# Top Secret: XA-23 Judge

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## Abstract

The XA-23 *Judge* is a close air support (CAS) aircraft that is being developed primarily for the use of the United States Military. While the military is the largest client of the XA-23 project, there are numerous stakeholders in the XA-23, including the US Government in general, taxpayers living in the United States, and any US allies who may also be interested in purchasing of the XA-23. These stakeholders are the ones who ultimately determine what the function of the aircraft must be.We then comprehend these needs and transform them into necessary requirements for the aircraft. Following the acquisition of all necessary stakeholders, needs, and requirements, the potential risks behind the development of the aircraft were carefully analyzed and scored.

Once all of the necessary background information was gathered about the aircraft, sizing and design of certain aspects could begin. Next, we were able to develop a sizing algorithm which yielded weight estimates for the XA-23. This algorithm used inputs such as payload weight, cruising altitude, and loiter times. After completion of initial sizing, aerodynamic design went under way. The wing was designed and characteristics such as the aspect ratio and efficiency factor were then obtained using XLFR5. After aerodynamic design, other important features of the aircraft, such as gun and engine placement and their contractors were chosen. Following these design details, calculations were then performed based upon all of the information thus far, in order to obtain values such as range, endurance, and wing characteristics.

In the end, the XA-23 aircraft is a modernization of the A-10 Thunderbolt II. This was the best possible design route to follow, as the A-10 has a stellar track record and it would be very difficult to design an entirely new aircraft to serve the same purpose. Many key features of the A-10 remain present on the XA-23, though a variety of design aspects are updated or changed to improve further upon the success and efficiency of the A-10.

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## 1 Introduction

The A-10 Thunderbolt II, more commonly known as the “Warthog”, was introduced in March 1977 by Fairchild Republic, for use by the United States Air Force (Jenkins, 1998, pp. 18, 20). The A-10 runs twin General Electric TF34-GE-100 Turbofans ("A-10 Thunderbolt II Specifications"). The engines are positioned on top of the wings, to better protect them from enemy ground-based fire. The primary function of the aircraft is to provide Close Air Support (CAS) to troops on the battlefield while having a very quick response time. The Warthog is also devastating to enemy armored vehicles, due to its highly lethal armament.

The centerpiece of the Thunderbolt II is its 30mm GAU-8 Avenger Gatling gun, which is positioned at the nose of the plane, just beneath the pilot. This gun can fire roughly 3900 rounds per minute of armor piercing incendiary ammunition ("A-10 Thunderbolt II Specifications"). The GAU-8 is a crucial part of the A-10. In fact, the aircraft was actually designed around the Avenger. The A-10 has been in service with the US military since 1977, though its role in the near future is currently in question.

Our goal is to design an aircraft to replace the outdated, but outstanding A-10 Thunderbolt II. The US military is in search of an aircraft with similar CAS capabilities to the A-10, while being cheaper to operate, and also retaining the success of the A-10. The XA-23 Judge is the solution we have developed to replace Fairchild’s 40 year-old Warthog. The Judge retains a number of specific features from the A-10, such as the twin high-bypass turbofan engines, with an H-tail configuration. The aircraft mimics these design aspects of the A-10 due to their important roles in the success of the Warthog.The XA-23 also possesses some new features of its own, like the integration of the canopy into the fuselage, and the tapered airfoil design. Overall, the XA-23 hopes not only to maintain the success of its predecessor, but to improve upon it, through integrating new design aspects and technological advances.

**Our mission** is to develop a simple, cost effective, efficient attack plane that perform close air support at high levels of accuracy, while also being able to operate after taking heavy amounts of damage.

# 2 Needs and Requirements Analysis

## 2.1 Stakeholders

This list is a comprehensive list of people and organizations who have a stake in the project, ranging from the highest level government officials, to those who have contributed to our project through their tax dollars. These individuals or organizations have been identified as such because they are either the ones paying us to design and develop this system, or are the ones who will be using the system directly.

- **US Government:** Our main stakeholder is the United States government, more specifically, the Army and the Air Force. Both the Army and the Airforce would be using the A-10 replacement for ground support. Thus, they are interested in an attack aircraft to replace the 41 year-old A-10 Thunderbolt II.
  - **United States Air Force:** The USAF is the organization that will be using the new A-10 in combat missions and close air support. It will be their pilots that are flying the aircraft and will benefit from its effectiveness and ease of flying.
  - **United States Army:** The U.S. Army will benefit from the new A-10 as it will provide close air support to troops on the ground. Also, the generals, or commanding officers, who call in support from the A-10 so the effectiveness and response time of the aircraft will be of great interest to them.
- **Allies of the US Government:** Any allies of the United States can be viewed as stakeholders, as they will likely be interested in purchasing our plane to improve their military strength as well.
- **Contractors:** A variety of contractors and subcontractors will be involved in the development of our aircraft, ranging from engines to bolts, thus making them crucial stakeholders of our project as well.

- **Workers:** Workers refers to the people on the factory floor who will be physically assembling our aircraft. These employees are important stakeholders because without them, the aircraft cannot be completed, and they depend on our aircraft development for employment.
- **Taxpayers:** US taxpayers are a very important stakeholder in our project. The role of the taxpayers is funding the purchase of any amount of aircraft that the United States government may choose to buy. The taxpayers are also the ultimate beneficiary as well, as the aircraft will be used to secure their freedom.

### 2.2 Needs

The needs for a replacement aircraft for the A-10 can be identified based on the stakeholders and what they specify the aircraft must be capable of doing. This includes needs from all respective stakeholders, from the taxpayers to the actual pilots. Some of the most important needs for the aircraft originate from the cost to build and operate each aircraft, such as the need for fuel efficiency. The needs for a close air support aircraft to replace the A-10 are as follows:

1. The aircraft must be fuel efficient for long range missions in addition to long durations of loitering.
2. It needs to have a short takeoff and landing distance and off-runway landing capabilities for missions in harsh environments.
3. The aircraft must be agile, in order to avoid incoming fire.
4. It should have maximum cockpit protection to protect the pilots.
5. It should maintain the ability to land after suffering heavy damage to ensure that no aircraft are shot down.
6. The aircraft should possess minor stealth capabilities, to ensure safer attack missions.
7. It must be highly lethal to effectively suppress enemy targets, ranging from infantry to vehicles.
8. The engines have to sustain the maximum desired airspeed, while also generating an adequate amount of thrust for the aircraft.

9. The aircraft needs to be cost-effective to produce and service in large numbers and quickly.

## 2.3 Requirements

The requirements of our aircraft were provided to us by our stakeholders, which were then converted into needs for our aircraft. These requirement describe exactly what the plane must be able to do, and why. The provided requirements focus on the needs for a plane more capable and up-to-date than the current A-10 Thunderbolt II.

