Design of a Single Seat Light Sport Aircraft Seaplane

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Abstract *- In between World War 1 and the 1960's there was a period of extensive research and design work on seaplanes until they were made obsolete by longer range airplanes and more airports. It wasn't until relatively recently that design started to pick up again in the 80's with the Dornier advanced technology amphibious aircraft and are starting to make a comeback especially in the Light Sport Aircraft specification because of their versatility, relatively low price, and ease of obtaining a license. The aim of this paper is the use of a combination of modern methods and past research to do the preliminary design, sizing, performance, and stability analysis of a single seat seaplane. The aircraft must conform to the specifications laid out by the FAA for light sport aircraft for the maximum takeoff weight, speed, and stall speed while incorporating the other specifications in its design for propeller, and landing gear.*

Introduction

The concept of seaplanes was very attractive in the early days of airplane design. The lack of airports and ground facilities in those days and the increase in safety when flying over open seas for long distances made them desirable.

They really came into their own after the First World War with races like the Schneider Cup and increased military interest driving forward research and innovation with attention being paid to both boat planes, in which the hull was like a boats hull, and pontoon planes where they replaced the landing gear with pontoons for water operations.

Pontoon aircraft were more successful for smaller aircraft because they could be retrofitted on some normal aircraft and they could be taken off if they weren't needed reducing weight and drag. They could also be designed with the engine, wings and center of gravity relatively close to each other like normal aircraft simplifying their stability while the pontoons meant that they less prone to being damaged while moving in the water by submerged objects, and any damage would not mean hull or structural damage. While boat hulled aircraft have to deal with the increased weight and drag that the hull requires as well as having to keep the engine and propellers as high as necessary from the spray created on takeoff and landing. On the other hand, for larger airplanes pontoons do not scale well to larger aircraft making boat planes more ideal. The largest of which, the Hughes H-4 Hercules or "Spruce Goose" being 218 ft. long with a 320 ft. wingspan.

They started to be phased out after the Second World War because of more access to airfields and overall reliability increases and didn't start to become popular again until the 1980s. In modern times they are especially becoming more popular for smaller aircraft such as light sport aircraft because of their versatility making it more attractive for sport flyers and the relative ease of getting a sport pilot license giving them a higher possible customer base.

The purpose of this paper is the design of such an aircraft in the style of the old Schneider Cup racers like the Macchi M.33 and float fighters like the Potez Po.453 while becoming much lighter and easier to fly as a modern aircraft within the FAA specifications of light sport aircraft.

Light Sport Aircaft

Light sport aircraft are defined by the FAA as simple-to-operate, easy-to-fly aircraft that can include powered parachutes, weight-shift control aircraft, balloons, airships, gliders and gyroplanes. Fixed wing airplanes included in this category must meet a certain performance definition. For seaplanes they are:

- Maximum gross takeoff weight of 1,430 lbs.
- Maximum stall speed of 45 knots
- Maximum speed in level flight of 120 knots
- Single reciprocating engine
- Fixed or ground adjustable propeller
- One to two person occupancy
- Unpressurized cabin

- Retractable landing gear for seaplanes

Initial Sizing

Initial sizing started from a preliminary sketch of the desired airplane, made by looking at aircraft with similar specifications and looks. The design chosen is similar to a Potez Po.452-3 with a high wing and engine and separate hull and tail as shown in Figure 1.

Initial Drawing

The initial aspect ratio of 7.5 and empty weight fraction were taken from the averages of the collected data of other similarly sized LSA seaplanes as well as an estimated range of 400 n.m. and a velocity of 115 mph.

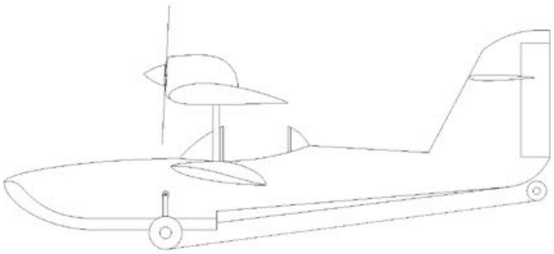


Figure 1 - Basic Drawing

For the wing loading, the W/S of several other LSA seaplanes as well as the calculated wing loading at takeoff, climb, cruise, and stall were compared and the lowest of these chosen. The W/S at takeoff was chosen since it most closely matched the other LSA seaplanes, 9.918.

A preliminary empty weight was estimated using the simplified takeoff-weight equation from [1] and solving for the takeoff gross weight giving the following equation.

$$\boldsymbol{W_0} = \frac{\boldsymbol{W_{crew}} + \boldsymbol{W_{payload}}}{\boldsymbol{1} - \left(\frac{\boldsymbol{W_f}}{\boldsymbol{W_0}}\right) - \left(\frac{\boldsymbol{W_e}}{\boldsymbol{W_0}}\right)} \quad (1)$$

The weight of the crew and the payload were based on looking at similar aircraft and selecting values appropriate for the size. Since it's a single seat aircraft, the crew weight was made higher to be able to accommodate larger pilots, at 240 lb.

Fuel Fraction Estimation

The fuel fraction was estimated by calculating the mission segment weight fractions for a simple cruise mission. Using a simple cruise mission is appropriate in this case because the aircrafts use is basic since all the weights besides fuel will stay constant and the plane is only being designed for cruising. This type of mission has the following legs: Warmup and Takeoff, Climb, Cruise, Loiter, and Landing. For this preliminary calculation, historical mission segment weight were used for the warmup and takeoff, climb and landing.

This resulted in a maximum gross takeoff weight of 1306 lb, empty weight of 966 lb. and a fuel weight of 140 lb

Layout

The seaplane will now be laid out using the preliminary specification calculated previously.

Wing Sizing

A rectangular wing was chosen because of the ease of manufacture would make it more economical and any repairs would be easier even if it would be less efficient. While it was given no twist or dihedral, it was given 3 degrees of incidence to increase lift at takeoff considering that it will also be at an angle while at rest in the water. For the chosen gross weight, wing loading and aspect ratio, sizing gives a span of 31 ft., a chord of 4.2 ft. and a surface area of 131.68 sq. ft. The NACA 4418 airfoil was chosen because of its high lift and popular use in seaplanes.

Tail Sizing

For the same reason of simplicity, the horizontal tail was chosen as rectangular using a symmetrical NACA-0009 airfoil. The aspect ratio chosen was 5 and the resulting surface area of 27.42, span of 11.71 ft, and chord of 2.34 ft.

