AerE 462
Aerospace Senior Design

Air Nautilus Draft Plan
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Submitted by

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Submitted to

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Executive Summary

This draft report includes a general overview of the AirNautilus project based off of DARPA RFP BAA-09-06 and the group's progress to date. This includes a project requirement section, literature survey, performance criteria and design concepts, and the plan/schedule for this project. Using all of this information the group will move into the next phase of the design process such as modeling and the beginning of component selection. All of this will lead to our final write up and presentation at the end of the semester.

Request for proposal specifications

DARPA is soliciting innovative research proposals on the topic of a Submersible Aircraft. In particular, DARPA is interested in a feasibility study and experiments to prove out the possibility of making an aircraft that can maneuver underwater. The proposal needs to outline a conceptual design along with identifying the major technological limitations that need to be overcome in order to maneuver an aircraft underwater. In addition to the conceptual design studies, performers need to outline experiments or computational models that will be used to demonstrate that the major technological limitations can be overcome.

Range

There are three range objectives set for the platform that correspond to the anticipated three modes of operation: 1) airborne; 2) surface; and 3) subsurface. The minimal required airborne tactical radius of the platform is 1000 nautical miles (nm). The minimum surface tactical radius (defined as flight near the surface of the water which may or may not leverage the ground effect) is 100 nautical miles. The minimum subsurface tactical range is 12 nautical miles. Note that the ranges quoted are the tactical (i.e. one-way) ranges. The platform would need to be able to transit into theater, insert and extract personnel without refueling and this would require the total operational range to be 1000 nm airborne, 200 nm surface, 24 nm subsurface. The extraction is considered complete once the surface transit is finished. At that point in the mission the submersible airplane could meet up with additional air or sea support assets and refuel.

Loiter

The platform should be capable of loitering in a sea-state five, in theater between inserting and extracting personnel for up to 3 days (72 hours). The craft does not need to be submerged during loitering operations; it can operate at the surface.

Payload

The platform should be capable of transporting 8 operators, as well as all of their equipment, with a total cargo weight of 2000 pounds.

Depth

The operating depth of the platform will be constrained by balancing the need to reduce depth in order to minimize structural loads and snorkel complexity with the need to increase depth in order to minimize any potential signatures that could be generated by perturbing the free surface. The effect that the submerged platform will have on the free surface is exponentially proportional to the depth; therefore the platform should be able to operate at a relatively shallow depth and only have the snorkel affect the free surface.

Speed

The speed of the platform in each mode of operation must allow the system to complete a tactical transit (1000 nm airborne, 100 nm surface, 12 nm sub-surface) trip in less than 8 hours. This 8 hour time must include any time required by the platform to reconfigure between modes of operation.

Weight

Proposers need to demonstrate an ability to estimate the weight of their concept design and will need to propose an experiment or model that will demonstrate that a craft of the estimated weight and volume can fly and submerge.

Flow Conditions

Proposers need to demonstrate that the platform can operate as required in the anticipated dissimilar operating conditions. Successful proof of concept should include experiments and/or models that demonstrate the ability of a given geometry to function as desired in both air and liquid fluid flow regimes at different speeds.

Structures

Proposers need to demonstrate through a computational model and/or experiment that their concept for the platform structure can operate in the anticipated range of loading environments. When considering the pressure loading in the submerged condition, the proposers need to account for the fact that there will be a pressure gradient along the height of the hull which will be a function of depth. This pressure gradient will be unsteady because it is a function of the free surface elevation that will be constantly changing.

Wing geometry

Proposers need to demonstrate with a mockup or computational model all concepts for reconfiguration, retraction, and/or any other modification to the geometry of the platform that will be required in order to exhibit the desired operational envelope.

Power Generation/Energy Storage

The proposers need to demonstrate via experiment and or model based calculations that they can supply the required quantity and types of fuel and oxidizer to the engine during all modes of operation.

Market/Literature survey

The resources used for this project for research has been a mix of expert consulting, textbook reading, and online/offline research. Because this aircraft has no previous comparisons, the research was focused on certain aspects of the aircraft. For example, the engine comparison was done using engines from similar sized/weight aircraft. Research into submarines was also done in order to better understand how this aircraft can be submersed and the challenges faced by this task.

Experts that have been consulted have been primarily for structural analysis, battery needs for the power required, motor usage and energy requirements, and for general planning and organizational reasons.

The textbooks used have included:

Aircraft Performance and Design, John D. Anderson Jr, Copyright 1999, McGraw Hill publishing

Fluid Dynamic Drag, Sighard F. Hoerner, Copyright 1965

A large amount of research has been done online.

Design Concept and Performance Criteria

The team's design concept was broken down into six different groups each researching and submitting ideas and data to the rest of the group. These groups were: submersing methods, engine cooling, electrical motors/batteries, structures, corrosion effects, and propulsion. This section will cover each of these groups trade studies, the systems specifications based off the trade studies, and the technical challenges created by these problems/solutions. Based on these studies a plan is forming and specific tasks are being assigned in the group.

Submersing an Aircraft

The requirements are: aircraft had to reach a depth of 30ft, object has to fly, provide enough space for cargo and passengers, not be too heavy, and good dynamics for both flight and underwater. Research was done to indicate the best and most efficient way of achieving this. Due to the fact that a plane/submarine idea has never been produced, most of this research was done on submarines. A trade off study was done on all plausible configurations (Table 1).

Currently, there are two different ways to submerse an object in water; static and dynamic diving. Dynamic diving is where the forward force of the object along with dive planes submerses the object into the water. These types of objects inherently float and therefore always have positive buoyancy. Most all military submarines use this type of diving. The second, static diving uses ballast tanks to take in water to change the buoyancy of the object. Because aircraft are inherently light weight, their density is also very low, so static diving is the direction of this trade study.

There are three different ways to use ballast tanks; saddle tanks, single hull, and double hull (Fig 1). Saddle tanks are located on the exterior of the object and therefore lead to increased size and more drag. Due to these negative factors, they were ruled out immediately. Single hull and double hull ballast tanks seem viable, but made the decision to use double hull to increase the interior space. General numbers were run to estimate the amount/weight of water that would be taken in for different structural configurations (Table 2). We could easily achieve equal weight of water compared to the aircraft to ensure it sinks. However, recent structural studies have concluded that boron epoxy would provide the best structural material to ensure aircraft will be able to withstand all structural forces. Boron epoxy, like all epoxies, is relatively buoyant. With this, it would be extremely difficult to take in any amount of water to sink the aircraft.

Due to this new design, research is now being shifted into the direction of completely filling portions of the aircraft with water and leaving only necessary parts in dry areas. With this design, we would be able to pick up the required cargo and passengers underwater. However, there is a fine line that needs to be examined to ensure that the stability of the aircraft underwater is good. All portions that are dry need to be modeled and set up in a way so the underwater performance is optimal.

