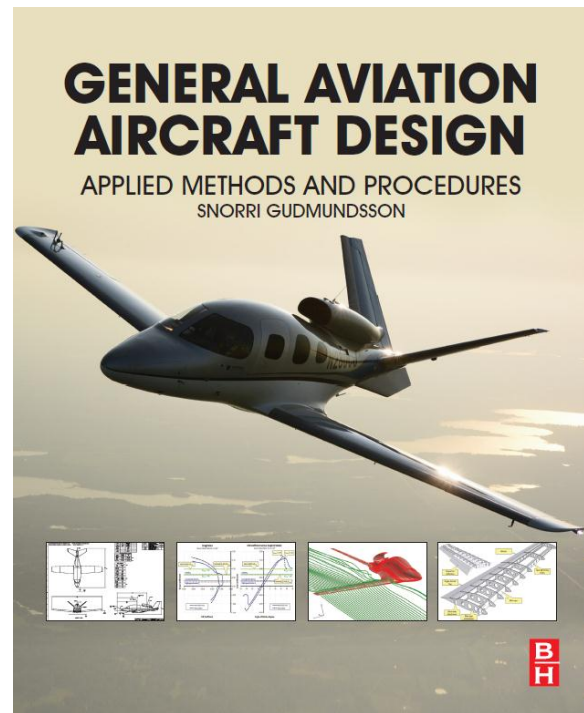# APPENDIX C3: Design of Seaplanes

This appendix is a part of the book **General Aviation Aircraft Design: Applied Methods and Procedures** by Snorri Gudmundsson, published by Elsevier, Inc. The book is available through various bookstores and online retailers, such as www.elsevier.com, www.amazon.com, and many others.

The purpose of the appendices denoted by C1 through C5 is to provide additional information on the design of selected aircraft configurations, beyond what is possible in the main part of Chapter 4, *Aircraft Conceptual Layout*. Some of the information is intended for the novice engineer, but other is advanced and well beyond what is possible to present in undergraduate design classes. This way, the appendices can serve as a refresher material for the experienced aircraft designer, while introducing new material to the student. Additionally, many helpful design philosophies are presented in the text. Since this appendix is offered online rather than in the actual book, it is possible to revise it regularly and both add to the information and new types of aircraft. The following appendices are offered:

C1 – Design of Conventional Aircraft
C2 – Design of Canard Aircraft
C3 – Design of Seaplanes (this appendix)
C4 – Design of Sailplanes
C5 – Design of Unusual Configurations

Figure C3-1: A Lake LA-250 Renegade, shown here during climb after T-O, is a popular option for amphibious aircraft. The large deflected flap on the horizontal tail is a hydraulically actuated trim tab used for slow speed operations only. It trims out the thrust effect of the highly mounted piston-propeller, improving its handling. (Photo by Phil Rademacher)

C3.1 Design of Seaplane Configurations

Seaplanes are specialized aircraft that can operate off water and, thus, are completely independent of regular land based airfields. Such airplanes appeal to many people who associate them with the ultimate freedom offered only by aviation; being able to fly into the wilderness and land on an obscure lake, far away from the hustle and bustle of modernity. Besides appealing to adventurers, such aircraft are also very useful from a utility standpoint. They are ideal for law enforcement or reconnaissance operations near coastal areas. It is a drawback that such aircraft call for a special pilot training to help avoid the number of possible dangerous scenarios in their operation and require specialized techniques and knowledge of water surface characteristics to make the takeoff and landing safe[1].

Additional operational issues include the maintenance of a rigorous corrosion protection necessary to ensure the longevity of the airframe and susceptibility to dings and damage to the hull as it slams into waves or floating debris, or when sliding up on a sandy beach, or banging against a dock. This requires a sturdy hull and for that reason, seaplanes are heavier than conventional aircraft. Moreover, as discussed later, the hull must also feature as specific shape for operations on water. Unfortunately, this shape is not aerodynamically efficient. Therefore, seaplanes also generate more drag and, thus, have both lower rate-of-climb and cruising speed than conventional aircraft of same power.

The term *seaplane* is used for an airplane designed to operate from water. Generally, there are three kinds of seaplanes; *floatplanes*, *flying boats*, and *amphibians*. A *floatplane* is effectively a landplane that has had its landing gear removed and replaced with pontoons that are partially submerged floats (see Figure C3-2). Such floats place the fuselage well above the water surface. A *flying boat* is a type of seaplane in which the occupants and freight is carried inside a fuselage specifically designed to function as a hull for operation on the water. For this reason they are also called *hull seaplanes*. An *amphibian* is an aircraft that features a hull-type fuselage for water operations and retractable landing gear to allow landings to be made on land (see Figure C3-3). Generally, floatplanes are thought to be easier to dock than hull-type seaplanes[2], as their wings sit higher and they don't have sponsons that tend to interfere with docking operations.
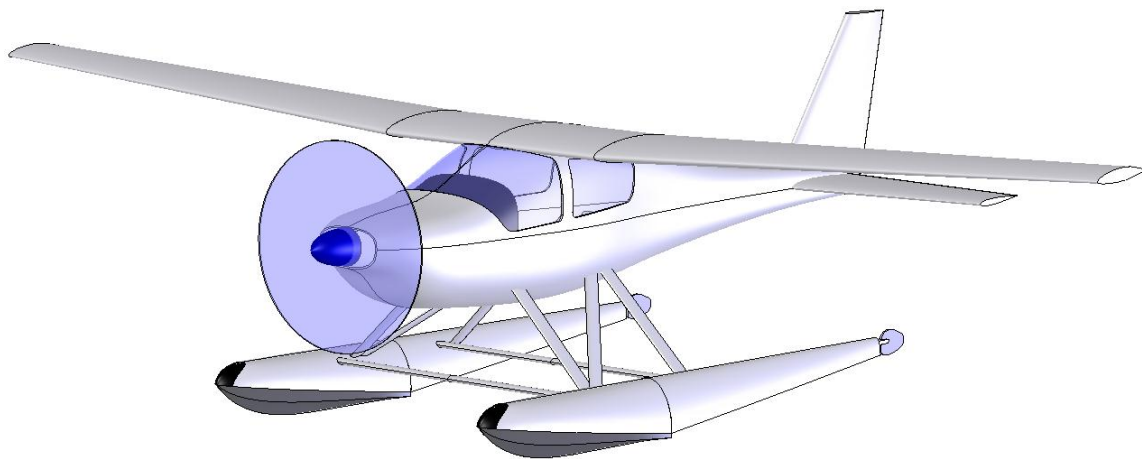

Figure C3-2: A floatplane configuration.

While the methods presented in this appendix mostly pertain to the design of classical seaplanes, the reader should be aware of other methodologies to T-O and land. A good example of a different approach is the LISA Akoya, a twin-seat amphibious LSA, which uses hydrofoils rather than conventional hull design. This method vastly reduces the drag of the configuration, allowing it to climb and cruise faster than otherwise possible.

Basic Requirements for Seaplanes

Table C3-1 summarizes a number of characteristics the designer should emphasize in the design of seaplanes. These are gathered from various sources.

Table C3-1: A Summary of Important Capabilities for Seaplane Design

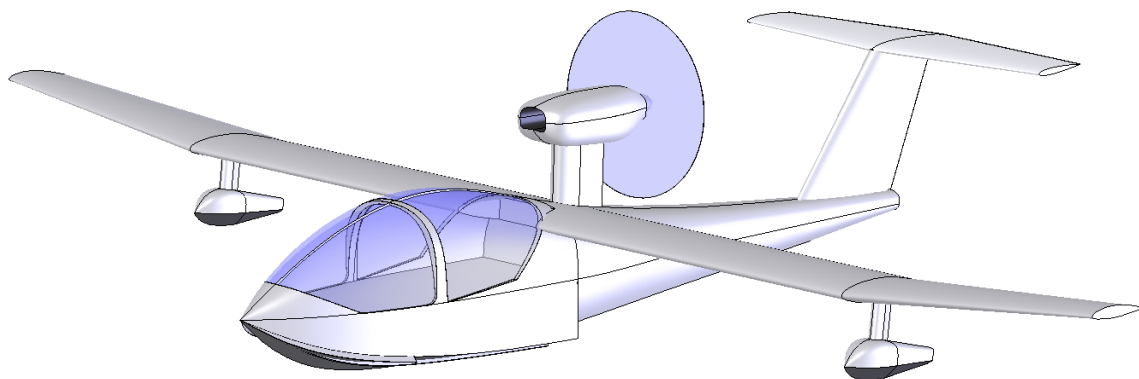|		
1.	Low speed operations on water	• The vehicle must be watertight. This is particularly important for doors, windows, and access panels that cover dry components. • The vehicle must possess transverse and longitudinal hydrostatic stability (at all speeds). • The vehicle must feature means to control the airplane when aerodynamic forces are small or absent, for instance water rudders. • If equipped with propellers, the rudder(s) should be placed in the propwash to aid with control on water. • The hull must be capable of allowing the airplane to be "beached."
2	High speed operations on water	• The hull must be capable of withstanding impact with various floating debris. • There must be provisions to protect the propulsive unit and the airframe from the spray of water. • The vehicle must be controllable in the water at all airspeeds from rest to lift-off speed.
4	T-O performance	• The vehicle should be capable of taking off in less than 60 seconds • Maximum T-O distance should be no greater than 10000 ft for a large seaplane, and preferably less than 5000 ft.
5	Cruise	• The vehicle should have as low drag as possible to improve its utility capability.
6	Landing	• It should be possible to land the vehicle without excessive impact forces to the airframe. • It should not generate excessive water spray upon touch-down and while on the step. • The vehicle must be controllable in the water at all airspeeds from touch-down speed to rest. • The cockpit design should allow the pilot good visibility to the water to help with the judging of altitude.

Figure C3-3: An amphibious configuration.

A number of GA and homebuilt seaplanes that the aspiring designer should be aware of and inspect for good and bad ideas are presented in Table C3-2.

Table C3-2: Selected Seaplanes and Amphibians.

Configuration	Example Aircraft
Amphibian	Anderson Kingfisher, Osprey 2, Spencer S-12-E Air Car, Taylor Coot Amphibian, Thurston TA16 Trojan, Volmer VJ-22 Sportsman, Airmax Seamax M22, Mermaid M6, Icon A5, Colyaer S100 Freedom, AeroVolga LA-8, SeaRey, Piaggio P136, LISA Akoya.
Flying boat	Short Sunderland, Consolidated PBY-5 Catalina, Dornier Do J Wa, Dornier Libelle, Do-18, Do-24, Dornier Seastar, Dornier S-Ray 007, Spratt Control Wing.
Floatplane	A large number of options, including various Cessna and De Havilland of Canada built aircraft.

C3.1.1 Basics of Seaplane Hydrodynamics

The Archimedes Principle

The principle is named after Archimedes of Syracuse (287-212 BCE), who first discovered this law. The law states that any object, entirely or partially immersed in a fluid, experiences a force of buoyancy equal to the weight of the fluid displaced by it. The law ignores surface tension (capillarity) acting on the body. The Archimedes Principle leads to several mathematical results of interest.

The first result of interest is the *apparent weight of objects* submerged in a liquid. Mathematically, this can be written as follows:

$$W_a = W_{object} - F_{df}$$

(C3-1)

Where;
W_a = Apparent weight of the object as measured in the liquid.
W_{object} = True weight of the object in reference fluid (e.g. air) or vacuum.
F_{df} = Weight of the displaced fluid (liquid or gas).

The second result of interest is the *buoyancy force*, F_{buoy} also denoted by Δ, which can be estimated from:

$$F_{buoy} = \rho_W \cdot g \cdot V\!\!\!/ = \Delta$$

(C3-2)

Where;
g = Acceleration due to gravity.
$V\!\!\!/$ = Volume of the object (which is the volume of the fluid displaced).
ρ_W = Mass density of the displaced fluid (liquid or gas).

Density of pure water is 62.5 lb_f/ft^3 or 9807 N/m^3 (1000 kg/m^3). Density of seawater is 63.8 to 64.7 lb_f/ft^3 or 10003 to 10150 N/m^3 (1020-1035 kg/m^3), depending on the source. Note that if the object is floating, the volume, $V\!\!\!/$, is the submerged volume only. If the object is fully submerged, the volume is its entire volume.

This leads to the third result of interest; *floating tendency* as shown below:

$$F_{net} = mg - \rho_W g V\!\!\!/$$

(C3-3)

Where;
m = Mass of the object.

