The Golden Egg: An Austere Field Light Attack Aircraft
Team Angry Geese

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In response to the 2021 AIAA Undergraduate Team Aircraft Design Competition request for proposals, Team Angry Geese of the University of Alabama in Huntsville has developed a conceptual design, the "Golden Egg", an affordable light attack aircraft that can operate from short, austere fields and replace current helicopters in performing close air support missions. The aircraft must carry a crew of two, an integrated gun for ground targets, and at least 3000 pounds of armament. The aircraft must accomplish an attack mission with a full weapons load and a long-range ferry mission with a 60% weapons load. Additional design goals include enhanced survivability, the capability to deploy a variety of missiles, rockets, and bombs, and producing a "best-value" design that considers acquisition and operational costs. The baseline concept was developed after reviewing the design and performance of similar attack aircraft and helicopters. The current design has a streamlined body with an aspect ratio 6 tapered wing, a H-tail, and tricycle landing gear. An integrated F-404 turbofan engine allows the aircraft to meet flight requirements especially with its intake uniquely placed on top of the fuselage to mitigate potential debris hazards. The armament includes an integrated 20 mm gun and a combination of missiles and guided bombs. This initial design is estimated to weigh just under 24,407 lbf. Strategic material selection is currently being performed to reduce weight with structural strength, cost, and survivability in mind.

I. Nomenclature

AR = Aspect Ratio
$C_{d,i}$ = Induced Drag Coefficient
C_L = Lift Coefficient
TOW = Take Off Weight
e_0 = Oswald Efficiency Factor
Λ_{LE} = Leading Edge Sweep Angle
ω = Aerodynamic Cleanliness
TSFC = Thrust Specific Fuel Consumption

II. Executive Summary

Team Angry Geese is a Senior Design team of aerospace and mechanical engineering students at the University of Alabama in Huntsville. The team is participating in the 2021 AIAA Undergraduate Team Design Competition. The team designed the "Golden Egg", an affordable light attack aircraft that can operate from short, austere fields and replace current helicopters in performing close air support missions. The aircraft must carry a crew of two, an integrated gun for ground targets, and at least 3000 pounds of armament. The design process began by understanding the Request for Proposal (RFP) presented by AIAA containing an in-depth breakdown of the requirements, objectives and goals for a design mission and a ferry mission. A House of Quality was derived from the RFP including additional requirements that the team deemed necessary. A Concept of Operations (ConOps) was developed for each mission. The project has been broken down to different aspects and features such as the weapons system, propulsion system,

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and landing gear with research focused on finding these systems that best meet the requirements and the missions. The team extensively researched aircraft built for similar CAS missions. The weight, wingspan, aspect ratio, payload capacity and other selected characteristics were compiled. Design features such as tail configuration, fuselage style, and wing shape were also considered. After extensive research and team discussion, an initial design and CAD model were created including estimates of the gross weight, thrust, and aerodynamic shape. Power required and power available curves for the current concept were also generated and compared to required mission performance. Trade studies are ongoing to refine the design. Results of these analyses will be continually evaluated to make sure the design satisfy the IAA requirements. This paper presents our how the Angry Geese team developed the initial concept for the Golden Egg and the current configuration features and performance. Additional work to mature the design will also be discussed.

III. RFP Analysis

A. Requirement and Objectives

The AIAA RFP specifies six mandatory requirements for the aircraft. The first is short austere field performance. This includes taking off and landing over a 50 ft obstacle in less than 4,000 ft and operating from austere fields at a density altitude of up to 6,000 ft with semi-prepared runways and a California Bearing Ratio of 5. The second requirement is a payload of at least 3,000 lbs of armament. The third is an integrated gun for ground targets. The fourth requirement is a service life of 15,000 hours over 25 years. The fifth requirement is a service ceiling of greater than 30,000 ft. The last requirement is a crew size of 2 with zero-zero ejection seats. The RFP specifies two design goals or desired objectives. The first goal is enhanced survivability, including armor for the cockpit and engine, reduced infrared and visual signatures, and countermeasures. Another goal is the ability to carry and deploy a variety of weapons such as rail-launched missiles, rockets, and 500 lb bombs. Other constraints are for all components to have Technology Readiness Level 8 or above and meet military airworthy standard MIL-STD-516C.

B. Design Mission

Figure 1 illustrates the various Design Mission Phases. The fully loaded aircraft must carry the two crew members and at least 3,000 lbf of armaments. The aircraft needs to warm up and taxi in five minutes, be able to take off within 4000 ft from an austere field and clear a 50 ft obstacle. The aircraft must then climb to a cruise altitude of at least 10,000 ft and cruise for 100 nm. The next stage is for the aircraft to descend to 3000 ft within 20 minutes of its initial climb and loiter on station for four hours with no stores dropped. Once the attack mission is finished (whether stores are deployed or not), the aircraft must climb back to its cruising altitude and cruise 100 nm. It then must descend and land in less than 4000 ft at an austere field, clearing a 50 ft obstacle. Following landing, taxi and shutdown must be done in five minutes. There needs to be enough fuel reserves to climb 3000 ft and loiter for 45 minutes in case landing is aborted.

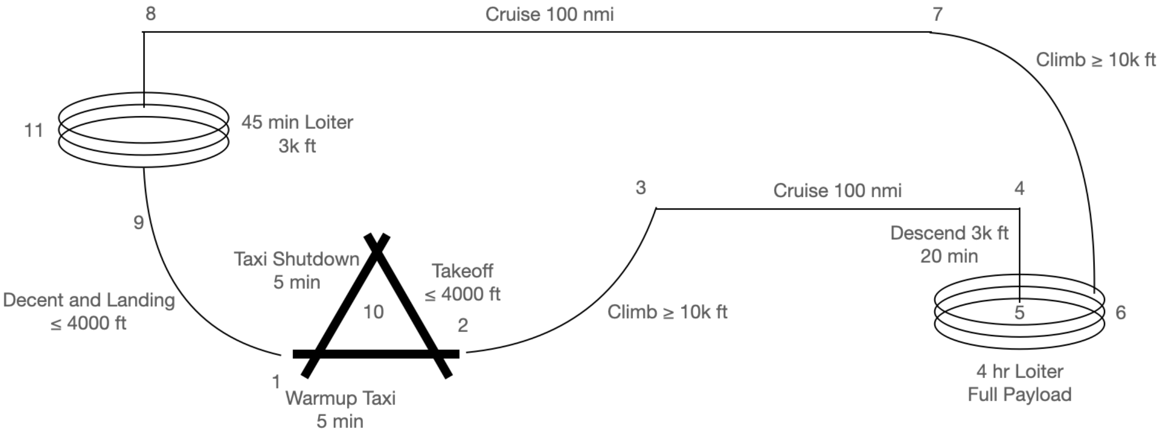


Fig. 1 Design Mission ConOps (full weapons load)