Figure 1: Different Type of Ballast Tanks

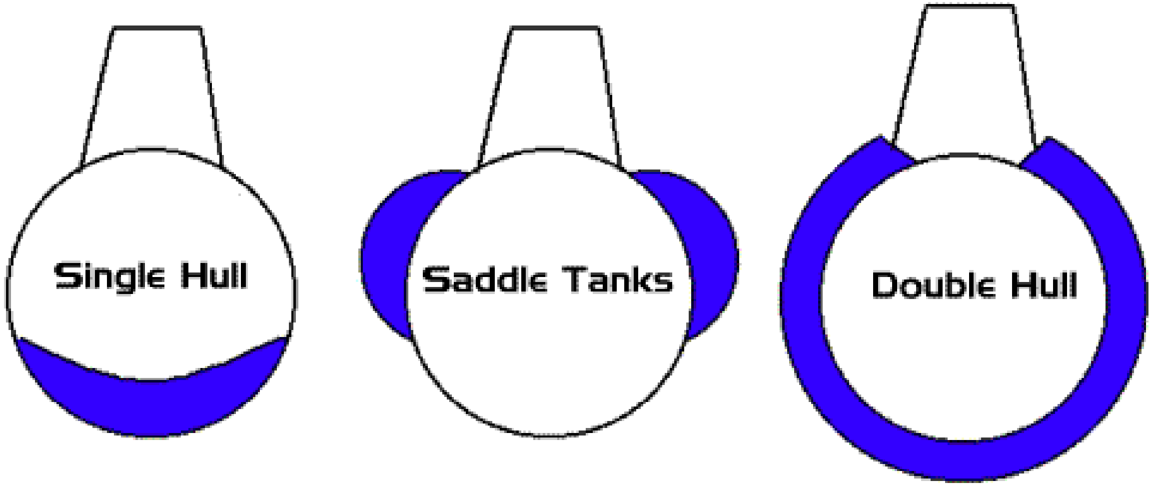
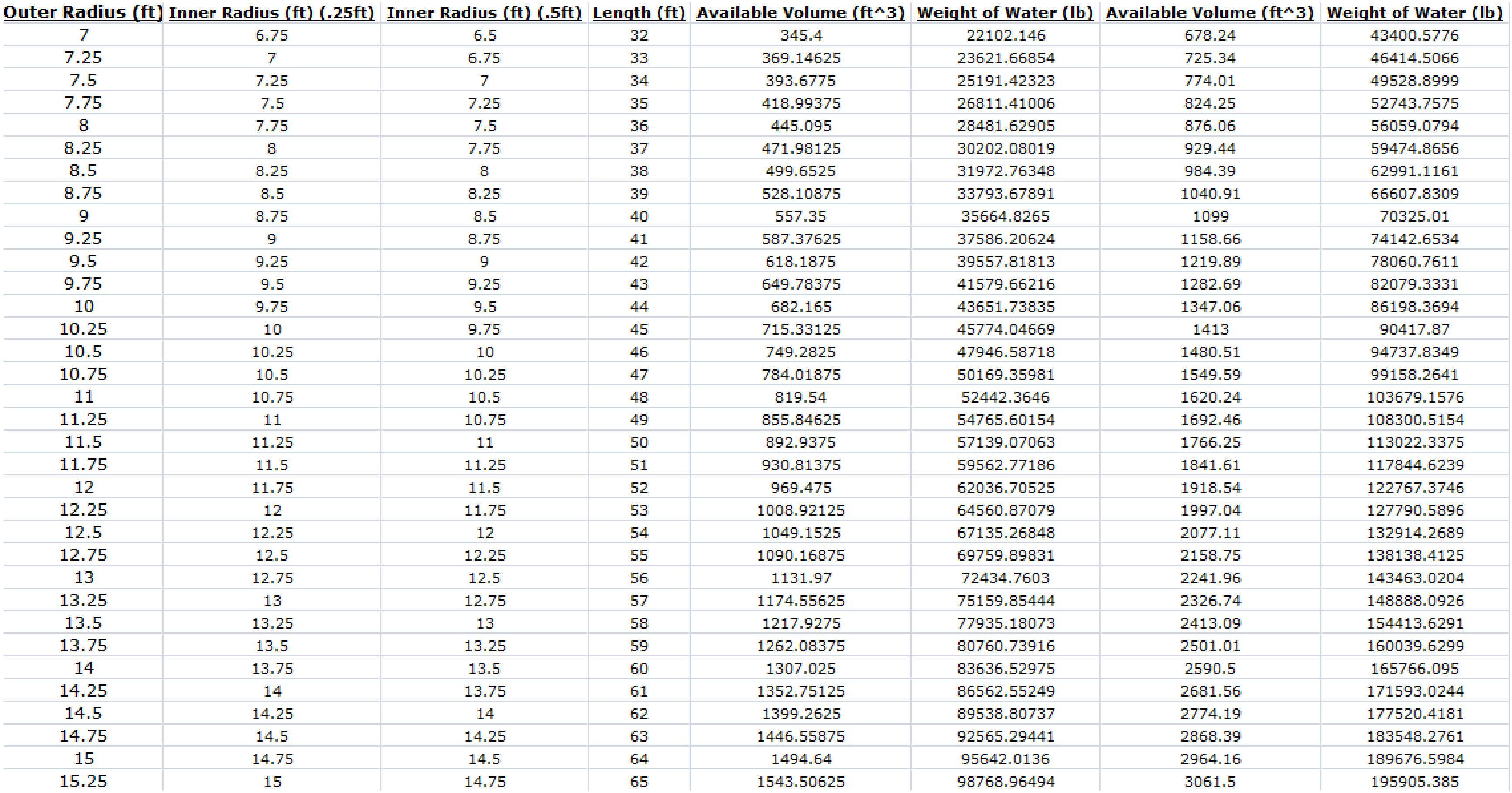


Table 1: Trade-off Study (DD=Dynamic Diving, SD=Static Diving, SH & DH Single/Double Hull)

Requirements	**Weight**	**DD**	**SD w/ST**	**SD w/SH**	**SD w/DH**
Aerodynamic	2	2	0	2	2
Water Dynamics	2	2	0	2	2
Efficient	1.5	0	1	2	2
Weight	1.5	2	2	2	2
Power	1	0	1	2	2
Totals		11	5.5	16	16

Table 2: Volume and water weight calculations



Outer Radius (ft)	Inner Radius (ft) (.25ft)	Inner Radius (ft) (.5ft)	Length (ft)	Available Volume (ft^3)	Weight of Water (lb)	Available Volume (ft^3)	Weight of Water (lb)
7	6.75	6.5	32	345.4	22102.146	678.24	43400.5776
7.25	7	6.75	33	369.14625	23621.66854	725.34	46414.5066
7.5	7.25	7	34	393.6775	25191.42323	774.01	49528.8999
7.75	7.5	7.25	35	418.99375	26811.41006	824.25	52743.7575
8	7.75	7.5	36	445.095	28481.62905	876.06	56059.0794
8.25	8	7.75	37	471.98125	30202.08019	929.44	59474.8656
8.5	8.25	8	38	499.6525	31972.76348	984.39	62991.1161
8.75	8.5	8.25	39	528.10875	33793.67891	1040.91	66607.8309
9	8.75	8.5	40	557.35	35664.8265	1099	70325.01
9.25	9	8.75	41	587.37625	37586.20624	1158.66	74142.6534
9.5	9.25	9	42	618.1875	39557.81813	1219.89	78060.7611
9.75	9.5	9.25	43	649.78375	41579.66216	1282.69	82079.3331
10	9.75	9.5	44	682.165	43651.73835	1347.06	86198.3694
10.25	10	9.75	45	715.33125	45774.04669	1413	90417.87
10.5	10.25	10	46	749.2825	47946.58718	1480.51	94737.8349
10.75	10.5	10.25	47	784.01875	50169.35981	1549.59	99158.2641
11	10.75	10.5	48	819.54	52442.3646	1620.24	103679.1576
11.25	11	10.75	49	855.84625	54765.60154	1692.46	108300.5154
11.5	11.25	11	50	892.9375	57139.07063	1766.25	113022.3375
11.75	11.5	11.25	51	930.81375	59562.77186	1841.61	117844.6239
12	11.75	11.5	52	969.475	62036.70525	1918.54	122767.3746
12.25	12	11.75	53	1008.92125	64560.87079	1997.04	127790.5896
12.5	12.25	12	54	1049.1525	67135.26848	2077.11	132914.2689
12.75	12.5	12.25	55	1090.16875	69759.89831	2158.75	138138.4125
13	12.75	12.5	56	1131.97	72434.7603	2241.96	143463.0204
13.25	13	12.75	57	1174.55625	75159.85444	2326.74	148888.0926
13.5	13.25	13	58	1217.9275	77935.18073	2413.09	154413.6291
13.75	13.5	13.25	59	1262.08375	80760.73916	2501.01	160039.6299
14	13.75	13.5	60	1307.025	83636.52975	2590.5	165766.095
14.25	14	13.75	61	1352.75125	86562.55249	2681.56	171593.0244
14.5	14.25	14	62	1399.2625	89538.80737	2774.19	177520.4181
14.75	14.5	14.25	63	1446.55875	92565.29441	2868.39	183548.2761
15	14.75	14.5	64	1494.64	95642.0136	2964.16	189676.5984
15.25	15	14.75	65	1543.50625	98768.96494	3061.5	195905.385

Buoyancy

Buoyancy is the principle that explains why an object floats or rises to the surface. An object completely or partially immersed in fluid is pushed up by a force that is equal to the weight of the displaced fluid. Force of buoyancy, Fb is equal to the density of water (ρ) times the volume (v) times the gravity (g) of the submerged object. Mathematically, it can be written as:

$$F_b = \rho * v * g \qquad \text{Equation (1)}$$

Buoyant force is caused by gravity which is acting on the fluid. There are three types of buoyant forces that are required to study for the stability of structure; positively buoyant, negatively buoyant and neutrally buoyant. An object is positively buoyant, if the weight of the object is less than the buoyancy (or object less dense than the fluid), it is negatively buoyant if the weight of the object is greater than the buoyancy force (or object is heavy than the fluid beneath it) and neutrally buoyant when both forces are equal to each other. Such condition is attainable by keeping object under equilibrium conditions both above the surface and below the water surface. The methods for submersing our aircraft have already been discussed above under section "Submersing Aircraft". The objective for finding buoyancy calculations and analysis is very necessary for the stable operations underwater that are required for this project. The aircraft needs to be neutrally buoyant during all the operations under water by keeping the balance water volume inside its ballast tanks.

Buoyancy Calculations

Assumptions:

The following assumptions were applied in analyzing the buoyancy forces on our models.

- Density of water: The value for the density of water is considered as 63.9 pound per cubic feet (1025 kg/m^3). This is coming from the fact that sea water is usually heavier than the fresh water. The density of sea water depends upon temperature and salinity of water. As temperature increases density decrease, however it increases as the salinity of water increases. Although density varies at different points in sea water, it is good to use the value of 63.9 pound per cubic feet (1025 kilogram per cubic meter).