If $F_{net} > 0$ the object will sink (weight greater than buoyancy). If $F_{net} < 0$ the object will float (weight less than buoyancy). The expression can be used to estimate volume for any watercraft (including seaplanes), as well as balloons and airships. When the volume is filled with a different type of gas, such as in the case of Helium balloons or airships, the expression must include the effect of the gas, i.e.:

$$F_{net} = mg + (\rho_1 - \rho_2)g V\!\!\!/$$

(C3-4)

Where; ρ_1 = Mass density of the fluid used to displace the heavier fluid (e.g. Helium).
                ρ_2 = Mass density of the displaced fluid (e.g. air).

Note that the density of the fluid used to displace the heavier fluid will depend on its pressure inside the volume. The greater the pressure, the greater is the density. This can be estimated using the *Ideal Gas Law*, repeated here for convenience:

$$\rho = \frac{p}{RT}$$ (C3-5)

Where p is the pressure of the corresponding gas, R is the specific gas constant, which is 1716 ft·lb$_f$/(slug·°R) or 287.058 J/(kg·K) for air, and T is the temperature of the gas.

The fourth result of interest is *hydrostatic weighing*, which allows the density of an object or a liquid to be determined by measuring its weight in and out of the liquid. This can be done without a prior knowledge of its volume. This is achieved using the following expression.

$$\frac{\rho_{object}}{\rho_{liquid}} = \frac{W_{in\ air}}{W_{in\ air} - W_{in\ liquid}}$$ (C3-6)

Where; $W_{in\ air}$ and $W_{in\ liquid}$ = Weight of object measured in air and in liquid
                ρ_{object} = Mass density of the object.
                ρ_{liquid} = Mass density of the liquid.

Hull Speed
All bodies that move in water generate substantially greater hydrodynamic drag than they do in less viscous fluids such as air. In accordance with the *Archimedes Principle*, a body, entirely or partially, immersed in a fluid experiences a force of buoyancy equal to the weight of the fluid it displaces. In order to move, this fluid must be forced out of the way. This creates water waves that emanate from its bow and stern and are, sensibly, called bow and stern waves.

As an example, and as is revealed by observing actual boats, the length of these waves is initially only a fraction of the length of the hull. However, with an increased speed, they grow in length. At a specific speed, called the *hull speed*, the wavelength equals the length of the hull[3]. This is accompanied by a substantial increase in the hydrodynamic drag because the hull pitches up as it attempts to ride on top of the bow wave. If not correctly shaped, this inflicts a serious hurdle for further acceleration of the hull, often making the hull speed the maximum speed that can achieved (see a schematic of the condition in Figure C3-4).

Speedboats circumvent the hull speed problem by shaping the hull with a flat plane that allows hydrodynamic lift to be generated. This lift is known as *hydroplaning* and partially lifts the boat out of the water, reducing the magnitude of the wave system and, thus, the drag. This allows speedboats to accelerate to speeds well above their hull speed. Similar hull geometry is designed into a seaplane or the floats of a float plane to allow it to accelerate to liftoff speed. A formula to calculate the hull speed of a vessel is presented below in interest of completeness, but its derivation is beyond the scope of this text.

Hull speed: $V_{hull} \approx K_{hull} \sqrt{\text{Hull Water Length}}$ in knots   (C3-7)

Where $K_{hull} \approx 1.3$ to 1.5 knots/ft$^{\frac{1}{2}}$ or 4.5 to 5.0 km/(h·ft$^{\frac{1}{2}}$) with the hull water length in ft or m, respectively. The hull of a seaplane is shaped not unlike that of a speedboat to generate a large hydrodynamic lift even as the vehicle moves relatively slowly in water. The lift is created as the hull deflects water downward. Once a certain speed is

exceeded, the seaplane will lift out of the water and will thereafter be mostly supported by hydroplaning. This dramatically reduces the hydrodynamic drag and ultimately allows the airplane to accelerate to lift-off speed.
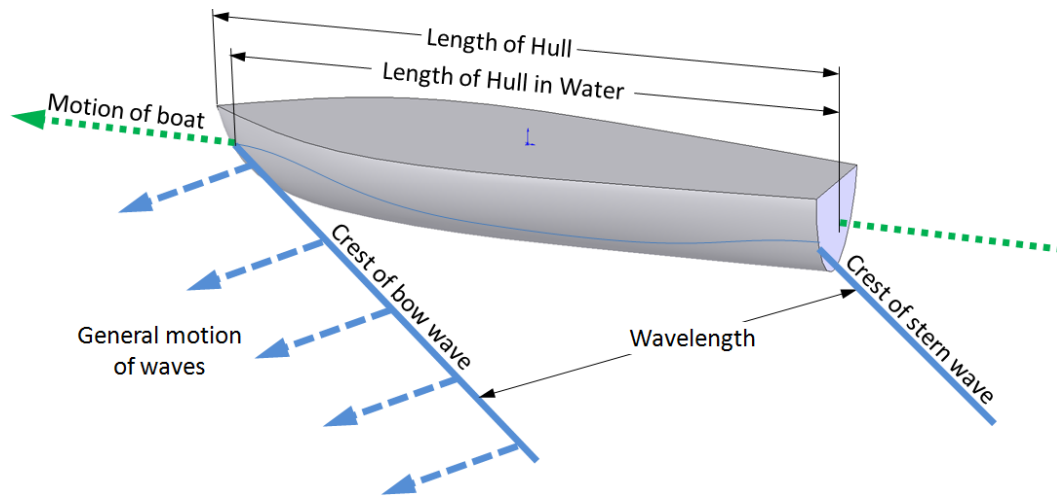

Figure C3-4: A schematic showing a hull moving in water with the bow and stern waves coinciding, constituting *hull speed*.

The primary difference between the hull of the seaplane and a speedboat is that the seaplane features a discontinuity in the bottom hull, not present in speedboats. This discontinuity is called a *step* (see Figure C3-11) and does two things: (1) Once the aircraft begins to hydroplane, the surface area in contact with the water reduces substantially, further reducing the hydrodynamic drag, and (2) once near liftoff speed it allows the airplane to rotate. Pilots call it to "get onto the step" when the aircraft begins to hydroplane. Selected details from the lower surface of a seaplane is shown in Figure C3-11 and discussed below.

Hydrostatic Stability

Hydrostatic stability refers to the tendency of a floating vessel to return to its *at-rest* attitude, once forcibly tilted one way or the other. Any such vessel must have hydrostatic stability about two axes; the *longitudinal* and *transverse* (see Figure C3-5). The former refers to the axis along its length (from stern to bow) and the latter to an axis normal to the former, as shown in the figure. Both are normal to a vertical axis that goes through the *Center of Gravity* (CG) of the vessel. The CG has already been discussed at length and it is assumed here that the reader is familiar with methods to determine it.

Center of Buoyancy

Before proceeding further, a couple of concepts must be defined. The *Center of Buoyancy* (CB) is the centroid of the hydrostatic pressure force acting on the submerged part of a vessel. Determining the location of the CB is a fundamental problem that must be solved before a vessel can be declared stable or unstable. The CB of any planar cross-section can be found using the expression below, where the terms are defined in Figure C3-6. The location of the Center of Buoyancy is found from:
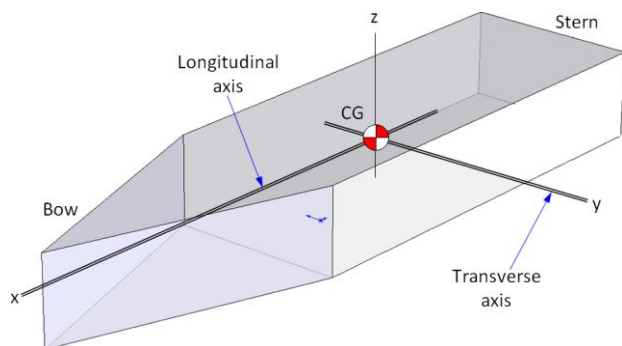

Figure C3-5: A basic floating vessel configuration.

$$y_{CB} = \frac{\int y \cdot z(y) dy}{\int z(y) dy} \qquad (C3\text{-}8)$$

$$z_{CB} = \frac{\int z \cdot y(z) dz}{\int y(z) dz} \qquad (C3\text{-}9)$$

Note that the 3-dimensional location of the CB for ships, boats, floats, and seaplanes is generally determined by estimating it in two planes; the x-z and y-z planes in Figure C3-5. This is only permissible if the body has a plane of symmetry, such as the x-z plane.
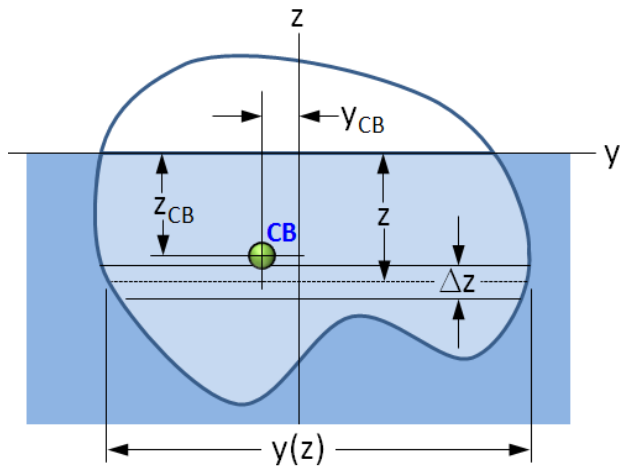

Figure C3-6: A 2-dimensional submerged body.

EXAMPLE C3-1:
Find the CB of the cross-sectional area in Figure C3-9.

SOLUTION:
We can see that we only need to apply Equation (C3-8) to one half of the geometry, thanks to its symmetry. We can also see that when z = 0, then y = 5 and when z = -10, then y = 0. This means that the equation for the side of the area is simply y = (z/2 + 5). Inserting these into Equation (C3-8) yields:

$$z_{CB} = \frac{\int z \cdot y(z) dz}{\int y(z) dz} = \frac{\int_{-10}^{0} z \cdot (z/2 + 5) dz}{\int_{-10}^{0} (z/2 + 5) dz}$$

$$= \frac{\left. \frac{z^3}{6} + \frac{5z^2}{2} \right|_{-10}^{0}}{\left. \frac{z^2}{4} + 5z \right|_{-10}^{0}} = \frac{83\frac{1}{3}}{-25} = -3\frac{1}{3} \text{ ft}$$

Figure C3-7: A triangular cross-sectional area used to demonstrate how CB can be calculated.

Metacenter and Metacentric Height
The *Metacenter* is an imaginary point whose determination is imperative to determining if the vessel is stable or unstable. Consider Figure C3-8, which shows the cross-section of a vessel, initially at rest (left), and then disturbed so it tilts through an angle θ (right). The rotation moves the *Center of Buoyancy* (CB) sideways, a distance Δy away from its at-rest position, and generates a restoring moment in the process (see Figure C3-8), whose magnitude is given by:

Restoring moment:
$$M_R = W \cdot \Delta y = \rho_W \theta \int_A y^2 dA = \rho \theta I_{zz} \qquad (C3\text{-}10)$$

Where: A = Cross-sectional area
I_{zz} = Second area moment (aka second moment of area) of the submerged cross-section
ρ_W = Density of the liquid in which the body is submerged

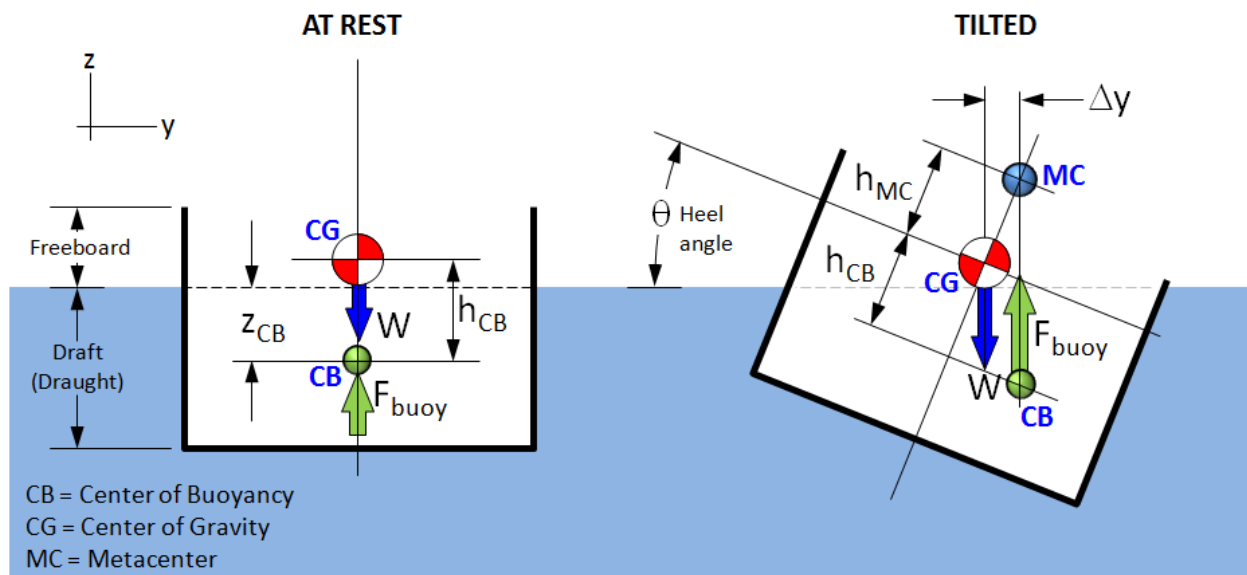**Figure C3-8: Fundamentals of hydrostatic stability. As the body is tilted, the center of buoyancy shifts sideways due to the change in the submerged geometry. The off-set force F$_{buoy}$ generates a restoring (or righting) moment.**

A derivation of Equation (C3-10) is provided in Reference 4. Note that the relation holds as long as θ has a sufficiently small value. The second area moment, I_{zz}, is taken about the z-axis and only includes the part of the body that is submerged.

