EXTROVERT

ADVANCED CONCEPT EXPLORATION

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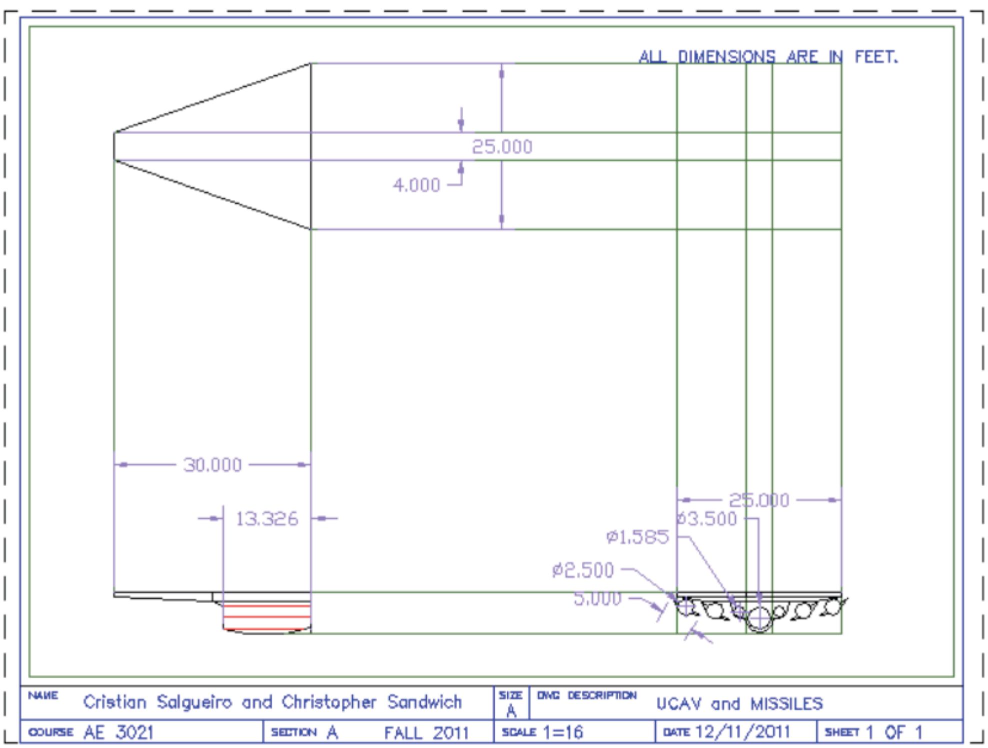
AE3012BF11

What We Learned in AE3021



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Disclaimer

AE 3021BF11 Conceptual Design

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Abstract

The goal of this report is to provide a conceptual design for a Theater High Altitude Area Defense (THAAD) class missile interceptor. The components for the interceptor include a large subsonic carrier aircraft that holds four supersonic unmanned combat aerial vehicles (UCAV) each with four hypersonic airbreathing weapons. The design will be compared to a ground based missile interceptor of the same class already in existence.

Historical Data

In order to make initial weight and size estimations, historical data on comparable aircraft was gathered. For the subsonic carrier component information was gathered from the B-52, K-135, and C-5. UCAV estimations were based on the D-21, A-12, SR-71, X-15, and Bell X-2. Historical data relating to hypersonic vehicles such as the X-51 and the X-43 were also gathered.

Ground-based THAAD

The specifications for Lockheed-Martin's ground-based THAAD interceptor battery are:

Length: 20.25 ft
Diameter: 13.4 in
Weight: 2000 lb
Speed: 9200 ft/s
Ceiling: 93 miles
Range: 125 miles
Isp: 300 seconds

Based on these specifications, the ground-based interceptor is capable of going from warning to kill in approximately 324 seconds.

Mission Requirements

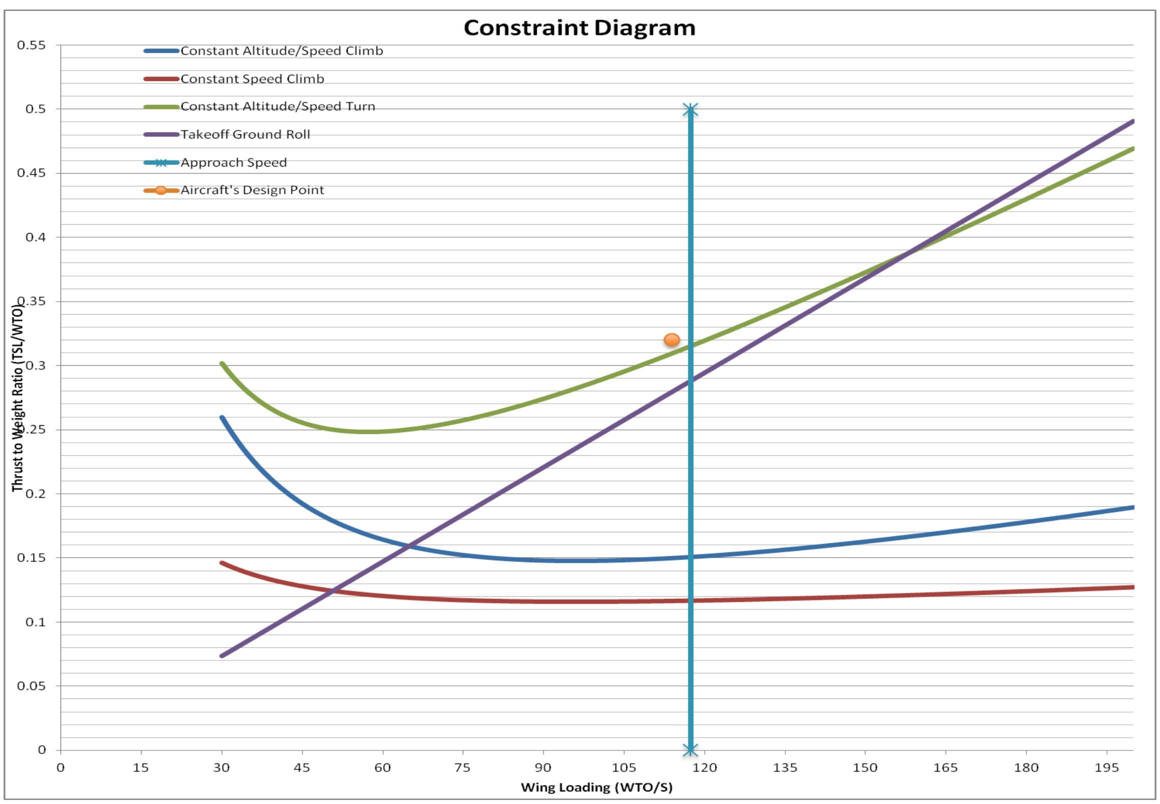
The transonic patrol carrier is expected to cruise at Mach 0.6 at an altitude of 40000 feet. The UCAV must be able to takeoff from the carrier, accelerate to Mach 4, rapidly climb to an altitude of 150000, and glide to sea-level and land regardless of whether or not it fires its weapons. The hypersonic weapons must accelerate to Mach 8 and kill the target with kinetic energy alone.

