on their physical significance and importance in hull design. In this paper the most commonly used ones are discussed with respect to their effects on resistance, porpoising, spray and impact loads. It is found that there are certain interactions among the parameters which makes it difficult to treat each one in an isolated manner. However, a number of well established trends exist which are illustrated by some examples from published model scale test results.

The theoretical treatment of hull hydrodynamics is still at an early stage due to the complexity of the flow and the absence of seaplane development work over the past twenty years.

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