The intersection of a vertical line drawn through the CB and the rotated line that goes through the CG is the *metacenter* (again, see Figure C3-8). If the metacenter is above the CG, its value is *positive*. This means the vessel has a tendency to right itself and return to its at-rest attitude. Conversely, a *negative metacenter* implies the vessel is unstable and will rotate until it finds another stable orientation. For the operators of unstable ships and seaplanes, this pretty much means upside down; a highly undesirable orientation. Figure C3-8 should help the reader visualize that once a certain tilt angle is achieved, the arm denoted by Δy may begin to shorten again. This means that once a certain tilt angle is achieved, the metacenter will end up below the CG; the vessel has become unstable.

Reference 4 also derives the following handy expressions:

Shift distance of CB:
$$\Delta y = \rho_W \theta \frac{I_{zz}}{W} = \theta \frac{I_{zz}}{V} \approx (h_{CB} + h_{MC})\theta \qquad \text{(C3-11)}$$

Where:
h_{CB} = Distance between CB and CG
h_{MC} = Distance between MC and CG
V = Displaced volume of the liquid (= W/ρ)

Metacentric height:
$$h_{MC} = \frac{\Delta y}{\theta} - h_{CB} = \frac{I_{zz}}{V} - h_{CB} = \rho_W \frac{I_{zz}}{W} - h_{CB} \qquad \text{(C3-12)}$$

Metacentric Heights for Seaplanes
Diehl[5] states it has been established empirically that seaplanes have good hydrostatic stability as long as the transverse and longitudinal metacentric heights are similar. However, the transverse metacenter should not be larger than the longitudinal one. Satisfactory stability is achieved if the metacentric height is given by:

$$h_{MC} = K\sqrt[3]{W_0} \tag{C3-13}$$

Where: K = Constant that depends on the type of seaplane
          W_0 = Gross weight of the seaplane in lb_f

Values for the constant K are given in Table C3-3. The metacentric height for a flying boat with wingtip floats, such as the 35000 lb_f Consolidated PBY-5 Catalina should be around 32.7 ft. The value for a 2690 lb_f Lake LA-4-200 Buccaneer should be around 13.9 ft.

Table C3-3: Properties of the Two Models

Type of Seaplane	Constant K
Flying boats with sidefloats	0.75
Flying boats with wingtip floats	1.0
Floatplanes with one main float	1.2
Floatplanes with two main floats	1.4

Diehl is also the author of NACA TN-183[6], in which a number of results of interest to the designer of seaplanes are presented. The reference suggests that for single or twin float seaplanes, the transverse and longitudinal metacentric heights should be designed to match the following values:

Transverse metacentric height
(for twin floats only):

$$h_{MC_T} = \frac{19.5 \cdot B \cdot L \cdot s^2}{W_0} \tag{C3-14}$$

Longitudinal metacentric height
(for single and twin floats):

$$h_{MC_L} = \frac{2.10 \cdot n \cdot B \cdot L^3}{W_0} \tag{C3-15}$$

Where: B = Beam (width of float) in ft   s = Spacing between floats (center-to-center) in ft
          L = Float length in ft W_0 = Gross weight in lb_f
          n = Number of floats

Estimating Float Geometry
Note that using the metacentric height obtained using Equation (C3-13) with Equation (C3-14) can be used to estimate a suitable spacing (s) between the floats of twin-float seaplanes, given known length (L) and beam (B). This leads to the following expression:

Recommended spacing for twin floats:

$$s = \frac{0.2679 \cdot W_0^{2/3}}{\sqrt{L \cdot B}} \tag{C3-16}$$

The units are in ft and the value for K from Table C3-3 is 1.4. Similarly, a recommended float length (L) which results in satisfactory static stability can be estimated using Equation (C3-13) with Equation (C3-15), given the beam (B). The resulting expression is shown below:

Recommended floats length:

$$L = 0.7809 W_0^{4/9} \left[\frac{K}{nB} \right]^{1/3} \tag{C3-17}$$

EXAMPLE C3-2:

Consider the vessel of Figure C3-9. Determine the following parameters if it is placed in pure water:

(a) Maximum buoyancy force.
(b) Center of buoyancy when completely submerged.
(c) Find the draft if it weighs 300 lb$_f$, where the weight is applied at the CG?
(d) Determine the transverse meta-center. Is it stable?
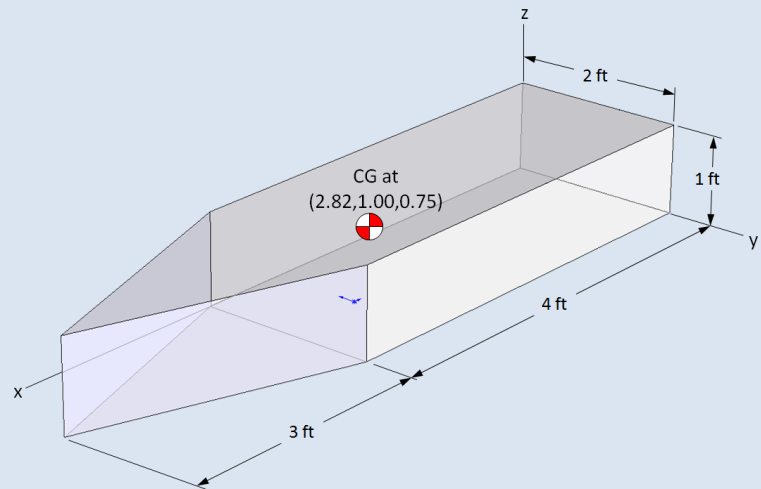(e) Determine the longitudinal meta-center. Is it stable?

SOLUTION:

(a) The maximum buoyancy force is the weight of the water the vessel can displace – in other words; the density of water (62.5 lb$_f$/ft^3) times the volume, denoted by V, of the vessel. This is calculated as follows:

Figure C3-9: A hypothetical vessel used for Example C3-2.

$$V = 4 \times 2 \times 1 + \tfrac{1}{2} \times 3 \times 2 \times 1 = 11\,\text{ft}^3 \quad \Rightarrow \quad F_{max} = \rho_W V = 62.5 \times 11 = 687.5\,\text{lb}_f$$

(b) By inspection, the transverse CB is at the plane of symmetry at the coordinates $(y_{CB}, z_{CB}) = (1, 0.5)$ ft. The x-coordinate of the longitudinal CB, on the other hand, has the same coordinates as the centroid of the combined rectangular and triangular regions in the x-y plane. Taking advantage of the simplicity of the geometry, this can be calculated as follows (where the subscript 1 refers to the rectangular area and 2 to the triangular one). Note that the centroid of the rectangle is located at $x_{C1} = 2$ ft and the triangular one at $x_{C2} = 4+3/3 = 5$ ft:

$$x_{CB} = \frac{x_{C_1} \cdot A_1 + x_{C_2} \cdot A_2}{A_1 + A_2} = \frac{(2) \cdot (2 \times 4) + (5) \cdot (\tfrac{1}{2} 2 \times 3)}{8 + 3} = \frac{31}{11} \approx 2.82\,\text{ft}$$

Therefore, when fully submerged, the CB is located at: $(x_{CB}, y_{CB}, z_{CB}) = (2.82, 1, 0.5)$ ft

(c) Due to the simplicity of the geometry, it is easy to see that the draft is W/F$_{max}$ = 300/687.5 = 0.436 ft (i.e. the bottom 0.436 ft will be submerged). Note that this means that the CB has a different location in space (here it is about ½ of 0.436 ft).

(d) Since the CG is conveniently placed above the CB (see Figure C3-9), which means the vessel will pretty much be oriented without any tilting. Therefore, the longitudinal metacenter can be found from Equation (C3-12), where the second area moment of the submerged cross-section in the plane of symmetry. Noting that the cross-section is rectangular, the I$_{zz}$ can be found from the standard expression:
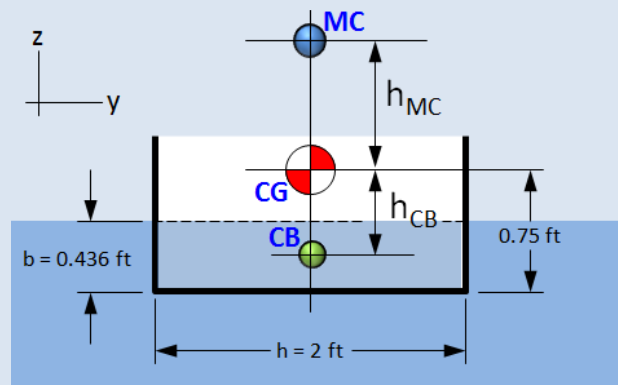

Figure C3-10: The vessel cross-sectional view, showing the draft of 0.436 ft at a weight of 300 lb$_f$.

$$I_{zz} = \frac{bh^3}{12} = \frac{0.436 \times 2^3}{12} = 0.2907 \text{ ft}^4$$

The distance between the CG and the CB, h_{CB}, can be obtained by inspection and is given by:

$$h_{CB} = 0.75 - \frac{0.436}{2} = 0.532 \text{ ft}$$

Therefore, the metacentric height of the transverse metacenter can be found as follows, using Equation (C3-12):

$$h_{MC} = \rho \frac{I_{zz}}{W} - h_{CB} = (62.5)\frac{0.2907}{300} - 0.532 = -0.471 \text{ ft}$$

The vessel is transversely <u>unstable</u>– the CG is too high above the CB.

(e) Finally, determine the longitudinal metacenter. First, calculate the second area moment again, this time using the length of the vessel (along the x-axis) as the value of h. Again, the cross-section in the plane-of-symmetry is rectangular, so I_{zz} is easily determined as it was in part (d):

$$I_{zz} = \frac{bh^3}{12} = \frac{0.436 \times 7^3}{12} = 12.46 \text{ ft}^4$$

The metacentric height of the longitudinal metacenter is determined as shown below, again using Equation (C3-12):

$$h_{MC} = \rho \frac{I_{zz}}{W} - h_{CB} = (62.5)\frac{12.46}{300} - 0.532 = +2.064 \text{ ft}$$

As one would expect, the longitudinal metacenter is well above the CG, so the vessel is longitudinally <u>stable</u>.

Frictional Resistance of Submerged Surfaces

The most basic expression used to calculate the frictional resistance of a plank in tow, is that of William Froude (1810-1879). Froude experimentation led to the discovery that speed and surface properties are fundamental to the magnitude of the resistance, formulated below[7]:

Froude's liquid resistance formula: $\boxed{R_{Froude} = f \cdot S_{wet} \cdot V^n}$ (C3-18)

Where: f = Coefficient of frictional resistance
S_{wet} = Wetted area in ft²
V = Speed in knots
n = Constant, dependent on surface quality.

The term f varies depending on surface quality. For surfaces ranging from 2 to 20 ft in length, it can be taken to be 0.012 to 0.010 for smooth surfaces, 0.0231 to 0.0137 for surface quality resembling fine grit sandpaper, 0.0257 to 0.0152 for medium grit sandpaper, and 0.0314 to 0.168 for coarse type sandpaper. It is acceptable to interpolate linearly for most applications. The term n is usually close to 2, so assuming n = 2 is accurate enough for most applications. This way, the coefficient of frictional resistance for a smooth 10 ft long surface can be estimated using a parametric representation as shown below:

$$f = \left(\frac{20-L}{20-2}\right)0.012 + \left(1 - \frac{20-L}{20-2}\right)0.010 = 0.011$$

Therefore, a 10 ft long surface of 20 ft² wetted area moving at 30 knots will generate 0.011 x 20 x 30² = 198 lb$_f$ of resistance.