Transonic Patrol Carrier Conceptual Design

Weight Estimation

Thus far the weight estimations have been done for both the carrier and the UCAV. The carrier is assumed to resemble a B52 bomber that uses eight high bypass turbofan engines that produce a maximum of 20000 lbs of thrust each. Using historical regression data from Jan Roskam's Airplane Design Part 1 the gross weight was found estimating a payload weight of the four UCAV being at 15,291 lbs each. Pulling common high bypass military transport aircraft mass fuel fractions, the fuel weight was also calculated and from there the Gross Weight was then iteratively stepped through to find the actual gross weight. The fuel weight was found to be 231670 lbs. The empty weight was found to be 211378 lbs and the gross weight was found to be 499390 lbs. The equation to do this is below.

$$\log_{10} W_E = \frac{\log_{10} W_{TO} - A}{B}$$

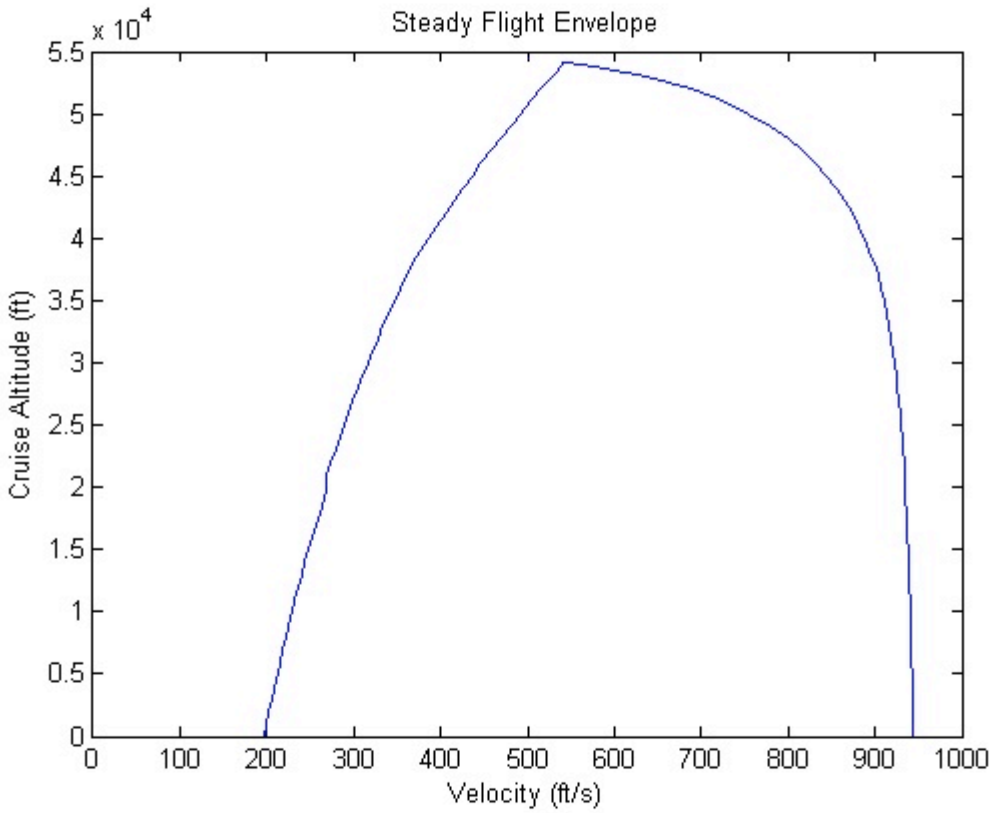


Specifications

Wingspan: 199 ft.
Chord: 20.95 ft.
Wing Area: 4188 sq. ft.
Aspect Ratio: 9.55
Wing Loading: 119 lb/sq. ft.
CD0: 0.0179
Thrust: 160,000 pounds at sea-level

Performance

Below is the steady level flight envelope for the carrier. The carrier is expected to cruise at 40000 feet which is well within the capabilities of the vehicle.

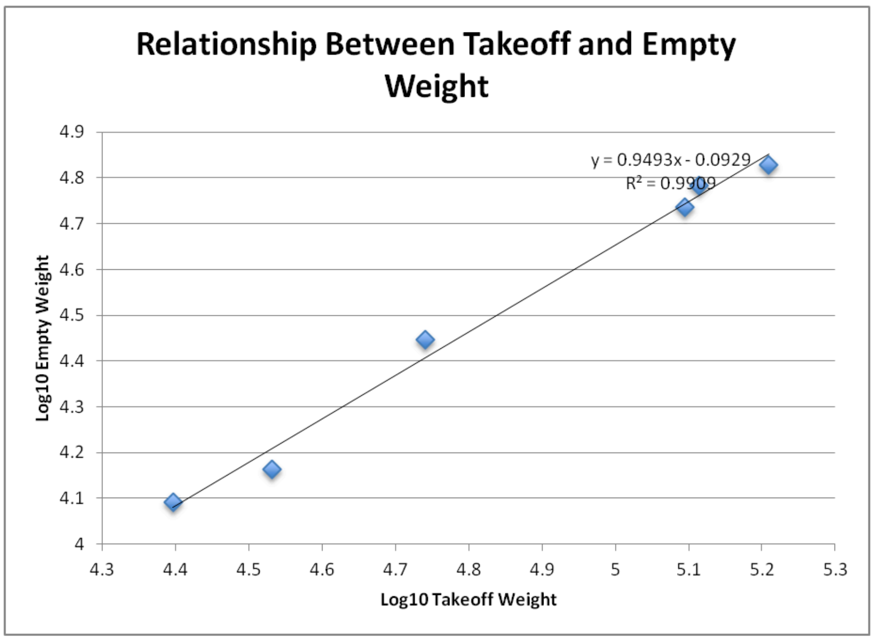


At a cruise altitude of 40000 feet the range and endurance were calculated to be 95785 miles and 16.49 hours, respectively. The carrier is able to make a 180 degree turn at Mach 0.6 at an altitude of 40000 feet in 42 seconds. The total takeoff distance for the carrier is 4674 feet and the total landing distance is 4267 feet. All of these performance parameters meet the mission requirements

Unmanned Combat Aerial Vehicle Conceptual Design

Weight Estimation

The UCAV was done similarly but Roskam did not include any supersonic data so the regression coefficients were found by compiling empty weight and takeoff information for various supersonic aircraft.