1. The plane must be able to perform Airborne Armed Overwatch (AAO) for 4 hours, at a distance of 500 nautical miles away from the runway, in order to ensure that is it ready to support ground troops as soon as possible. (Need 1 & Need 2)
2. An additional requirement of the aircraft is that is must have a weapons payload consisting of a single 35mm cannon, capable of firing 750 rounds, with 14,000 pounds of munitions storage. Having this will ensure the aircraft is prepared to attack any target. (Need 7)
3. Our plane needs to have a ceiling of 45,000 ft for cruising to and from missions. (Need 8)
4. Another requirement is the plane must have a short takeoff distance of 6000 ft, so it can enter combat quickly when needed. (Need 2)
5. The aircraft should cruise at 200 knots true airspeed (KTAS) and have a max speed of 300 KTAS.(Need 8)
6. The aircraft must also have a maximum load factor of 8 g, to make sure it is able to be agile while ultimately holding up to large stress in flight. (Need 3)
7. The aircraft must have titanium armor cockpit protection for both pilots. (Need 4 )
8. The aircraft must be developed under a short period of time and relatively simple to manufacture, to meet the service date of 2025. (Need 9)
9. Our A-10 replacement aircraft must have a healthy supply chain to facilitate manufacturing, so that they can fully replace current fleet of A-10s. (Need 9)
10. The production rate of the aircraft should exceed 70 units per year to meet the demand of current mission needs. (Need 9)

11. Our redesign must cost less than $25 million per unit to attract potential buyers. (Need 9)
12. The flight operational cost per hour should remain as low as the original A-10 and should not exceed $7,000 per hour. (Need 9)
13. An estimable amount of investment will be flowing into a certain region where the manufacturing is taking process. This project should have an expected economic impact on that region which is represented in jobs created or GDP growth. (Need 9)
14. Engines are easily detachable for maintenance. (Need 9)

## 2.4 Preliminary Risk Analysis

Though our aircraft will face a myriad of risks in deployment with various armed forces, most minor failures will be mitigated through the implementation of proper operating procedures, vehicle design requirements, and trouble-shooting options that will allow for the aircraft to return to base safely. Regarding any more severe failure, the design requirements will be made to ensure maximum pilot survivability rate, and recovery of the aircraft itself through precautions, specific failure modes, and matching the legendary ruggedness of the original A-10 in the design requirements of its successor.

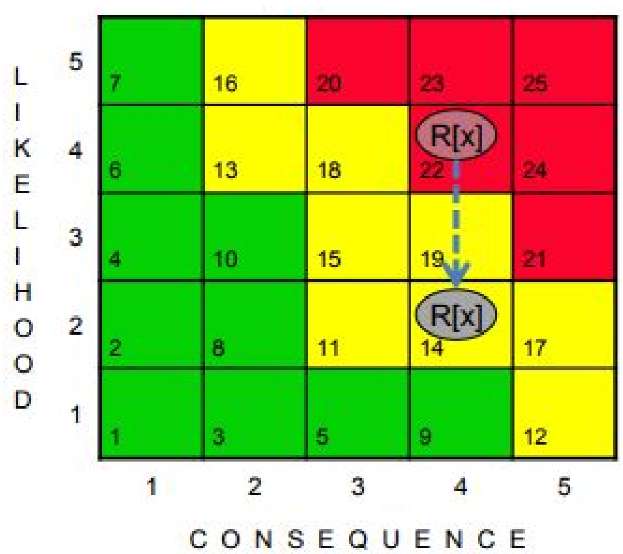


*Figure 1: Risk Analysis table (*NASA*).*

Each risk score assigned below (the fourth column in table 1), is assigned by using the above figure. Figure 1 is NASA's risk analysis table, which is used to analyze risks based on the consequences of taking the risk and the likelihood of a risk occurring. Each assigned risk score can be noted in the above figure. From there, we ranked the risks in terms of risk score (highest to lowest) in order to understand what risks we should be most worried about involving the performance of our aircraft.

*Table 1: Risk Analysis Table*

| Ranking | Risk Title | Rationale | Risk score | Mitigation |
|---|---|---|---|---|
| 1 | Being shot down/taking heavy damage | Fire from enemy forces, colliding with foreign objects | 21 | Rugged build of aircraft and proper countermeasure. |
| 2 | Landing Gear Failure | Consequence of Mechanical failures, and damage from enemy fire. | 14 | Manual backup and ability to belly land in extreme cases. |
| 3 | Engine Failure | Running out of fuel, external damage | 17 | Armor for engines, large fuel reserves |
| 4 | Gun Jam | Mechanical | 11 | Regularly clean and maintain on board weapons |
| 5 | Systems failure | computer, electrical, mechanical, etc. | 15 | Regular check and maintenance, backup systems and emergency plans |
| 6 | High Costs | Engine parts and systems are expensive, jet fuel is expensive | 18 | Smart management of project funds |
| 7 | Collateral Damage | Ground attack creates the risk of harming non-targets (civilians, property, | 15 | The aircraft will be designed to withstand such damage and be able to return to base. |

## 3 Concept Generation, Selection, and Development

This section will describe our design process. We will start with basic concept generation, and then document our methodology as we worked toward developing our final design.

### 3.1 Concept Generation and Selection

For initial concept generation, we developed four high-level concepts, from which we chose the final design. These four concepts were each developed separately from each other, to try and avoid any similarities in design. From there, we analyzed each concept based on the key features of its design. These key features are mentioned for each design below.

Our analysis of each design feature included weighing the positives and negatives of each design in terms of what they will accomplish for our aircraft. An example of this would be the orientation of our wing. Some of our designs implemented flat wings, while others had dihedral wings. We analyzed this situation based on important factors, such as lift, drag, weight, and wing-mounted armaments. Each of our four design analyses are discussed below.

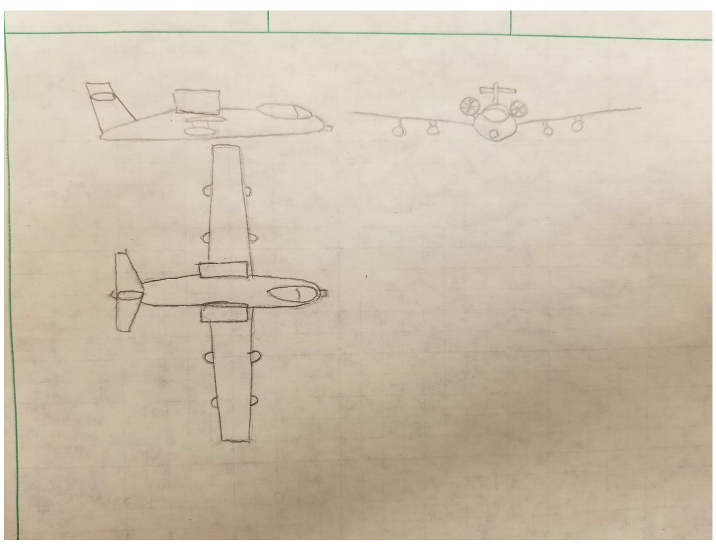

*Figure 2: Concept Sketch 1 (Peyton Garrison)*

**Key Features of Concept 1:**

- Concept 1 features a high aspect ratio, to increase efficiency and allow more room for wing-mounted pylons.

- The engines are located directly above wings to protects them from enemy ground fire.
- Implements a T-tail which allows better pitch control, and the elevators receive smoother, faster air.