C. Ferry Mission

Figure 2 illustrates the various phases of the Ferry Mission. For this mission, the aircraft must carry the two crew members and 60% of its maximum armament load. The aircraft must warm up and taxi within 5 minutes, be able to take off within 4000 ft from an austere field, and clear a 50 ft obstacle. The aircraft must then climb to a cruise altitude of at least 18,000ft and cruise at least 900 nmi. It then must descend and land in less than 4000 ft at an austere field, clearing a 50 ft obstacle. Following landing, taxi and shutdown must be done in five minutes. There needs to be enough fuel reserves to climb 3000 ft and loiter for 45 minutes in case landing is aborted.

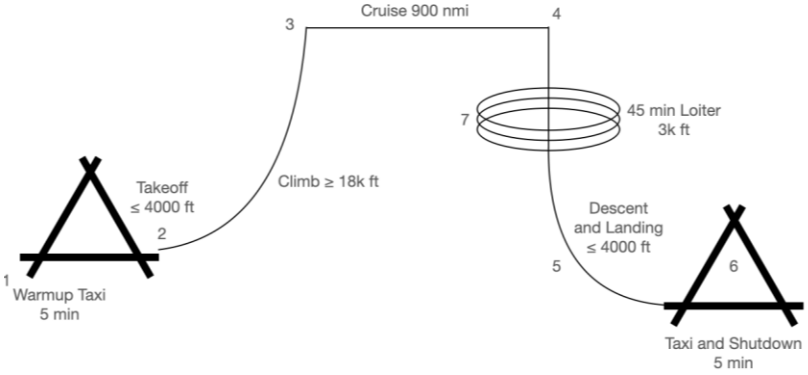
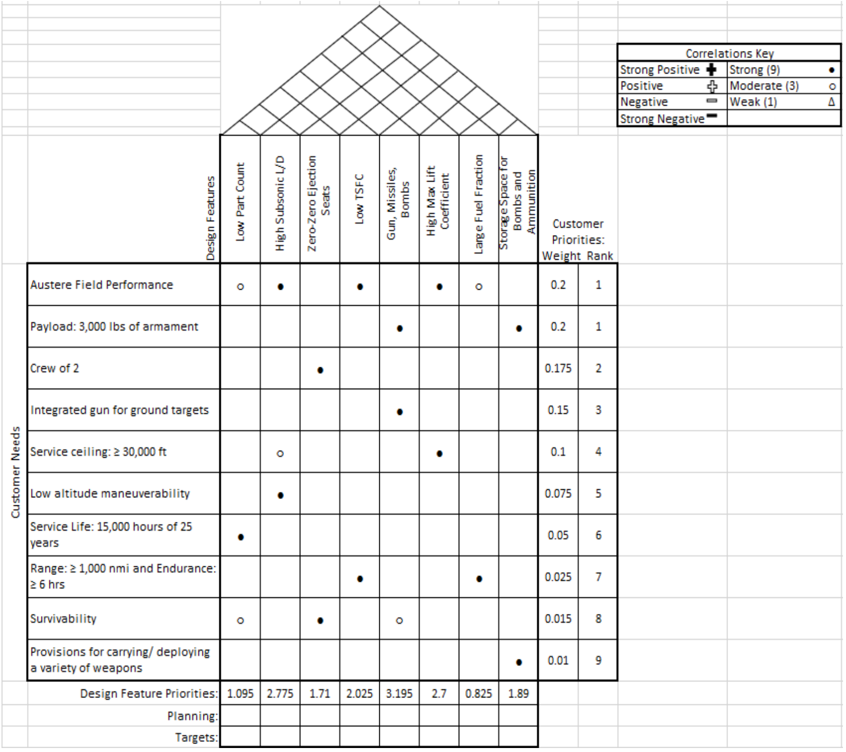


Fig. 2 Ferry Mission ConOps (60% weapons load)

D. House of Quality

Figure 3 shows the House of Quality. The majority of the customer needs were drawn directly from the RFP. Range of greater than or equal to 1,000 nmi and endurance of greater than or equal to 6 hrs were specified to satisfy both the design and ferry missions. Low altitude maneuverability was added because the aircraft is filling the role of attack helicopters. These customer needs were ranked and weighted based on importance to the missions. They were also correlated with the design features, represented by the symbols in the correlation key. The design feature priorities were calculated by multiplying the weight in the row by the value of the symbol shown in the correlation key and adding them for that column.



Correlations Key			
Strong Positive	✚	Strong (9)	●
Positive	✙	Moderate (3)	○
Negative	▭	Weak (1)	Δ
Strong Negative	▬		

Customer Needs / Design Features	Low Part Count	High Subsonic L/D	Zero-Zero Ejection Seats	Low TSFC	Gun, Missiles, Bombs	High Max Lift Coefficient	Large Fuel Fraction	Storage Space for Bombs and Ammunition	Customer Priorities: Weight	Rank
Austere Field Performance	○	●		●		●	○		0.2	1
Payload: 3,000 lbs of armament					●			●	0.2	1
Crew of 2			●						0.175	2
Integrated gun for ground targets					●				0.15	3
Service ceiling: ≥ 30,000 ft		○				●			0.1	4
Low altitude maneuverability		●							0.075	5
Service Life: 15,000 hours of 25 years	●								0.05	6
Range: ≥ 1,000 nmi and Endurance: ≥ 6 hrs				●			●		0.025	7
Survivability	○		●		○				0.015	8
Provisions for carrying/ deploying a variety of weapons								●	0.01	9
Design Feature Priorities:	1.095	2.775	1.71	2.025	3.195	2.7	0.825	1.89		
Planning:										
Targets:										