C3.1.2 Operation of Seaplanes on Water

Pilot operation of seaplanes is beyond the scope of this text. Common techniques are described in References 1 and 8. Both reveal there is a large number of important, albeit, easily overlooked features that must be kept in mind when designing seaplanes. Some have to do with the low and high speed operation of the vehicle on water, others with the structural and hydrodynamic properties of the hull or floats. The designer must be aware of other important topics the in order to properly design controls and structure for such airplanes. One such topic is regulations. The nature of seaplane operations requires special rules to be adhered to. Most of them are set forth in 14 CFR Part 1, 61, and 91. Generally, nautical terms are used when considering seaplanes, so the designer may want to become familiar with some of them. For instance, *port* and *starboard* are used for left and right, *windward* and *leeward* for upwind and downwind sides of a body, and so on. The nose of the airplane is called a *bow* and the bottom of the empennage is the *stern*.

Consider Figure C3-11, which shows a number of features that are present on seaplane hulls. The hull always features a *keel* to help guide the vehicle along a straight line by resisting motion to the sides. As stated earlier, a *step* is the discontinuity in the bottom of the hull that reduces hydrodynamic drag and allows the airplane to rotate. It does so by introducing a layer of air between the wake and the rearstep. Sometimes the keel features a short but structurally robust plate, called a *skeg*, which extends a few inches beyond the step. Its purpose is to prevent the plane from tipping back onto the tail when sitting on floats on land. It is more commonly present on floatplanes. A *chine* refers to the seam where the side of the hull joins the bottom. Its purpose is to direct the water spray away from the hull and contribute to hydrodynamic lift. Between the keel and chine are structural members called *sister keelson*. Their purpose is to add strength to the hull and provide additional guidance tendency similar to that provided by the keel. Sister keelsons can often be found on floats, where they allow the airplane to sit on the floats on land. The *spray rails* are mounted along the chines to reduce the amount of water spray that can hit the propeller. Water spray can be very destructive to a propeller – in particular at high RPMs.

Figure C3-12 shows a floatplane and identifies typical components of the floats. The *forward* and *aft spreader bars* ensure the floats do not separate during water operations. They tend to react the separation force in tension. The system of *struts* transfer water loads into the fuselage hard points. The floats must feature *retractable water rudders* to allow the pilot to control the airplane in water. They must be retractable, because they get in the way of advanced operation on water, such as when approaching a dock by reversing in strong wind and other docking operations[8].

Landing a seaplane can be tricky and the technique depends on the condition of the surface of the water. Generally, pilots have to contend with three types of water conditions; a *normal rippled water*, *glassy or mirror-like water*, and *rough water*. Each calls for dissimilar landing technique, again, emphasizing the need for specialized pilot training. For instance, and contrary to intuition, the glassy landing is challenging because the pilot cannot use wave height of the water for visual clues as to how high above water the airplane is. For such reasons, it is prudent to provide good visibility in a new seaplane design.

The operation of seaplanes on water, in particular saltwater, requires a rigorous adherence to corrosion protection. This is necessary for all aluminum seaplanes, as saltwater will corrode through the material in a short amount of time if left unprotected. Aluminum should be covered using materials such as polychromate primer or zinc chromate. Regular inspections should be mandated, particularly in hard to see areas that are subject to standing water. Also, the hull and sponsons should feature holes with removable plugs to allow water that may collect during normal water operation to leak out.
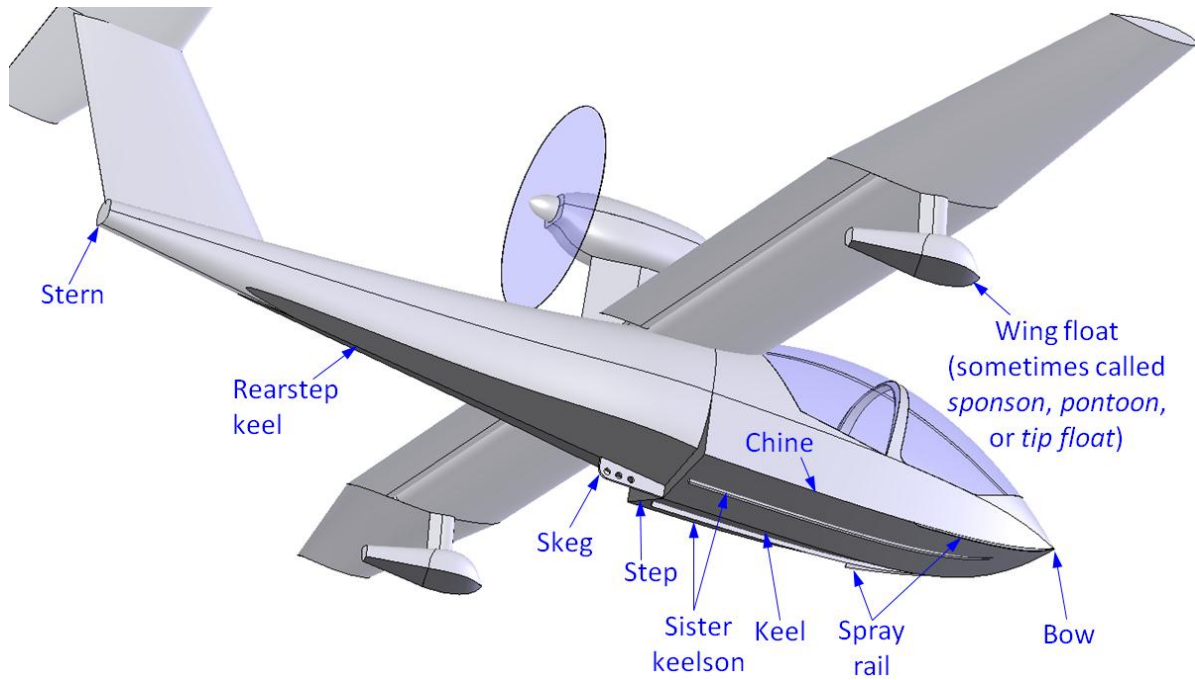
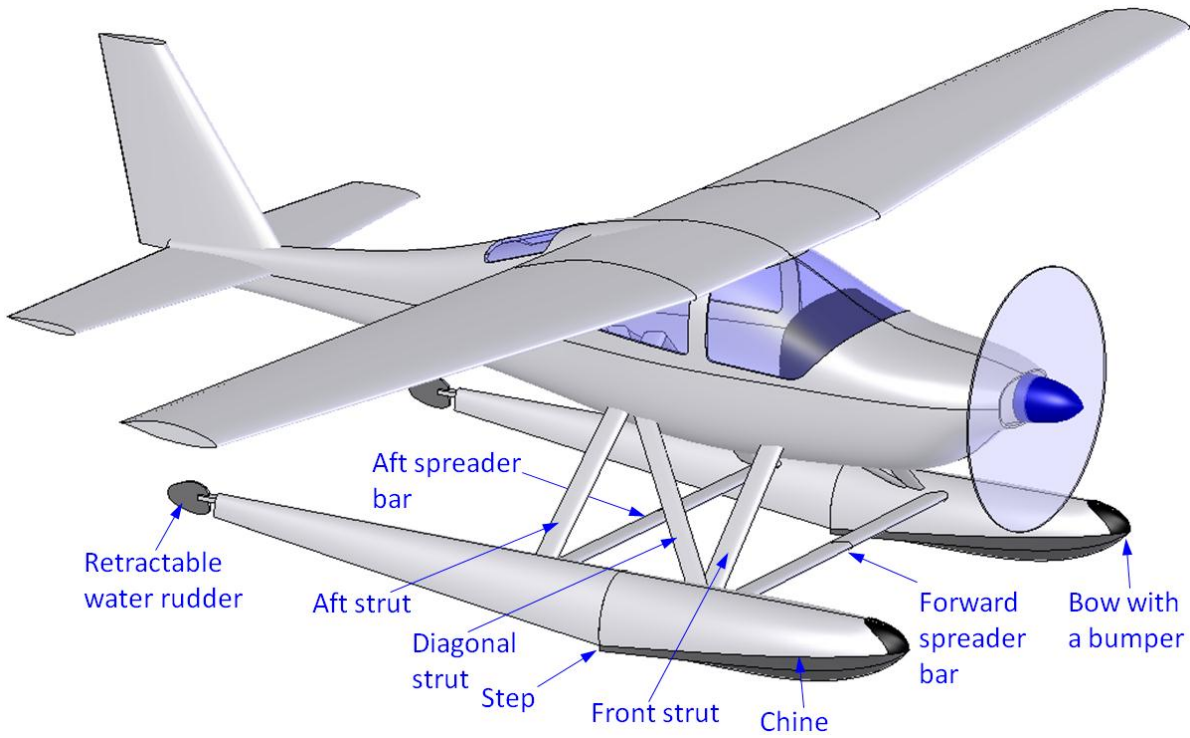**Figure C3-11: A schematic showing important details on the lower surface of a seaplane.**

Figure C3-12: A schematic showing important details on the lower surface of a seaplane.

C3.1.3 Seaplane Design Tips

Figure C3-13 shows a number of cross-sections for a conventional seaplane hull, indicating complexity not present in ordinary fuselages. Stinton[9] and Thurston2 list a number of helpful design tips that any hull design seaplane must offer. Faure8 discusses floatplanes from the standpoint of the experienced pilot and offers a great insight into how such airplanes are operated. While aimed at pilots, it is highly recommended that novice seaplane designers read such text for increased awareness. Nelson[10] and Wood[11] also offer great many tips for seaplane design, although these references may be hard to find nowadays. Tips from many of these have been collected and are presented below for convenience:

Buoyancy and hydrostatic stability
Buoyancy is achieved by ensuring the volume of the hull will displace enough water to support the weight of the aircraft. The designer must ensure the interaction between the CG and the metacentric height of the hull provides a restoring moment. This is accomplished on floatplanes by separating the floats as shown in Figure C3-14, where the angle θ ranges from 45°-55°, or by using Equation (C3-16). The resulting ratio w/h is thus approximately 1.4-1.7. On floatplanes, this is usually done by mounting special floats near the tip of the wing (called tip floats, pontoons, sponsons, or auxiliary floats). However, the same effect is also achieved by widening the lower part of the airplane in order to raise the metacentric height. The Icon A5 is an example of such an aircraft.

Low water-drag and high hydrodynamic lift
The hull must be shaped to generate enough vertical force at a low speed to lift the airplane onto the step, allowing it to accelerate to liftoff airspeed. In order to accomplish this, it should have a flat or curved deadrise. Hydrodynamic drag must also be reduced, requiring a step to be designed into the hull at the proper location.

Figure C3-13: Cross-sectional geometries for the forward and aft hull of a conventional flying boat. (From Reference [12])

Suppression of water spray
The hull must be shaped to force water spray sideways and away from sensitive areas, such as propellers, engine and cabin air inlets. The use of spray rails may be required to reduce the amount of water. Spray can be suppressed by increasing the curvature of the hull between the keel and chines ("flaring" see Figure C3-15). It is advantageous to incline the keel 1°-2° up as is demonstrated in Reference 13.