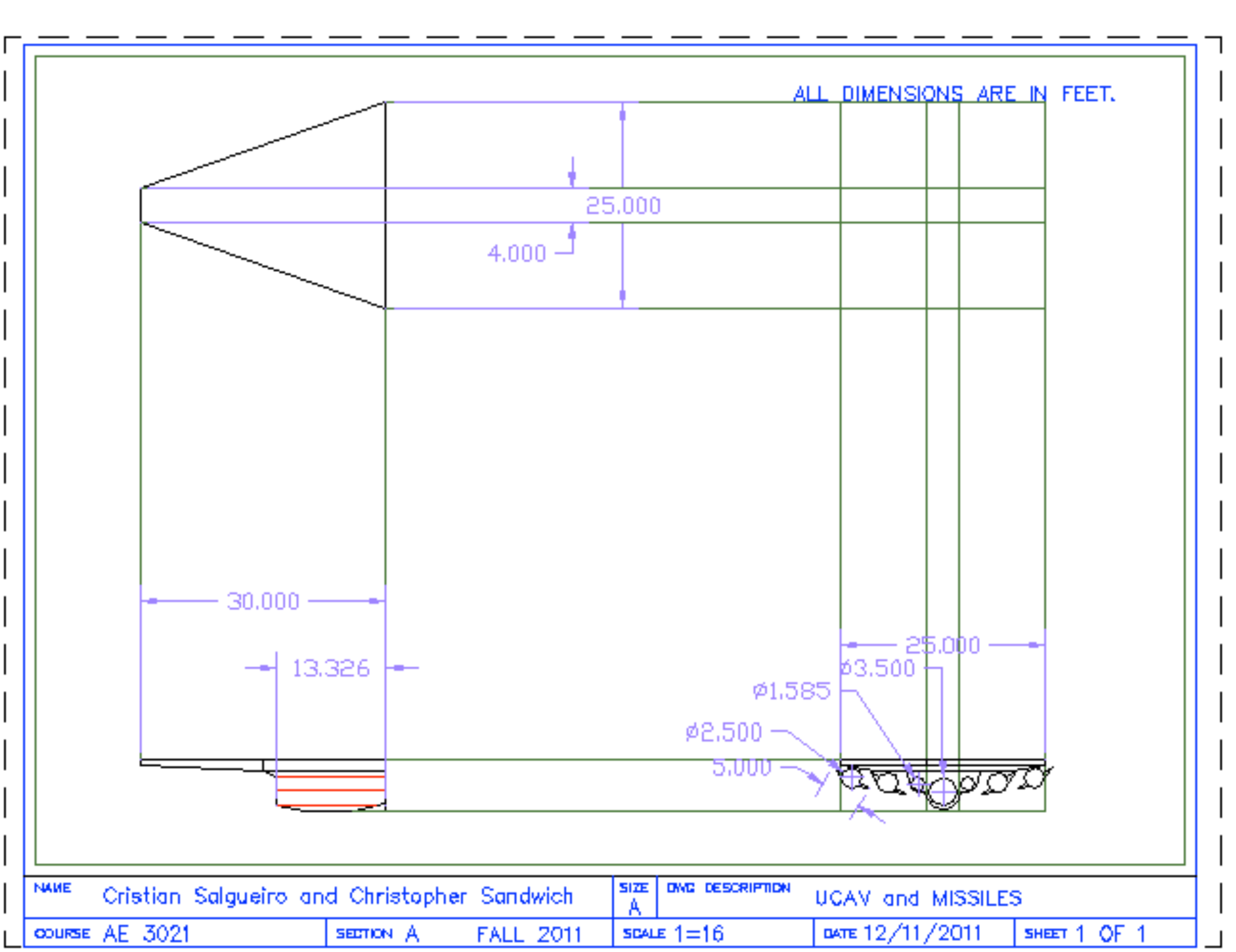
From researching the supersonic aircrafts named in the historical data section, the other performance parameters to determine the amount of fuel used in cruise and climb. Using those fractions the gross weight was found in the same way as the carrier aircraft. The gross weight was found to be 15291lbs and the empty weight was found to be 6860 lbs. The weight of the hypersonic weapons has been estimated to be about 500lbs each. As these weights are calculated more in depth to include supersonic and hypersonic drag, it will change the gross weights of first the UCAV and consequently the carrier weight will also increase. Right now the hypersonic data is too scarce to base the previous iterative process used for the UCAV and the carrier so until the aerodynamic qualities of hypersonic flight are more closely observed, 500lbs estimation can be easily assumed accurate.

Specifications

Wing Span: 25 ft
Max Chord: 30 ft
Sweep Angle: 67 degrees
Aspect Ratio: 1.67
Wing Loading: 42.76 lb/sq. ft
CD0: .016
Thrust: 40,000 pounds at sea-level

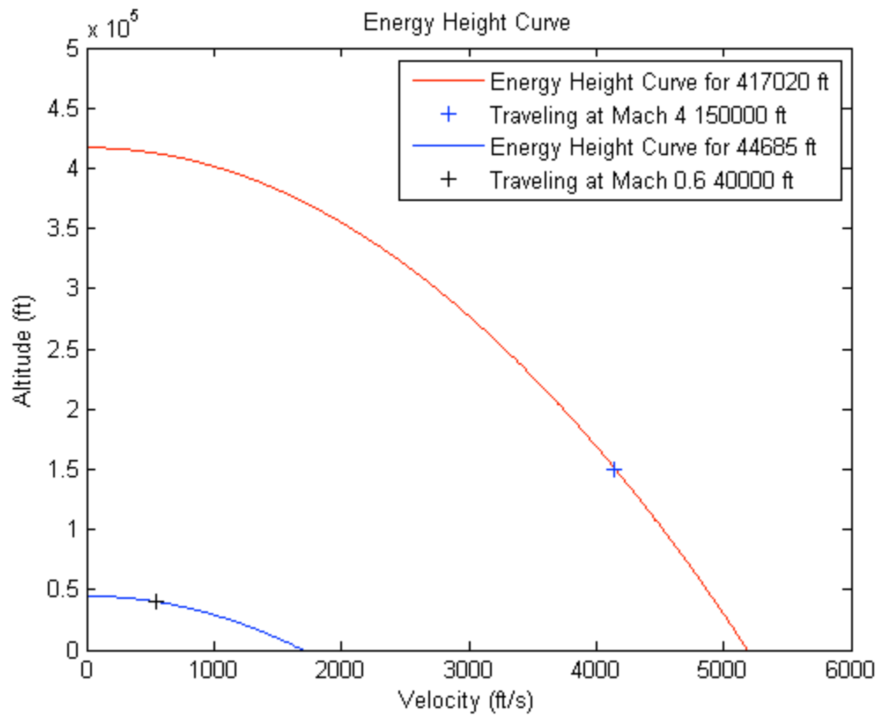
Configuration

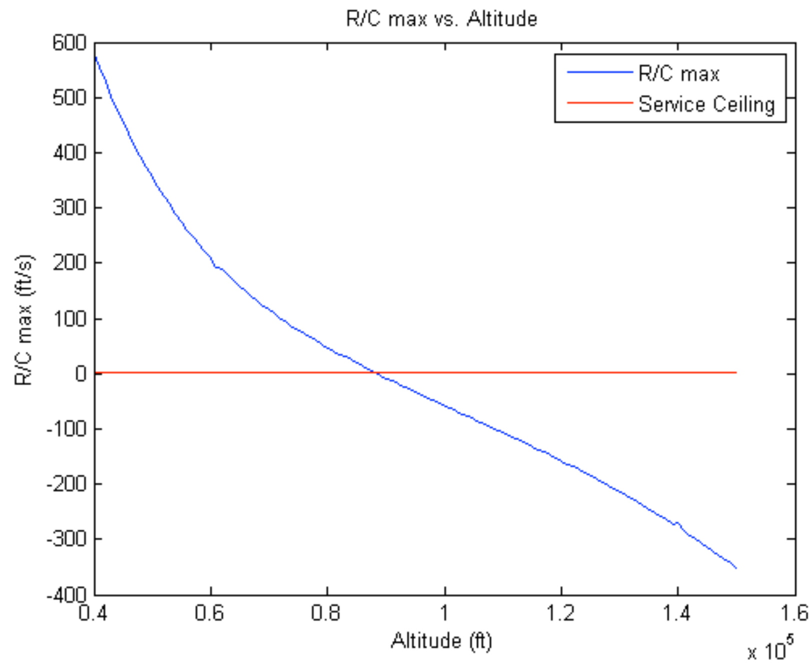
The UCAV is meant to store a total of four hypersonic weapons. As seen in the three view below the UCAV operates primarily off of one ramjet engine and utilizes an additional two rocket boosters with an Isp of 300 seconds to accelerate up to supersonic speeds and achieve the heavy climb requirements needed for this particular aircraft. The power plant is placed on the lower surface along with the four weapons which have been rotated slightly in order to prevent their wings from touching.