Fig. 3 House of Quality

IV. CAS Database

Table 1 summarizes a review of previous military aircraft used to create an initial design. The first major decision was choice of propulsion system. Factors for selecting a turbofan over a turboprop or turboshaft is the aircraft's ability to meet the 20 min flight time to the loiter destination for the design mission. A minimum speed of 675 ft/**s** is needed to fly the 100 nmi and descend to 3k ft within 20 minutes of initial climb. The A-29 Super Tucano flies at a maximum of 540 ft/s [REF]. A turboprop introduces "left turning tendencies" [REF] One of the fastest helicopters, the Sikorsky X-2, has a top speed of approximately 405 ft/s [REF]. Although a turboprop aircraft will perform better closer to the ground, a turbofan will get the aircraft to its destination faster. The team recognizes that the turbofan may cost more to operate and be more complex to maintain in the field. The speed advantage was considered the most important factor in choosing the turbofan.

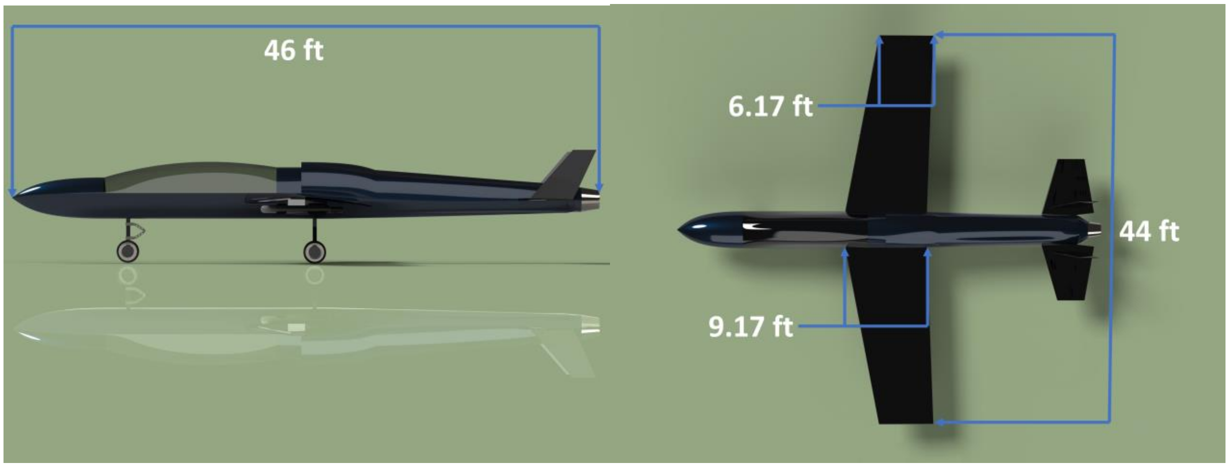
The more traditional fighter jets shown in Table 1 are also being used in some CAS roles. These high-speed designs typically have low aspect rations, such as the F-16 with an aspect ratio of about 3.09 [REF]. When reviewing the different mission requirements, it seemed logical to incorporate a high aspect ratio wing into the design to promote lift and endurance of the aircraft. This conclusion was made from examining aircraft such as the Cessna A-37 Dragonfly [REF] and the A-10 [REF], both of which have relatively straight wings with a high aspect ratio of 6.2 and 6.54, respectively.

Table 1. Engine Number Comparison of Different CAS Aircraft

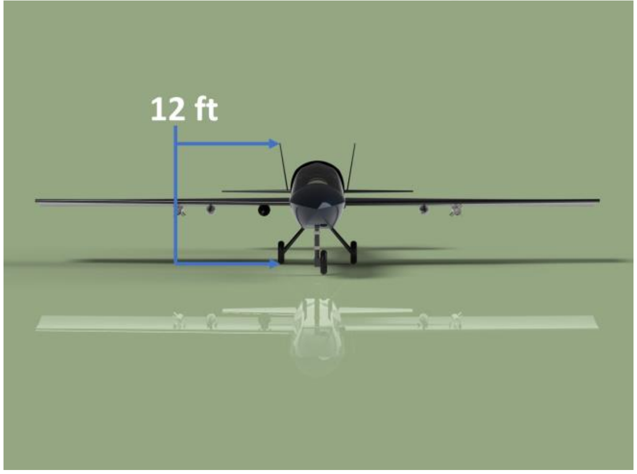
ACFT	# Eng	Thrust [lbf]	Max TOW [lbf]	T/W	Range [nm]	Armament [lbm]	Armament / Max TOW
A-37 [REF]	2	4,800	11,700	0.410	270	3,000	0.256
AV-8B [REF]	1	23,800	31,000	0.768	90	9,000	0.290
A-29 [REF]	1	4,046	11,900	0.34	450	3,400	0.286
A-10 [REF]	2	18,130	51,000	0.355	695	16,000	0.314
F-18 [REF]	2	44,000	66,000	0.667	1,275	17,750	0.269
F-15 [REF]	2	50,000	68,000	0.735	3,000	3,310	0.049
AH-64 [REF]	2	1,800 [SHP]	15,075	-	216	4,000	0.265

V. Baseline Configuration

Figure 4 shows the conceptual design for the Golden Egg light attack aircraft that will be analyzed further in this report. The overall length, from tip to nozzle end, is 46 ft. The wingspan is 44 ft. The 6.17 ft tip chord and the 9.17 ft root chord provides a taper ratio of 0.673 and an aspect ratio of 6. The overall height of the aircraft will be 12 ft with the landing gear extended and 8 ft retracted. This aircraft will feature a tandem cockpit for a dual crew, top mounted air-intake for the single turbofan engine, and dual rudder to provide redundancy in the event of possible damage. The high aspect ratio wing will supply sufficient lift to meet the required payload capacity and mission performance. The aircraft shown has an example 3000 lb weapons setup with two air to ground missiles, two 250 lb bombs, one 500 lb bomb, and one 20 mm gun with associated ammo. The missiles and bombs hang under the wings while the gun and its ammo are contained within the fuselage, with the barrel of the gun protruding from underneath the wing at the connection point to the fuselage on the right side of the plane. The materials used in The Golden Egg have been chosen to reflect high performance while maintaining a reasonable budget, using high grade metals in the fuselage and airframe and composites in the wing and tail.



a.) Side View **b.) Top View**



c.) Front View

Fig. 4 Initial concept – The Golden Egg - Layout

VI. Weight and Structures

Table 2 provides a weight summary for the current concept aircraft. Structural weights were estimated from the component surface areas, thickness and material densities. The fuselage and vertical tails were just assumed to be skins of aluminum to represent an aluminum structure with a composite skin. Armor weight was obtained from adding additional thickness to applicable surface areas including about 30% of the fuselage and 50% of the wings and tail then applying a density. Additionally, estimated maximum fuel requirements, weapon requirements, general systems and crew contributed the additional weight components shown in Table 2.