Per Reference 13, refinement in the hull design, such as flared hull bottoms and increased fore- and afterbody deadrise warping, improves hydrodynamic characteristics of the hull, even though the gains may not warrant the added complexity and cost of manufacturing. This mostly pertains to aluminum aircraft – composite hulls offer a promising potential, as compound surfaces are far easier to manufacture using that technology. Composite materials also have an outstanding service history in and around water, as can be seen by the sheer number of speedboats and jet-skis whose hulls are composite laminates. Reference 13 concludes that narrow hulls offer less resistance (a fact well known to athletic rowers), however, their draft is greater and this increases water spray.
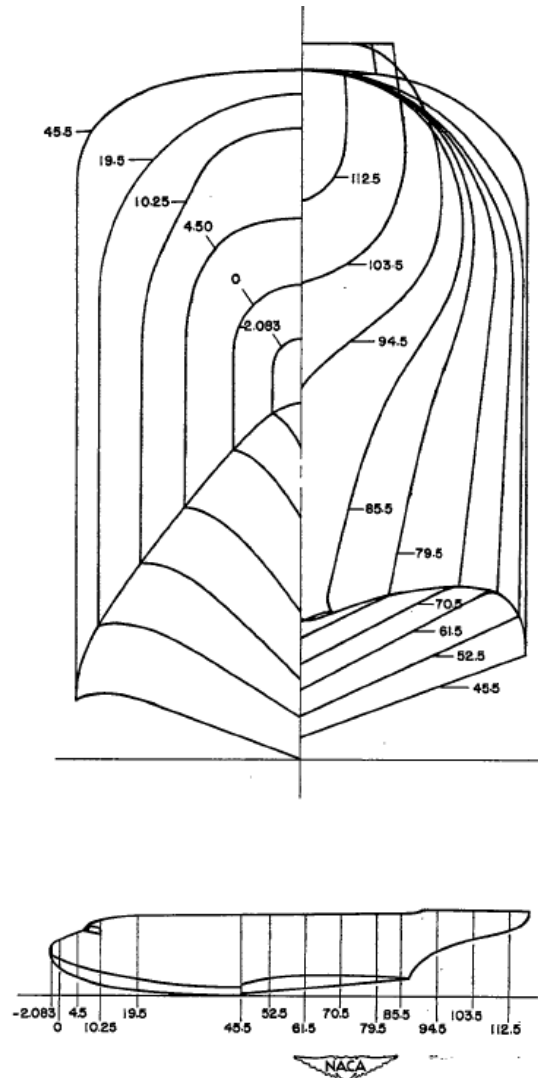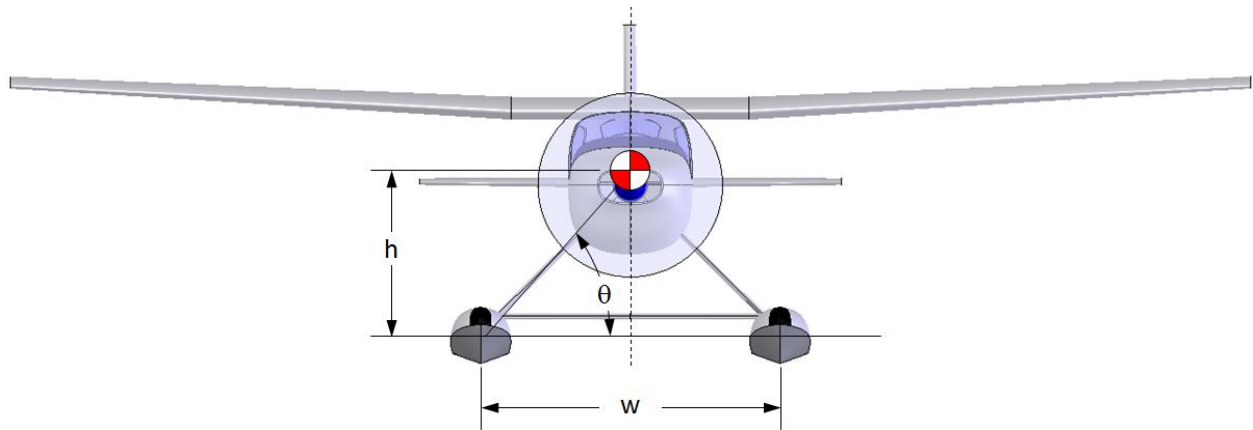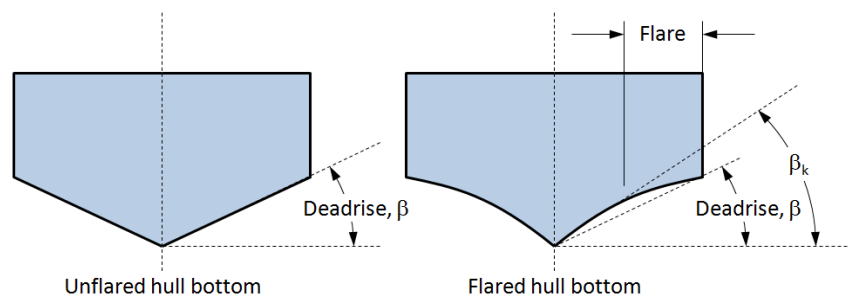
Figure C3-14: Placement of floats.

Figure C3-15: Two common shapes of hull bottoms; an unflared and flared ones.

Dynamic stability on the Step

Three types of dynamic instability affect seaplanes once they are on the step: *porpoising*, *skipping*, and *pattering*. Porpoising is a rhythmic pitching motion of a seaplane, caused by the dynamic instability in forces acting on the bottom of the floats1. The sensation is often likened to that when rocking back and forth. The phenomena can occur if the airplane exceeds a relatively narrow range of pitch attitudes and begins as a cyclic pitch oscillation that may increase and terminate with the aircraft nosing into the water and a possible capsizing. It can also occur if the longitudinal attitude of the airplane is too high while on the step. This can cause the airplane to stall and drop the nose into the water. Porpoising can also be caused by the step being placed too far forward of or behind the CG9. Porpoising can be reduced by flattening the aft part of the fore body to about 1.5 times the beam. This will ensure more uniform pressure along the bottom, whereas a curved section would result in varying pressure which promotes a more dynamic response.

Skipping is instability that may occur when landing at excessive speed with the nose pointed too high or when crossing the wake of a boat1. The sensation is likened to an up and down bounce. A hull, whose step is shallow and, thus, leads to poor ventilation behind it, is more prone to skipping. Pattering is a short period pitch oscillation.

Reference 14 presents methods to estimate the response of ships that extend to seaplanes as well.

Maneuverability and Controllability

The airplane should feature means for control while in the water at low airspeeds, when aerodynamic control is minimal. This is done by installing a rudder at the stern. Once on the step, the hull should feature a straight keel to help the airplane move along a straight line. Adding sister keelsons may be called for to improve the directional stability. Excessively long forebody will reduce directional stability in the water and may cause it to ground loop (i.e. "water-loop")[9]. Reducing such tendency requires an enlarged vertical tail, ideally placed in the propwash for increased control authority.

Step Geometry

The edge of the step is placed slightly aft of the CG, approximately as shown in Figure C3-16. The angle made to the vertical will then range approximately between 10° and 15°. The intent is to allow the airplane to rotate effortlessly. The height of the step is typically approximately 0.05 to 0.08 x Beam[13]. As has already been stated, this surface discontinuity greatly increases the aerodynamic drag of the vehicle and is effectively the "cost" of designing a seaplane. The drag problem is a hard one to remedy, as is discussed in Reference 15, which explores a number of step designs intended to reduce drag.

Sternpost Angle

The sternpost angle typically ranges from about 7°-9°. This will allow the seaplane to rotate to a higher AOA once on the step without the rearstep keel entering the water. If the rearstep enters the water, the hydrodynamic drag will increase and this will reduce acceleration and lengthen the T-O run.

Forebody Flat

The length of the forebody float should be approximately 1.5 x Beam. This is important to reduce porpoising tendency.

Figure C3-16: A schematic showing important details that must be considered when designing a seaplane.

Deadrise Angle

Deadrise angle typically ranges from 15° to 40°. The greater this angle, the less is the water impact load (hull load) and this directly affects the weight of the airframe. It will also make water landings feel smoother. However, the larger angle results in a hull that sits deeper in the water. This way, if the intention is to allow the aircraft to be beached, the larger deadrise angle could make this impossible – the airplane will run aground far from dry land

(relatively speaking). There is a golden medium between the two, lower hull loads and being able to beach the airplane; clearly, it is the responsibility of the designer to find it.

The hull load factor is usually estimated using 14 CFR 23.572. Figure C3-17 shows hull load factors estimated for an LSA style amphibious aircraft. Per 14 CFR Part 1.1, such an aircraft may have a gross weight as high as 1430 lb_f and have a stalling speed no higher than 45 KCAS without the use of high lift devices. (An important note: on July 29th, 2013, the FAA granted the Icon A5 LSA an exemption from these weight limits, permitting a gross weight of 1680 lb_f). The stall speed limit is reflected by the dashed vertical line. The dotted horizontal line represents the minimum hull load factor of 2.33, i.e. if the calculated load factor is less than that value, it must be replaced with 2.33. Reference 13 states that warping the deadrise of the afterbody is an effective means to reduce the height of the step by about 50% (page 20).

Figure C3-17: Hull load factors for a range of deadrise angles, calculated for an LSA aircraft whose gross weight is 1430 lb_f.

Tip Floats, Auxiliary Floats, Sponsons, and Pontoons.
Per 14 CFR Part 23.757, auxiliary floats must be arranged such they provide a restoring moment of at least 1.5 times the upsetting moment of the tilted seaplane, when fully submerged. This moment is determined as the product of the tip float displacement and its spanwise location along the wing, denoted by y_{float}. The larger the distance y_{float} is (see Figure C3-16) the smaller the volume of the tip float. Effectively, a smaller tip float will reduce aerodynamic drag, but the impact loads per § 23.535 Auxiliary float loads, will increase the magnitude of the reaction forces.

Wave Height Limitations
The seaplane should feature a powerful engine to reduce its take-off distance on water and to make up for the increased drag and gross weight. There is a limit to the wave height of water a seaplane of a given hull displacement can safely handle. Based on Reference 2 the following empirical expression can be used to estimate the wave height as a function of gross weight:

Maximum wave height:
$$h_{wave} \approx 1.25 \ln(W_0) - 8.6414$$
(C3-19)

Aerodynamic Drag

Seaplanes, whether amphibious or floatplanes are generally very draggy. This is evident in Table 15-18. The shape of the hull, or the floats and their associated support structure, generates a lot of drag. As has already been discussed, the shape of this geometry is dictated by the hydrodynamic operation of the airplanes and, therefore, it is practically impossible to reduce its drag. Drag must therefore be minimized by other means, such as using streamlined cleats (which are used to tie the seaplane) or the use of flush rivets (or composite materials). Struts should always feature thick symmetrical airfoil, such as generic NACA strut airfoils or standard streamlined strut sections (see Section 13.5.1, *Drag of Streamlined Struts and Landing Gear Pant Fairings*).

C3.1.4 Seaplane Take-Off Estimation

The estimation of seaplane T-O distance is more complicated than that of conventional land aircraft. This is due to the disparate sources of drag the seaplane must overcome. Not only does it experience aerodynamic drag, but also water resistance, which depends on the speed of the vehicle in the water, which, in turn, depends on its attitude in the water (trim angle). Reference 11 presents the following method for this purpose.

First, the following concepts must be defined:

Buoyancy force (or load) coefficient:
$$C_\Delta = \frac{F_{buoy}}{\rho_W B^3} = \frac{\Delta}{\rho_W B^3}$$
(C3-20)

A desirable range of C_Δ at gross weight is generally between 1 and 2 (per Reference 11). As the airplane generates aerodynamic lift during the T-O run, its value will gradually reduce to 0 at lift-off. This means that the resistance will vary as well, as it is dependent on the displacement of the hull in the water. The resistance is placed into coefficient form as follows. Its value must be obtained for any given geometry using towing tests in a water tank.

Resistance coefficient:
$$C_R = \frac{R}{\rho_W B^3}$$
(C3-21)

C_R is a function of the load coefficient, C_Δ, as well.

Speed coefficient:
$$C_V = \frac{V}{\sqrt{gB}}$$
(C3-22)

Where: B = Beam of the seaplane (its largest submerged width of the hull)
          R = Water resistance force
          V = Speed with respect to the water

To evaluate hulls of different length-to-beam ratios (L/B), the following coefficients must also be introduced, as they are typically used in the literature to document the variation of load and resistance:

Buoyancy force coefficient:
$$C_{\Delta_2} = \frac{F_{buoy}}{\rho_W L^2 B} = C_\Delta \left(\frac{B}{L}\right)^2$$
(C3-23)

Resistance coefficient:
$$C_{R_2} = \frac{R}{\rho_W L^2 B} = C_R \left(\frac{B}{L}\right)^2 \qquad \text{(C3-24)}$$

Speed coefficient:
$$C_{V_2} = \frac{V}{g^{1/2} L^{1/3} B^{1/6}} = C_V \left(\frac{B}{L}\right)^{1/3} \qquad \text{(C3-25)}$$

Moment coefficient:
$$C_{M_2} = \frac{M}{\rho_W \left(L^2 B\right)^{4/3}} \qquad \text{(C3-26)}$$

Draft coefficient:
$$C_{DR} = \frac{d}{\left(L^2 B\right)^{1/3}} \qquad \text{(C3-27)}$$

Rolling moment coefficient:
$$C_{M_R} = \frac{M_R}{\rho_W \left(L^2 B\right)^{4/3}} \qquad \text{(C3-28)}$$

Where:
    d = Draft in ft or m
    g = Acceleration due to gravity
    M = Trimming moment (which affects the trim angle)
    M_R = Rolling moment, in ft·lb$_f$ or N·m

The evaluation of the trim angle (see Figure C3-16) is also important because the trimming moment, M, must be near zero at low speed when the elevator is ineffective. Then, as the airspeed increases, the pilot can adjust the trim moment using the elevator to change the airplane trim angle for minimum water resistance, R, if not the minimum of the sum of R and aerodynamic drag.