Energy Height

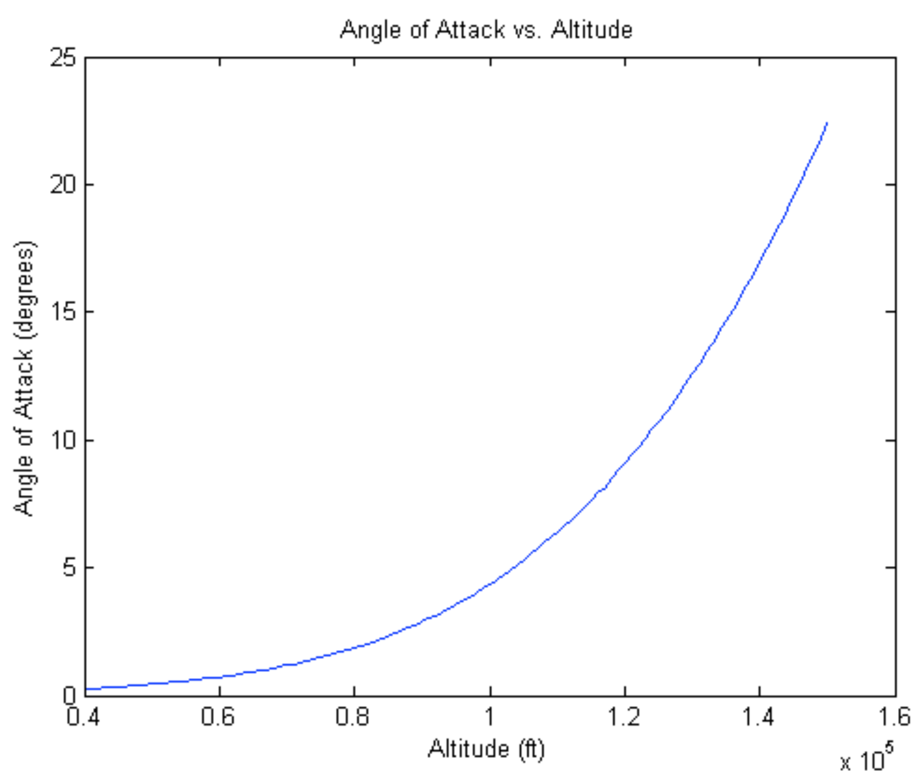
Shown below is the energy height for the carrier and the Supersonic UCAV. Both plots also show the operating point at the final mission specification as a plus sign on the plot. This allowed the flight characteristics such as service ceiling to be analyzed. The second figure belowt shows that the rate of climb goes to zero well before the 150,000ft requirement. The rocket boosters therefore had to be included, in order to get the UCAV to the proper altitude to release any of the hypersonic weapons.



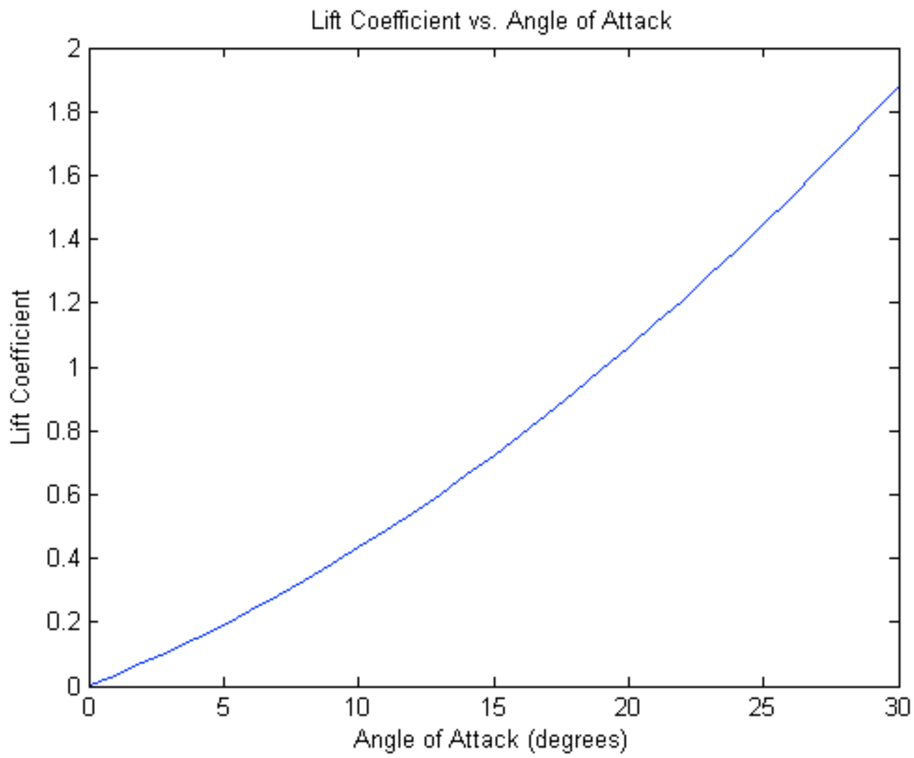


Aerodynamic Coefficients of UCAV

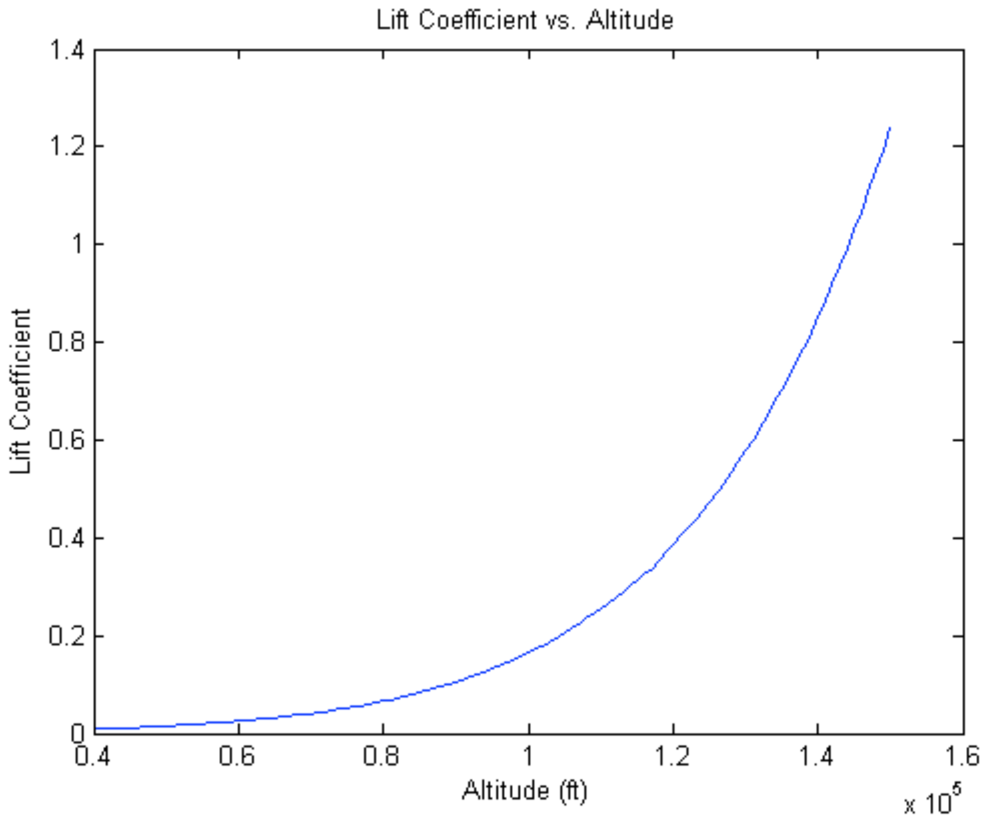
The lift coefficient required for the UCAV varies during the climbing part of the mission. In order to find these values, lift coefficient was found as a function of required angle of attack. With all other things remaining constant, in order to keep the lift condition to maintain climb, the angle of attack must be increased with increasing altitude. This graph can be found below.