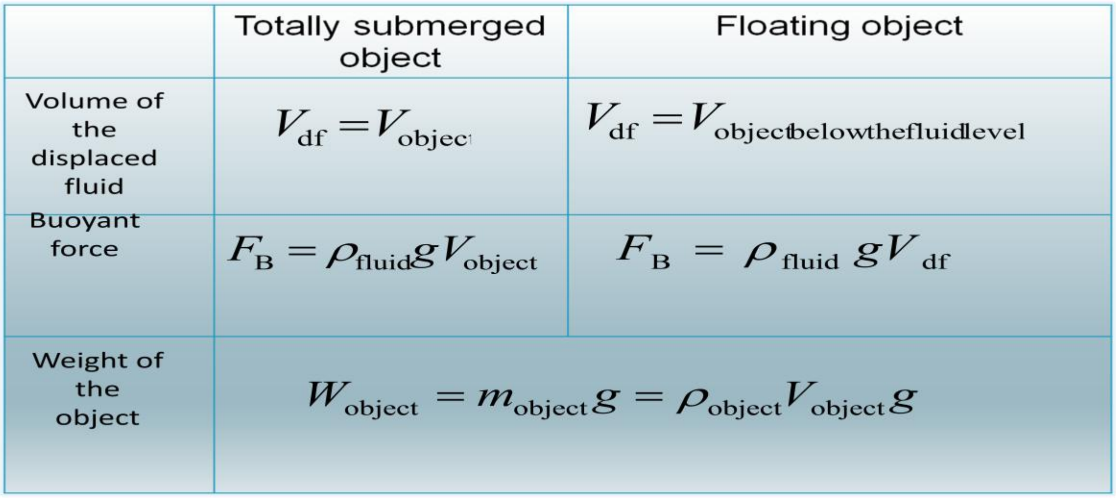
- Shape: The shape of the object is hollow cylinder. This shape is chosen because submarines can withstand under high pressures and crushing loads due to compression.

- The mass of the submersible aircraft is 50, 000 lb and the force of gravity g= 32.2 ft per second square which is acting in the downward direction.

Cases Analyzed

The following two cases were analyzed for each of our model approaches (See table below):

- Partially submerged object under buoyancy force
- Totally or completely submerged object under buoyancy force



	Totally submerged object	Floating object
Volume of the displaced fluid	$V_{\text{df}} = V_{\text{objec}}$	$V_{\text{df}} = V_{\text{object below the fluid level}}$
Buoyant force	$F_{\text{B}} = \rho_{\text{fluid}} g V_{\text{object}}$	$F_{\text{B}} = \rho_{\text{fluid}} g V_{\text{df}}$
Weight of the object	$W_{\text{object}} = m_{\text{object}} g = \rho_{\text{object}} V_{\text{object}} g$	

<u>Model 1: Simplified Cylinder Model</u>

In the first simplified model, we first treated an object (submersible aircraft) as long hollow cylinder with height of 32 feet, inner and outer radii of 6.75 feet and 7 feet respectively (see table 2). For this model the force of drag is ignored that acts when object move up or down inside the fluid. The two forces acting are the force of gravity in the downward direction and the buoyancy force in the upward direction. This helped us in analyzing about the volume of water that is being displaced and how much volume of water we need to take in for submerging the aircraft in water. The buoyancy force was calculated and estimates were made from results, whether an object is positively buoyant or negatively buoyant, or neutrally buoyant.

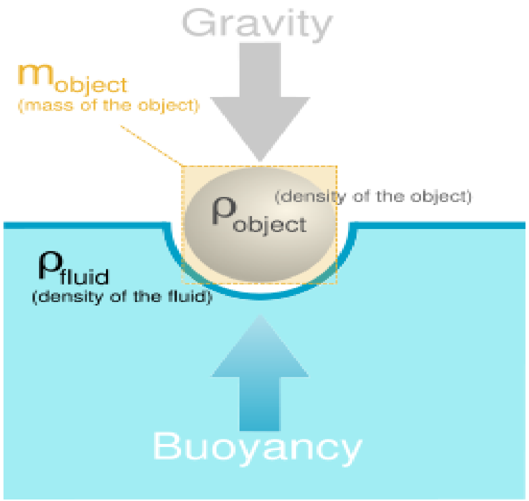


Figure: Forces on the object under buoyancy

The total volume of the cylindrical object found was 345.4 cubic feet. We used the volume expression for the hollow cylinder, which can be written as:

$$V= (\pi * Ro^{2} * h) - (\pi * r_i^{2} * h) = \pi * h (Ro^{2} - r_i^{2}) \qquad \text{Equation (2)}$$

Where, Ro is the outer radius of the object in feet, $r_i =$ inner radius of the object in feet and h is the height of the hollow cylinder in feet.

We first assumed that our object is partially submerged in the water. The weight of 50, 000 object found to be 1.61E 6 pounds. Under this condition the volume of water displaced by object is 777 cubic feet, which is 21. 8 cubic meter approximately. The volume for the partially submerged object was the half of original volume. The forces of buoyancy found for both the partially submerged object and the completely submerged object were 3.71 E + 5 pounds, and 7.43 E +5 pounds. Comparing both values with the weight of the object it seems that our object is sinking and is negatively buoyant. This is not the desired result and we further need to reconfigure our model assumptions to reach more feasible results.

Model 2: Object with force of drag

It was more practical to introduce the force of drag now on our model when it moves up or down in water with certain velocity. We remodeled our design for this purposes and this time considered the coefficient of drag (C_d) as 0.1 and velocity as 32.8 feet per second just for running the calculations. The net force, Fnet was calculated by adding all the forces acting on our object; the buoyancy force, F_b (upward direction), the force of gravity (downward), and the drag force- depending on whether our object is moving up or down. This can be written mathematically:

$$F_{net}= F_g + F_b+ F_d \qquad \text{Equation (3)}$$

The force of drag was calculated using the drag equation:

$$\text{Drag (D)} = 0.5 * \rho * V^2 * S * C_d$$

Equation (4)

Where, Capital S is the surface area of the object under observation that can be calculated using the relationship:

$$S= 2\pi r_i\, h + 2\pi\, Ro\, h + 2*\pi * (Ro^{2} - r_i^{2}) \qquad \text{Equation (5)}$$

The decision was made based on our calculation, whether we are negatively buoyant or positively buoyant. The magnitude of the resulting drag force determined is 9.57 E 6 pounds when object is moving inside the fluid medium. There is no drag on the object when it is sitting in equilibrium position on the surface of the fluid. In this case the buoyancy force is same as we found in our first model i.e. 3.71 E + 5 pounds. The final value of forces is positive for both partially and completely submerged object, which means that our model is always positively buoyant. However, if we make it dense our assumption will not be the same. The two value of net force, for both partially and completely submerged object are 8.34

E + 6 pounds, and 8.70 E 6 respectively are positive in magnitude which proofs that the object in our model is always positively buoyant, which is desired result for the objects submerged in the water.

Future work

In the future stability and buoyancy calculations are required using the stability curves and dynamics of the submarines. For this purpose more research is required in the area related to the terminologies of ship's hydrostatics, stability and moment, finding the metacenter, center of gravity and center of buoyancy.

Engine Cooling

Ceramics are by nature a very brittle, yet strong, material. This combination of strength and brittleness lead to a very large problem when a ceramic material needs to be cooled rapidly. As a ceramic warms, it will expand determined by its coefficient of thermal expansion. When the ceramic is rapidly cooled, the enlarged structure must condense to its cooled size but the bonds of the molecules are too strong to allow the structure to shrink that quickly. The result is large cracks in the ceramic from tiny microscopic cracks to large specimen shattering cracks.

The solution to this problem may have been found with the work of George P. Liang and U.S. Patent number 5,039,562. Patent 5,039,562 demonstrates an array of skewed cooling air conduits in the ceramic turbine which allow air to more freely pass over the ceramic. These conduits provide more surface area which provides a higher means of dispensing excess heat. This allows the ceramic turbine to operate at a cooler temperature and takes less time to completely cool after functioning. (Figure 1)

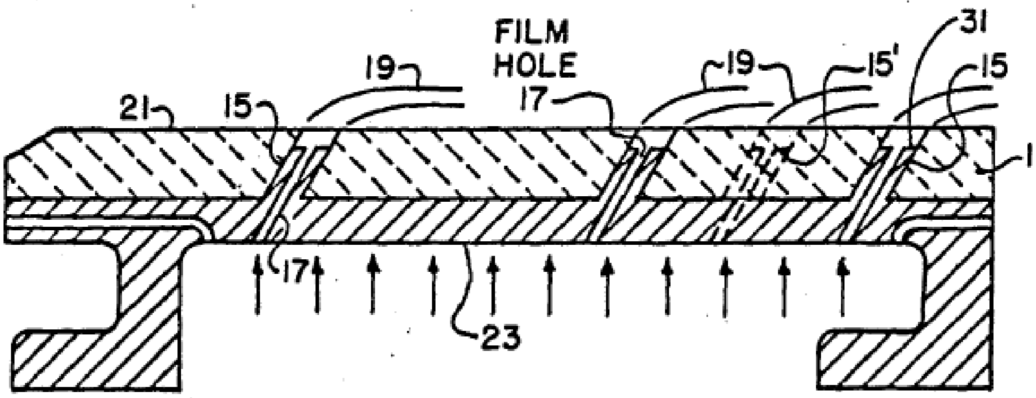


Figure 1: Sectional side view of ceramic conduits

Electrical motors/batteries

Initial ideas:

Initial ideas and research show that using battery solely will not solve the problem of power need for such a large, multi-task platform.