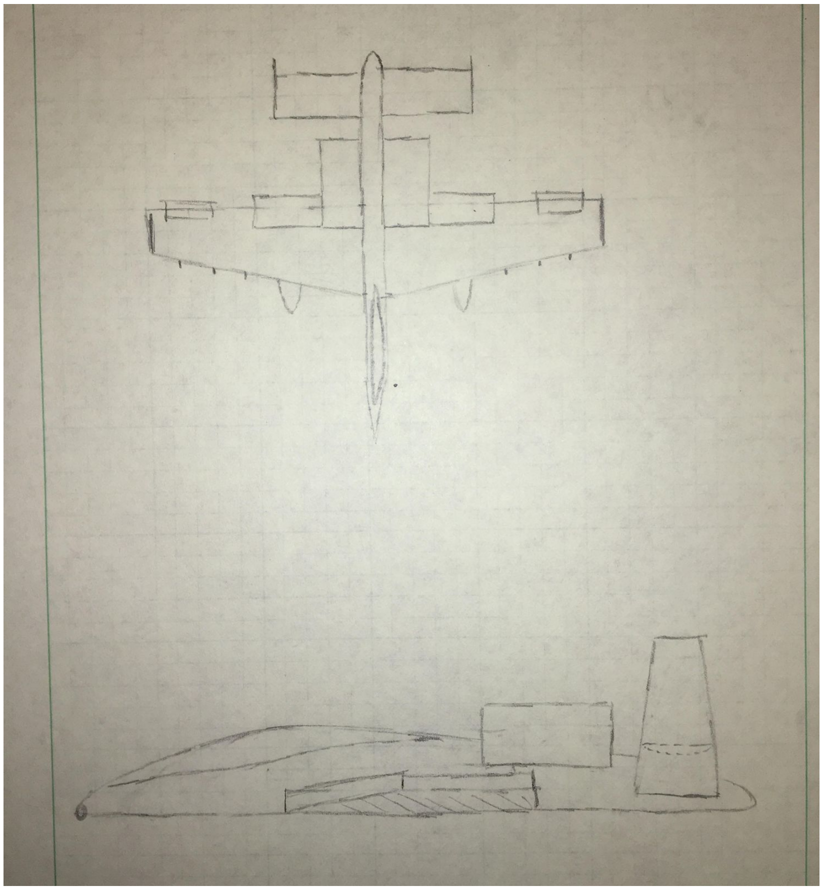

*Figure 3: Concept sketch 2 (Alex Bossert)*

**Key Features of Concept 2:**

- This concept integrates the canopy better into the side profile of the fuselage, which decreases drag in the canopy area.
- Incorporates a tapered airfoil from 6713 at the root to 0013 at the tip, which decreases the effects of wingtip vortices.
- Makes use of winglets, to decrease drag and help reduce the effects of wingtip vortices.

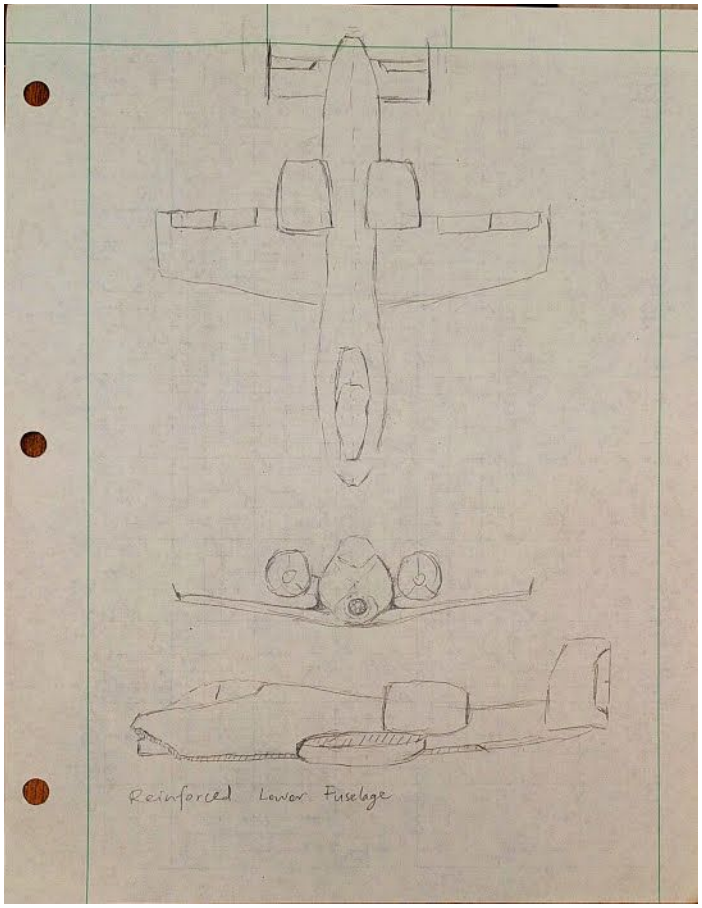


*Figure 4: Concept sketch 3 (Zhanpeng Yang)*

**Key features of Concept 3:**

- This design includes a reinforced lower fuselage for better protection and skidding capability in emergency landings.
- The engines are shifted forward to provide better protection from the wing during strafing.
- Concept 3 uses winglets to improve thrust and decrease drag due to wingtip vortices.
- Features a lower aspect ratio to permit more maneuverability during combat and evasion.

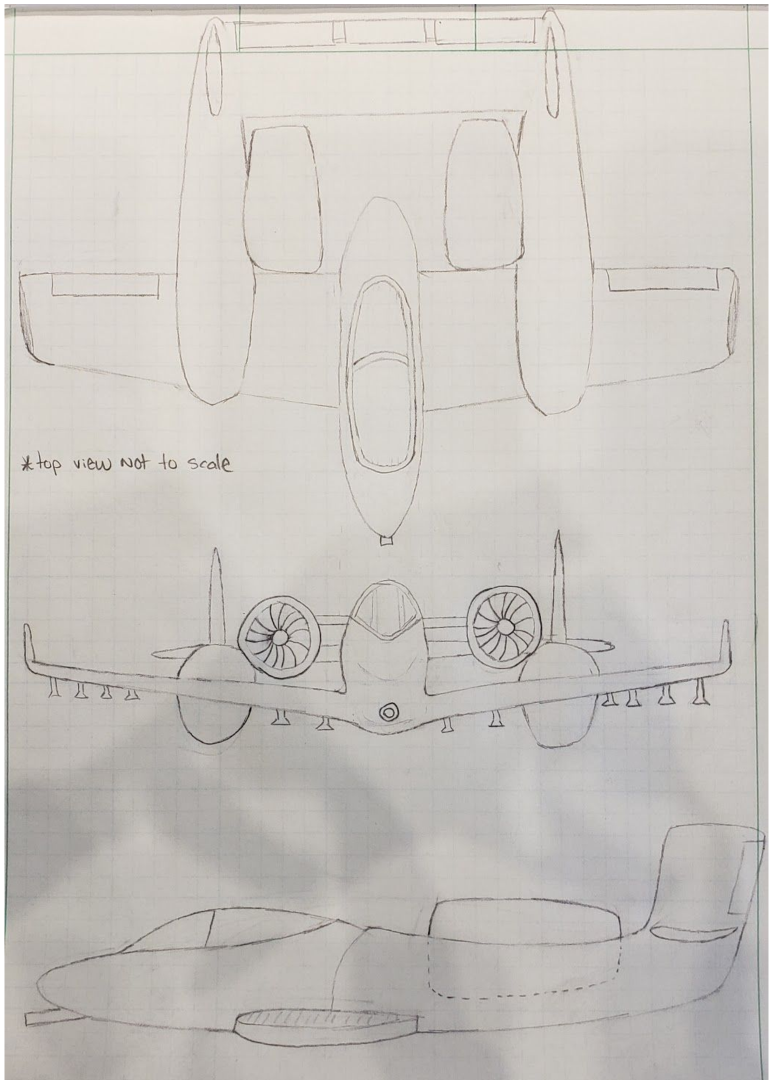


*Figure 5. Concept sketch 4 (Zach Rauch)*

**Key Features of Concept 4:**

- Concept 4 makes use of a twin boom tail, to increase fuel capacity, rigidity of the aircraft structure, and maintains the additional lift generated from engine exhaust over the horizontal stabilizer.
- Also has a wider horizontal stabilizer, which increases the aircraft's stability while in flight, and is also able to retain more damage.
- The engines mounted between tail booms, which better protects the engines from enemy fire, as well as reducing drag over body.
- Includes a shorter overall fuselage design, to improve agility and maneuverability.

