# MAVERICC Conceptual Design Review

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**In response to the 2021 AIAA Undergraduate Team Aircraft Design Competition request for proposals, the Manned Aerial Vehicles for Escort and Rapid Incursion of Close Combat (MAVERICC) Team from the University of Alabama in Huntsville is developing a design for 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 accommodate a crew of two. Additional design goals include enhanced survivability and the ability for deploying a variety of weapons including an integrated gun for ground targets. The aircraft must accomplish an attack mission with a full weapons load and a long-range ferry mission with a 60% weapons load. The current concept is a twin-boom design with dual Pratt & Whitney PT6 turboprop engines mounted on the rectangular high wing. The innovative armament package includes a 20mm gun integrated in the nose, a swivel-mounted 30mm chain gun in the aft fuselage between the tail booms, and a combination of rockets, missiles, and small diameter bombs externally mounted on wing hardpoints. An integrated countermeasures dispenser system provides enhanced survivability. The current aircraft design weighs 15,000 lbf with the crew and with a full load of weapons and fuel. Analyses and trade studies are in progress to finalize the aircraft's dimensions and overall weight, estimate flight performance, and perform an analysis of recurring, acquisition, and operating costs.**

## I. Nomenclature

| | |
|---|---|
| $T_A$ | = Thrust Available |
| $T_R$ | = Thrust Required |
| P | = Power |
| $P_R$ | = Power Required |
| $P_{A,alt}$ | = Power at Altitude |
| $P_{A,SL}$ | = Power at Sea Level |
| $\eta_{prop}$ | = Propeller Efficience |
| $V_\infty$ | = Freestream Velocity |
| $\rho$ | = Density |
| $\rho_{SL}$ | = Density at Sea Level |
| $c$ | = Chord of Wing |
| $b$ | = Wing Span |
| $S$ | = Planform Area |
| $e$ | = Span Efficiency Factor |
| $\alpha_{L=0}$ | = Angle of Attack at Zero Lift |
| $a_0$ | = Lift Curve Slope (airfoil) |
| $a$ | = Lift Curve Slope (finite wing) |
| $C_L$ | = Lift Coefficient |
| $C_D$ | = Drag Coefficient |
| $C_{Di}$ | = Induced Drag Coefficient |
| $c_{Do}$ | = Zero Lift Drag Coefficient |

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## II. Project Summary

The Manned Aerial Vehicles for Escort and Rapid Incursion of Close Combat Team from the University of Alabama in Huntsville is developing a design for an affordable light attack aircraft that can operate from short, austere fields and replace current helicopters in performing close air support missions. This aircraft must meet a range of criteria, such as carrying a payload of 3000 pounds of armament and to be able to hold a crew of two people. To begin the design process, the team compiled a database of current CAS aircraft in order to create an initial concept design. Various design features were considered, such as having one or two engines. After these things were analyzed in terms of their strengths and weaknesses, a concept design was defined including major dimensions to determine parameters for the aircraft such as planform area, wing loading and wing span. This design is expected to change as analyses and trade studies will finalize the aircraft's dimensions and overall weight, estimate flight performance, and operating costs**.**

## III. Project Overview

### A. Design Requirements

The AIAA design challenge requirements include the following: takeoff and land on short, austere terrain fields on semi-prepared runways or dirt paths; be able to carry 3000 pounds of armament; have an integrated gun for ground targets; have a service life of 15000 hours over the span of 25 years`; be able to reach a service ceiling of more than 30000 feet; be able to have two crewmates on board with zero-zero ejection seats. Some optional requirements include being able to carry a variety of weapons, such as rail-launched missiles and rockets, and to have a consideration for survivability, such as including armor around the cockpit and engines. The aircraft also must be able to complete both attack and ferry missions, which are described in the next section.