This is because:

- Batteries usually cannot produce a large amount of power with the constraint in weight that is needed for the airplane to take off.
- The large current draw when starting the motor may drain the battery power

However, the battery solution itself has the advantage of:

- Don't need snorkel for oxygen supply during submergence
- The battery is rechargeable and does not have "battery memory"

Based on these initial ideas, we conducted research in different battery technologies, and came to the conclusion to use the widely-used lithium ion battery. This could be a possible solution as there are currently 2 applicable commercial products that use this technology.

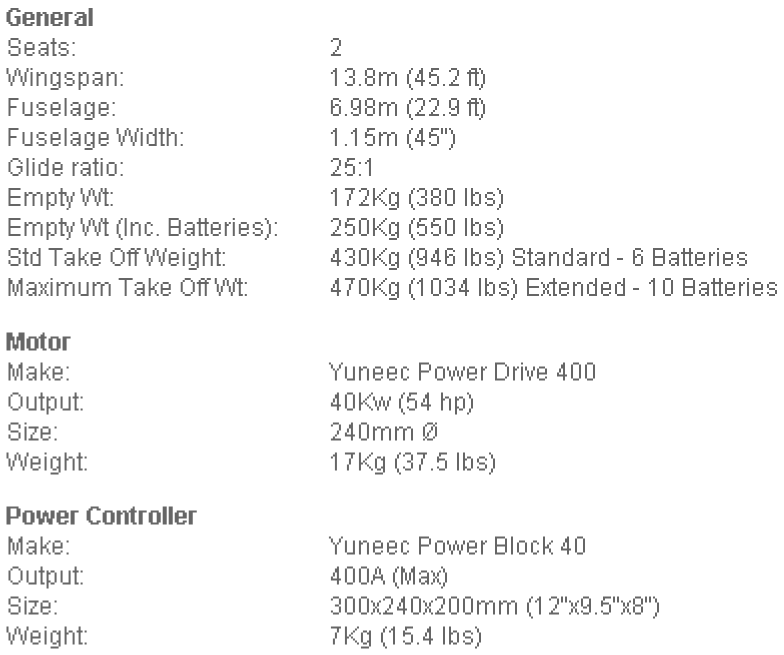
They are:

- The Yuneec E430 aircraft – the first electric aircraft in the world that was designed for commercial production
- The Nissan LEAF automobile using 100% electric battery

Details of research:

1. The Yuneec E430 aircraft

Specification



General

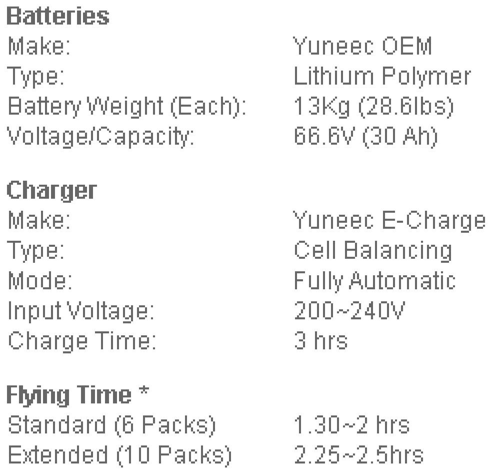
Seats:	2
Wingspan:	13.8m (45.2 ft)
Fuselage:	6.98m (22.9 ft)
Fuselage Width:	1.15m (45")
Glide ratio:	25:1
Empty Wt:	172Kg (380 lbs)
Empty Wt (Inc. Batteries):	250Kg (550 lbs)
Std Take Off Weight:	430Kg (946 lbs) Standard - 6 Batteries
Maximum Take Off Wt:	470Kg (1034 lbs) Extended - 10 Batteries

Motor

Make:	Yuneec Power Drive 400
Output:	40Kw (54 hp)
Size:	240mm Ø
Weight:	17Kg (37.5 lbs)

Power Controller

Make:	Yuneec Power Block 40
Output:	400A (Max)
Size:	300x240x200mm (12"x9.5"x8")
Weight:	7Kg (15.4 lbs)



Batteries

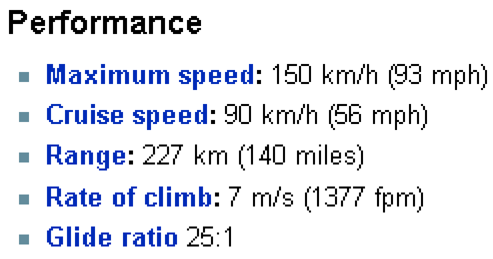
Make:	Yuneec OEM
Type:	Lithium Polymer
Battery Weight (Each):	13Kg (28.6lbs)
Voltage/Capacity:	66.6V (30 Ah)

Charger

Make:	Yuneec E-Charge
Type:	Cell Balancing
Mode:	Fully Automatic
Input Voltage:	200~240V
Charge Time:	3 hrs

Flying Time *

Standard (6 Packs)	1.30~2 hrs
Extended (10 Packs)	2.25~2.5hrs



Performance

- **Maximum speed:** 150 km/h (93 mph)
- **Cruise speed:** 90 km/h (56 mph)
- **Range:** 227 km (140 miles)
- **Rate of climb:** 7 m/s (1377 fpm)
- **Glide ratio** 25:1

2. The Nissan LEAF automobile

The Nissan LEAF is powered by a fully rechargeable lithium ion battery. Developed by Nissan, its breakthrough laminated design delivers twice the power and range of more conventional lithium ion batteries in a package that's half the size.

Battery & charging: There are 2 modes of charging

- Full charging: 16-18 hours at 110V, 4-8 hours at 220V (depending on amps)
- Fast charging: ~30 minutes to 80%
- LEAF uses a unique laminated Lithium-Ion battery with a capacity of 24kWh and a power of over 90kW
- A single charge will take you and Nissan LEAF up to 100 miles.
- Can be charged even when the battery are not empty (topping up). It is not affected by partial charging. It does not have "battery memory."
- The battery will have a lifespan of about 5 years under normal use. By 6 years, it will have decreased to about 80% capacity.
- Estimated cost: 90 cents/charge - 3x less expensive than gas to travel the same dist.
- The battery is being built by AESC, the Automotive Energy Supply Corporation.

Conclusion and Challenges:

One solution to be brought in is using and additional fuel motor to help preventing drainage of battery when start/restart the platform when it needs to transform

Challenges:

- How to build the battery with larger capacity since our platform needs more power
- How to build a close in range station that is available for recharging

Structure

- The following are the four choices for the submersible aircraft structure:
    a. The structure for the submersible aircraft is made of Aluminum.
    b. The structure should be light weight and made from composite material.
    c. The structure may be made of Titanium or
    d. The submersible aircraft with steel.

- Relevant requirements:

    a. Submersible
    b. Must Fly
    c. Single Platform
    d. Range-Air:1000nm, Surface 200nm, Submerged 24nm
    e. Transit Time: 8hrs
    f. 3-Day Loiter period
    g. Payload-8 people+2000 lbs=4000lbs
    h. Depth: Avoid detection

- Plusses and minuses of each concept:
  Aluminum
  Plusses: light weight, relatively strong
  Minuses: Corrosion and fatigue cracking are the major problems
  Titanium
  Pluses: strong and light, durable, excellent corrosion resistant, high temperature Properties
  Minuses: Very expensive per pound as compare to aluminum and steel
  Composite
  Pluses: very strong, very light, can be tailored for strength and stiffness, advanced composite structures have superior fatigue performance
  Minuses: Hard to detect damage to material, impacts can reduce the strengths of composite laminates, particularly in compression
  Steel
  Pluses: Very strong, high susceptibility to corrosion
  Minuses: very heavy

Material	Ultimate Strength (MPa)	Density (g/cm^3)	Strength/ Density
Steel	760	7.8	97.436
Aluminum	455	2.7	168.519
Titanium	900	4.51	199.557
Composites	5650	1.75	3228.571

Decision Matrix

		Aluminum	Titanium	Composite	Steel
Submersible	Weight 1	1	2	2	3
Must Fly	Weight 2	2	2	2	0
Range	Weight 3	1	2	3	0
Depth	Weight 4	1	2	2	3
Sums of values times weights		5	8	8	6

Conclusion

Comparing the ratings that are given in the design matrix it seems obvious that titanium and composites are the most feasible for our structure design variable as compare to other materials like steel and aluminum.

After this research, and comparing various structural materials, composites were selected for their strength benefits and their low weight. Five composite combinations were analyzed for their specific properties using a given layup (Table 1). After comparing the five options, Boron Epoxy was selected as the best composite since it has the highest bending modulus.

Ansys Analysis

After selecting the material, ANSYS was used to determine if the material could withstand the water pressure at roughly 35 feet under water. This pressure was determined to be approximately one standard atmosphere (101325.01 N/m^2). The first test was to apply this pressure on a square meter surface of the material. This created a deflection of 11.17 cm at the center (Figure 1), with a maximum stress of 1.15 GPa on the edges (Figure 2).

Cylindrical Shape

The deflection seems a little high so the second test was the same pressure on a hollow cylinder three meters long, with a radius of one meter. This produced a deflection of only .114 millimeters (Figure 3) and a maximum stress of 21.8 MPa (Figure 4).