The length-to-beam ratio, L/B, is typically around 5 to 9, but can be as large as 15 (such as the Martin P6M jet powered seaplane designed in the 1950s). High L/B, while less draggy in the water, will result in a slender body that is usually not be suitable for small seaplanes.

Typical shape of water resistance and trim angle variation versus speed coefficient are presented in Figure C3-18 and Figure C3-19. The data is based on actual towing test results for two distinct hulls shapes; conventional and planing-tail, presented in Reference 12. The investigation of the reference indicates the planing-tail geometry not only offers superior hydrodynamic characteristics, but aerodynamic as well. The shape of the resistance curves in Figure C3-18 are of a classical shape, in which water resistance increases until the aircraft gets up on the "step." The ratio F_{buoy}/R indicates the magnitude of the resistance, for if $F_{buoy} = W_0$, it amounts to about 22% of the weight of the conventional and 15% of the weight of the planing-tail fuselage. The former represents a formidable difficulty for conventional flying boats. However, the reference does not attribute the lower resistance of the planing-tail hull solely to its geometry.

The "hump" or the peak of the curves (especially noticeable for the conventional hull) results from the aircraft approaching its hull speed. Standard operations of seaplanes dictate that when this happens the pilot will rotate the airplane sharply to try to help it "get on the step."

The trim angle indicates the orientation of the seaplane in the water during the T-O run. This characteristic is of great importance to the T-O analysis, as it directly affects the AOA. The AOA is determined by adding the trim angle to the AOI of the wing with respect to the tangent to the keel (to which the trim angle refers). Figure C3-19 shows how the trim angle varies with the speed coefficient for the two hull styles. The planing-tail hull merely

requires a 2° increase in trim angle over the duration of the T-O, requiring simpler pilot correction. Also note how this is taken into account in the T-O analysis of Example C3-3.

Figure C3-18: Water resistance versus speed coefficient for two hull styles; a conventional and planing-tail shows the latter generates substantially less resistance and has smaller hump than the former. (Reproduced from Reference 12)

The trim angle curve for the planing-tail hull can be approximated using the following expression. Note that it cannot be used for the conventional hull:

$$\alpha_{trim} = \alpha_1 + \frac{(\alpha_2 - \alpha_1)}{2}\left(1 + \tanh(AC_V + B)\right) \qquad \text{(C3-29)}$$

Where: A and B = Constants, calculated as shown below
α_1 = Trim angle at the start of the T-O run (where it begins to rise = C_{V1})
α_2 = Trim angle at the end of the T-O run (where its begins to no longer rise = C_{V2})

Constant A: $$A = 5.294/(C_{V2} - C_{V1}) \qquad \text{(C3-30)}$$

Constant B: $$B = -(2.647 + AC_{V1}) \qquad \text{(C3-31)}$$

A reliable T-O analysis for seaplanes calls for its physics to be simulated and integrated over the duration of the T-O, similar to what is done for landplanes. However, this calls for the resistance and trim angle to be simulated in a manner similar to what is implemented below in Example C3-3.

Figure C3-19: Trim angle versus speed coefficient for the two hull styles shows the planing-tail requires simpler trimming than the conventional. (Reproduced from Reference 12)

DERIVATION:

We proceed similar to the derivation of Equation (15-106). Consider the curve of Figure C3-20. Then, we observe that the argument of the hyperbolic tangent can be determined by solving for it, as shown below:

$$AC_V + B = \tanh^{-1}\left[\frac{2(\alpha_{trim} - \alpha_1)}{(\alpha_2 - \alpha_1)} - 1\right]$$

Noting that $-1 \leq \tanh(x) \leq 1$, this allows the two following expressions to be written:

When $C_V = C_{V1}$, then $\alpha_{trim} = \alpha_1$:

$$AC_{V1} + B = \tanh^{-1}(-1)$$

When $C_V = C_{V2}$, then $\alpha_{trim} = \alpha_2$:

$$AC_{V2} + B = \tanh^{-1}(+1)$$

Figure C3-20: The trim angle of the planing-tail hull behaves similar to the curve above.

Since the inverse arguments lead to infinite results, we have to reduce them to values that will allow the constants A and B to be evaluated with reasonable accuracy. For instance, if we replace the arguments -1 and +1 with -0.99 and +0.99, respectively, we get the following useful result:

$$\left. \begin{array}{l} AC_{V1} + B = \tanh^{-1}(-0.99) = -2.647 \\ AC_{V2} + B = \tanh^{-1}(+0.99) = +2.647 \end{array} \right\} \quad \Rightarrow \quad \left\{ \begin{array}{l} A = 5.294/(C_{V2} - C_{V1}) \\ \\ B = -(2.647 + AC_{V1}) \end{array} \right.$$

EXAMPLE C3-3:

A flying boat of the planing tail configuration is being designed for eight occupants. Estimate the T-O distance, given the following information:

Fuselage beam	B =	5.0 ft
Fuselage water length	L =	27.8 ft
Wing span	b =	49.0 ft
Wing area	S =	375 ft²
Wing Aspect Ratio	AR =	6.41 ft²
Wing AOI with respect to keel	i_W =	4.5°
Gross weight	W_0 =	8000 lb$_f$
Engines	N_e =	2
Engine power	P_{BHP} =	450 BHP each
Propeller diameter	D_P =	8.5 ft
Spinner frontal area	$A_{spinner}$ =	7.0 ft²
Maximum speed at 5000 ft	V_{max} =	175 KTAS, when η_p = 0.82
Thrust function at max power	T =	$0.01040 \cdot V^2 - 10.065 \cdot V + 3225$, in lb$_f$; V is in ft/s
Drag coefficient	C_D =	$0.06 + 0.058 \cdot C_L^2$
Water resistance coefficient	C_R =	$0.0011 \cdot C_V^3 - 0.0221 \cdot C_V^2 + 0.1062 \cdot C_V - 0.0149$
Trim angle	α_{trim} =	$7 + \tanh(3.553 \cdot C_V - 3.891)$
Density of sea water	ρ_W =	63.5 lb$_f$/ft³

Note that the modeling for the trim angle and water resistance coefficient is shown in Figure C3-21. The graph shows that the curve fitting formulation offers a good fit to the original test data. Of course, this is done to allow simple analysis to be performed in a spreadsheet. The trim angle formulation uses (C_{V1}, α_1) = (0.35, 6°) and (C_{V2}, α_2) = (2, 8°) with Equation (C3-29).

Figure C3-21: Trim angle and resistance coefficient modeling for this example

Assumption 1:

In this example, account for the reduction in resistance with loading using the following expression:

$$C_{R\Delta} = C_R \cdot \left(C_\Delta / C_{\Delta_0} \right)$$

Where: C_{Δ_0} = Load coefficient at the T-O weight and rest

Note that this expression is only used here to model the reduction in the water resistance with displacement of the hull. It is based on the observation that with an increase in wing lift, the draft of the hull will decrease too and so will the resistance. For real applications, the relationship between draft and resistance must be determined by experiment.

Assumption 2:

Once the speed coefficient exceeds 7.5, the value of R is zero. There is no guarantee that the airplane is airborne at this moment, but rather it is hydroplaning. This means that the bottom of the airplane is still in contact with water and, thus, generates resistance. Account for this hydroplaning friction using the Froude frictional resistance of Equation (C3-18), assuming that a wetted area of 1'x B (= 5 ft²) and smooth surface, whose frictional coefficient f amounts to 0.012.
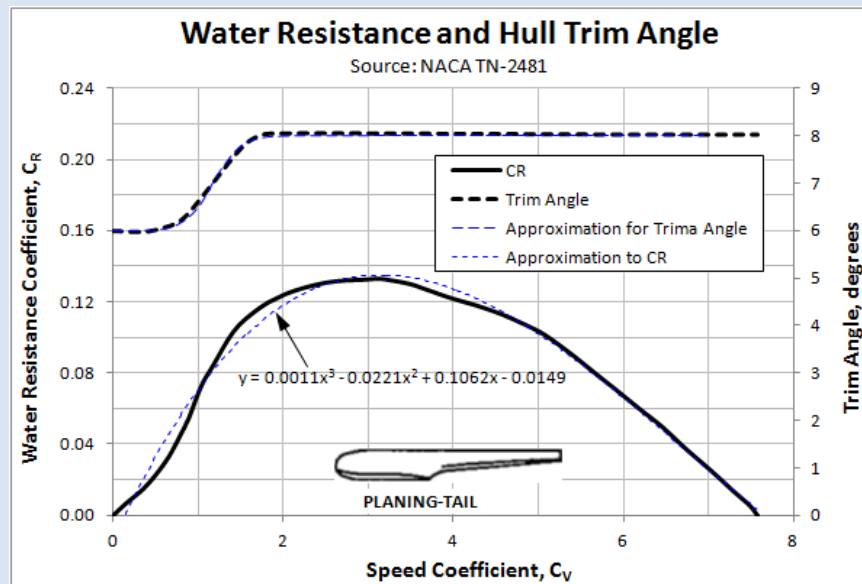
Assumption 3:

As the seaplane begins its T-O run, the engine is already generating some thrust. Pilot technique often dictates that the thrust is increased slowly rather than quickly – observation shows over 6-10 seconds before the throttle is fully open. Account for this technique by assuming a 10 second throttle up time, using the follow model:

$$r = \begin{cases} 0.25 + 0.75(t/10) & \text{if } t < 10 \text{ sec} \\ 1 & \text{if } t \geq 10 \text{ sec} \end{cases}$$

Then, multiply the thrust by this factor to account for the ramp-up. This model will ensure that initially, 25% of the maximum thrust is applied and once t > 10 seconds, the full thrust available at the given airspeed is used.

SOLUTION:

Using the appropriate data given above, the thrust function was created using Equation (14-40), where T_{STATIC} is calculated using Equation (14-64) and propeller efficiency, η_p, of 0.82 was assumed at a maximum airspeed of 175 KTAS at 5000 ft.

The resulting analysis is shown in Table C3-4. The columns are calculated as follows, using the row with ID 10 as a numerical example (note that additional significant digits are shown in row 10 for this reason):

Column	Content
1	Contains the elapsed time, here obtained by adding 0.5 sec to the previous value: 4.0 + 0.5 = 4.5 sec.
2	Difference between time steps. $\Delta t = 4.5 - 4.0 = 0.5$. Note that dissimilar time steps are allowed.
3	Water or airspeed (no wind condition) in knots. Calculated by dividing the speed in ft/s by 1.688.
4	Speed in ft/s, obtained using numerical integration scheme of Equation (17-22). Example: $V_{10} = V_9 + a_9 \cdot \Delta t_{10} = 15.09 + 4.149 \times 0.5 = 17.16$ ft/s
5	Dynamic pressure: $q = \tfrac{1}{2} \cdot \rho \cdot V^2$. Example: $q_{10} = \tfrac{1}{2} \cdot 0.002378 \cdot (17.16)^2 = 0.3502$ lb$_f$/ft²
6	Speed coefficient, calculated using Equation (C3-22). Example: $C_{V_{10}} = V_{10} / \sqrt{gB} = 17.16 / \sqrt{32.174 \times 5} = 1.353$