### B. Concept of Operations

The team constructed two ConOps graphics to illustrate both the design mission (Fig. 1) and the ferry mission (Fig. 2) that this aircraft will have to perform. For both missions, the aircraft must take off and land within a distance less than 4000 feet with 50 foot obstacles at the end of the austere runway. In addition, in both missions the aircraft must be able to be warmed up/shutdown and taxied within five minutes and have a service ceiling of at least 30000 feet. The design mission (Fig.1) requires the aircraft to achieve a range of at least 200 nautical miles, a cruise altitude of greater than 10000 feet, a loitering time of 4.75 hours (or 4 hours and 45 minutes), and a weapons payload of at least 3000 pounds of armament including ammunition for integrated guns. The design mission begins with warm up/taxi, after which it must take off from the potentially unprepared runway. Once the aircraft has climbed to cruise altitude, it will cruise for 100 nautical miles then descend to an altitude of 3000 feet. From the initial climb to descent, no more than 20 minutes should have elapsed. Once at this altitude, the aircraft must be able to loiter, evade, and/or attack for at least four hours. For design purposes, we assume the aircraft only loiters, meaning the armament weight will remain at max for the return flight, in which the aircraft climbs back to cruise altitude, cruises 100 nautical miles, then lands and shuts down under the same conditions. As a safety precaution, the aircraft must have enough fuel reserved left to climb to 3000 feet and loiter for an additional 45 minutes.

For the long-range ferry mission (Fig. 2), a longer cruise distance of 900 nautical miles is required, as well as a cruise altitude of greater than 18000 feet, a loitering time of 0.75 hours (or 45 minutes), and a weapon payload that is 60% of the full armament load carried during the design mission. As mentioned above, the ferry mission will begin under the same conditions as seen in the design mission, in which the taxi/warmup and takeoff phases are the same. After takeoff however, the aircraft will now climb to a greater cruise altitude, in which the altitude will be at least 18000 feet and specifically chosen to maximize speed or range. Once this altitude is achieved, the aircraft will cruise for 900 nautical miles, then descend, land and taxi/shutdown under the same conditions. For the ferry mission, the aircraft must also still have enough fuel reversed to climb to 3000 feet and loiter for 45 minutes.

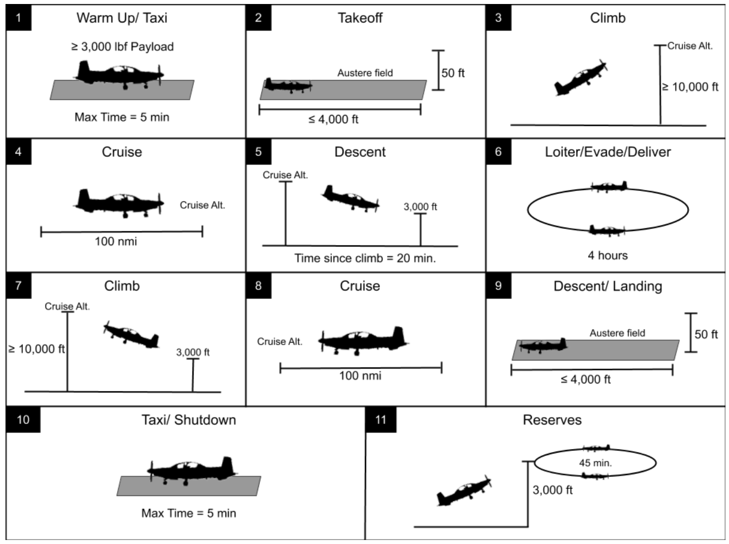



**Figure 1 Design Mission ConOps.**

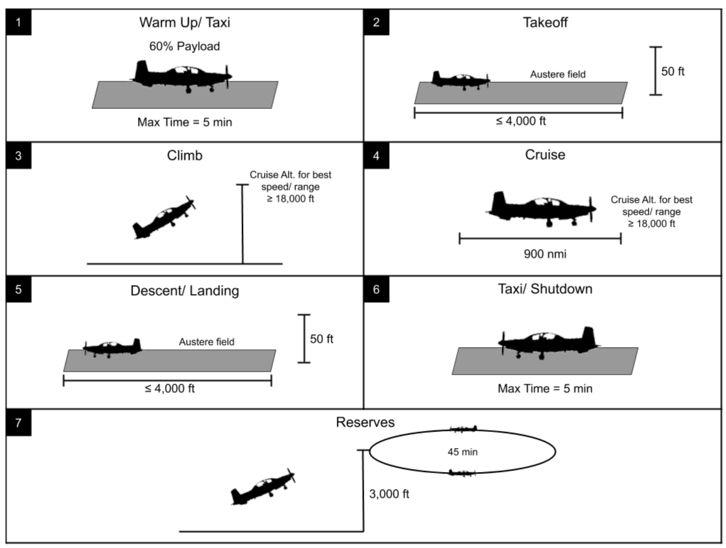



**Figure 2 Ferry Mission ConOps.**

## C. House of Quality

A House of Quality matrix (Fig. 3) was created to assure the design process aligned with the requirements of the AIAA. The left column lists the main requirements while the right columns identify requirement ratings and priority rank. The top row lists design features that help accomplish the requirements. The center section shows the positive correlation between the design features and the customer needs. As shown in Fig. 3, many of the proposed ideas do aid in meeting the main objectives, as well as some of the optional, ideal ones such as aircraft survivability. These ideas will be discussed and explained more throughout the paper.