Additional research was also conducted about submarine materials and the general shapes that are required for withstand under high pressures. This was done with the purpose in mind, whether our structure is able to bear the compression loads that external pressure is putting on the shell of submersible aircraft. Looking the estimates shown in (Table 1) for the structure and comparing Ansys results it is obvious that cylindrical shape is the best choice for our submersible aircraft. Thought about the large flat areas was also given, but it seems not feasible, because the pressure could bend the material relatively easily.

Table 1: Composite Comparison

[0;10/90;5/45;7]s	Bending Longitudinal Modulus (Gpa)	Bending Transverse Modulus (Gpa)	Bending Shear Modulus (Gpa)	Bending Poisson's Ratio NU12	Bending Coupling Ratio NU16	Torsion Coupling Coef. NU61
1 Graphite Epoxy	154.79	33.81	8.37	0.1162	-0.1446	-0.1146
2 Boron Epoxy	175.18	43.8	7.08	0.1254	-0.1838	-0.1838
3 Graphite Epoxy	118.33	26.85	7.78	0.1299	-0.1162	-0.1162
4 Glass Epoxy	33.99	12.5	4.35	0.1881	-0.0462	-0.0462
5 Aramid Epoxy	65.22	15.18	2.83	0.1525	-0.1698	-0.1698