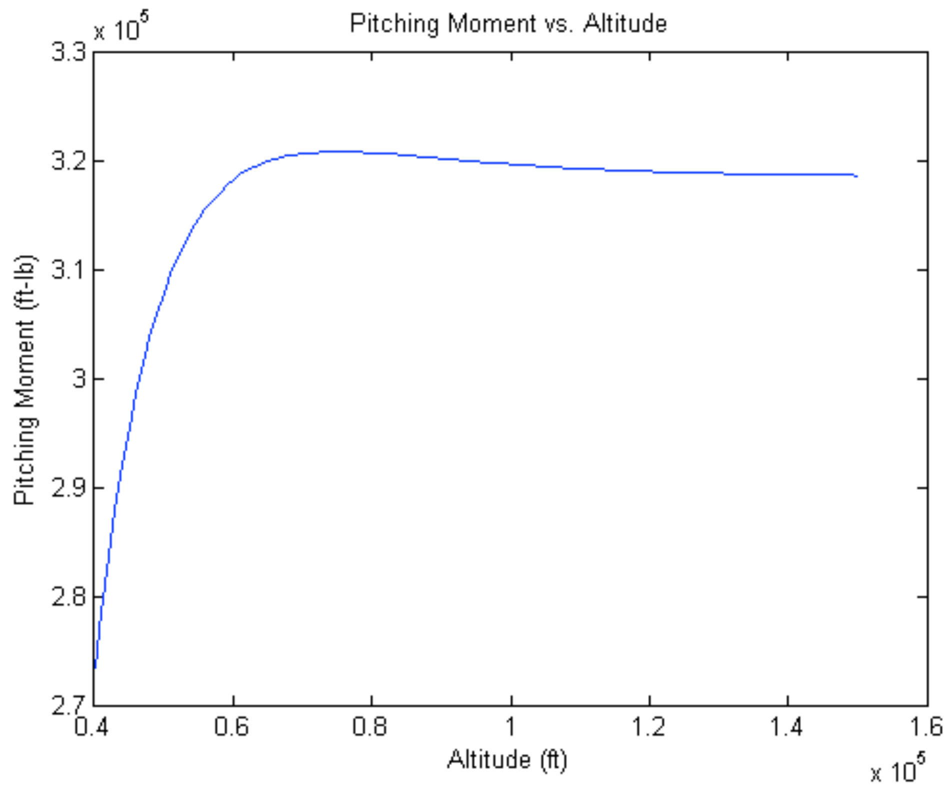
Lift coefficient varying with angle of attack was approximated using the Polhamus suction analogy. Appropriate coefficients for the potential component and the vortex lift component were estimated to be 2.2 and 3.2, respectively. The plot can be found below. At very high angle of attack the approximation becomes less accurate because of vortex burst which will most likely occur at 25 degrees angle of attack.



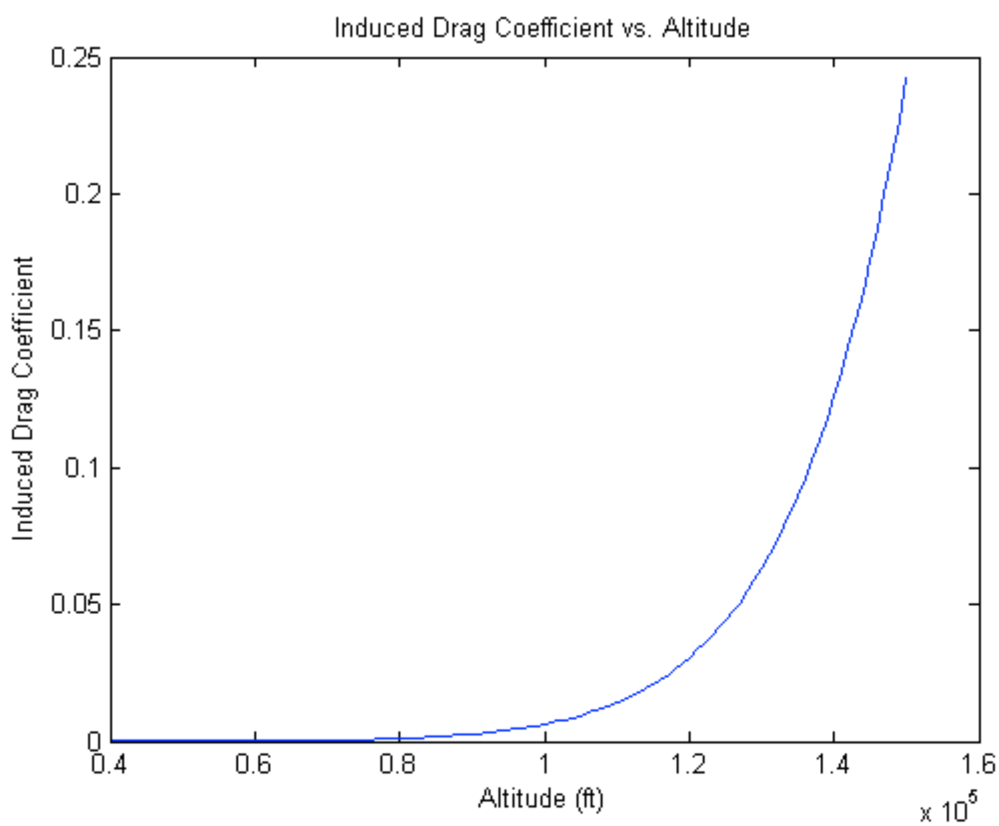
Using the above two plots, lift coefficient is plotted as a function of altitude below. What this graph shows is not that there is more lift at higher altitudes, but that in order to maintain steady level flight at each altitude, the angle of attack must be increased thus increasing Lift coefficient.



Using results from slender wing theory, the center of pressure is located 20’ from the nose of the UCAV. Pitching moment and induced drag coefficient were also calculated at Mach 4 conditions using slender wing theory and are plotted as functions of altitude below.