Following the development of each of these four design concepts, we analyzed the positives and negatives of each design, and which features would be best to have, and why. An example of a factor that was weighed in on was the tapered airfoil design. It was nearly unanimous that the tapered airfoil would be a positive feature to have, no matter the concept chosen. As a result of multiple features like this being introduced in the design process, it became clear that the best aircraft would be a culmination of each of the four generated concepts. As a result, our design evolved into our final design, which will be discussed further in the next section, 3.2, detailed concept generation.

## 3.2 Detailed Concept Development

Throughout this section, we will go into some calculations and configurational elements we analyzed while focusing on a more detail-oriented concept development for our aircraft.

### 3.2.1 Preliminary Sizing and Dimensions

The initial design process for our aircraft includes preliminary calculations to estimate weight, as well as some aircraft dimensions. These initial data values will be used again in later calculations, specifically during detailed concept development.

Using a MATLAB program developed on the basis of Chapter 3 from *Aircraft Design* (Raymer, 2012, pp. 15-37), we obtained initial estimates for the takeoff weight. Many inputs are used in the process of calculating the approximate takeoff weight for an aircraft. These inputs are: payload weight, distance to the mission, engine type, unit type (metric or imperial), loiter time during mission, loiter time after mission, mach number cruising speed, lift to drag ratio, and initial guess of the weight. This also allows us to obtain other useful values, such as empty weight and estimated fuel weight. Calculated weight estimates can be seen in Table 2.

To begin sizing the aircraft we used the A-10 for our initial guesses as well as our own weight requirement. The maximum takeoff weight of the current A-10 is about 50,000lbs (23,000 kg). Our process for finding our approximate takeoff weight involves using a MATLAB code with several inputs related to the plane and the its requirements. These inputs are payload weight, distance to mission, engine type, units type (metric, customary), loiter times, cruising speed of the plane in mach number, the lift to drag ratio, and the initial guess of the weight. The code starts with finding the fuel weight fraction by finding the fuel weight fraction of each phase of its intended mission. Then, it finds the empty weight fraction using the formula for empty weight fraction. A new weight is calculated using these two fractions and the original guess. If it is not within a certain tolerance, the value is changed, a new empty weight fraction is calculated, and an all new weight is found until it is within the tolerance.

*Table 2: Preliminary Weight Estimation.*

| **Calculated Weights** | **Weight (lbs {kg})** | **Approximate Quantity** |
|---|---|---|
| Takeoff Weight | 52179 {23668} | N/A |
| Empty Weight | 20898 {9479} | N/A |
| Fuel Weight | 17282 {7839} | 2,880 gallons (~6 lbs/gal) |
| Crew Weight (Requirement) | 500 {227} | 2 crew with ~30 lbs. equipment |
| Payload Weight (Requirement) | 14,000 {6350} | 700 rounds+missiles+drop tanks |

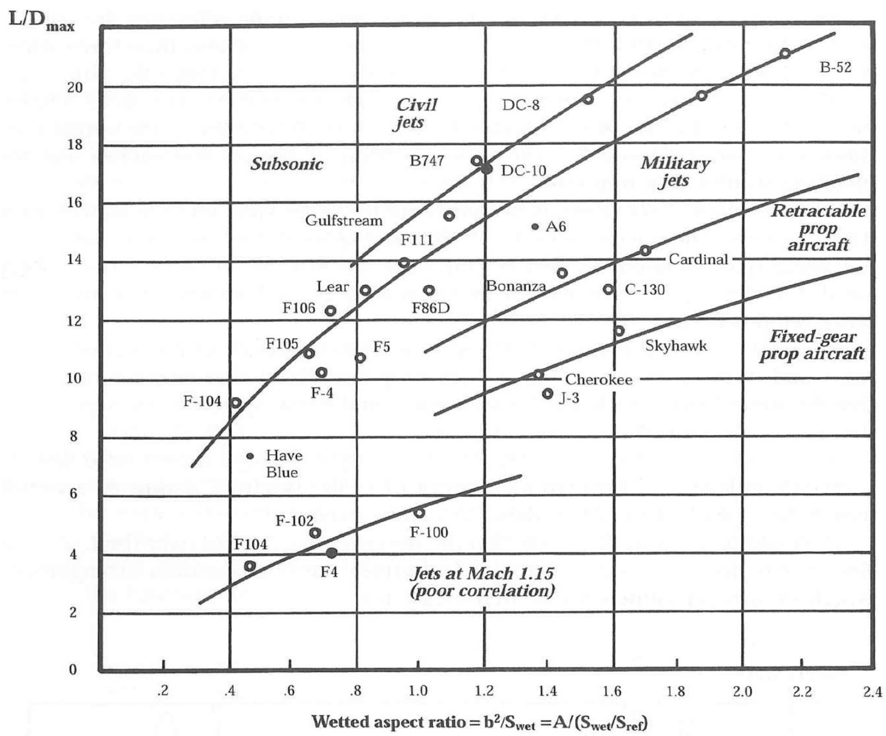


*Figure 6: Maximum lift-to-drag ratio trends* (Raymer, 2012, p. 26)

Preliminary Sizing Numbers:

- Fuselage
  - Height: 7 ft
  - Width: 6.5 ft
  - Length: 59 ft
- Wings (calculated)
  - Partition 1
    - Airfoil: NACA 6713
    - Half Span: 9.8 ft
  - Partition 2
    - Airfoil: NACA 6713 at the root, NACA 0013 at the tip
    - Half Span: 21.6 ft
  - Area: 610.2 $ft^2$
  - Aspect Ratio: 6.5
- Configuration
  - Low mounted, dihedral wings, with winglets
  - Rear Mounted Dual Rudders and Low Horizontal stabilizer
  - Dual high-bypass turbofan engines mounted to the fuselage behind the wing

We chose the size of the fuselage based on the current size of the A-10 fuselage except slightly larger to accommodate 2 people. For the wings, we decided that the root airfoil would be the same as the A-10 (NACA 6713) and the tip airfoil would be a NACA 0013 to reduce induced drag at the wingtips. We also decided to make the aspect ratio the same as the A-10, but increase the wingspan to 63 ft so we can fly slower and still generate enough lift at cruise for Steady Level Unaccelerated Flight (SLUF). With the aspect ratio and wingspan the area would need to be 610.2 $ft^2$. A low wing configuration was chosen for the same reason as on the A-10, it provides better stability and maneuverability. The rear mounted dual rudders and low horizontal stabilizer, which are also on the A-10, provide better control by providing air directly to the stabilizers. Lastly, we modelled our plane after the A-10 again by mounting the engines to the fuselage behind the wing.

### 3.2.2 General Aircraft Configuration

- Engines
  - Placement of the engines just in front of the horizontal stabilizer allows for control surface manipulation to ensure takeoff and landing in 6000 ft.
  - XA-23 is to be fitted with two Rolls Royce BR700-710 series turbofans, modified for military use, each providing around 15,000 lbf of thrust (BR710).
  - The engines will be configured such that they can be easily removed in case they need to be serviced or replaced.
- Gun
  - The XA-23 will include a 35mm canon to fire 700 rounds at ground-based targets for close air support. This canon will need to be contracted to an exterior company to be made, as there are no existing 35mm machine guns capable of being mounted on an aircraft.
- Pylons
  - The aircraft will include room to store 14,000 lbs of ordnance on the wing mounted pylons, such as air-to-air missiles, air-to-land missiles or drop tanks.
- Cabin
  - Features reinforced plexiglass cabin that is able to take considerable damage and still keep pilots safe.
  - The cabin is also to be pressurized such that the pilots can withstand up to 8 g's while flying.
- Landing gear
  - Landing gear is to be rugged enough to takeoff and land safely numerous times from bad runways during combat with little to no maintenance.