The vertical tail has the same NACA-0009 airfoil, an aspect ratio of 1.65 and a taper ration of 0.45; resulting surface area of 16.46 sq. ft., a root chord of 4.36 ft., a mean chord 1.96 ft. and a mean aerodynamic chord of 3.31 ft.

Fuselage

To get the fuselage size (2) was used with the constants "a" and "C" coming from a table in [1] that provides a statistical equation for length developed from the data of many airplanes. The constants for "Homebuilt-metal/wood" were selected because that type of airplane provides the closes match to LSA seaplanes in other charts.

$$Length = aW_o^c \quad (2)$$

Tire Sizing

In order to keep the landing gear as simple as possible the airplane is being designed with a taildragger landing gear arrangement. In this arrangement, the front man landing gear carry 90% of the weight and the rear wheel the remaining 10%. Using the statistical tire sizing method shown in [1] for general aviation aircraft gives front tires with a diameter of 14" and a rear tire of 8"

Propeller Sizing

Because the airplane has a high mounted engine above the center of gravity it produced additional forces and moments which are detrimental to water take offs since it can tilt the plane forward instead of onto the step. A 3-blade propeller was chosen so that it could have a smaller diameter of 60 inches while at the same time having similar thrust to a larger 2 blade propeller of 65 inches. This allows the engine to be mounted closer to the hull.

Fuselage Body Curve Equations

Because it is a seaplane which uses its hull instead of pontoons the shape of the hull had to be carefully selected. In [2] different hull shapes suitable for small amphibian aircraft are tested for their hydrodynamic characteristics at takeoff and landing. From this paper, the model 1057-04 was chosen because it had a larger range of stable trim, lower resistances and slightly lower takeoff times at higher speeds, at the cost of more spray because of the smaller beam. Research in [2] provided curve equations for this model for the keel, forebody and afterbody equations for model 1057-04 which were used to shape the hull.

Beam

The width, or beam, was chosen by comparing similar double seater seaplanes. 3 ft was chosen because it is wide enough for one person and not too narrow to sit lower in the water and be more stable when taking off from water.

Deadrise

The deadrise angle typically ranges from 15 to 40 degrees. Higher angles lower the water impact load and can make water landings feel smoother but can make the hull sit deeper in the water. Because the plane is a light single seater 15 degrees was chosen since the hull will not be too tall so a shallower draft will help it deal with waves better and keep the possibility of water spraying into the cockpit low. The deadrise is 15 degrees from the step to the front of the forebody flat and then increases to 30 degrees at the bow which helps with waves spray

Forebody

For fuselage forebody, there needs to be a flat section from the step called the forebody flat. The forebody flat needs to be approximately 1.5x the beam and is there to reduce porpoising. In this case, the forebody flat is 1.5 x 3ft = 4.5 ft.

From the forebody flat to the bow, I use the curve equations from NACA 2503 model 1057-04 in the previous section.

Step

The step is typically placed between 10 to 15 degrees vertically from the center of gravity. After adjusting the center of gravity, the step is now at 13 degrees from the CG. The step height is typically from 0.05 to 0.08 of the beam, 0.08 was used which give a step height of 2.88 inches.

Afterbody

The afterbody sternpost angle is typically from 7 to 9 degrees and was chosen to be 7 degrees.

Wetted Area Estimation

The wetted area was calculated using (3) with the top area and side area taken from Solidworks because of the complex shape of the hull. The resulting wetted area is 148 sq. ft.

$$S_{wet} \cong 3.4 \left(\frac{A_{top} + A_{side}}{2} \right) \quad (3)$$

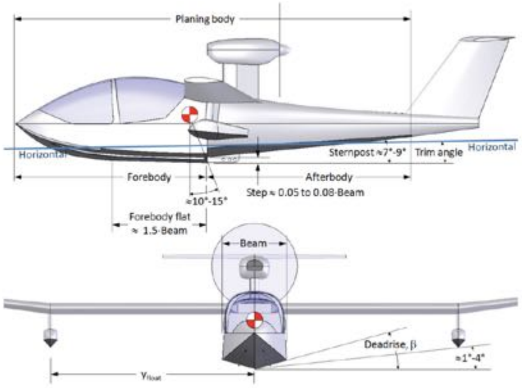


Figure 2 - Seaplane Geometry [3]

Aerodynamics

The aerodynamic properties of the seaplane are calculated based on the designed hull.

Lift Curve Slope

The lift curve slope is important for a number of things at the conceptual stage such as helping set the wing incidence angles properly. Using the semi empirical formula from [1] the lift curve slope for the wing was found to be 5.46 per rad and for the horizontal tail it is 4.83

Drag: Component Buildup Method

The component buildup method for drag estimates the drag for each component of airplane the using a flat-plate skin-friction drag coefficient and a component form factor that estimates pressure drag due to viscous separation. Using this method the component drag was calculated for the fuselage, the vertical and horizontal tail, landing gear, estimated struts supporting the wings and engine, the windshield which for this aircraft was chosen as an open cockpit, cooling and miscellaneous engine drag. This results in a parasitic drag coefficient of 0.3063.

Weights

The weight of all the components of the seaplane were calculated using the aircraft statistical weights method from [1] which gives estimates for the wing, horizontal tail, vertical tail, fuselage, landing gear, installed engine, fuel system, flight controls, hydraulics, electrical system, fuel system, flight controls, avionics and furnishings. Some other weights not covered by these equations unique to seaplanes were added such as tip floats, anchor and mooring lines. The wing and fuselage weights were adjusted using data from similar airplanes and the propeller weight was taken from 3 blade props available for the Rotax 912.

Once the weights were calculated in Table 1 their placement was approximated from similar aircraft and the position of the center of gravity of the aircraft was calculated as shown in Figure 3.