Pitching Moment vs. Altitude
x 10^5
3.3
3.2
3.1
3
2.9
2.8
2.7
Pitching Moment (ft-lb)
0.4
0.6
0.8
1
1.2
1.4
1.6
Altitude (ft)
x 10^5



Induced Drag Coefficient vs. Altitude
0.25
0.2
0.15
0.1
0.05
0
Induced Drag Coefficient
0.4
0.6
0.8
1
1.2
1.4
1.6
Altitude (ft)
x 10^5

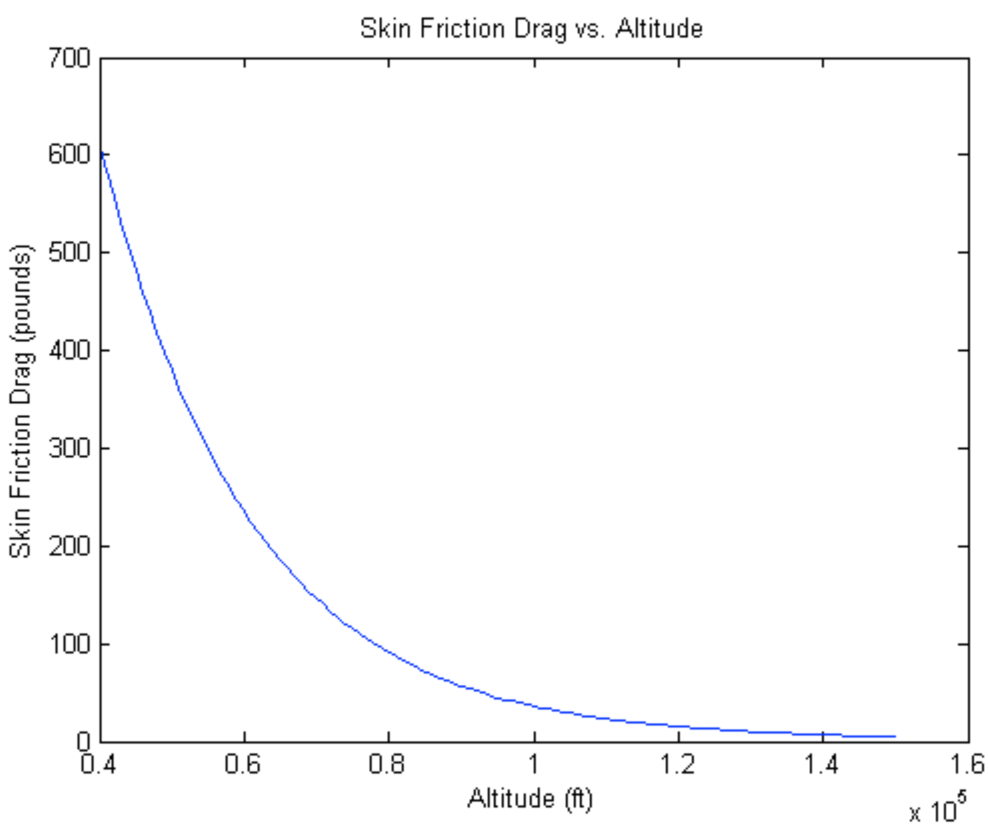
Drag Estimations

Skin friction drag for the UCAV flying at Mach 4 was estimated using the modified Shultz-Grunow equation with the Boeing reference temperature

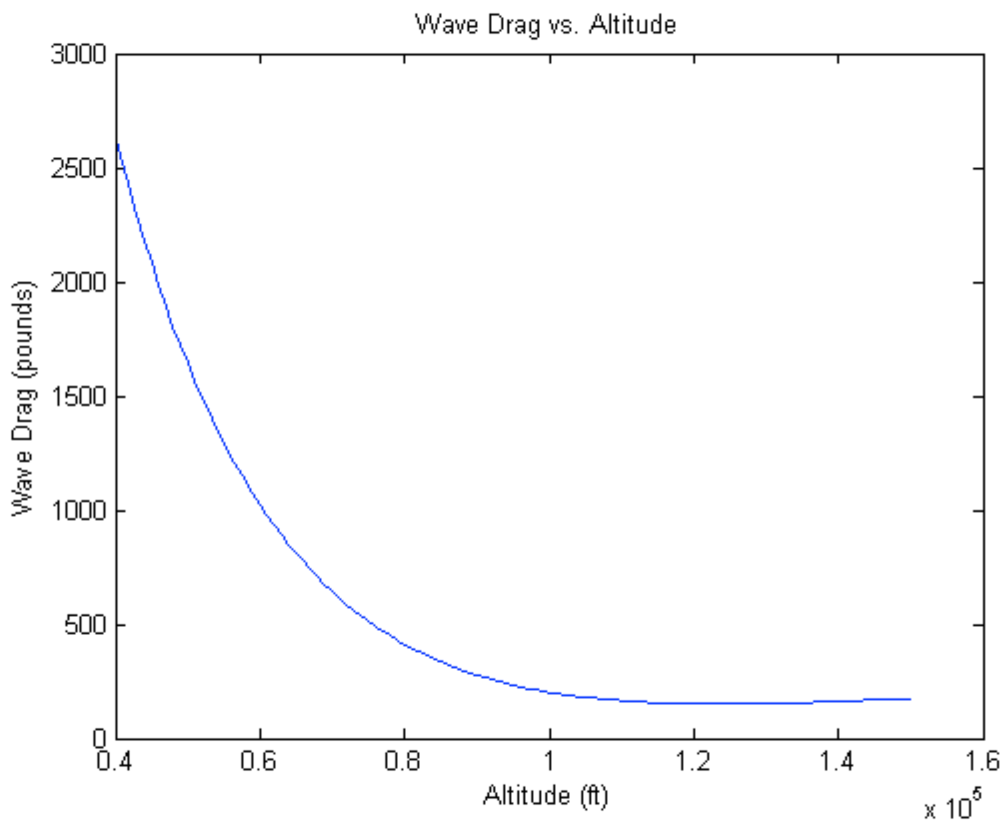
.

$$Cf = 0.295 \frac{T_\infty}{T^*} \left[\log\left(Re\,x \frac{T_\infty}{T^*} \frac{\mu_\infty}{\mu^*} \right) \right]^{-2.45}$$