7	Resistance coefficient, calculated using the polynomial for C_R given in the problem statement. Example: $\quad C_{R10} = 0.0011 \cdot C_{V10}{}^3 - 0.0221 \cdot C_{V10}{}^2 + 0.1062 \cdot C_{V10} - 0.0149 = 0.09174$
8	Angle of trim, calculated using the polynomial for α_{trim} given in the problem statement. Example: $\quad \alpha_{trim10} = 7 + \tanh(3.553 \cdot C_{V10} - 3.891) = 7.516°$
9	Angle of attack, α, is the sum of the angle-of-trim and wing incidence angle (given as 4.5° in the problem statement. This way, $\alpha_{10} = 7.516° + 4.5° = 12.02°$
10	Lift coefficient, calculated using the expression for C_L given in the problem statement. Example: $\quad C_{L10} = 0.2 + 4.62 \cdot \alpha_{10} \cdot \pi/180 = 1.169$
11	Drag coefficient, calculated using the expression for C_D given in the problem statement. Example: $\quad C_{D10} = 0.06 + 0.058 \cdot C_{L10}{}^2 = 0.1393$
12	Lift force, calculated using $L = q \cdot S \cdot C_L$. Example: $L_{10} = q_{10} \cdot S \cdot C_{L10} = 0.349 \cdot 375 \cdot 1.169 = 153.5 \, lb_f$
13	Drag force, calculated using $D = q \cdot S \cdot C_D$. Example: $D_{10} = q_{10} \cdot S \cdot C_{D10} = 0.349 \cdot 375 \cdot 0.1393 = 18.29 \, lb_f$
14	Ramp-up factor, calculated as described in Assumption 3. The time elapsed for the 10th row is 4.5 seconds, which is less than 10 sec. Therefore, $r_{10} = 0.25 + 0.75 \times 4.5/10 = 0.5875$
15	Thrust force, calculated using the expression for T given in the problem statement. Example: $\quad T_{10} = 0.01040 \cdot V_{10}{}^2 - 10.065 \cdot V_{10} + 3225 = 1795 \, lb_f$
16	Load or displacement or F_{buoy}, calculated by subtracting the lift from the weight of the aircraft. Example: $\quad D_{10} = W - L_{10} = 8000 - 153.5 = 7846 \, lb_f$
17	Buoyancy or load coefficient, calculated using Equation (C3-20) and the load from Column 16. Example: $\quad C_{\Delta 10} = \Delta_{10} / \left(\rho_W B^3 \right) = 7846 / \left(63.5 \times 5^3 \right) = 0.9885$
18	Resistance coefficient, reduced to account for reduced draft. Calculated in accordance with Assumption 1, where $C_{\Delta_0} = C_{\Delta_1} = 1.008$. Example: $\quad C_{R\Delta 10} = C_{R10} \cdot \left(C_{\Delta 10} / C_{\Delta 0} \right) = 0.09174 \cdot (0.9885/1.008) = 0.08998$
19	Water resistance, calculated using Equation (C3-21). Note that an IF() statement is used in Microsoft Excel to ensure that if C_R happens to be negative as a consequence of the curvefit polynomial (a possible scenario near C_V of 0 and 7.5). This stems from the fact that a cubic polynomial is used to approximate C_R and it is only valid for $0 < C_R \leq 7.5$. Therefore, the IF() statement forces the resistance to 0 for any C_Vs > 7.5. Once C_V exceeds 7.5, the only resistance caused by the water is the Froude resistance in the next column. This is justified based on the observation that the airplane is out of the water and on the step; its only contact with water is through hydroplaning. Example: $\quad R_{10} = C_{R\Delta 10} \left(\rho_W B^3 \right) = 0.08998 \left(63.5 \times 5^3 \right) = 714.2 \, lb_f$
20	Hydroplaning resistance, calculated using Froude's formula of Equation (C3-18). Note that it is not taken into account until around t = 8.5 s, as this is when the plane is getting on the step. Example: $\quad R_{Froude10} = f \cdot S_{wet} \cdot V_{10}^2 = 0.012 \times 5 \times (17.16/1.688)^2 = 6.202 \, lb_f$ However, since the time is 4.5 sec, its value is force to be zero, using an IF() statement in Microsoft Excel.
21	Net force acting on the airplane: $\quad T_{net10} = T_{10} - D_{10} - R_{10} - R_{froude10} = 1063 \, lb_f$
22	Acceleration of the airplane: $\quad a_{10} = T_{net10}/(W/g) = 1056/(8000/32.174) = 4.273 \, ft/s^2$
23	Distance in ft, obtained using numerical integration scheme of Equation (17-23). Example: $\quad V_{10} = S_9 + V_9 \cdot \Delta t_{10} + a_9 \cdot \Delta t_{10}{}^2 = 29.39 + 15.09 \times 0.5 + 4.149 \times 0.5^2 = 37.47 \, ft$

Table C3-4: T-O Performance Prediction

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Time		Water/Airspeed		q	C_v	C_R	α_{trim}	α	C_L	C_D	Lift	Drag	r	Thrust-r	$\Delta = W - L$	C_Δ	$C_{R\Delta}$	R	R_{Froude}	T_{net}	a	s
ID	t, sec	Δt, sec	KTAS	ft/s	lb$_f$/ft²			deg	deg			lb$_f$	lb$_f$		lb$_f$	lb$_f$			lb$_f$	lb$_f$	lb$_f$	ft/s²	ft
1	0.0		0	0.0	0.0	0.00	-0.0149	6.00	10.50	1.047	0.1235	0	0	0.25	806	8000	1.008	-0.0149	0	0	806	3.24	0
2	0.5	0.5	1	1.6	0.0	0.13	-0.0016	6.00	10.50	1.047	0.1236	1	0	0.29	923	7999	1.008	-0.0016	0	0	922	3.71	0
3	1.0	0.5	2	3.5	0.0	0.27	0.0127	6.01	10.51	1.047	0.1236	6	1	0.33	1037	7994	1.007	0.0127	101	0	935	3.76	2
4	1.5	0.5	3	5.4	0.0	0.42	0.0263	6.02	10.52	1.048	0.1237	13	2	0.36	1150	7987	1.006	0.0263	208	0	940	3.78	4
5	2.0	0.5	4	7.2	0.1	0.57	0.0391	6.04	10.54	1.050	0.1239	25	3	0.40	1261	7975	1.005	0.0389	309	0	949	3.82	7
6	2.5	0.5	5	9.2	0.1	0.72	0.0510	6.10	10.60	1.055	0.1246	39	5	0.44	1371	7961	1.003	0.0508	403	0	963	3.87	11
7	3.0	0.5	7	11.1	0.1	0.87	0.0622	6.25	10.75	1.067	0.1260	59	7	0.48	1479	7941	1.000	0.0618	490	0	982	3.95	16
8	3.5	0.5	8	13.1	0.2	1.03	0.0728	6.57	11.07	1.092	0.1292	83	10	0.51	1586	7917	0.997	0.0720	572	0	1005	4.04	22
9	4.0	0.5	9	15.09	0.3	1.19	0.0826	7.05	11.55	1.131	0.1342	115	14	0.55	1692	7885	0.993	0.0814	646	0	1032	4.149	29.39
10	4.5	0.5	10	17.16	0.3502	1.353	0.09174	7.516	12.02	1.169	0.1393	153.5	18.29	0.5875	1795	7846	0.9885	0.08998	714.2	0.000	1063	4.273	37.47
11	5.0	0.5	11	19.3	0.4	1.52	0.1002	7.80	12.30	1.192	0.1424	198	24	0.63	1897	7802	0.983	0.0977	775	0	1098	4.41	47
12	5.5	0.5	13	21.5	0.5	1.70	0.1078	7.93	12.43	1.202	0.1439	248	30	0.66	1996	7752	0.977	0.1045	829	0	1137	4.57	57
13	6.0	0.5	14	23.8	0.7	1.88	0.1147	7.98	12.48	1.206	0.1444	304	36	0.70	2094	7696	0.970	0.1104	876	0	1181	4.75	68
14	6.5	0.5	16	26.2	0.8	2.06	0.1208	7.99	12.49	1.207	0.1446	369	44	0.74	2189	7631	0.961	0.1153	915	0	1230	4.95	81
15	7.0	0.5	17	28.6													0.952	0.1191	945	0	1285	5.17	94
16	7.5	0.5	18	31.2													0.942	0.1217	966	0	1344	5.41	109
17	8.0	0.5	20	33.9													0.930	0.1231	977	0	1410	5.67	126
18	8.5	0.5	22	36.8													0.916	0.1232	978	0	1482	5.96	143
19	9.0	0.5	24	39.7													0.901	0.1218	967	33	1526	6.14	163
20	9.5	0.5	25	42.8													0.884	0.1190	945	39	1606	6.46	183
21	10.0	0.5	27	46.0													0.864	0.1147	911	45	1692	6.80	206
22	10.5	0.5	29	49.4													0.842	0.1089	864	51	1679	6.75	229
23	11.0	0.5	31	52.8													0.819	0.1020	810	59	1674	6.73	255
24	11.5	0.5	33	56.2													0.794	0.0943	748	66	1674	6.73	282
25	12.0	0.5	35	59.6													0.767	0.0858	681	75	1678	6.75	311
26	12.5	0.5	37	62.9													0.739	0.0769	610	83	1684	6.77	342
27	13.0	0.5	39	66.3													0.709	0.0676	537	93	1690	6.80	374
28	13.5	0.5	41	69.7													0.678	0.0582	462	102	1696	6.82	408
29	14.0	0.5	43	73.1													0.645	0.0490	389	113	1699	6.83	444
30	14.5	0.5	45	76.5													0.610	0.0399	317	123	1698	6.83	481
31	15.0	0.5	47	80.0													0.574	0.0314	249	135	1691	6.80	520
32	15.5	0.5	49	83.4													0.536	0.0234	186	146	1678	6.75	561
33	16.0	0.5	51	86.7													0.498	0.0163	130	158	1657	6.67	604
34	16.5	0.5	53	90.1													0.458	0.0101	80	171	1629	6.55	648
35	17.0	0.5	55	93.3													0.417	0.0049	39	183	1592	6.40	694
36	17.5	0.5	57	96.5													0.376	0.0007	0	196	1553	6.25	741
37	18.0	0.5	59	99.7	11.8	7.86	-0.0073	8.00	12.50	1.208	0.1446	5349	640	1.00	2325	2651	0.334	-0.0024	0	209	1476	5.93	790
38	18.5	0.5	61	102.6	12.5	8.09	-0.0157	8.00	12.50	1.208	0.1446	5672	679	1.00	2302	2328	0.293	-0.0046	0	222	1401	5.63	841
39	19.0	0.5	62	105.4	13.2	8.31	-0.0232	8.00	12.50	1.208	0.1446	5988	717	1.00	2279	2012	0.253	-0.0058	0	234	1328	5.34	893
40	19.5	0.5	64	108.1	13.9	8.52	-0.0299	8.00	12.50	1.208	0.1446	6295	754	1.00	2258	1705	0.215	-0.0064	0	246	1259	5.06	946
41	20.0	0.5	66	110.6	14.6	8.72	-0.0357	8.00	12.50	1.208	0.1446	6593	789	1.00	2239	1407	0.177	-0.0063	0	258	1191	4.79	1001
42	20.5	0.5	67	113.0	15.2	8.91	-0.0407	8.00	12.50	1.208	0.1446	6882	824	1.00	2220	1118	0.141	-0.0057	0	269	1127	4.53	1057
43	21.0	0.5	68	115.3	15.8	9.09	-0.0449	8.00	12.50	1.208	0.1446	7161	857	1.00	2203	839	0.106	-0.0047	0	280	1065	4.28	1114
44	21.5	0.5	70	117.4	16.4	9.26	-0.0485	8.00	12.50	1.208	0.1446	7429	890	1.00	2186	571	0.072	-0.0035	0	290	1006	4.05	1172
45	22.0	0.5	71	119.5	17.0	9.42	-0.0514	8.00	12.50	1.208	0.1446	7688	920	1.00	2171	312	0.039	-0.0020	0	301	950	3.82	1231
46	22.5	0.5	72	121.4	17.5	9.57	-0.0537	8.00	12.50	1.208	0.1446	7935	950	1.00	2157	65	0.008	-0.0004	0	310	896	3.60	1291
47	23.0	0.5	73	123.2	18.0	9.71	-0.0555	8.00	12.50	1.208	0.1446	8173	979	1.00	2143	-173	-0.022	0.0012	0	320	845	3.40	1352

Water Resistance and Drag versus KCAS (embedded chart)

Vertical axis (left): Water Resistance and Drag, lb$_f$ — scale 0, 200, 400, 600, 800, 1000, 1200.
Vertical axis (right): Displacement Load, Δ, lb$_f$ — scale 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000.
Horizontal axis: Airspeed (or water speed), KCAS — scale 0, 10, 20, 30, 40, 50, 60, 70.

Curve labels: Total Resistance, Aerodynamic Drag, Hydroplaning Resistance, Water Resistance, Displacement Load.

Legend: Total Resistance, Aerodynamic Drag, Hydroplaning Resistance, Water Resistance, Displacement Load.

C3.1.5 14 CFR Part 23 Regulations Specifically for Seaplanes

In addition to paragraphs that apply to conventional aircraft, a specific selection applies only to seaplanes. These are listed below. The aspiring seaplane designer should familiarize himself with these regulations, as they provide a great insight into issues that pertain to seaplanes only and they are intended to prevent.

§ 23.237 Operation on water.
A wave height, demonstrated to be safe for operation, and any necessary water handling procedures for seaplanes and amphibians must be established.

§ 23.239 Spray characteristics.
Spray may not dangerously obscure the vision of the pilots or damage the propellers or other parts of a seaplane or amphibian at any time during taxiing, takeoff, and landing.

§ 23.521 Water load conditions.
(a) The structure of seaplanes and amphibians must be designed for water loads developed during takeoff and landing with the seaplane in any attitude likely to occur in normal operation at appropriate forward and sinking velocities under the most severe sea conditions likely to be encountered.