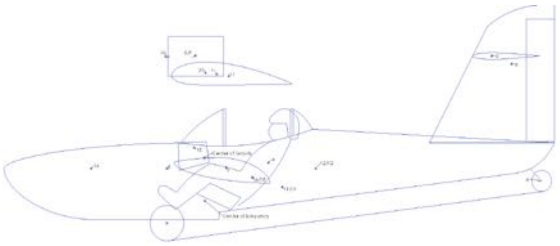
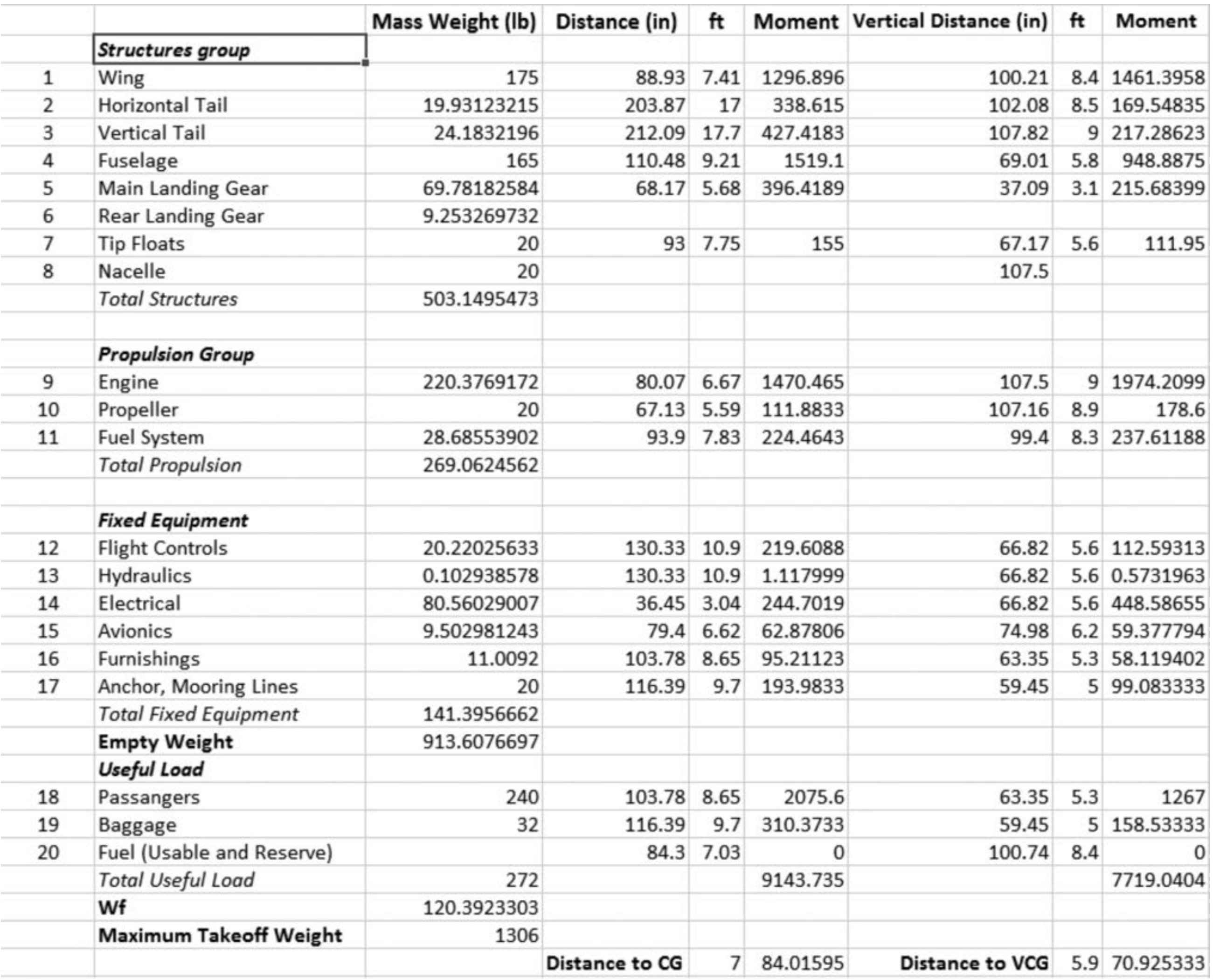


Figure 3 - Component Weight Locations

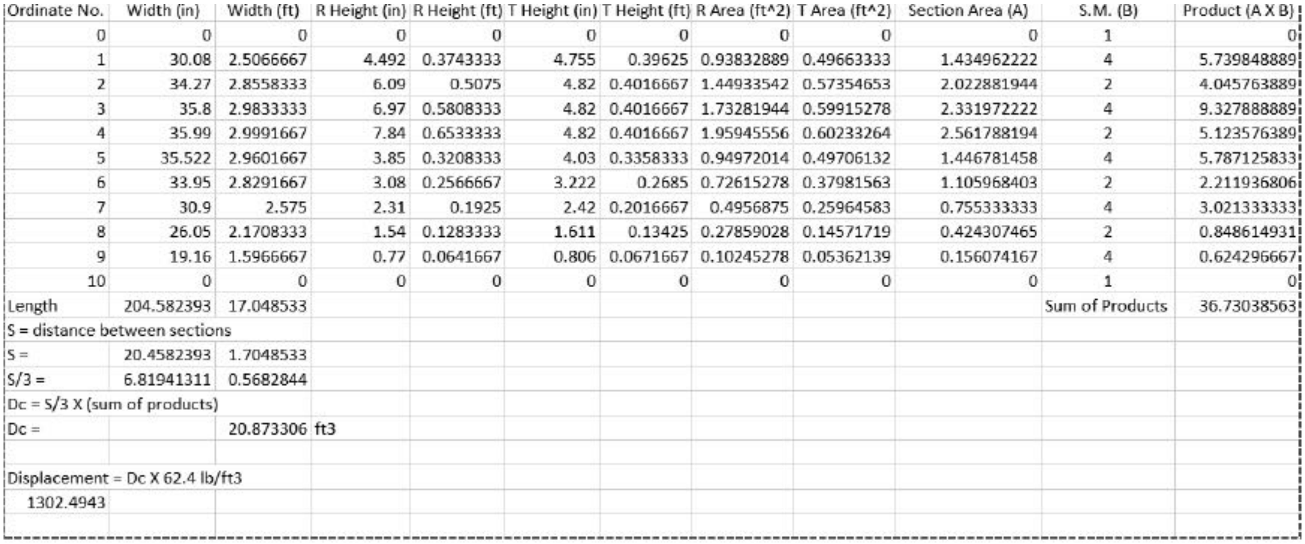
Water Line

To calculate the water line Simpsons Rule for displacement was used because of the seaplane hulls complex shape. A water line was chosen and divided into 10 sections, of which the cross-sectional area was calculated and from that the volume and displacement were computed in Excel in the spreadsheet in Table 2. If it was more or less than then weight of the seaplane then the water line was adjusted and the displacement was calculated again until a satisfactory one was found. The resulting