Aluminum will compose most of the fuselage structure other than the skin and armor. Wing skin and inner stringers should be composed of a carbon/epoxy composite, while the wing spar(s) will be aluminum or titanium to accommodate the wing loading. The leading edges will employ aluminum or titanium for impact and erosion resistance. The horizontal tail will have a similar material composition to the wing. The vertical tail encounters additional loads and stresses unlike the horizontal tail and wings so most of it will be composed of aluminum or titanium other than the skin. Layers of Kevlar bonded boron carbide serve as the general armor located primarily on the underside of the wing, underside of tail and crucial areas of the fuselage. The canopy will be vacuum formed acrylic in line with other military aircraft. Composites may carry higher costs and maintenance than aluminum or titanium, but allow for lower takeoff weights and are reasonably repaired with a multi-tile panel design

The definition of an inner structure will include the addition of full-cantilever wing spars, wing stringers, fuselage longerons, fuselage frames, a fuselage keel and leading-edge skins. Armor thickness and location may change depending on weight and durability requirements. Blast shields may be incorporated within the internal structure to protect the engine and crew compartments. A V-n diagram will also be developed to describe the aircraft's flight and maneuvering envelope based on maximum structural loading.

Table 2. Weight Summary

Component	Weight (lbs)	Component	Weight (lbs)	Component	Weight (lbs)
Fuselage*	1632	Fuel	11000	Weapons	3000
Canopy	173	Fuselage Armor	437	General Systems	260
Wings*	617	wing armor	1028	Crew	500
Tail, Horizontal*	58	tail armor	97		
Tail, Vertical*	136	Engine	2365	Total Weight	21302

*Weight of the outer surface with a thickness of 0.1181 inches (3 millimeters) for composite structures and 0.25 inches for aluminum structures. Currently does not include inner structures.

VII. Propulsion and Power

A preliminary study was performed for each phase of the mission using a constraint master equation [11], seen as Eq. 1 below, to estimate what the thrust to weight ratio and wing loading needs to be as shown in Fig. 5. Takeoff and landing constraint curves are not shown because the limits were negligible. Based historical research of thrust to weight and wing loading for CAS aircraft and the curves of Fig. 5, the initial selection of engine to be used is a General Electric F404-IN20 Low Bypass Turbofan. The F404 has a baseline thrust of 16,000 lbf and a 1.85 lbm/lbf-h TSFC [11]. The F404 turbofan has increased reliability, improved fuel consumption, and updated computer from its earlier models.

$$\frac{T_{SL}}{W_{TO}} = \frac{\beta}{\alpha}\left\{K_1 n^2 \frac{\beta}{\alpha}\left(\frac{W_{TO}}{S}\right) + K_2 n + \frac{C_{D0}+C_{DR}}{\frac{\beta}{\alpha}\left(\frac{W_{TO}}{S}\right)} + \frac{P_s}{V}\right\} \tag{1}$$

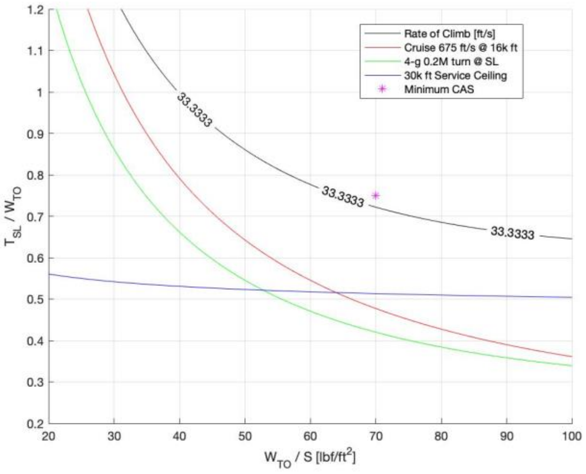


Fig. 5 Thrust to Weight Ratio vs. Wing Loading

Figure 5 illustrates the limits for this mission. Each phase of the mission was analyzed using a master constraint equation [11] to estimate what the thrust to weight ratio and wing loading need to be. Constants in the master constraint equation were selected from current attack aircraft. Takeoff and landing constraint curves are not shown because the limits were negligible. Based on historical research of thrust to weight and wing loading for CAS aircraft and preliminary study performed to create Fig. 5, the initial selection of engine to be used is a General Electric F404-IN20 Low Bypass Turbofan. The F404 has a baseline thrust of 16,000 lbf and a 1.85 lbm/lmf-h TSFC. The F404 turbofan has increased reliability, improved fuel consumption, and updated computer from its earlier models.