### 3.2.3 Wing Configuration and Calculations

- Aspect Ratio: 6.5 (same as current A-10)
- Oswald efficiency factor (e) = 0.773, obtained from xflr5
- L/D = 16.8
- Wingspan: 63 ft
- Mean chord length: $c_{ave} = 9.83\,ft$

$$S = \frac{b^2}{AR} = \frac{63^2}{6.5} = 610.6\,ft^2$$

Drag Polar: $C_d = C_{d,0} + \frac{C_L^2}{\pi e AR}$

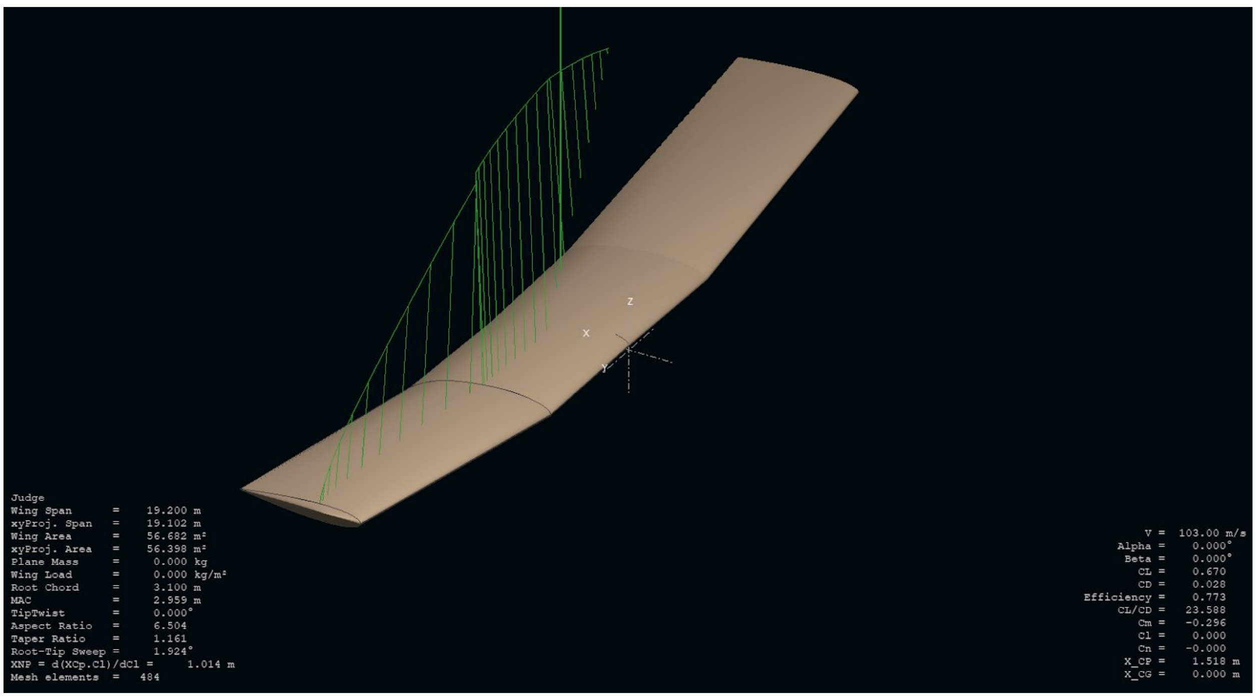


*Figure 7: XFLR5 model of the wing, complete with tapered airfoil design.*

As obtained from XFLR5, the zero-lift drag coefficient is $C_{d,0} = 0.014$, and the lift-dependent drag coefficient is $K = \frac{1}{\pi e AR} = \frac{1}{\pi(0.773)(6.5)} = 0.063$

Therefore, the drag polar for our specific aircraft becomes:

$C_D = 0.014 + 0.063{C_L}^2$

$c_{Root} = 10.2ft$, 6713 profile (Same as current A-10)

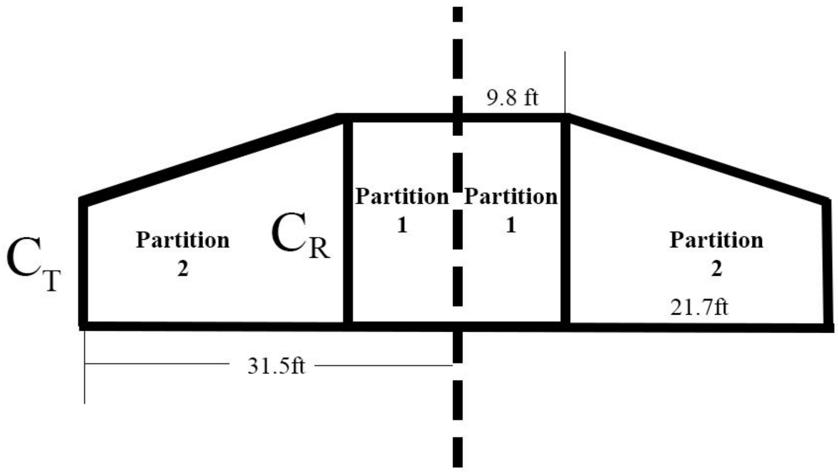


*Figure 8: Sketch of wing layout*

Area of Wing, S:

$S = Partition\,1 + Partition\,2$

$S = [l_1 * c_R] + [\frac{1}{2} * l_2 * (c_T + c_R)]$

$c_{Tip} = \frac{2\,(S - (l_1 * c_R))}{l_2} - c_R$

$c_{Tip} = \frac{2(610.6\,ft^2 - (19.6ft*10.2ft))}{43.4\,ft} - 10.2\,ft = 8.725\,ft$

### 3.2.4 Range and Endurance Calculations

Specific fuel consumption rate for our high-bypass turbofan engines, $c = 0.32\frac{lb}{lbf \cdot hr}$ (BR710).

Gravitational constant: g = 32 $\frac{ft}{s^2}$

Air density at flight ceiling $\rho = 4.5134 * 10^{-4}\ \frac{slug}{ft^3}$

Gross (Takeoff) Weight $mg_1 = 51479\ lb.$

Empty Weight $mg_2 = 20898\ lb.$

$$Range = \frac{2}{c}\sqrt{\frac{2g}{\rho S} * \frac{C_L}{C_D^2}}(\sqrt{m_1} - \sqrt{m_2})$$

$$\left(\frac{C_L}{C_D^2}\right)_{max} = \frac{9}{16}\sqrt{\frac{1}{3KC_{D,0}}} = \frac{9}{16}\sqrt{\frac{1}{3*0.063*0.014}} = 10.935$$

**Max range at $\left(\frac{C_L}{C_D^2}\right)_{max}$ and required flight ceiling**

$$Range = \frac{2}{\left(\frac{0.32\frac{lb}{lbf \cdot hr}}{3600\frac{s}{hr}}\right)}\sqrt{\frac{2*32\frac{ft}{s^2}}{(0.00045134\frac{slug}{ft^3})*(610.6ft^2)} * 10.935} * \left(\sqrt{\frac{51479\ lb}{32\frac{ft}{s^2}}} - \sqrt{\frac{20898\ lb}{32\frac{ft}{s^2}}}\right)$$

$$= (22500) * (50.39286712) * (14.55374875) = 16501615.36\,ft = 3125.3\ miles$$

$$Endurance = \frac{1}{c} * \frac{C_L}{C_D} * ln\left(\frac{m_1}{m_2}\right)$$

$$\left(\frac{C_L}{C_D}\right)_{max} = \frac{1}{2}\sqrt{\frac{1}{KC_{D,0}}} = \frac{1}{2}\sqrt{\frac{1}{0.063*0.014}} = 16.8$$

$$Endurance_{max} = \frac{1}{\left(\frac{0.32\frac{lb}{lbf \cdot hr}}{3600\frac{s}{hr}}\right)} * 16.8 * ln\left(\frac{51479}{20898}\right) = 170387.37s = 47.3hr$$

The above calculations of range and endurance ensure that the XA-23 is capable of meeting its Armed Airborne Overwatch (AAO) requirement of 4 hour overwatch at a 500 nm radius.