Table 1- Component Weights, Center of Gravity



		Mass Weight (lb)	Distance (in)	ft	Moment	Vertical Distance (in)	ft	Moment
	Structures group							
1	Wing	175	88.93	7.41	1296.896	100.21	8.4	1461.3958
2	Horizontal Tail	19.93123215	203.87	17	338.615	102.08	8.5	169.54835
3	Vertical Tail	24.1832196	212.09	17.7	427.4183	107.82	9	217.28623
4	Fuselage	165	110.48	9.21	1519.1	69.01	5.8	948.8875
5	Main Landing Gear	69.78182584	68.17	5.68	396.4189	37.09	3.1	215.68399
6	Rear Landing Gear	9.253269732						
7	Tip Floats	20	93	7.75	155	67.17	5.6	111.95
8	Nacelle	20				107.5		
	Total Structures	503.1495473						
	Propulsion Group							
9	Engine	220.3769172	80.07	6.67	1470.465	107.5	9	1974.2099
10	Propeller	20	67.13	5.59	111.8833	107.16	8.9	178.6
11	Fuel System	28.68553902	93.9	7.83	224.4643	99.4	8.3	237.61188
	Total Propulsion	269.0624562						
	Fixed Equipment							
12	Flight Controls	20.22025633	130.33	10.9	219.6088	66.82	5.6	112.59313
13	Hydraulics	0.102938578	130.33	10.9	1.117999	66.82	5.6	0.5731963
14	Electrical	80.56029007	36.45	3.04	244.7019	66.82	5.6	448.58655
15	Avionics	9.502981243	79.4	6.62	62.87806	74.98	6.2	59.377794
16	Furnishings	11.0092	103.78	8.65	95.21123	63.35	5.3	58.119402
17	Anchor, Mooring Lines	20	116.39	9.7	193.9833	59.45	5	99.083333
	Total Fixed Equipment	141.3956662						
	Empty Weight	913.6076697						
	Useful Load							
18	Passangers	240	103.78	8.65	2075.6	63.35	5.3	1267
19	Baggage	32	116.39	9.7	310.3733	59.45	5	158.53333
20	Fuel (Usable and Reserve)		84.3	7.03	0	100.74	8.4	0
	Total Useful Load	272			9143.735			7719.0404
	Wf	120.3923303						
	Maximum Takeoff Weight	1306						
			Distance to CG	7	84.01595	**Distance to VCG**	5.9	70.925333



Ordinate No.	Width (in)	Width (ft)	R Height (in)	R Height (ft)	T Height (in)	T Height (ft)	R Area (ft^2)	T Area (ft^2)	Section Area (A)	S.M. (B)	Product (A X B)
0	0	0	0	0	0	0	0	0	0	1	0
1	30.08	2.5066667	4.492	0.3743333	4.755	0.39625	0.93832889	0.49663333	1.434962222	4	5.739848889
2	34.27	2.8558333	6.09	0.5075	4.82	0.4016667	1.44933542	0.57354653	2.022881944	2	4.045763889
3	35.8	2.9833333	6.97	0.5808333	4.82	0.4016667	1.73281944	0.59915278	2.331972222	4	9.327888889
4	35.99	2.9991667	7.84	0.6533333	4.82	0.4016667	1.95945556	0.60233264	2.561788194	2	5.123576389
5	35.522	2.9601667	3.85	0.3208333	4.03	0.3358333	0.94972014	0.49706132	1.446781458	4	5.787125833
6	33.95	2.8291667	3.08	0.2566667	3.222	0.2685	0.72615278	0.37981563	1.105968403	2	2.211936806
7	30.9	2.575	2.31	0.1925	2.42	0.2016667	0.4956875	0.25964583	0.755333333	4	3.021333333
8	26.05	2.1708333	1.54	0.1283333	1.611	0.13425	0.27859028	0.14571719	0.424307465	2	0.848614931
9	19.16	1.5966667	0.77	0.0641667	0.806	0.0671667	0.10245278	0.05362139	0.156074167	4	0.624296667
10	0	0	0	0	0	0	0	0	0	1	0
Length	204.582393	17.048533								Sum of Products	36.73038563
S = distance between sections											
S =	20.4582393	1.7048533									
S/3 =	6.81941311	0.5682844									
Dc = S/3 X (sum of products)											
Dc =		20.873306	ft3								
Displacement = Dc X 62.4 lb/ft3											
1302.4943											

Table 2 - Simpsons Rule Displacement

waterline can be seen in Figure 11. While this type of displacement calculation yields a decently accurate displacement which can be used to calculate stability, further modeling will later used to calculate it exactly.

Center of Buoyancy

Because the cross section is symmetric, the center of buoyancy is at the center of gravity of the cross section using the water line from the previous section which is in turn at the centroid of the cross section.

Figure 4 - Water Line Area and Centroid Side View

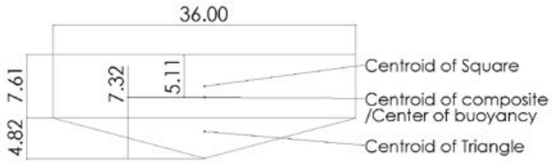


Figure 5 - Waterline at Center of Gravity Front View

Propulsion

Using the available engine data for the Rotax 912 plus the propeller data arrived at earlier their combined performance can be plotted for the performance envelope that the seaplane must fit in as shown in Figure 6.

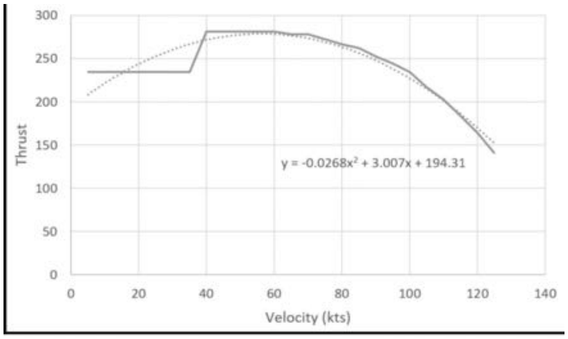


Figure 6 - Thrust vs Velocity

As-Drawn Performance

At this point the seaplane specifications as designed are taken and the performance of the aircraft can be estimated.

Stall

The stall speed of an aircraft is a major factor in flying safety, as failures to maintain a lying speed make up a large part of fatal accidents yearly. General aviation aircraft under 12,500 lbs have max stall speed of 61kts, the FAA specifies that LSA can have a stall speed no higher than 45 kts owing to the fact that LSA have a lower overall speeds and power. The stall speed of an aircraft is directly related to the wing loading and maximum lift coefficient, shown in (4). For this aircraft the stall speed is 41 kts, just under the 45 kts maximum.

$$V_{stall} = \sqrt{\frac{2\ W/_S}{\rho C_{L_{max}}}} \quad (4)$$

Takeoff Distance – Land

T-O distance on land can be broken down into two parts. "Ground roll", which is the distance to when the tires leave the ground, and "obstacle clearance distance" which is the distance when the plane will clear a 50ft obstacle. By calculating the takeoff parameter and analyzing the takeoff distance estimation table in [1] the ground roll was shown to be 500ft and 900ft to clear a 50ft obstacle.