Figure 1-Square Deflection

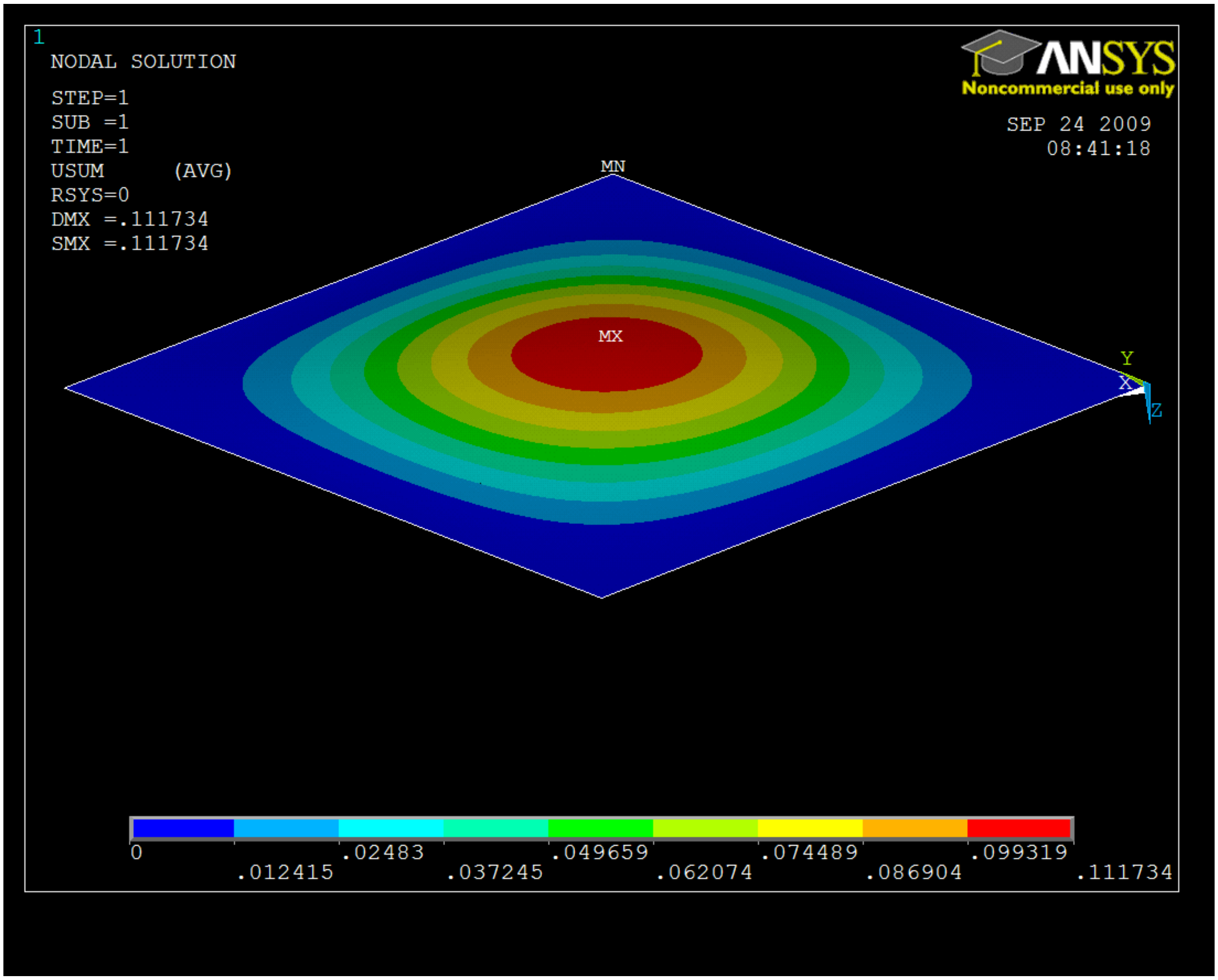


Figure 2-Square Stress

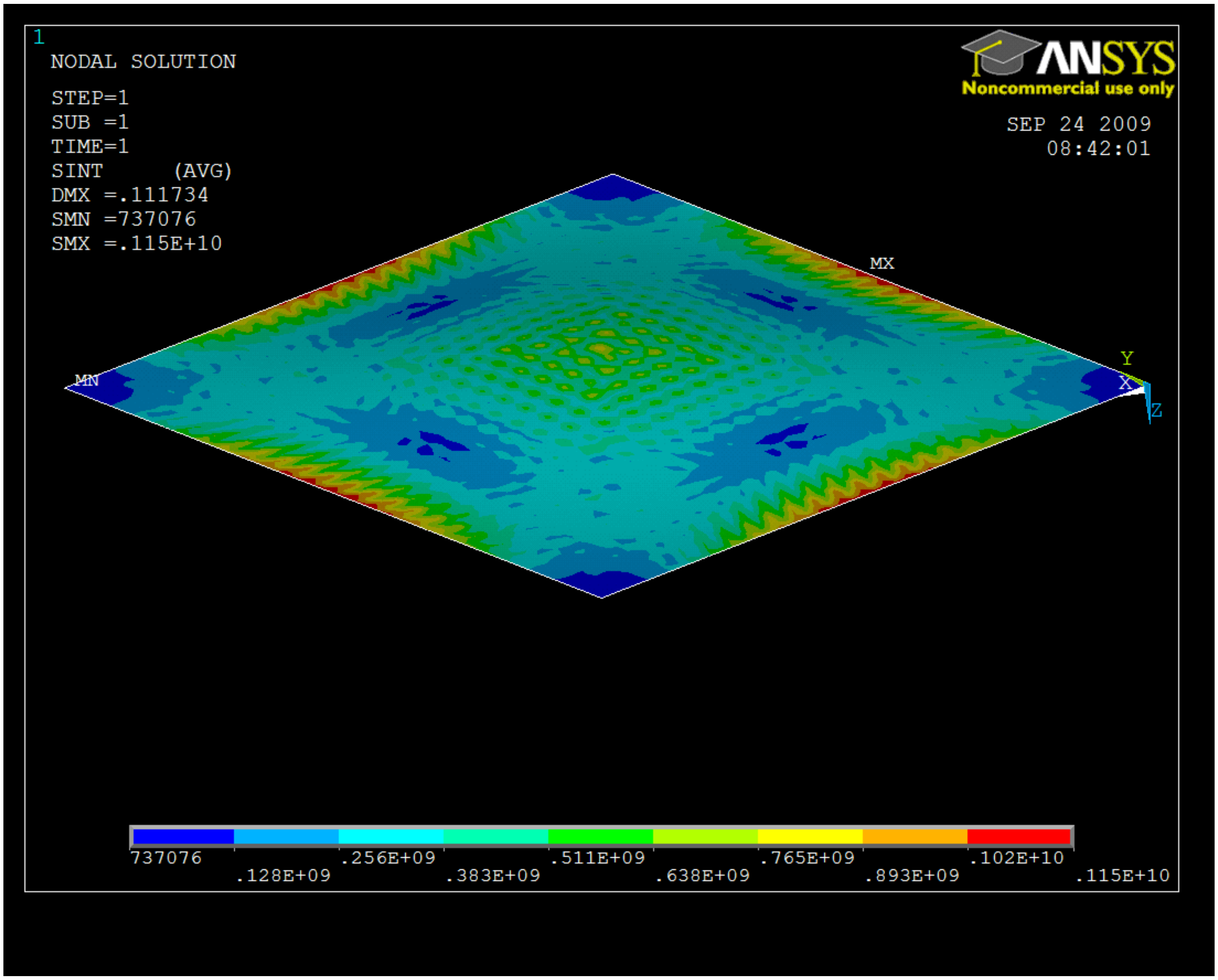


Figure 3-Cylinder Deflection

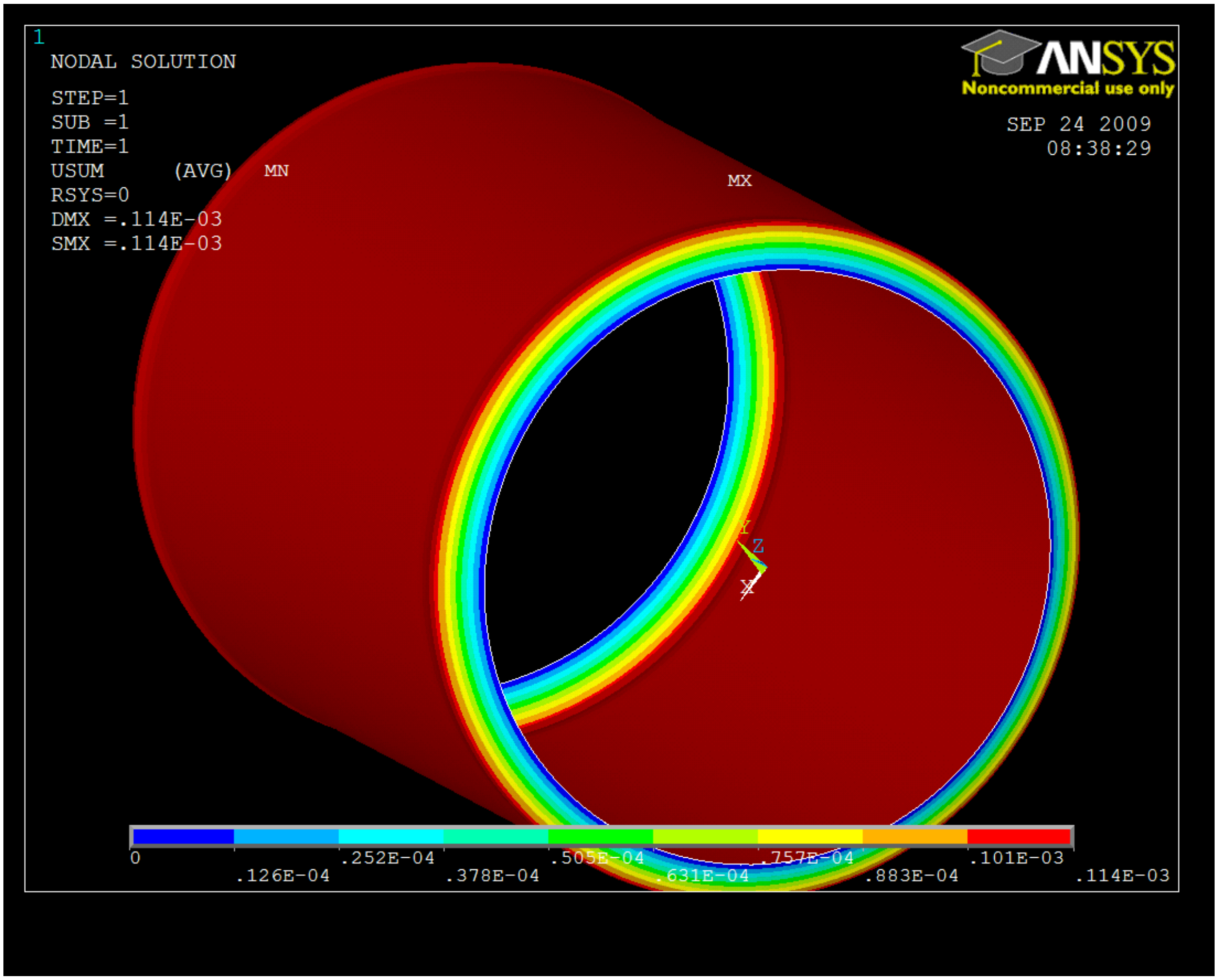
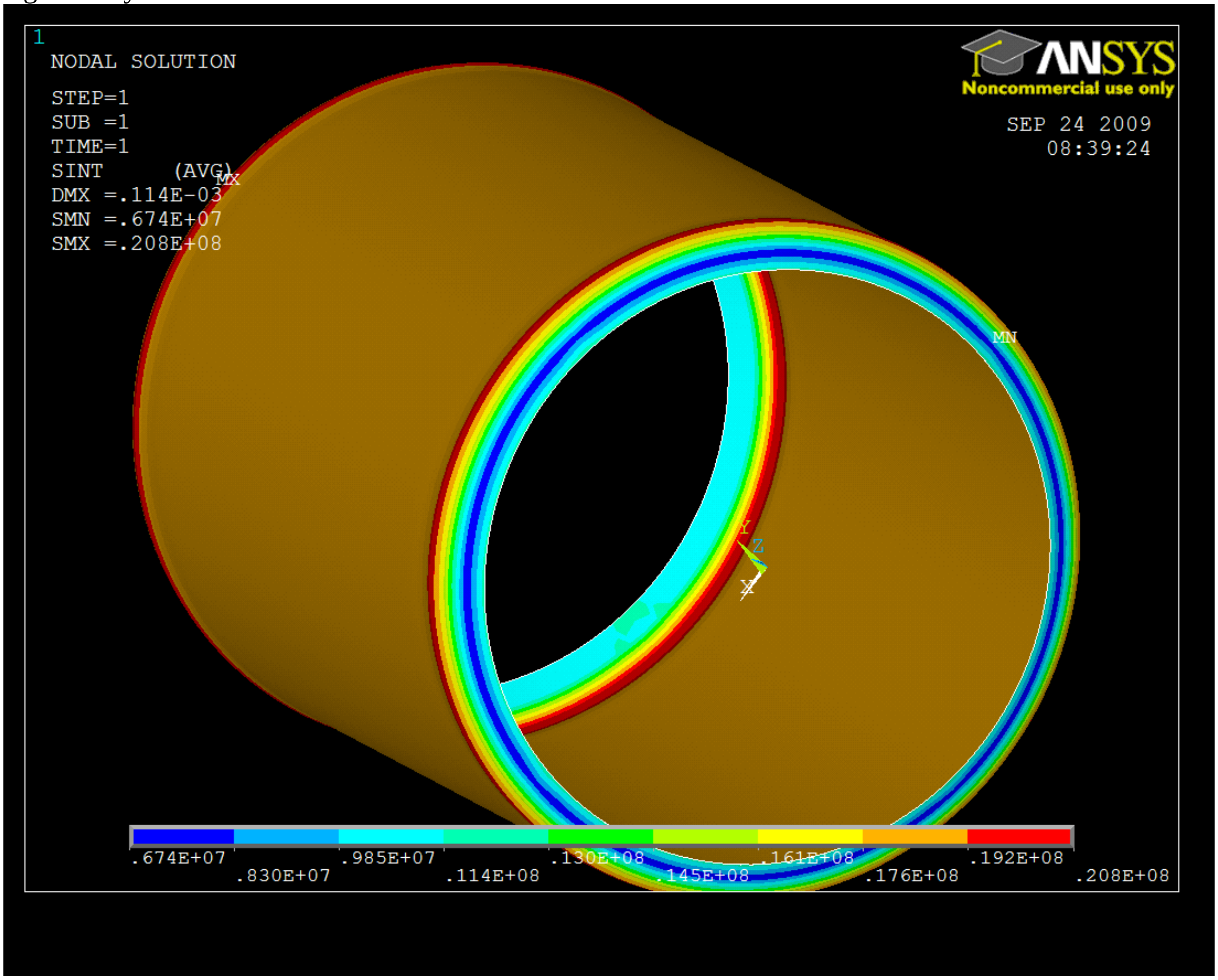


Figure 4-Cylinder Stress



Corrosion

Coatings for preventing corrosion in air and seawater are a major problem facing this project. As a result, this outer shell of the aircraft must be sealed with a material which has an ability to resist both air corrosion and salt water corrosion. Because of this aircraft has to fly in the air, the material used to seal the composite skin of the aircraft must be very light. On the other hand, the aircraft is also a submarine so the weight of it cannot be too small, and it has to have a larger density than the water density in order to immerse in to the seawater, and not cause a large buoyancy effect on the aircraft. These two ideas are totally opposite so a balance is needed.

There are 4 options to use in coating for this aircraft

- a) Zinc
- b) Aluminium
- c) Stainless Steel
- d) titanium
- e) Polyester resin

2) Requirements
   - a) Prevent air corrosion
   - b) Prevent seawater corrosion
   - c) impervious to water and air
   - d) Weight/density must able to give abilities to the aircraft submerge in to the seawater and fly in the air.

3) Plusses and Minuses
   - a) Zinc : density: 7.14g/cm^3
     - i) Cons
       - (1) Has a high density
       - (2) Has little reaction with dry air at room temperature
     - ii) Pros
       - (1) Forms adherent gray in humid air, inhibits further corrosion.
       - (2) Has low seawater electrode potential

   - b) Aluminium: density: 2.70g/cm^3
     - i) Cons
       - (1) It has to be very pure to have the best corrosive resistance.
     - ii) Pros
       - (1) Has a low density but higher than water
       - (2) Form oxide layer which is strongly adherent and protective in many corrosive environment.