### 3.2.5 CAD Visualization

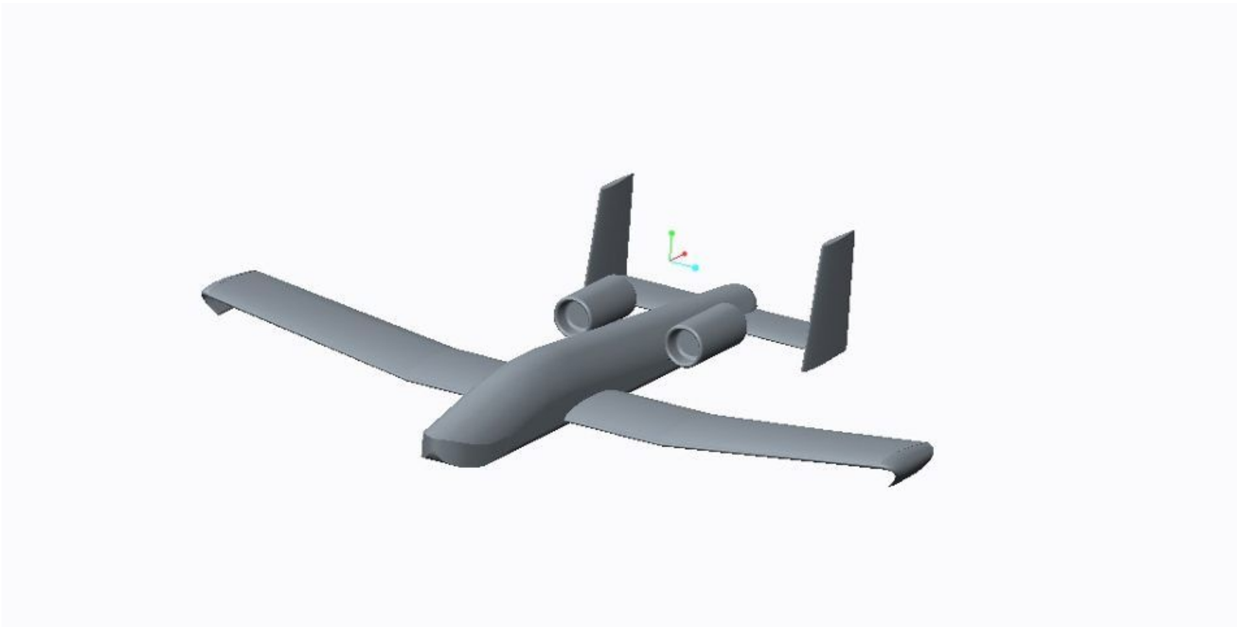

*Figure 9: CAD representation of XA-23 Judge (Orthographic View)*

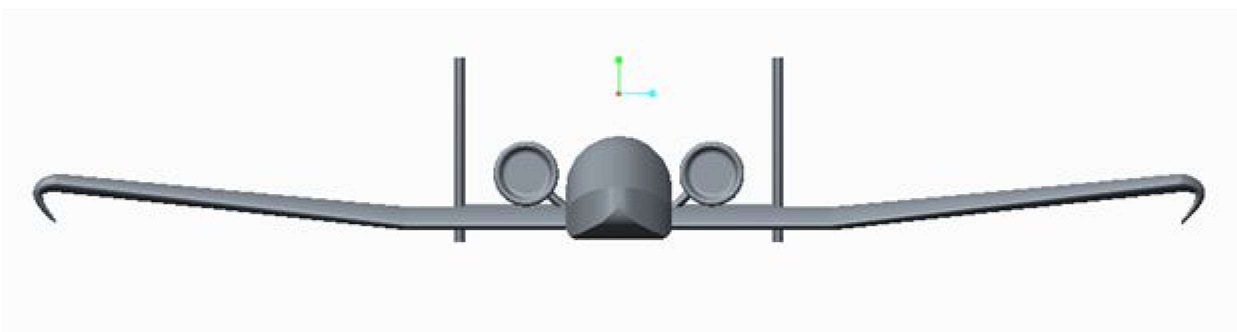

*Figure 10: CAD representation of XA-23 Judge (Front View)*

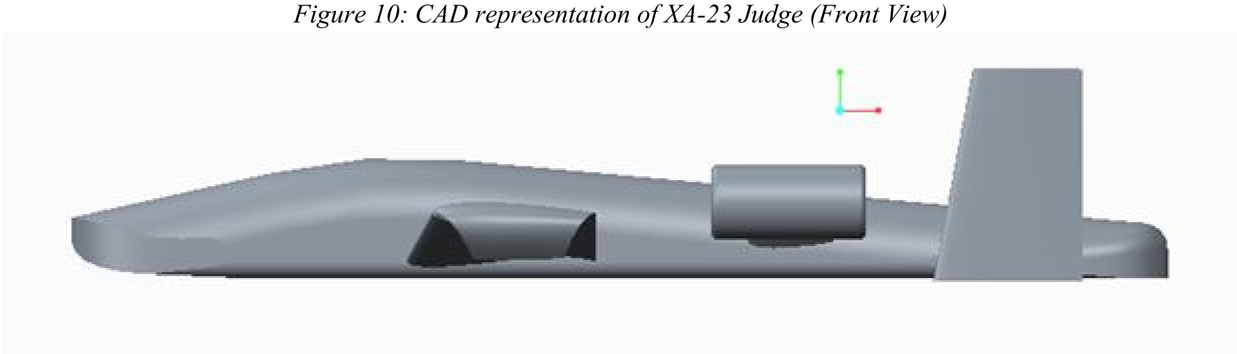

*Figure 11: CAD representation of XA-23 Judge (Side View)*

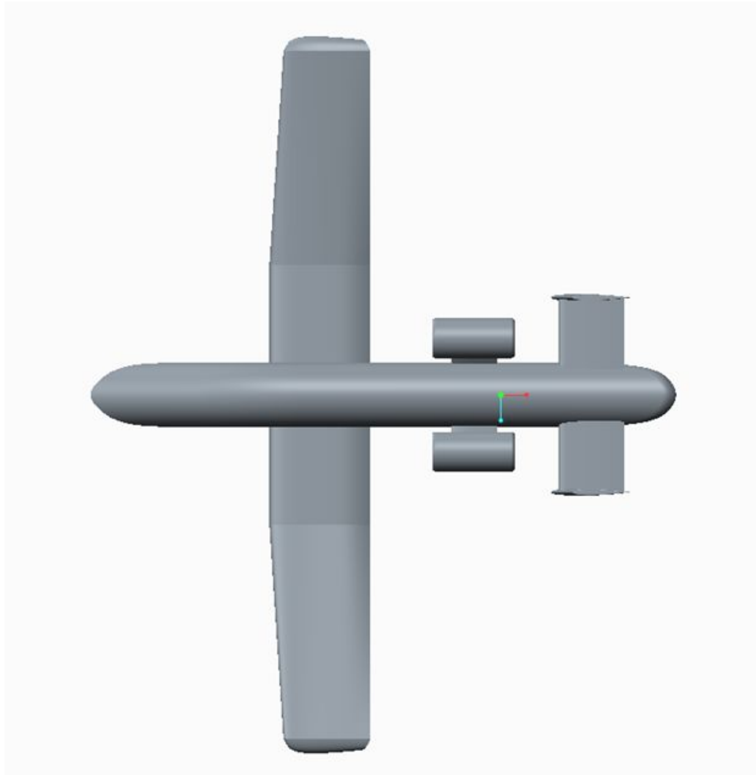

*Figure 12: CAD representation of XA-23 Judge (Top View)*

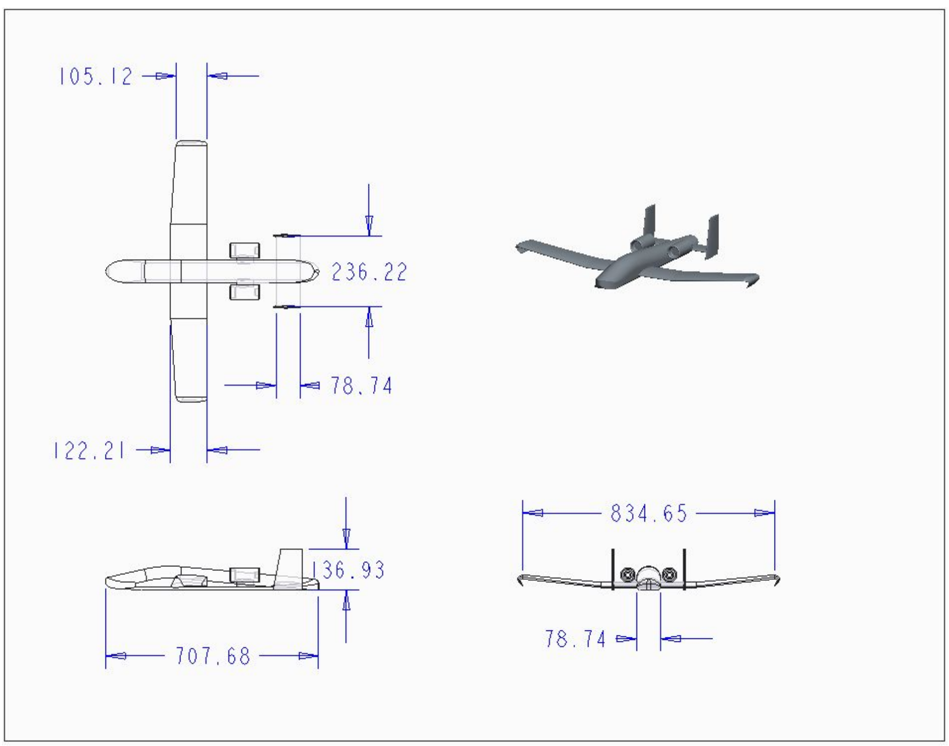


*Figure 13: CAD representation of XA-23 Judge (Dimensions(in inches))*

# 4 Conclusions

In this section we will be reviewing our work throughout the semester and reflecting on what we accomplished and some things that we could have done differently. We will also take a step back to objectively evaluate our design and state what we would have done had we continued our design of this aircraft.

## 4.1 Design Evaluation

Our design, the XA-23, has very similar aerodynamic characteristics to the A-10 in terms of the the max lift-to-drag ratio, as a result of reusing as much original system as possible. The calculation of the aircraft specifications we performed based on the conceptual sizing of aircraft fits well in the required specifications and is within reasonable margin of the original A-10. Since we are retrofitting a majority of parts from the A-10, the cost of deployment is projected to be relatively low. These preliminary results are promising, however, some requirements that we cannot confirm are the economic impacts, and evaluating the protection capability of the cockpit. These requirements are beyond our field of expertise and thus we cannot provide concrete proof of them.

## 4.2 Next Steps

Some of our next steps would include using computational fluid dynamics (CFD) to evaluate different wing designs and their aerodynamic characteristics. Additionally, more time would be spent on the CAD to add details like the correct engine and the payload. Furthermore, we would spend more time analyzing the economics behind the configuration of the aircraft. This would include researching whether it would be efficient in terms of time and money to have a new engine contracted for the XA-23, and analyzing the cost of contracting the 35mm canon. We would also invest time in researching the systems and controls to be integrated into the XA-23 to ensure that it meets the same technological standards as today’s attack planes. In general, there are a lot more details we would continue to work on to further improve our aircraft design, but many of them are outside the scope of this class.