Takeoff Distance – Water

Estimating T-O distance for seaplanes is more complicated than from conventional aircraft because they experience not only aerodynamic drag but also water resistance which is dependent on aircraft speed and its attitude in the water. In order for it to take off successfully it must overcome all the sources of drag.

	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/ft^2			deg	deg			lb_f	lb_f		lb_f	lb_f			lb_f	lb_f	lb_f	ft/s^2	ft
1	0	0	0	0	0	0	-0.0149	6.00023	9.00023	1.20118	0.10867	0	0	0.25	194.31	1306	0.76174	-0.0149	0	0	194.31	4.78693	0
2	0.5	0.5	1.41793	2.39346	0.00681	0.24362	0.00968	6.00144	9.00144	1.20123	0.10868	1.07742	0.093	0.2875	198.52	1304.92	0.76111	0.00967	5.5257	0	192.901	4.75222	1.19673
3	1	0.5	2.82558	4.76958	0.02705	0.48547	0.03157	6.00896	9.00896	1.2019	0.10877	4.28085	0.36959	0.325	202.598	1301.72	0.75924	0.03147	17.9857	0	184.237	4.53878	3.58152
4	1.5	0.5	4.17	7.03897	0.05891	0.71647	0.05025	6.0503	9.0503	1.20558	0.10422	9.35225	0.80851	0.3625	206.383	1296.65	0.75628	0.04980	28.5116	0	177.063	4.36204	7.101
5	2	0.5	5.46208	9.21999	0.10107	0.93846	0.06621	6.2428	9.2428	1.22272	0.10636	16.2738	1.41566	0.4	209.935	1289.73	0.75225	0.06539	37.3676	0	171.152	4.21641	11.711
6	2.5	0.5	6.71101	11.3282	0.15258	1.15305	0.07986	6.82339	9.82339	1.2744	0.11301	25.6052	2.27051	0.4375	213.283	1280.39	0.7468	0.07829	44.7439	0	166.269	4.09612	17.3751
7	3	0.5	7.92432	13.3763	0.21274	1.36151	0.0915	7.54378	10.5438	1.33852	0.12163	37.4969	3.40724	0.475	216.456	1268.5	0.73987	0.08887	50.7918	0	162.256	3.99727	24.0632
8	3.5	0.5	9.10835	15.3749	0.28106	1.56494	0.10139	7.88061	10.8806	1.3685	0.1258	50.649	4.65608	0.5125	219.475	1255.35	0.7322	0.09746	55.6966	0	159.123	3.92007	31.7507
9	4	0.5	10.2695	17.3349	0.35729	1.76445	0.10972	7.97229	10.9723	1.37666	0.12696	64.7699	5.97313	0.55	222.364	1241.23	0.72396	0.10428	59.5971	0	156.794	3.8627	40.4181
10	4.5	0.5	11.4137	19.2663	0.44134	1.96103	0.11667	7.99366	10.9937	1.37856	0.12723	80.1169	7.39393	0.5875	225.14	1225.88	0.71501	0.10951	62.5857	0	155.16	3.82245	50.0513
11	5	0.5	12.5459	21.1775	0.53325	2.15557	0.12235	7.99854	10.9985	1.379	0.12729	96.8311	8.93798	0.625	227.817	1209.17	0.70526	0.11328	64.7395	0	154.14	3.79731	60.64
12	5.5	0.5	13.6707	23.0762	0.63315	2.34882	0.12687	7.99966	10.9997	1.3791	0.1273	114.98	10.6137	0.6625	230.409	1191.02	0.69467	0.1157	66.1249	0	153.671	3.78576	72.1781
13	6	0.5	14.7921	24.969	0.74129	2.54149	0.13032	7.99992	10.9999	1.37912	0.12731	134.619	12.4266	0.7	232.926	1171.38	0.68322	0.11688	66.7989	0	153.7	3.78649	84.6626
14	6.5	0.5	15.9137	26.8623	0.85796	2.7342	0.13274	7.99998	11	1.37913	0.12731	155.809	14.3826	0.7375	235.375	1150.19	0.67086	0.1169	66.8107	0	154.182	3.79836	98.0937
15	7	0.5	17.0388	28.7615	0.98357	2.92751	0.1342	8	11	1.37913	0.12731	178.619	16.4883	0.775	237.765	1127.38	0.65756	0.11584	66.204	0	155.073	3.8203	112.474
16	7.5	0.5	18.1704	30.6716	1.11855	3.12193	0.13472	8	11	1.37913	0.12731	203.133	18.7511	0.8125	240.1	1102.87	0.64326	0.11377	65.0187	0	156.33	3.85128	127.81
17	8	0.5	19.3112	32.5972	1.26341	3.31793	0.13435	8	11	1.37913	0.12731	229.44	21.1795	0.85	242.384	1076.56	0.62792	0.11075	63.2927	0	157.912	3.89025	144.109
18	8.5	0.5	20.4635	34.5424	1.41869	3.51592	0.13311	8	11	1.37913	0.12731	257.639	23.7825	0.8875	244.621	1048.36	0.61147	0.10685	61.0636	0	159.775	3.93614	161.38
19	9	0.5	21.6294	36.5104	1.58495	3.71624	0.13101	8	11	1.37913	0.12731	287.833	26.5697	0.925	246.812	1018.17	0.59386	0.10214	58.3705	0	161.871	3.98779	179.635
20	9.5	0.5	22.8106	38.5043	1.76279	3.91919	0.12808	8	11	1.37913	0.12731	320.13	29.551	0.9625	248.957	985.87	0.57502	0.09668	55.2552	0	164.151	4.04394	198.887
21	10	0.5	24.0085	40.5263	1.95279	4.125	0.12434	8	11	1.37913	0.12731	354.634	32.7361	1	251.056	951.366	0.55489	0.09058	51.7636	0	166.556	4.1032	219.151