VIII. Aerodynamics

The data presented in Fig. 6 compares the performance of four candidate airfoils: the NACA 0008, NACA 22112, NACA 2418, and NACA 6716 airfoils. The 0008, 2418, and 6716 airfoils were selected as candidate airfoils because they have been used on retired or existing attack aircraft in the United States' arsenal - the A-4 Skyhawk, A-37 Dragonfly, and A-10 Thunderbolt II, respectively. The NACA 22112 was selected as a representative airfoil of the NACA five-digit family of airfoils. As shown in Fig. 6, the NACA 6716 offers lift coefficients substantially higher than the competing airfoils and exhibits relatively high lift to drag ratios at low angles of attack. However, the NACA 6716 has a much higher moment coefficient suggesting that this airfoil would require a large empennage, possibly offsetting the performance advantages. As a result, the NACA 6716 was not selected. The remaining airfoils generally offered similar performance regarding lift coefficient and lift to drag ratio with certain important exceptions. First, the NACA 0008 appears to offer the worst performance of the remaining airfoils (lower C_l / C_d and relatively poor stall performance) and was not selected for this reason. The NACA 22112 and 2418 airfoils offer very similar performance. However, the NACA 2418 airfoil also has a substantially higher moment coefficient. Despite this, the NACA 2418 airfoil was selected over the 22112 due to its superior stall performance. Specifically, at angles of attack exceeding twenty degrees, the loss of lift experienced by the NACA 22112 is precipitous when compared to the gradual loss of lift demonstrated by the NACA 2418. However, airfoil choice will be reconsidered further to ensure that the best possible airfoil for the aircraft's missions is selected. Aerodynamic analysis of possible combinations of high-lift devices will be completed soon, followed by an analysis of a complete wing design and drag build-up estimates.

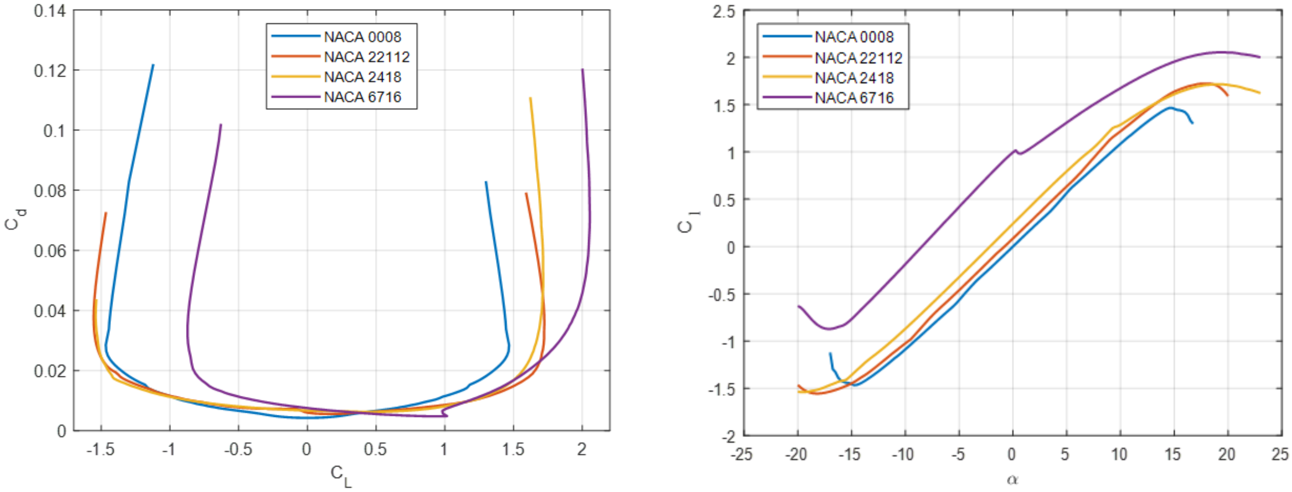


Fig. 6 Airfoil Performance Comparison

IX. Performance

Take off distance, ceiling, rate of climb, endurance, range, and maneuverability are all very important for the CAS aircraft support role. At this stage of design, meeting the take-off distance, endurance and range requirements are the most critical. Preliminary calculations for endurance and range are conducted using the current design's lift and drag coefficients and specific thrust of the GE F404-IN20 engine. The craft is modeled to have a constant pessimistic TOW of 24,000 lbs neglecting reduced mass from fuel burn. In combination with modeling climbs with a standard maximum climb rate at the density altitude endpoint and the rest of the mission requirements a specific fuel consumption of 0.79

lbf/lbm/hr [4] was used in estimating the ferry and strike missions fuel requirements as shown in Table 3. Minimizing the takeoff distance can be achieved through the use of high lift devices, high thrust to weight ratios, and low wing loadings. Inspiration was drawn from the A-10 warthog since it has the most similar CAS role. The A-10 uses two segment fowler flaps and small inboard leading-edge slats to increase lift at takeoff in addition to turbojet propulsion which produce more thrust at higher altitudes than turboprop or conventional piston propellor engines. Our aircraft is designed to have similar high lift devices to the warthog which should greatly reduce the takeoff distance at the required density altitude.

Table 3. Fuel Weight Needed for each Mission Stage

	Design Mission		Ferry Mission	
Phase:	Task:	Fuel Requirements [lbf]	Task:	Fuel Requirements [lbf]
1	Warm Up/Takeoff 5 minutes	-	Warm Up/Takeoff 5 minutes	-
2	Takeoff at ≤ 4,000 ft	70	Takeoff ≤ 4,000 ft	70
3	Climb to ≥ 10,000 ft; with range credit	120	Climb to cruise altitude ≥ 18,000 ft (20,000 ft); with range credit	270
4	Cruise 100 nm	870	Cruise 900 nm	7,100
5	Descend to 3,000 ft no range credit	-	Landing at austere field ≤ 4,000 ft, clear 50 ft obstacles	-
6	Loiter 4 hrs max	7,600	Taxi / Shutdown 5 minutes	-
7	Climb to cruise altitude ≥ 10,000 ft; with range credit	100	Reserves Sufficient for climb to 3,000 ft and 45 minute loiter	1,420
8	Cruise 100 nm	870		
9	Landing at austere field ≤ 4000 ft	-		
10	Taxi / Shutdown 5 minutes	-		
11	Reserves Sufficient for climb to 3000 ft and 45 minute loiter	1,420		
	Total	11,000	Total	8,900

X. Stability and Control

Because the aircraft needs to perform close air support to ground forces, it needs to balance stability with maneuverability. The A-10 represents this balance, so our stability and control criteria were closely drawn from it. In order to ensure the aircraft has positive longitudinal static stability, the center of gravity will be located in front of the neutral point (i.e. closer to the nose). The A-10's static margin of 0.13 was chosen for our initial design. The engine will be placed behind the wings which causes a nose up moment about the aircraft. With consideration of fuselage volume, the fuel and/or payload will be placed in front of the wings to place the center of gravity where we need it to be Because this aircraft will remain subsonic throughout its mission, the wing will be placed so that its c/4 is near the center of gravity. A mid-wing configuration will be used to sustain neutral lateral stability without dihedral.