### 4.3 Lessons Learnt

Over the course of the semester spent working on this project, we learnt a variety of lessons. These lessons range anywhere from working in teams to aircraft design. First, we learned that communication is essential for being successful engineers. Communication can expand into multiple different lessons as well, such as learning to schedule with other people in order to have the most amount of time to work on our project. Another major lesson that we learned from this project is how to effectively communicate issues with each other and how to resolve any conflict. For example, if one member implemented a feature to our design that the rest of us were not happy with, we learned how to all have a collective conversation and discuss what we think and why. This is a crucial lesson to be applied when working in future teams.

In addition to intrapersonal lessons, we also learned some technical lessons. One technical lesson we learned is that you have to consider a lot of different factors when designing an aircraft. For example, when designing an aircraft, its not simply, “Let’s make an airplane that does *this*”, its much more involved, and includes systems engineering, such as risk analysis, listening to stakeholders and customers, and making the best aircraft possible for everyone who is invested. We also learned as a team that sizing an aircraft is a very difficult process. In this course, we were only able to hit the tip of the iceberg, and get very rough estimates of weight. We also learned that there is no exact weight to approximate, and even if you do account for all necessary factors, your weight estimate will almost surely be different than your actual production weight. All in all, we learned a wide variety of lessons from this project and this course, both technical and intrapersonal. These lessons will be very beneficial to know further down the road as our careers as engineers develop.

**References**

A-10 Thunderbolt II Specifications. (n.d.). Retrieved April 20, 2018, from http://www.northropgrumman.com/Capabilities/A10ThunderboltII/Pages/Specifications.aspx

BR710 (n.d.). In *Rolls Royce*. Retrieved from https://www.rolls-royce.com/products-and-services/civil-aerospace/business-aviation/br710.aspx#/

Jenkins, D. R. (1998). *Fairchild-Republic A/OA-10 Warthog*. North Branch, MN: Specialty Press.

National Aeronautical and Space Administration. (2014). *Risk Review Template.* Retrieved from https://www.nasa.gov/sites/default/files/atoms/files/ivv_t2006_-_ver_g.pdf.

Raymer, D. P. (2012). *Aircraft design: A conceptual approach*(4th ed.). Reston, VA: American Institute of Aeronautics and Astronautics.