22	10.5	0.5	25.2239	42.5779	2.15551	4.33382	0.11981	8	11	1.37913	0.12731	391.449	36.1345	1.0375	253.107	914.551	0.53342	0.0839	47.9472	0	169.025	4.16402	240.44
23	11	0.5	26.4573	44.6599	2.37147	4.54574	0.11451	8	11	1.37913	0.12731	430.668	39.7547	1.075	255.107	875.332	0.51055	0.07675	43.8636	0	171.489	4.22472	262.77
24	11.5	0.5	27.7087	46.7723	2.60111	4.76075	0.10849	8	11	1.37913	0.12731	472.371	43.6044	1.1125	257.054	833.629	0.48622	0.06925	39.5771	0	173.872	4.28344	286.156
25	12	0.5	28.9775	48.914	2.84478	4.97875	0.10178	8	11	1.37913	0.12731	516.622	47.6891	1.15	258.941	789.378	0.46041	0.06152	35.1591	0	176.093	4.33815	310.613
26	12.5	0.5	30.2625	51.0831	3.10267	5.19953	0.09444	8	11	1.37913	0.12731	563.457	52.0124	1.1875	260.765	742.543	0.4331	0.0537	30.6871	0	178.066	4.38675	336.154
27	13	0.5	31.5619	53.2764	3.37483	5.42278	0.08653	8	11	1.37913	0.12731	612.882	56.5749	1.225	262.52	693.118	0.40427	0.04592	26.2439	0	179.701	4.42703	362.792
28	13.5	0.5	32.8732	55.49	3.66109	5.64809	0.07811	8	11	1.37913	0.12731	664.868	61.3736	1.2625	264.198	641.132	0.37395	0.03835	21.9155	0	180.909	4.4568	390.537
29	14	0.5	34.1933	57.7184	3.96104	5.8749	0.06929	8	11	1.37913	0.12731	719.34	66.402	1.3	265.795	586.66	0.34218	0.03113	17.7883	0	181.605	4.47393	419.397
30	14.5	0.5	35.5186	59.9553	4.27408	6.1026	0.06015	8	11	1.37913	0.12731	776.179	71.6487	1.3375	267.304	529.821	0.30902	0.0244	13.9462	0	181.709	4.4765	449.374
31	15	0.5	36.8445	62.1936	4.5991	6.33042	0.05081	8	11	1.37913	0.12731	835.214	77.0982	1.375	268.72	470.786	0.27459	0.01831	10.4667	48.8707	132.284	3.2589	480.471
32	15.5	0.5	37.8098	63.823	4.84325	6.49627	0.04392	8	11	1.37913	0.12731	879.551	81.191	1.4125	269.691	426.449	0.24873	0.01434	8.1956	51.465	128.84	3.17403	512.383
33	16	0.5	38.75	65.41	5.0871	6.65781	0.03717	8	11	1.37913	0.12731	923.837	85.279	1.45	270.589	382.163	0.2229	0.01088	6.21672	54.0563	125.037	3.08036	545.088
34	16.5	0.5	39.6625	66.9502	5.32949	6.81458	0.03062	8	11	1.37913	0.12731	967.856	89.3423	1.4875	271.416	338.144	0.19723	0.00793	4.53122	56.632	120.91	2.97869	578.563
35	17	0.5	40.5448	68.4396	5.56924	6.96617	0.02431	8	11	1.37913	0.12731	1011.4	93.3614	1.525	272.172	294.605	0.17183	0.00548	3.13335	59.1796	116.498	2.86998	612.782
36	17.5	0.5	41.3949	69.8746	5.80524	7.11223	0.01826	8	11	1.37913	0.12731	1054.25	97.3176	1.5625	272.862	251.747	0.14683	0.00352	2.01121	61.6873	111.846	2.75537	647.72
37	18	0.5	42.211	71.2522	6.03641	7.25246	0.0125	8	11	1.37913	0.12731	1096.23	101.193	1.6	273.487	209.765	0.12235	0.00201	1.1478	64.1438	107.003	2.63607	683.346
38	18.5	0.5	42.9919	72.5703	6.2618	7.38662	0.00707	8	11	1.37913	0.12731	1137.17	104.971	1.6375	274.052	168.833	0.09847	0.00091	0.52222	66.5388	102.02	2.51331	719.631
39	19	0.5	43.7363	73.8269	6.48054	7.51453	0.00196	8	11	1.37913	0.12731	1176.89	108.638	1.675	274.56	129.109	0.0753	0.00019	0	68.8632	97.0589	2.3911	756.544
40	19.5	0.5	44.4446	75.0225	6.69213	7.63622	-0.0028	8	11	1.37913	0.12731	1215.32	112.185	1.7125	275.016	90.6836	0.05289	-0.0002	0	71.1116	91.7194	2.25956	794.056
41	20	0.5	45.1139	76.1523	6.89521	7.75121	-0.0072	8	11	1.37913	0.12731	1252.2	115.59	1.75	275.422	53.8047	0.03138	-0.0003	0	73.2695	86.5634	2.13253	832.132
42	20.5	0.5	45.7456	77.2185	7.08965	7.85974	-0.0113	8	11	1.37913	0.12731	1287.51	118.849	1.7875	275.784	18.4932	0.01079	-0.0002	0	75.3357	81.5989	2.01023	870.741
43	21	0.5	46.341	78.2236	7.27542	7.96205	-0.0151	8	11	1.37913	0.12731	1321.24	121.963	1.825	276.105	-15.248	-0.0089	0.00018	0	77.3096	76.8318	1.89279	909.853
44	21.5	0.5	46.9017	79.17	7.45253	8.05838	-0.0186	8	11	1.37913	0.12731	1353.41	124.932	1.8625	276.39	-47.406	-0.0277	0.00068	0	79.1916	72.2656	1.7803	949.438
45	22	0.5	47.429	80.0602	7.62105	8.14898	-0.0218	8	11	1.37913	0.12731	1384.01	127.757	1.9	276.642	-78.012	-0.0455	0.0013	0	80.9824	67.9023	1.67281	989.468