Aircraft control will be provided by two ailerons, two elevators, and two rudders. These control surfaces were chosen to complement the horizontal and vertical tails and the wing, and they will provide the aircraft with the capability to effectively pitch, roll, and yaw. The two-rudder design comes with the added benefit of redundancy in case one rudder is damaged in combat.

Additional calculations will be performed as the center of gravity, aerodynamic center of the wing and horizontal tail, and overall basic initial dimensions of the aircraft are defined. For each step, the aircraft will be proved either statically stable or unstable in pitch. Changes will be proposed to produce static stability. After the aircraft is determined to be statically stable in pitch, it can then be assessed for lateral-directional stability.

XI. Mechanical Systems

A. Armaments

The three major components of the weapons systems are the gun, missiles, and bombs. Guns used on several past CAS aircraft were found to commonly range between 20 mm and 30 mm. The F-16 carries a 20 mm gun, the AV-8B Harrier II carries a 25 mm gun, and the Su-25 Frogfoot carries a 30 mm gun [5,6,7]. A 20 mm gun seemed the most reasonable from this data as it provided us with a large enough projectile and minimal weight. A smaller gun also allows for a larger amount of ammunition to be carried on missions. The M61 Vulcan 20mm cannon was chosen. Example equations for performance relate calculations can be found below in Eq's 2-3, regarding thrust required and total mass of fuel for the flight of one leg traveling 100,000 feet at 320 ft/s, where the aircraft CD is used to find:

$$T_R = \rho_\infty V_\infty^2 C_D S$$

$$T_R = 5.759x10^{-2}\ \frac{lbm}{ft^3}\ \left(320\ \frac{ft}{s}\right)^2 (0.1)\left(250\ ft^2\right)\left(\frac{1}{32.2\ \frac{lbm-ft}{lbf-s^2}}\right) = 4578.6\ lbf \tag{2}$$

$$m_{fuel} = F_r * SFC * t$$

$$m_{fuel} = 4{,}578.6\ \cancel{lb_f} * 0.79\frac{lb_m}{\cancel{lb_f} * \cancel{hour}} * \frac{100{,}000\ \cancel{ft}}{590\frac{\cancel{ft}}{\cancel{s}}} * \frac{1\ \cancel{hour}}{3{,}600\ \cancel{s}} = 314\ lb_m \tag{3}$$

When determining the best missile for the aircraft, it was assumed that the aircraft would be used in situations where air supremacy had been achieved. This assumption led to the choice of air-to-ground missiles instead of air-to-air. Research showed that a commonly used missile on similar CAS aircraft was the AGM-114 Hellfire. The Hellfire is a 100-class missile weighing between 98 lbs and 107 lbs [8]. Previous aircraft with the Hellfire include the AH-64 Apache, MQ-1 Predator, and the MQ-9 Reaper [8]. Research indicated the most common type of bomb used for similar aircraft was the MK-80 series. The requirements for our aircraft limited bomb size to a maximum of 500 lb. This allows for the use of the MK-81, a 250 lb bomb, and the MK-82, a 500 lb bomb. Both of these bombs are unguided bombs; however, the MK-82 can be fitted with joint direct attack munition (JDAM) guidance systems to improve accuracy. The JDAM addition for the MK-82 adds approximately 58 lbs, bringing the total bomb weight to 558 lbs.

B. Landing Gear and Ejection Seat

Based on the fact that the aircraft is made to be taking off and landing on semi-prepared runways, a tricycle landing gear with two wheels in the back and one in the front was chosen for the aircraft. This landing gear design was chosen over a tail dragger design in order to keep the plane as far off the ground as possible. This helps to prevent damage from loose debris from the rough conditions of the runway. Another added benefit to the tricycle design was increased pilot visibility during takeoff due to the front and rear of the plane being level. Having the plane level and further off the ground also simplifies rearmament.

An ejection seat was chosen based on what was used in similar aircraft. It was found that the ACES II ejection seat was used in the A-10, F-15, F-16, and F-22 [9]. This ejection seat has been proven effective and reliable so it was chosen as the best fit for our aircraft. More information needs to be gathered for other mechanical systems needed for the aircraft.

XII. Cost Analysis

The cost analysis of the aircraft has been broken down into non-recurring, acquisition, and operating cost. Non-recurring costs would include the developmental research, military airworthiness certifications, production tooling, facilities, and labor cost. This would be an estimate based on the same type of cost on current aircraft with similar features. Acquisition cost would include as detailed as possible a list of what materials, parts, and mechanical systems on the aircraft assuming the procurement of 50 aircraft. Things like carbon epoxy cost per square inch being $0.32 (in 2021) or the AGM-114 Hellfire costing $70,000 per unit (in 2021) will be needed to get a better idea of the acquisition cost. Operating cost much like the non-recurring cost will be based on aircraft with similar mechanical and propulsions systems on board to get a detailed idea of maintenance, fuel, or parts that might need replacing after a certain number of flight hours. This operating cost should provide what 15,000 hours over 25 years will look like cost wise and a maintenance cost per flight estimate. While providing a cost-effective aircraft is imperative, shortcuts that prevent the best performance and execution of the design and ferry mission will not be made.

XIII.Conclusion

Team Angry Geese's development and analysis of the Golden Egg aircraft will be refined in the coming months. Our current estimates indicate the initial conceptual design has the capability of meeting many of the design requirements, objectives, and goals. The analysis of the aircraft's performance will be further completed as details of the aerodynamics, propulsion system, and internal structure are confirmed. Completion of the stability and control section will be dependent on the final center of gravity and aerodynamic center calculated. Cost analysis will only become more detailed as further research is made. Team Angry Geese will continue to improve its design and identify potential design risks through the duration of this project.