$$\frac{T^*}{T_1} = 1 + 0.1198 M_1^{\ 2}$$



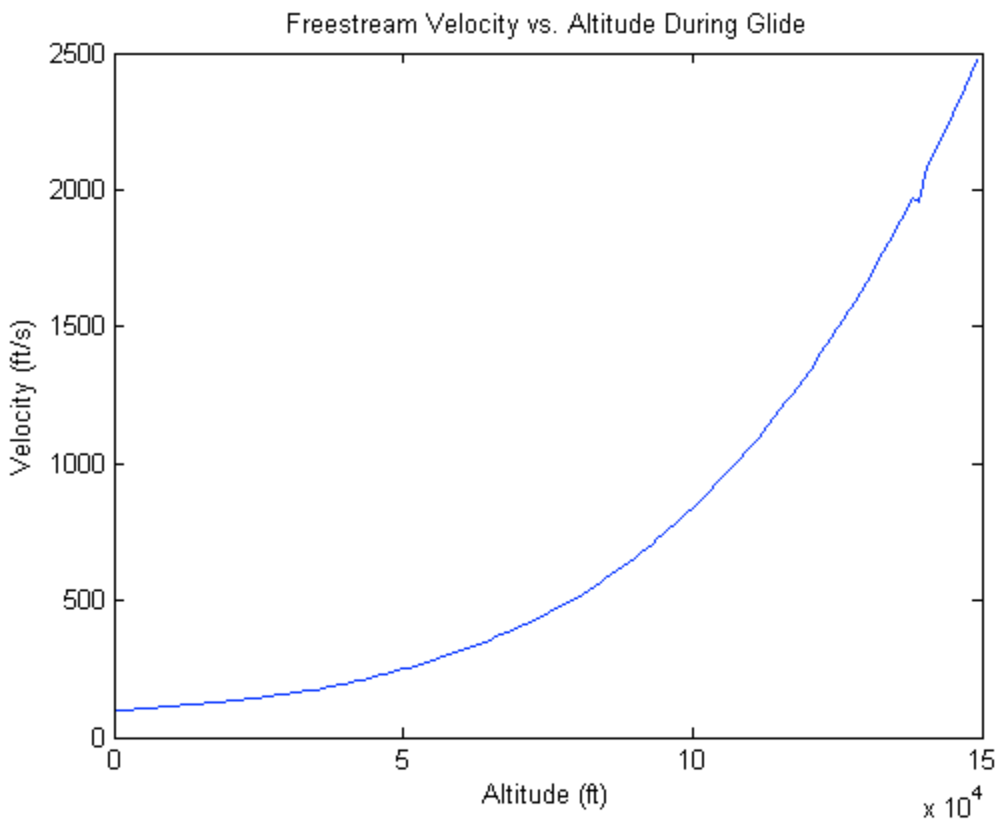
Wave drag coefficient was then calculated using nonlinear theory at Mach 4and then multiplied by dynamic pressure in order to determine wave drag as a function of altitude (shown below).



This shows that the UCAV is much more sensitive to wave drag than skin friction drag.

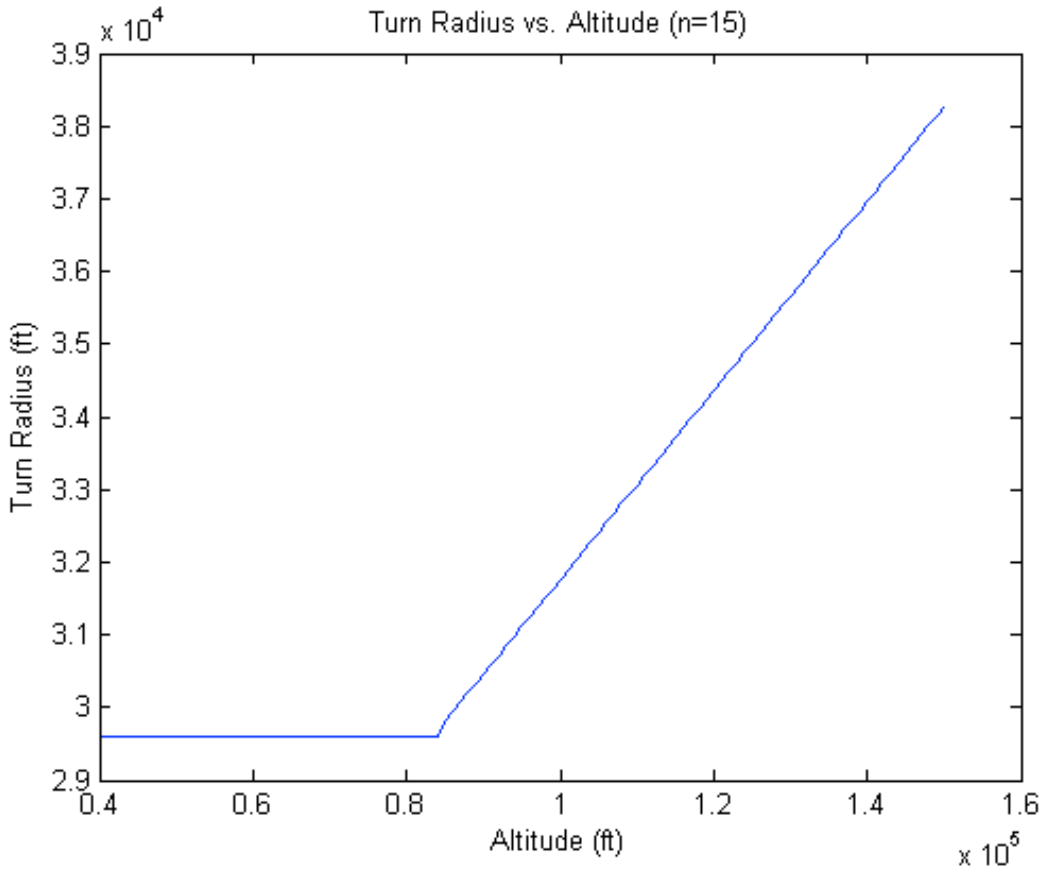
Gliding Performance

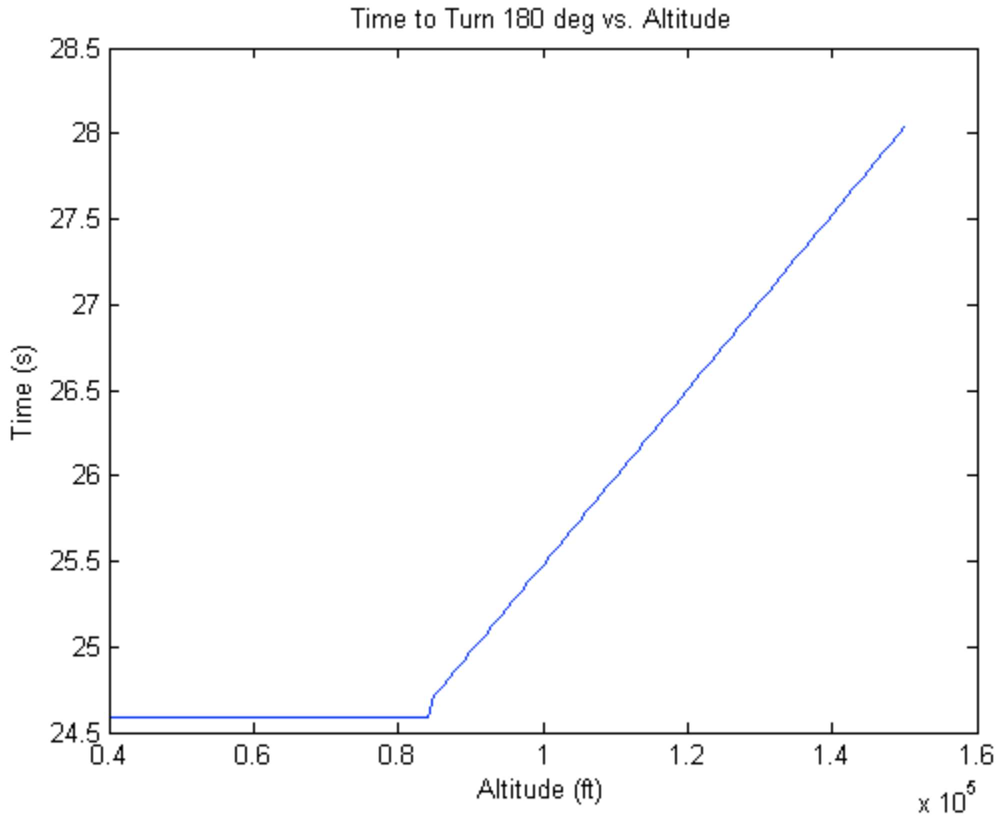
The UCAV is expected to descend from 150,000 feet to sea-level by gliding. The maximum lift to drag ratio was calculated to be 8.33 which gives a minimum glide angle of 6.84 degrees. The plot below shows how freestream velocity decreases with altitude in order to maintain the calculated lift to drag ratio.