Table 3 - Takeoff Distance Calculation

In order to have a reliable T-O analysis the physics had to be simulated and integrated over a duration while making use of simulated resistance and trim angles for a seaplane hull from [3] until the planes lift is sufficient. The overlap between the resistance and the Froude resistance shows the time when the seaplane transitions on to the step after which the Froude resistance is the only one the plane experienced. The seaplane takes off after 871 ft taking 20.5 seconds, which is close to other LSA seaplanes, but more accurate results will come from physical modeling and water tank testing.

Rate of Climb and Vmax

The maximum speed and rate of climb were plotted for sea level, the average LSA cruising altitude of 5,000 ft and the service ceiling of 10,000 ft. in order to get a good idea of how the altitude affects thrust and drag and the performance of the seaplane in Figure 7 and Figure 8. The maximum speed is 112 kts at sea level and the rate of climb increases from 15 ft/s to 17 ft/s as the seaplane increases altitude.

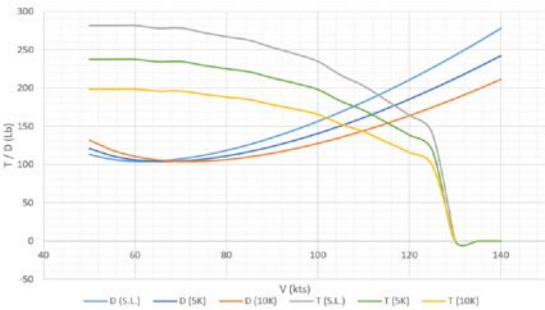


Figure 7 - Maximum Speed

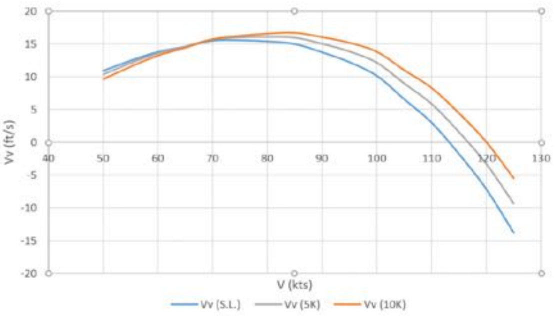


Figure 8 - Rate of Climb

Stability, Control and Handling

The static margin is the most important factor in the longitudinal stability of an aircraft. The higher the percentage the more stable an aircraft is. The desirability of a large or small static margin will greatly depend on they type of aircraft being designed, with aircraft g.a. aircraft having higher static margins ranging anywhere up to 19% to fighters with -15%. This seaplane was shown to have a power-off static margin on 15% and stick-free of 11%. In both cases it is in the range of other g.a. aircraft.

Spin Recovery

Spin will occur after stall in a bad or severely abused airplane and is primarily driven by the difference in lift of faster outer wing and stalled inner wing. In order to recover from a spin the rudder must be deflected against it, but only the part not blanketed by stalled air as shown in Figure 9 will aid in recovering from the spin denoted by the minimum allowable tail-damping power factor, or TDPF. For the seaplane, the TDPF is more double of the minimum with a TDPF of 3.72E-4 > 1.75E-4

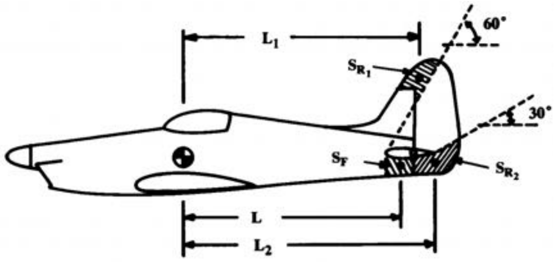


Figure 9 - Unstalled Tail Area [1]

Longitudinal Metacenter

All seaplanes must possess longitudinal and transverse hydrostatic stability at all times when at low speed on the water. This type of stability signifies that the vessel has a tendency to return to its at-rest attitude when tilted forcibly on any axis. The metacenter is in imaginary point which determines whether a vessel is stable or unstable. A metacenter above the center of gravity would be positive and implies that the vessel has a tendency to right itself and negative means that it is unstable and will not right itself.

The longitudinal metacenter lies in the axis along the length of the seaplane and in this case is shown to be 5 ft above the center of gravity, which means that it is indeed stable.

Transverse Metacenter

The transverse metacenter lies in the axis normal to the longitudinal and because of the orientation tends to be negative and thus unstable, in this case 1.356 ft below the center of gravity, requiring in floats to make it stable. The volume, displacement and placement required to make the seaplane stable is calculated from Figure 10. For float sizing I used the profile of a similar seaplanes float and the same curve equations from the hull to get the side profile and with the volume from this equation I got the required width for the volume. The resulting float volume is 1.78 cu. ft.

For the float placement I used 4 degrees from the water line to the bottom of the float. With this I can calculate that the floats have a righting moment of 964 lb. ft. As the floats must have at least double the righting moment of the disturbing moment, in this case 130 lb. ft., means that the seaplane is transversely stable.

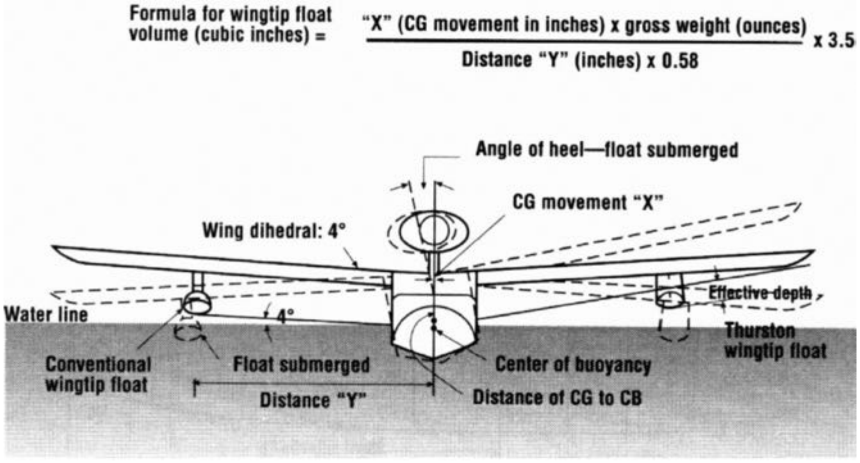


Figure 10 - Float Volume Calculation

Refined Sizing

At this point in the design due to the more detailed knowledge of the design the mission weight fraction can be done with more accuracy. Now the warmup and takeoff, and climb fractions can be computed without using historical values.

When redoing this my required fuel weight was too large and putting the aircraft overweight so the range was adjusted from 400 to 371 nautical miles in order to make weight. Lowering the range was chosen because the resulting range is still within the same ranges as other similarly sized LSA seaplanes.

The refined sizing still resulted in a gross weight of 1306 lb and a fuel weight of 120 lb, with lesser range.