**Appendix: Matlab Code**

```
function weight_calc(payload,distance,engine_type,unit_type,loiter1, loiter2,
mach_num,LDratio,initial_guess)

%%-------------

%Inputs:

%   1.payload - weight of the payload (in lb or kg)

%   2.distance - distance to the mission area (in nautical miles or km)

%   3.engine_type - 20 element character array specifying type of engine

%               (pure turbojet, low-bypass turbofan, high-bypass

%               turbofan, piston-prop, or turboprop)

%   4.unit_type - 6 element character array specifying either custom or

%             metric systems

%   5.loiter1 - loiter time desired during mission (in s)

%   6.loiter2 - loiter time desired when returning from mission (in s)

%   7.mach_num - mach number cruising speed of the aircraft

%   8.LDratio - lift to drag ratio

%   9.initial_guess - initial guess at weight of the aircraft(in lb or kg)

%Outputs:

%   1.caclulated weight of the aircraft

%%-------------
```

```
W_payload = payload; %weight of the payload

engine = engine_type;     %character array of the engine used

units = unit_type;        %character array of the units

lift_drag = LDratio;      %ratio of lift to drag

E1 = loiter1;             %endurance of plane during the mission

E2 = loiter2;             %endurance of plane of the way back

W_g = initial_guess;      %guess weight of the plane

if units == 'metric'

   range = distance*1000;  %range of the aircraft (m)

   velo = mach_num*303.2;  %cruise velocity of the aircraft (m/s)

   tolerance = 10;         %parameter to determine accuracy of answer

   weight = 'kg';          %character array for displaying final answer

elseif units == 'custom'

   range = distance*6076;  %range of the aircraft given (ft)

   velo = mach_num*994.8;  %cruise velocity of aircraft (ft/s)

   tolerance = 50;         %parameter to determine accuracy of answer

   weight = 'lb';          %character array for displaying final answer

end

if engine == 'pure turbojet      '

   L_D_cruise = 0.866*lift_drag;   %lift drag ratio during cruise
```

```
    L_D_loiter = lift_drag;         %lift drag ratio during loiter
    SFC_C = 0.0002500;      %specific fuel consumption during cruise
    SFC_L = 0.0002222;      %specific fuel consumption during loiter
elseif engine == 'low-bypass turbofan '
    L_D_cruise = 0.866*lift_drag;   %lift drag ratio during cruise
    L_D_loiter = lift_drag;         %lift drag ratio during loiter
    SFC_C = 0.0002222;      %specific fuel consumption during cruise
    SFC_L = 0.0001944;      %specific fuel consumption during loiter
elseif engine == 'high-bypass turbofan'
    L_D_cruise = 0.866*lift_drag;   %lift drag ratio during cruise
    L_D_loiter = lift_drag;         %lift drag ratio during loiter
    SFC_C = 0.0001389;      %specific fuel consumption during cruise
    SFC_L = 0.0001111;      %specific fuel consumption during loiter
elseif engine == 'piston-prop         '
    L_D_cruise = lift_drag;         %lift drag ratio during cruise
    L_D_loiter = 0.866*lift_drag;   %lift drag ratio during loiter
    SFC_C = 0.0001111;      %specific fuel consumption during cruise
    SFC_L = 0.0001389;      %specific fuel consumption during loiter
elseif engine == 'turboprop           '
    L_D_cruise = lift_drag;         %lift drag ratio during cruise
```

```
    L_D_loiter = 0.866*lift_drag;   %lift drag ratio during loiter

    SFC_C = 0.0001389;      %specific fuel consumption during cruise

    SFC_L = 0.0001667;      %specific fuel consumption during loiter

end

phase1 = 0.97;    %fuel fraction for warm-up/takeoff

phase2 = 0.985;   %fuel fraction for climbing

phase3 = exp((-range*SFC_C)/(velo*L_D_cruise));%fuel fraction for cruising

phase4 = exp((-E1*SFC_L)/(L_D_loiter)); %fuel fraction for loitering

phase5 = phase3;                     %fuel fraction for cruising back

phase6 = exp((-E2*SFC_L)/(L_D_loiter)); %fuel fraction for loitering back

phase7 = 0.995;                      %fuel fraction for landing

mission_ratio = phase1*phase2*phase3*phase4*phase5*phase6*phase7;

                                 %fuel fraction for entire mission

fuel_fraction = 1.06*(1-mission_ratio); %final fuel fraction

empty_fraction = 0.93*W_g^-0.07;       %empty weight fraction

W_g_new = W_payload/(1-fuel_fraction-empty_fraction);

                                 %calculated weight of the aircraft

while W_g > (W_g_new+tolerance) || W_g < (W_g_new-tolerance)

    W_g = W_g+(W_g_new - W_g)*0.5;      %calculates new guess based on accuracy of
previous guess
```

```
    empty_fraction = 0.93*W_g^-0.07;    %calculates new empty weight fraction
    W_g_new = W_payload/(1-fuel_fraction-empty_fraction);
                                        %new calculated weight of the aircraft
end
a = fuel_fraction * W_g_new;
fprintf('Calculated weight of the plane is approximately %.0f %s\n',W_g_new, weight)
%displays the calculated weight of the aircraft with appropriate units
end
```

## Appendix: Weekly Update Emails

**21 January 2018**

*Hello from Team A10,*

*This week, we each individually did some research/gathered ideas for what we might like to do for our project plane. Additionally, we met on Tuesday and discussed the things which we researched, as well as covering our needs/stakeholders. Our plan for the upcoming week is to do the same, some individual research gathering, then meet to discuss and decide upon initial decisions, and possibly start creating designs. We didn't encounter any major problems this week, just a minor disagreement on choice of team name, which was quickly resolved.*

*Best,*

*Zach Rauch and Team A-10*

**28 January 2018**

*Hello,*

*This week we finished our first project update in which we identified the mission statement, stakeholders, needs, and requirement for this project. For next week we plan to work on the preliminary risk analysis and some concept generation. We had some debate this week on the issue of naming the new aircraft and this issue is likely to be resolved next week.*

*Team A-10*

**6 February 2018**

*We have begun our concept generation for the A10 redesign. We met today and brainstormed ideas of what we want and don't want in our design and how to go about meeting the requirements we were given. We will meet next week all having drawn preliminary sketches of our ideas.*

*Team A-10*

**11 February 2018**

*Hello,*

*During the previous week, we met on Tuesday and began to discuss design possibilities for our aircraft, as well as A-10 design history. For the upcoming week, we plan to put together preliminary sketches of what we think a good design for an A-10 replacement would look like and explain why. We have not encountered any problems recently.*

*Best,*

*Zach Rauch and Team A-10*

**18 February 2018**

*Hello,*

*Over the past week, we did not meet, in order to spend time preparing for exams in other classes. During the upcoming week, we plan to meet on Tuesday and discuss our initial design ideas and review the comments from Dr. Marais on our report draft.*

*Best,*

*Zach Rauch and Team A-10*

**25 February 2018**

*Hello, on behalf of team A-10,*

*Over the past week, we met on Tuesday to complete the requirements for project update 2, and turned the update in. For the upcoming week, we plan to meet again on Tuesday and begin to put together initial sketches of some ideas and discuss their benefits and downsides.*

*Best,*

*Zach Rauch and Team A-10*

**27 March 2018**

*Hello,*

*We met today in order to ensure that everything we needed for project update 3 was completed. We are currently ahead of schedule. We plan to meet again on Friday to begin CAD design for our aircraft. We also plan to meet next Tuesday again to continue on the report.*

*Best,*

*Zach and Team A-10*

**17 April 2018**

*Hello,*

*This week, we met to work on finalizing our calculations and a large portion of our project report. Next week we plan to finish up the report, and make our video.*

*Best,*

*Zach Rauch and Team A-10*