(b) Unless the applicant makes a rational analysis of the water loads, §§23.523 through 23.537 apply.

§ 23.523 Design weights and center of gravity positions.
(a) Design weights. The water load requirements must be met at each operating weight up to the design landing weight except that, for the takeoff condition prescribed in §23.531, the design water takeoff weight (the maximum weight for water taxi and takeoff run) must be used.

(b) Center of gravity positions. The critical centers of gravity within the limits for which certification is requested must be considered to reach maximum design loads for each part of the seaplane structure.

§ 23.525 Application of loads.
(a) Unless otherwise prescribed, the seaplane as a whole is assumed to be subjected to the loads corresponding to the load factors specified in §23.527.

(b) In applying the loads resulting from the load factors prescribed in §23.527, the loads may be distributed over the hull or main float bottom (in order to avoid excessive local shear loads and bending moments at the location of water load application) using pressures not less than those prescribed in §23.533(c).

(c) For twin float seaplanes, each float must be treated as an equivalent hull on a fictitious seaplane with a weight equal to one-half the weight of the twin float seaplane.

(d) Except in the takeoff condition of §23.531, the aerodynamic lift on the seaplane during the impact is assumed to be 2/3 of the weight of the seaplane.

§ 23.527 Hull and main float load factors.
(a) Water reaction load factors n_w must be computed in the following manner:

    (1) For the step landing case

$$n_w = \frac{C_1 V_{S0}^2}{\sqrt[3]{\tan^2 \beta \times W}}$$

    (2) For the bow and stern landing cases

$$n_w = \frac{C_1 V_{S0}^2}{\sqrt[3]{\tan^2 \beta \times W}} \times \frac{K_1}{\left(1 + r_x^2\right)^{2/3}}$$

(b) The following values are used:

(1) n_w = water reaction load factor (that is, the water reaction divided by seaplane weight).
(2) C_1 = empirical seaplane operations factor equal to 0.012 (except that this factor may not be less than that necessary to obtain the minimum value of step load factor of 2.33).
(3) V_{S0} = seaplane stalling speed in knots with flaps extended in the appropriate landing position and with no slipstream effect.
(4) β = Angle of dead rise at the longitudinal station at which the load factor is being determined in accordance with figure 1 of appendix I of this part.
(5) W = seaplane landing weight in pounds.
(6) K_1 = empirical hull station weighing factor, in accordance with figure 2 of appendix I of this part.
(7) r_x = ratio of distance, measured parallel to hull reference axis, from the center of gravity of the seaplane to the hull longitudinal station at which the load factor is being computed to the radius of gyration in pitch of the seaplane, the hull reference axis being a straight line, in the plane of symmetry, tangential to the keel at the main step.

(c) For a twin float seaplane, because of the effect of flexibility of the attachment of the floats to the seaplane, the factor K_1 may be reduced at the bow and stern to 0.8 of the value shown in figure 2 of appendix I of this part. This reduction applies only to the design of the carrythrough and seaplane structure.

§ 23.529 Hull and main float landing conditions.
(a) Symmetrical step, bow, and stern landing. For symmetrical step, bow, and stern landings, the limit water reaction load factors are those computed under §23.527. In addition—

(1) For symmetrical step landings, the resultant water load must be applied at the keel, through the center of gravity, and must be directed perpendicularly to the keel line;
(2) For symmetrical bow landings, the resultant water load must be applied at the keel, one-fifth of the longitudinal distance from the bow to the step, and must be directed perpendicularly to the keel line; and
(3) For symmetrical stern landings, the resultant water load must be applied at the keel, at a point 85 percent of the longitudinal distance from the step to the stern post, and must be directed perpendicularly to the keel line.

(b) Unsymmetrical landing for hull and single float seaplanes. Unsymmetrical step, bow, and stern landing conditions must be investigated. In addition—
(1) The loading for each condition consists of an upward component and a side component equal, respectively, to 0.75 and 0.25 tan β times the resultant load in the corresponding symmetrical landing condition; and
(2) The point of application and direction of the upward component of the load is the same as that in the symmetrical condition, and the point of application of the side component is at the same longitudinal station as the upward component but is directed inward perpendicularly to the plane of symmetry at a point midway between the keel and chine lines.

(c) Unsymmetrical landing; twin float seaplanes. The unsymmetrical loading consists of an upward load at the step of each float of 0.75 and a side load of 0.25 tan β at one float times the step landing load reached under §23.527. The side load is directed inboard, perpendicularly to the plane of symmetry midway between the keel and chine lines of the float, at the same longitudinal station as the upward load.

§ 23.531 Hull and main float takeoff condition.
For the wing and its attachment to the hull or main float—
(a) The aerodynamic wing lift is assumed to be zero; and

(b) A downward inertia load, corresponding to a load factor computed from the following formula, must be applied:

$$n_w = \frac{C_{TO}V_{S1}^2}{\sqrt[3]{\tan^2 \beta \times W}}$$

Where—

n_w = inertia load factor;

C_{TO} = empirical seaplane operations factor equal to 0.004;

V_{S1} = seaplane stalling speed (knots) at the design takeoff weight with the flaps extended in the appropriate takeoff position;

β = angle of dead rise at the main step (degrees); and

W = design water takeoff weight in pounds.

§ 23.533 Hull and main float bottom pressures.

(a) General. The hull and main float structure, including frames and bulkheads, stringers, and bottom plating, must be designed under this section.

(b) Local pressures. For the design of the bottom plating and stringers and their attachments to the supporting structure, the following pressure distributions must be applied:

(1) For an unflared bottom, the pressure at the chine is 0.75 times the pressure at the keel, and the pressures between the keel and chine vary linearly, in accordance with figure 3 of Appendix I of this part. The pressure at the keel (psi) is computed as follows:

$$P_K = \frac{C_2 K_2 V_{S1}^2}{\tan \beta_k}$$

where—

P_k = pressure (p.s.i.) at the keel;

C_2 = 0.00213;

K_2 = hull station weighing factor, in accordance with figure 2 of Appendix I of this part;

V_{S1} = seaplane stalling speed (knots) at the design water takeoff weight with flaps extended in the appropriate takeoff position; and

β_k = angle of dead rise at keel, in accordance with figure 1 of Appendix I of this part.

(2) For a flared bottom, the pressure at the beginning of the flare is the same as that for an unflared bottom, and the pressure between the chine and the beginning of the flare varies linearly, in accordance with figure 3 of appendix I of this part. The pressure distribution is the same as that prescribed in paragraph (b)(1) of this section for an unflared bottom except that the pressure at the chine is computed as follows:

$$P_{ch} = \frac{C_3 K_2 V_{S1}^2}{\tan \beta}$$

where—

P_{ch} = pressure (p.s.i.) at the chine;

C_3 = 0.0016;

K_2 = hull station weighing factor, in accordance with figure 2 of appendix I of this part;

V_{S1} = seaplane stalling speed (knots) at the design water takeoff weight with flaps extended in the appropriate takeoff position; and

β = angle of dead rise at appropriate station.

The area over which these pressures are applied must simulate pressures occurring during high localized impacts on the hull or float, but need not extend over an area that would induce critical stresses in the frames or in the overall structure.

(c) Distributed pressures. For the design of the frames, keel, and chine structure, the following pressure distributions apply:

(1) Symmetrical pressures are computed as follows:

$$P = \frac{C_4 K_2 V_{S0}^2}{\tan \beta}$$

where—   P = pressure (psi);
   C_4 = 0.078 C1(with C1computed under §23.527);
   K_2 = hull station weighing factor, determined in accordance with figure 2 of appendix I of this part;
   V_{S0} = seaplane stalling speed (knots) with landing flaps extended in the appropriate position and with no slipstream effect; and
   β = angle of dead rise at appropriate station.

(2) The unsymmetrical pressure distribution consists of the pressures prescribed in paragraph (c)(1) of this section on one side of the hull or main float centerline and one-half of that pressure on the other side of the hull or main float centerline, in accordance with figure 3 of Appendix I of this part.

(3) These pressures are uniform and must be applied simultaneously over the entire hull or main float bottom. The loads obtained must be carried into the sidewall structure of the hull proper, but need not be transmitted in a fore and aft direction as shear and bending loads.

§ 23.535 Auxiliary float loads.
(a) General. Auxiliary floats and their attachments and supporting structures must be designed for the conditions prescribed in this section. In the cases specified in paragraphs (b) through (e) of this section, the prescribed water loads may be distributed over the float bottom to avoid excessive local loads, using bottom pressures not less than those prescribed in paragraph (g) of this section.
(b) Step loading. The resultant water load must be applied in the plane of symmetry of the float at a point three-fourths of the distance from the bow to the step and must be perpendicular to the keel. The resultant limit load is computed as follows, except that the value of L need not exceed three times the weight of the displaced water when the float is completely submerged:

$$L = \frac{C_5 V_{S0}^2 W^{2/3}}{\tan^{2/3} \beta_s \left(1 + r_y^2\right)^{2/3}}$$

where—   L = limit load (lbs.);
        C_5 = 0.0053;
        V_{S0} = seaplane stalling speed (knots) with landing flaps extended in the appropriate position and with no slipstream effect;
        W = seaplane design landing weight in pounds;
        β_s = angle of dead rise at a station ¾ of the distance from the bow to the step, but need not be less than 15 degrees; and
        r_y = ratio of the lateral distance between the center of gravity and the plane of symmetry of the float to the radius of gyration in roll.

(c) Bow loading. The resultant limit load must be applied in the plane of symmetry of the float at a point one-fourth of the distance from the bow to the step and must be perpendicular to the tangent to the keel line at that point. The magnitude of the resultant load is that specified in paragraph (b) of this section.

(d) Unsymmetrical step loading. The resultant water load consists of a component equal to 0.75 times the load specified in paragraph (a) of this section and a side component equal to 0.025 tan β times the load specified in paragraph (b) of this section. The side load must be applied perpendicularly to the plane of symmetry of the float

at a point midway between the keel and the chine.

(e) Unsymmetrical bow loading. The resultant water load consists of a component equal to 0.75 times the load specified in paragraph (b) of this section and a side component equal to 0.25 tan β times the load specified in paragraph (c) of this section. The side load must be applied perpendicularly to the plane of symmetry at a point midway between the keel and the chine.

(f) Immersed float condition. The resultant load must be applied at the centroid of the cross section of the float at a point one-third of the distance from the bow to the step. The limit load components are as follows:

$$vertical = PgV \quad aft = \frac{C_X PV^{2/3}(KV_{S0})^2}{2} \quad side = \frac{C_Y PV^{2/3}(KV_{S0})^2}{2}$$

where—

P = mass density of water (slugs/ft^3)
V = volume of float (ft^3);
C_X = coefficient of drag force, equal to 0.133;
C_Y = coefficient of side force, equal to 0.106;
K = 0.8, except that lower values may be used if it is shown that the floats are incapable of submerging at a speed of 0.8 V_{S0} in normal operations;
V_{S0} = seaplane stalling speed (knots) with landing flaps extended in the appropriate position and with no slipstream effect; and
g = acceleration due to gravity (ft/sec^2).

(g) Float bottom pressures. The float bottom pressures must be established under §23.533, except that the value of K_2 in the formulae may be taken as 1.0. The angle of dead rise to be used in determining the float bottom pressures is set forth in paragraph (b) of this section.

§ 23.537 Seawing loads.
Seawing design loads must be based on applicable test data.

§ 23.751 Main float buoyancy.
(a) Each main float must have—

(1) A buoyancy of 80 percent in excess of the buoyancy required by that float to support its portion of the maximum weight of the seaplane or amphibian in fresh water; and

(2) Enough watertight compartments to provide reasonable assurance that the seaplane or amphibian will stay afloat without capsizing if any two compartments of any main float are flooded.

(b) Each main float must contain at least four watertight compartments approximately equal in volume.

§ 23.753 Main float design.
Each seaplane main float must meet the requirements of §23.521.

§ 23.755 Hulls.
(a) The hull of a hull seaplane or amphibian of 1,500 pounds or more maximum weight must have watertight compartments designed and arranged so that the hull auxiliary floats, and tires (if used), will keep the airplane afloat without capsizing in fresh water when—

(1) For airplanes of 5,000 pounds or more maximum weight, any two adjacent compartments are flooded; and

(2) For airplanes of 1,500 pounds up to, but not including, 5,000 pounds maximum weight, any single compartment is flooded.

(b) Watertight doors in bulkheads may be used for communication between compartments.

§ 23.757 Auxiliary floats.

Auxiliary floats must be arranged so that, when completely submerged in fresh water, they provide a righting moment of at least 1.5 times the upsetting moment caused by the seaplane or amphibian being tilted.

REFERENCES

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