Aspect Ratio Optimization

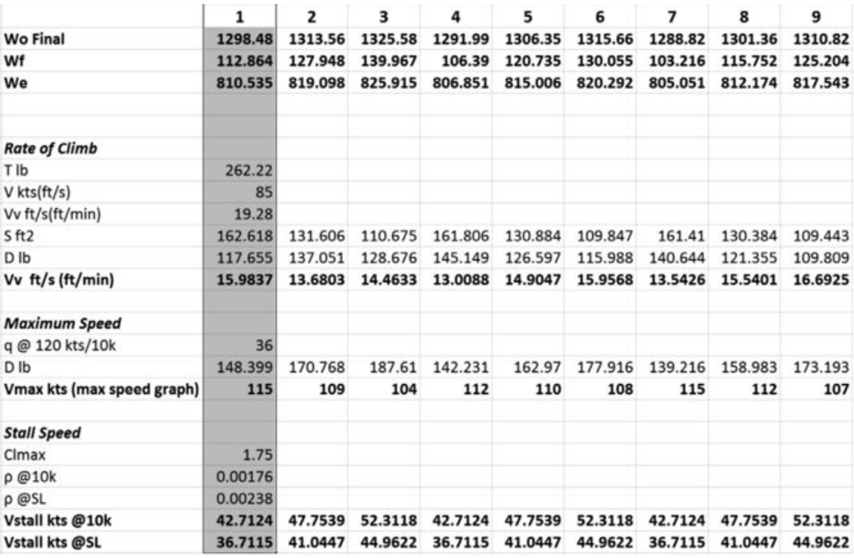
In order to optimize the seaplane the "sizing matrix" method was used. In this method two variables were selected and varied parametrically, in this case the wing loading and aspect ratio were selected because the engine is fixed; the wing loading was varied by +/- 20% and the aspect ratio by +/- 33% as shown in in Table 5. Then for each of these the gross weight, rate of climb, maximum speed, and stall speed were calculated and compared in Excel as shown in Table 5. Because of the relatively high stall speed at maximum altitude it was chosen as a major factor and it was found that lowering the wing loading and aspect ratio to 7.985 and 5.025 respectively gave it superior results in all the metrics chosen. The gross weight is reduced by 8 lbs., the rate of climb and maximum speed both increase 1 ft./s and 5 kts respectively, and the stall speed is reduced 5 kts at both the airplane ceiling altitude and sea level. In a further pass these will be chosen and the airplane will be resized and checked once more.

			W/S	
		7.9848	9.981	11.9772
A	5.025	1	2	3
	7.5	4	5	6
	9.975	7	8	9

Table 5 - Optimization Variation Chart

Summary and Conclusion

The preliminary design of this seaplane has been successful in putting together both old and new research to come up with a viable seaplane that could qualify as a light sport aircraft. While the simplified design of the wings and horizontal tail would help with ease of manufacture on the next run with the optimized aspect ratio it would be interesting to also design one with a different wing configurations to see which one would offer the best performance. The next step for this particular design would be to rework it using the optimized aspect ratio and wing loading then model it in a CAD program and test it both with computational fluid dynamics programs and physically with scale models in a wind tunnel and water tank.



	1	2	3	4	5	6	7	8	9
Wo Final	**1298.48**	**1313.56**	**1325.58**	**1291.99**	**1306.35**	**1315.66**	**1288.82**	**1301.36**	**1310.82**
Wf	**112.864**	**127.948**	**139.967**	**106.39**	**120.735**	**130.055**	**103.216**	**115.752**	**125.204**
We	**810.535**	**819.098**	**825.915**	**806.851**	**815.006**	**820.292**	**805.051**	**812.174**	**817.543**
Rate of Climb									
T lb	262.22								
V kts(ft/s)	85								
Vv ft/s(ft/min)	19.28								
S ft2	162.618	131.606	110.675	161.806	130.884	109.847	161.41	130.384	109.443
D lb	117.655	137.051	128.676	145.149	126.597	115.988	140.644	121.355	109.809
Vv ft/s (ft/min)	**15.9837**	**13.6803**	**14.4633**	**13.0088**	**14.9047**	**15.9568**	**13.5426**	**15.5401**	**16.6925**
Maximum Speed									
q @ 120 kts/10k	36								
D lb	148.399	170.768	187.61	142.231	162.97	177.916	139.216	158.983	173.193
Vmax kts (max speed graph)	**115**	**109**	**104**	**112**	**110**	**108**	**115**	**112**	**107**
Stall Speed									
Clmax	1.75								
ρ @10k	0.00176								
ρ @SL	0.00238								
Vstall kts @10k	**42.7124**	**47.7539**	**52.3118**	**42.7124**	**47.7539**	**52.3118**	**42.7124**	**47.7539**	**52.3118**
Vstall kts @SL	**36.7115**	**41.0447**	**44.9622**	**36.7115**	**41.0447**	**44.9622**	**36.7115**	**41.0447**	**44.9622**

Table 5A - Optimization Comparison

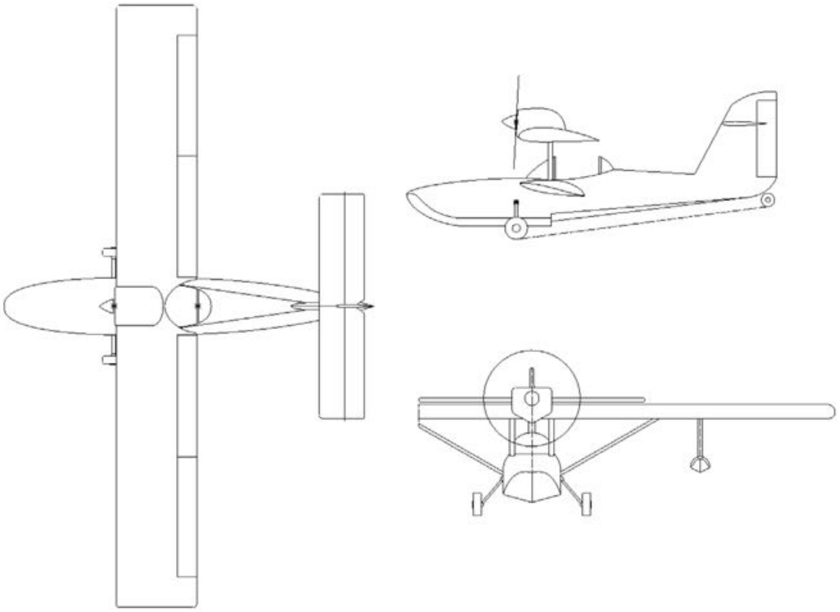


Figure 11 - 3 View of Seaplane

References

[1] P. Raymer Daniel, "Title of chapter in the book," in *Aircraft Design: A Conceptual Approach*, 5th ed. Reston Virginia: AIAA, 2012.

[2] W. C. Hugli, Jr, "Hydrodynamic investigation of a series of hull models," Stevens Institute of Tech., Washington, 1951.

[3] Snorri Gudmundsson, "Design of Seaplanes," in *General Aviation Aircraft Design*, 1st. ed. Oxford, United Kingdom: Elsevier, 2013.