   - c) Stainless Steel: density: 7.48-8g/cm^3
     - i) Cons
       - (1) Has a very high density

        - (2) Corrosion resistance can be adversely affected if the component is used in a non-oxygenated environment.
    - ii) Pros
        - (1) High oxidation-resistance in air at ambient temperature
        - (2) It is impervious to water and air, protecting the metal beneath.
        - (3) The protective layer quickly reforms when the surface is scratched.

- d) Titanium density: 4.59g/cm^3
    - i) Cons
        - (1) The oxide layer will gradually be thickened because of titanium and oxygen atoms diffusion, so it will increase the weight.

    - ii) Pros
        - (1) Immediately forms an oxide layer that protects the underlying metal from further oxidation.
        - (2) If the oxide layer is damage, it reforms in the presence of oxygen and water.
        - (3) Use in marine applications, such as hulls for surface ships and submarines.

- e) Polyester resin: density: 1.45 g/cm^3
    - i) Cons
        - (1) this material is formulated for superior adhesion to paints and metals, but cures very hard to resist surface trauma
    - ii) Pros
        - (1) It has good wear and adhesive properties,
        - (2) Good resistance to water

	Weighted values	Zinc	Aluminum	Stainless Steel	Titanium	Polyester resin
Prevent air corrosion	Excellent (1)	3	2	1	1	1
Prevent seawater corrosion	Good (2)	3	2	4	1	1
impervious to water and air	Bad (3)	1	1	1	1	1
Weight		3	2	4	3	1
Sums of weighted values		10	7	10	6	4

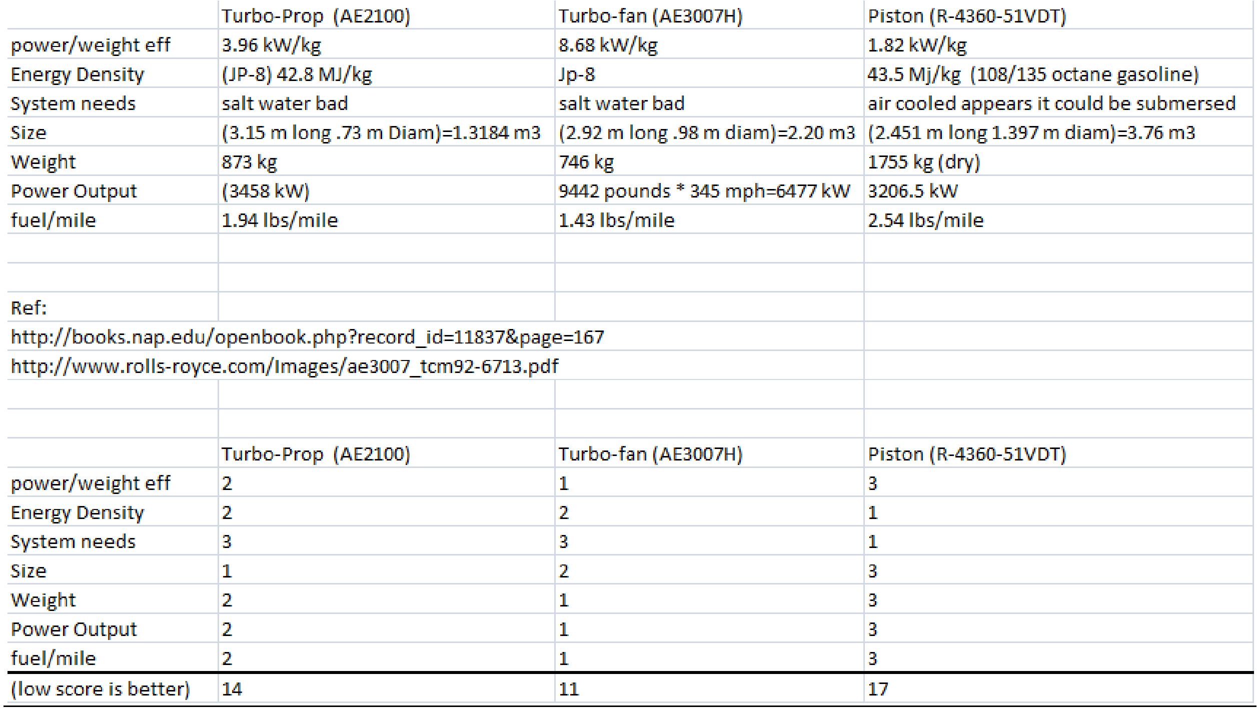
Except polyester resin, aluminum and titanium are better choices. However, the graphite-polymer composites are generally inert to sea water. Corrosion becomes a problem only when these composites are in electrical contact with metals while immersed in sea water. Coating the composite with these metals might help prevent such corrosion, but it would be probably done better to coat with a simple polymer outer layer because polymers bond better with other polymers and the coefficients of thermal expansion would be matched better between two polymers.

Therefore, the best way to get a better composite as a coating for this aircraft is to use a graphite filler to reinforce to the polyester resin. The typical fiber content of a polymer composite may range from 20% to 80% of the total weight. So, this method is not only can improve in mechanical properties, but also offer weight reduction and improved conductivity.

Propulsion

The trade studies done for propulsion comprised of two parts: 1. Engine type analysis 2. Power needs. Both of these studies were split, one for air, another for water. Engine selection was split into seven categories: power/weight efficiency, fuel energy density, system needs, size, weight, power, and fuel/mile. The engines for the three types were selected based on their power output and aircraft size/weight to match our initial estimates for this aircraft. (50000 pound aircraft)

Trade study table



	Turbo-Prop (AE2100)	Turbo-fan (AE3007H)	Piston (R-4360-51VDT)
power/weight eff	3.96 kW/kg	8.68 kW/kg	1.82 kW/kg
Energy Density	(JP-8) 42.8 MJ/kg	Jp-8	43.5 Mj/kg (108/135 octane gasoline)
System needs	salt water bad	salt water bad	air cooled appears it could be submersed
Size	(3.15 m long .73 m Diam)=1.3184 m3	(2.92 m long .98 m diam)=2.20 m3	(2.451 m long 1.397 m diam)=3.76 m3
Weight	873 kg	746 kg	1755 kg (dry)
Power Output	(3458 kW)	9442 pounds * 345 mph=6477 kW	3206.5 kW
fuel/mile	1.94 lbs/mile	1.43 lbs/mile	2.54 lbs/mile

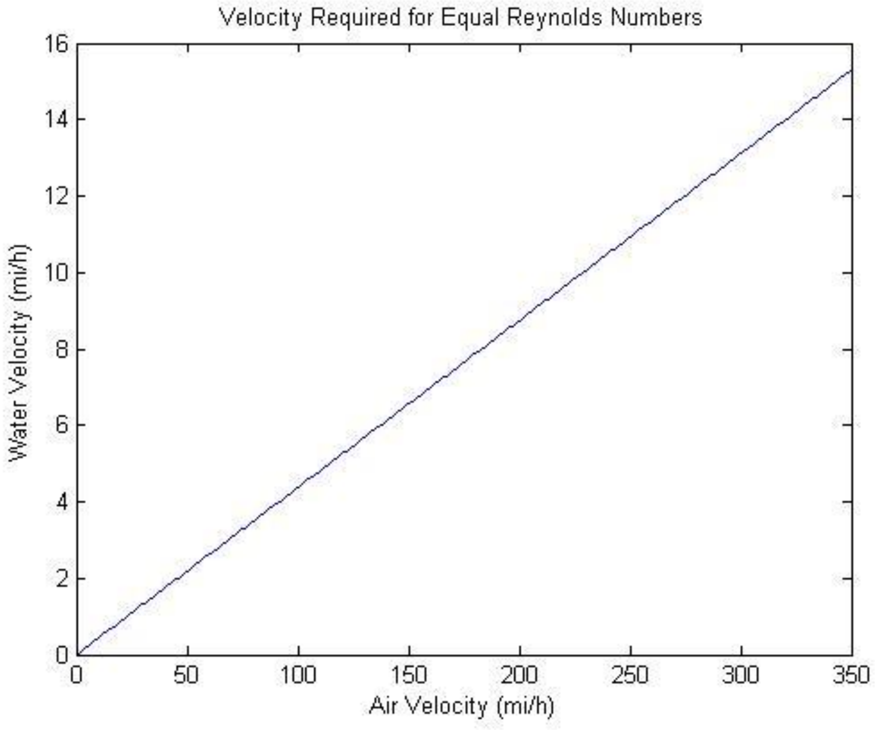
Ref:
http://books.nap.edu/openbook.php?record_id=11837&page=167
http://www.rolls-royce.com/Images/ae3007_tcm92-6713.pdf

	Turbo-Prop (AE2100)	Turbo-fan (AE3007H)	Piston (R-4360-51VDT)
power/weight eff	2	1	3
Energy Density	2	2	1
System needs	3	3	1
Size	1	2	3
Weight	2	1	3
Power Output	2	1	3
fuel/mile	2	1	3
(low score is better)	14	11	17

The three engines selected for the trade study were proven on aircraft of similar size and had sufficient power for our purposes. The turbo-prop AE2100 is the newest turbo-prop on military transports. These engines are extremely efficient at lower speeds and have a good amount of power for their size. The drawback is they really do not have any distinguishing feature that puts them above the piston or turbo-fan. They need to be sealed off from any salt-water like the turbo-fan and they are for low speeds only. The AE3007H turbo-fan is used on newer small commercial jets like the ERJ-145. It is extremely light weight and small in comparison to the other engines (No props). It also has a much higher speed and power output which makes it more efficient then the other two options. The final engine, a 27 cylinder engine made for the Boeing 303 is the last large piston engine used in an aircraft. The purpose of looking into piston engines was the ease of cooling; the engine can be submersed in salt water much easier and with less damage then the turbo-prop or turbo-fan. However, an analysis of air and water prop dual usage pushed this project towards turbo-fans. (As well as the speed increase by using turbo-fans.)