Turning Performance

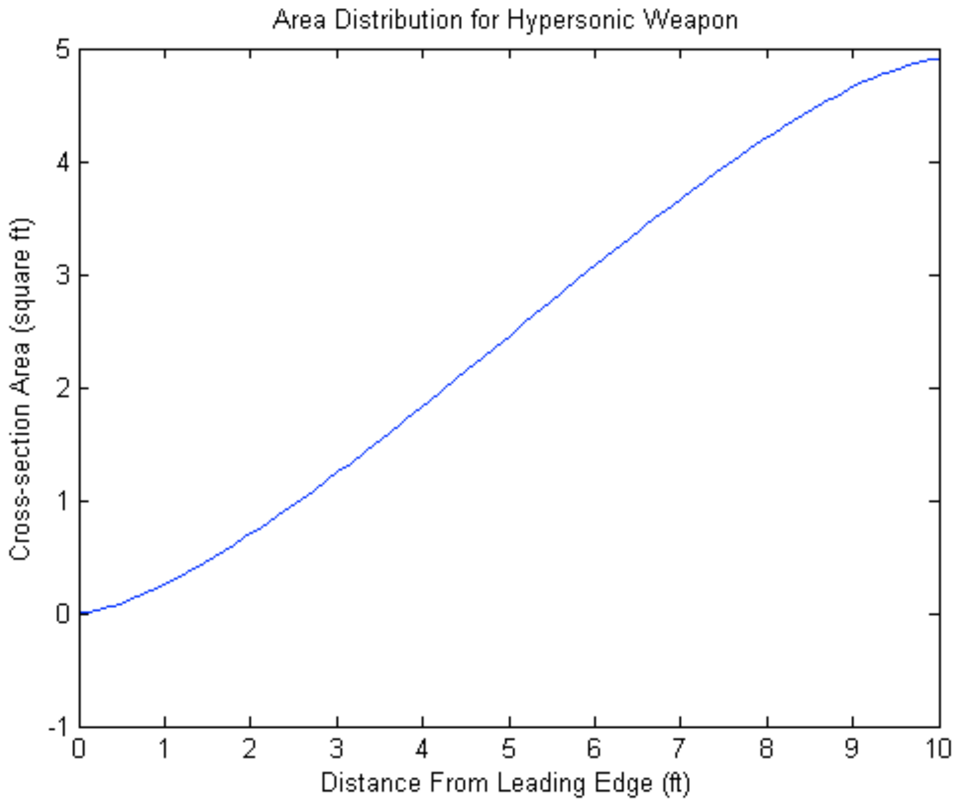
Turning performance of the UCAV was calculated for Mach 4 flight at a series of altitudes. The plots of turn radius and time to turn 180 degrees are shown below. The load factor was assumed to be 15 which is reasonable considering it is an unmanned vehicle. The constant portions of the graphs are due to the fact that the temperature in the stratosphere is constant. Since the temperature is constant and the Mach number remains constant, the speed must also be constant.

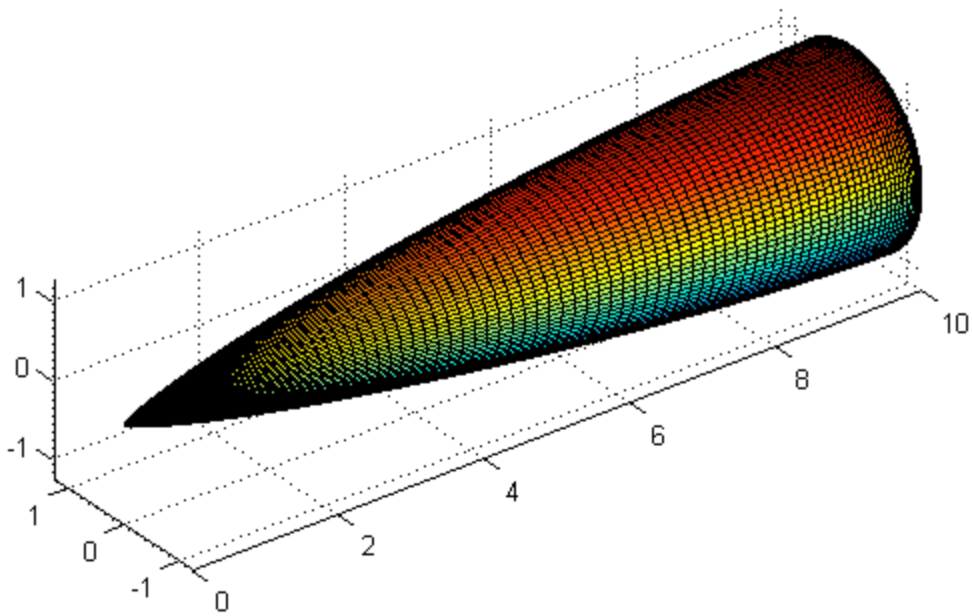



Time to Turn 180 deg vs. Altitude
28.5
28
27.5
27
26.5
26
25.5
25
24.5
Time (s)
0.4
0.6
0.8
1
1.2
1.4
1.6
Altitude (ft)
x 10^5

Hypersonic Weapon Conceptual Design

In order to minimize the wave drag of the hypersonic airbreathing weapon, the weapon was modeled using a Von Karman ogive. The base diameter of 3.5 feet and length of 10 feet used to calculate the shape were based on the dimensions of the UCAV such that the four weapons fit within the span and do not stick out past the leading edge. The cross-sectional area distribution as well as a simple model of the shape are shown below.





The above model is a simple model of the Von Karman ogive shape done as a body of revolution in MATLAB. Small fins will be added as control surfaces. This design yields a wave drag coefficient of .0625 which corresponds to a wave drag of 42 pounds. An approximation using Newtonian aerodynamics yielded a lift to drag ratio of 3.73.

Concluding Remarks

The AE3021BF11 went through numerous iterations to achieve a realistic system setting for fast response time on an incoming ICBM nuclear warhead. The aerodynamics for the subsonic, transonic, supersonic, and hypersonic regimes were calculated to validate the feasibility of this type of response system. The performance characteristics for all parts in this system were also calculated to compare to the current THAAD based design provided in a previous section. In conclusion, what we have conceived is a replacement for the current late response system needed to neutralize an oncoming ICBM from an enemy nation. Although it would be best to not ever be forced to put such a design into production, the AE 3021BF11 is a dependable defense aircraft capable of fully neutralizing any nuclear threat of today's technology. We appreciate the challenge that this project has given us and class this semester has been a pleasure. Thank you.

-Cristian Salgueiro
-Christopher Sandwich