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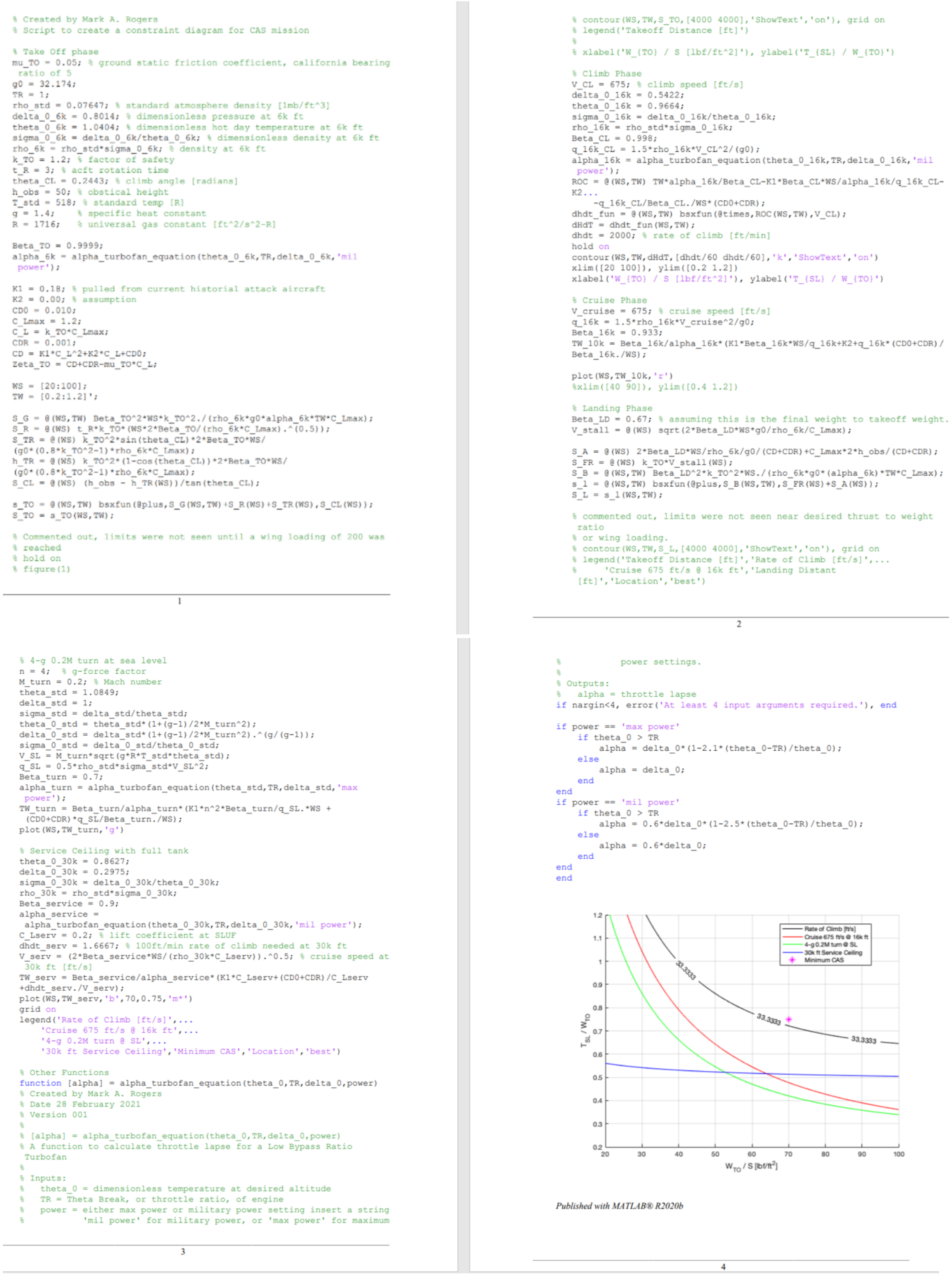
XV. Appendix



```
% Created by Mark A. Rogers
% Script to create a constraint diagram for CAS mission

% Take Off phase
mu_TO = 0.05; % ground static friction coefficient, california bearing
 ratio of 5
g0 = 32.174;
TR = 1;
rho_std = 0.07647; % standard atmosphere density [lmb/ft^3]
delta_0_6k = 0.8014; % dimensionless pressure at 6k ft
theta_0_6k = 1.0404; % dimensionless hot day temperature at 6k ft
sigma_0_6k = delta_0_6k/theta_0_6k; % dimensionless density at 6k ft
rho_6k = rho_std*sigma_0_6k; % density at 6k ft
k_TO = 1.2; % factor of safety
t_R = 3; % acft rotation time
theta_CL = 0.2443; % climb angle [radians]
h_obs = 50; % obstical height
T_std = 518; % standard temp [R]
q = 1.4;    % specific heat constant
R = 1716;   % universal gas constant [ft^2/s^2-R]

Beta_TO = 0.9999;
alpha_6k = alpha_turbofan_equation(theta_0_6k,TR,delta_0_6k,'mil
 power');

K1 = 0.18; % pulled from current historial attack aircraft
K2 = 0.00; % assumption
CD0 = 0.010;
C_Lmax = 1.2;
C_L = k_TO*C_Lmax;
CDR = 0.001;
CD = K1*C_L^2+K2*C_L+CD0;
Zeta_TO = CD+CDR-mu_TO*C_L;

WS = [20:100];
TW = [0.2:1.2]';

S_G = @(WS,TW) Beta_TO^2*WS*k_TO^2./(rho_6k*g0*alpha_6k*TW*C_Lmax);
S_R = @(WS) t_R*k_TO*(WS*2*Beta_TO/(rho_6k*C_Lmax).^(0.5));
S_TR = @(WS) k_TO^2*sin(theta_CL)*2*Beta_TO*WS/
(g0*(0.8*k_TO^2-1)*rho_6k*C_Lmax);
h_TR = @(WS) k_TO^2*(1-cos(theta_CL))*2*Beta_TO*WS/
(g0*(0.8*k_TO^2-1)*rho_6k*C_Lmax);
S_CL = @(WS) (h_obs - h_TR(WS))/tan(theta_CL);

s_TO = @(WS,TW) bsxfun(@plus,S_G(WS,TW)+S_R(WS)+S_TR(WS),S_CL(WS));
S_TO = s_TO(WS,TW);

% Commented out, limits were not seen until a wing loading of 200 was
% reached
% hold on
% figure(1)
```