One of the most difficult problems in trying to design AirNautilus is that the vehicle is required to operate in two very different environments; water and air. One way to illustrate this point is by comparing the velocity difference required to achieve the same Reynolds number in both environments. Reynolds number is the ratio of inertial forces to viscous forces in given flow conditions; when Reynolds numbers are equal we can assume that the flow characteristics are the same. As can be seen in Figure 1 to achieve the same flow the velocity in water must be much lower than that in air. Due to extreme difference in flow characteristics between air and water it became apparent that a propeller designed for a flight environment would not work very well under water.

Figure 1



After looking at the design space for the average velocities needed such that the vehicle could complete a tactical transit within the allotted time and a size estimate for the vehicle it was necessary to perform a preliminary power requirement estimate.

For power estimates the vehicle was taken at a steady level state:

$$Power = Drag * Velocity$$

$$Energy_{total} = Power * time$$

$$time = \frac{Range}{Velocity}$$

$$Drag = D_{wing} + D_{fuselage}$$

$$D_{wing} = C_{D,wing}\, q_{\infty} * S_{wing}$$

$$D_{fuselage} = C_{d,fuselage} * S_{fuselage}$$

$$C_{d,fuselage}\ C_{D,wing} = C_f + C_w + C_d$$

$$C_f = Coefficient\ of\ drag\ due\ to\ skin\ friction$$

$$C_w = Coefficient\ of\ wave\ drag$$

$$C_d = Coefficient\ of\ drag\ due\ to\ lift$$

$$q_{\infty} = \frac{1}{2} pV^2$$

$$S = Surface\ area\ of\ wing$$

Utilizing these equations a MATLAB script was created that would take aircraft parameters and generate power estimates.

To test the accuracy of the equations, parameters for the AE3007H aircraft were input into the script. This aircraft was chosen due to the belief that the AirNautilus will be of similar size. The following results were achieved:

Power Required in Flight = 12497730.500866 W

Energy Required in Flight = 210891832828.911990 J

10855.645466 lbs of fuel needed for flight

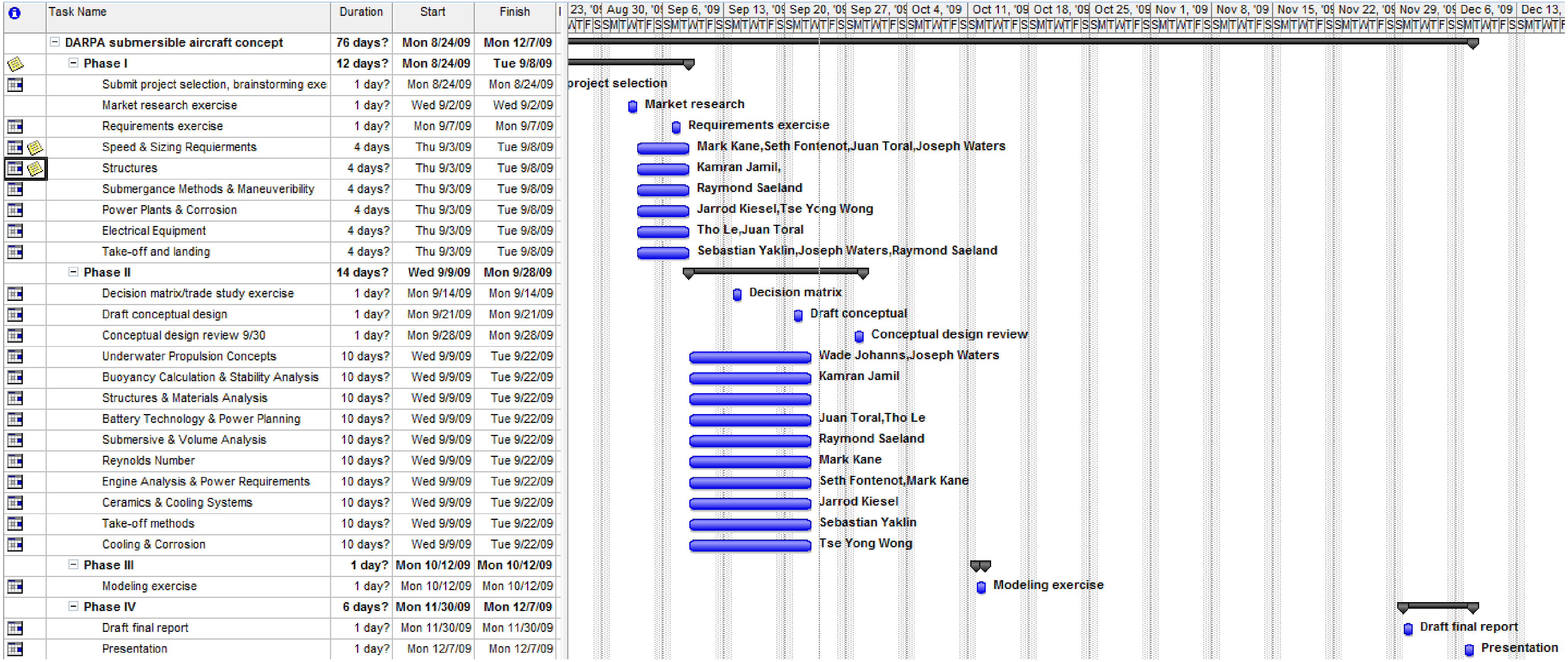
The actual amount of fuel carried by this aircraft is 12,000.0 lb, with this result the MATLAB calculations are considered to be accurate for our initial estimates. Substituting in the estimated values for AirNautilus provides the following power estimates:

```
Power Required in Flight = 12497730.500866 W
Power Required while Submerged = 23384.158408 W

Energy Required in Flight = 129365679439.051770 J
Energy Required while Submerged = 1985295122.770951 J

6659.091216 lbs of fuel needed for flight
```

Plan and Schedule



Task Name	Duration	Start	Finish
DARPA submersible aircraft concept	**76 days?**	**Mon 8/24/09**	**Mon 12/7/09**
Phase I	**12 days?**	**Mon 8/24/09**	**Tue 9/8/09**
Submit project selection, brainstorming exe	1 day?	Mon 8/24/09	Mon 8/24/09
Market research exercise	1 day?	Wed 9/2/09	Wed 9/2/09
Requirements exercise	1 day?	Mon 9/7/09	Mon 9/7/09
Speed & Sizing Requierments	4 days	Thu 9/3/09	Tue 9/8/09
Structures	4 days?	Thu 9/3/09	Tue 9/8/09
Submergance Methods & Maneuveribility	4 days?	Thu 9/3/09	Tue 9/8/09
Power Plants & Corrosion	4 days	Thu 9/3/09	Tue 9/8/09
Electrical Equipment	4 days?	Thu 9/3/09	Tue 9/8/09
Take-off and landing	4 days?	Thu 9/3/09	Tue 9/8/09
Phase II	**14 days?**	**Wed 9/9/09**	**Mon 9/28/09**
Decision matrix/trade study exercise	1 day?	Mon 9/14/09	Mon 9/14/09
Draft conceptual design	1 day?	Mon 9/21/09	Mon 9/21/09
Conceptual design review 9/30	1 day?	Mon 9/28/09	Mon 9/28/09
Underwater Propulsion Concepts	10 days?	Wed 9/9/09	Tue 9/22/09
Buoyancy Calculation & Stability Analysis	10 days?	Wed 9/9/09	Tue 9/22/09
Structures & Materials Analysis	10 days?	Wed 9/9/09	Tue 9/22/09
Battery Technology & Power Planning	10 days?	Wed 9/9/09	Tue 9/22/09
Submersive & Volume Analysis	10 days?	Wed 9/9/09	Tue 9/22/09
Reynolds Number	10 days?	Wed 9/9/09	Tue 9/22/09
Engine Analysis & Power Requirements	10 days?	Wed 9/9/09	Tue 9/22/09
Ceramics & Cooling Systems	10 days?	Wed 9/9/09	Tue 9/22/09
Take-off methods	10 days?	Wed 9/9/09	Tue 9/22/09
Cooling & Corrosion	10 days?	Wed 9/9/09	Tue 9/22/09
Phase III	**1 day?**	**Mon 10/12/09**	**Mon 10/12/09**
Modeling exercise	1 day?	Mon 10/12/09	Mon 10/12/09
Phase IV	**6 days?**	**Mon 11/30/09**	**Mon 12/7/09**
Draft final report	1 day?	Mon 11/30/09	Mon 11/30/09
Presentation	1 day?	Mon 12/7/09	Mon 12/7/09

Resources Needed: Computers, man hours, and relevant textbooks. (This project is conceptual and does not require physical resources.)