1

```
% contour(WS,TW,S_TO,[4000 4000],'ShowText','on'), grid on
% legend('Takeoff Distance [ft]')
%
% xlabel('W_{TO} / S [lbf/ft^2]'), ylabel('T_{SL} / W_{TO}')

% Climb Phase
V_CL = 675; % climb speed [ft/s]
delta_0_16k = 0.5422;
theta_0_16k = 0.9664;
sigma_0_16k = delta_0_16k/theta_0_16k;
rho_16k = rho_std*sigma_0_16k;
Beta_CL = 0.998;
q_16k_CL = 1.5*rho_16k*V_CL^2/(g0);
alpha_16k = alpha_turbofan_equation(theta_0_16k,TR,delta_0_16k,'mil
 power');
ROC = @(WS,TW) TW*alpha_16k/Beta_CL-K1*Beta_CL*WS/alpha_16k/q_16k_CL-
K2...
    -q_16k_CL/Beta_CL./WS*(CD0+CDR);
dhdt_fun = @(WS,TW) bsxfun(@times,ROC(WS,TW),V_CL);
dHdT = dhdt_fun(WS,TW);
dhdt = 2000; % rate of climb [ft/min]
hold on
contour(WS,TW,dHdT,[dhdt/60 dhdt/60],'k','ShowText','on')
xlim([20 100]), ylim([0.2 1.2])
xlabel('W_{TO} / S [lbf/ft^2]'), ylabel('T_{SL} / W_{TO}')

% Cruise Phase
V_cruise = 675; % cruise speed [ft/s]
q_16k = 1.5*rho_16k*V_cruise^2/g0;
Beta_16k = 0.933;
TW_10k = Beta_16k/alpha_16k*(K1*Beta_16k*WS/q_16k+K2+q_16k*(CD0+CDR)/
Beta_16k./WS);

plot(WS,TW_10k,'r')
%xlim([40 90]), ylim([0.4 1.2])

% Landing Phase
Beta_LD = 0.67; % assuming this is the final weight to takeoff weight.
V_stall = @(WS) sqrt(2*Beta_LD*WS*g0/rho_6k/C_Lmax);

S_A = @(WS) 2*Beta_LD*WS/rho_6k/g0/(CD+CDR)+C_Lmax*2*h_obs/(CD+CDR);
S_FR = @(WS) k_TO*V_stall(WS);
S_B = @(WS,TW) Beta_LD^2*k_TO^2*WS./(rho_6k*g0*(alpha_6k)*TW*C_Lmax);
s_l = @(WS,TW) bsxfun(@plus,S_B(WS,TW),S_FR(WS)+S_A(WS));
S_L = s_l(WS,TW);

% commented out, limits were not seen near desired thrust to weight
 ratio
% or wing loading.
% contour(WS,TW,S_L,[4000 4000],'ShowText','on'), grid on
% legend('Takeoff Distance [ft]','Rate of Climb [ft/s]',...
%     'Cruise 675 ft/s @ 16k ft','Landing Distant
 [ft]','Location','best')
```

2

```
% 4-g 0.2M turn at sea level
n = 4;  % g-force factor
M_turn = 0.2; % Mach number
theta_std = 1.0849;
delta_std = 1;
sigma_std = delta_std/theta_std;
theta_0_std = theta_std*(1+(g-1)/2*M_turn^2);
delta_0_std = delta_std*(1+(g-1)/2*M_turn^2).^(g/(g-1));
sigma_0_std = delta_0_std/theta_0_std;
V_SL = M_turn*sqrt(g*R*T_std*theta_std);
q_SL = 0.5*rho_std*sigma_std*V_SL^2;
Beta_turn = 0.7;
alpha_turn = alpha_turbofan_equation(theta_std,TR,delta_std,'max
 power');
TW_turn = Beta_turn/alpha_turn*(K1*n^2*Beta_turn/q_SL.*WS +
 (CD0+CDR)*q_SL/Beta_turn./WS);
plot(WS,TW_turn,'g')

% Service Ceiling with full tank
theta_0_30k = 0.8627;
delta_0_30k = 0.2975;
sigma_0_30k = delta_0_30k/theta_0_30k;
rho_30k = rho_std*sigma_0_30k;
Beta_service = 0.9;
alpha_service =
 alpha_turbofan_equation(theta_0_30k,TR,delta_0_30k,'mil power');
C_Lserv = 0.2; % lift coefficient at SLUF
dhdt_serv = 1.6667; % 100ft/min rate of climb needed at 30k ft
V_serv = (2*Beta_service*WS/(rho_30k*C_Lserv)).^0.5; % cruise speed at
 30k ft [ft/s]
TW_serv = Beta_service/alpha_service*(K1*C_Lserv+(CD0+CDR)/C_Lserv
+dhdt_serv./V_serv);
plot(WS,TW_serv,'b',70,0.75,'m*')
grid on
legend('Rate of Climb [ft/s]',...
    'Cruise 675 ft/s @ 16k ft',...
    '4-g 0.2M turn @ SL',...
    '30k ft Service Ceiling','Minimum CAS','Location','best')

% Other Functions
function [alpha] = alpha_turbofan_equation(theta_0,TR,delta_0,power)
% Created by Mark A. Rogers
% Date 28 February 2021
% Version 001
%
% [alpha] = alpha_turbofan_equation(theta_0,TR,delta_0,power)
% A function to calculate throttle lapse for a Low Bypass Ratio
 Turbofan
%
% Inputs:
%   theta_0 = dimensionless temperature at desired altitude
%   TR = Theta Break, or throttle ratio, of engine
%   power = either max power or military power setting insert a string
%           'mil power' for military power, or 'max power' for maximum
```

3

```
%           power settings.
%
% Outputs:
%   alpha = throttle lapse
if nargin<4, error('At least 4 input arguments required.'), end

if power == 'max power'
    if theta_0 > TR
        alpha = delta_0*(1-2.1*(theta_0-TR)/theta_0);
    else
        alpha = delta_0;
    end
end
if power == 'mil power'
    if theta_0 > TR
        alpha = 0.6*delta_0*(1-2.5*(theta_0-TR)/theta_0);
    else
        alpha = 0.6*delta_0;
    end
end
end
```

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Figure 7: Master Constraint