| Customer Needs / Design Features | Hardpoints (Bombs, Missiles, Rockets, External Tanks) | Turboprop Engine | Armored Cockpit/ Self-sealing Fuel Tanks | Flare Dispenser | Swivel Mounted Gun | Reduction of Drag | Weighting | Priority Rank |
|---|---|---|---|---|---|---|---|---|
| Austere Field Performance [R] | | ● | ● | | | ● | 0.25 | 1 |
| Payload of 3000 lb [R] | ● | | | | ● | | 0.20 | 2 |
| Integrated Gun [R] | | | | | ● | | 0.15 | 3 |
| 2 Crew Members [R] | | ● | | | | | 0.1 | 4 |
| Service Ceiling of 30,000 ft [R] | | ● | | | | | 0.1 | 5 |
| Service Life [R] | | | ● | ● | | | 0.1 | 6 |
| Survivability [O] | ● | | ● | ● | | | 0.05 | 7 |
| Weapon Variety [O] | ● | | | | ● | | 0.05 | 8 |

**Figure 3 House of Quality.**

## IV. Reference Aircraft Database

There are various aircraft that currently provide, or have in the past provided, close air support to support ground troops. A database of these aircraft was created to allow for easy access to information. These aircraft include the Boeing AH-64 Apache (Ref [1] [2]), the Icarus Aerospace TAV WASP (Ref [3]), and the North American Rockwell OV-10 Bronco (Ref [4]). The aircraft most influential in MAVERICC's design were the TAV WASP and the OV-10 Bronco, whose information is located inside tables 1 and 2.

**Table 1. Icarus Aerospace TAV WASP. [3]**

| General Characteristics | Performance |
|---|---|
| **Crew:** Up to 2 (pilot and wso, pilot only, unmanned)<br>**Max takeoff weight:** up to 21000lb<br>**Wing span:** 51ft (15.5m)<br>**Powerplant:** 2 x 1700 SHP | **Service ceiling:** 36,000 ft (10,900 m)<br>**Endurance unrefueled:** 6.5Hrs<br>**Range w/ 45 min reserve:** up to 1300NM |
| **Armament**<br>**Up to 11 external hard points:**<br>Up to 8000Lbs total load<br>One forward firing fixed cannon)<br>One belly mounted optionally installed (up to 30mm) 360-degree turret cannon | |

**Table 2. North American Rockwell OV-10 Bronco. [4]**

| General characteristics | Performance |
|---|---|
| **Crew:** 2<br>**Capacity:** cargo compartment for personnel (no seats) or 3,200 lb (1,451 kg) of freight<br>**Wingspan:** 40 ft 0 in (12.19 m)<br>**Wing area:** 291.0 sq ft (27.03 $m^2$)<br>**Aspect Ratio:** 5.50<br>**Wing Loading**: 50 lb/$ft^2$<br>**Airfoil:** NACA 64A315<br>**Max takeoff weight:** 14,444 lb (6,552 kg) (overload)<br>**Powerplant:** 2 × Garrett T76-G-420/421 turboprop engines, 1,040 shp (780 kW) each equivalent | **Maximum speed:** 250 kn (290 mph, 460 km/h) at sea level<br>**Combat range:** 198 nmi (228 mi, 367 km)<br>**Ferry range:** 1,200 nmi (1,400 mi, 2,200 km) with auxiliary fuel<br>**Service ceiling:** 30,000 ft (9,100 m)<br>**Rate of climb:** 3,020 ft/min (15.3 m/s) |

| | |
|---|---|
| **Propellers:** 3-bladed Hamilton Standard, 8 ft 6 in (2.59 m) diameter constant-speed fully feathering propellers | |
| **<u>Armament</u>**<br>**Guns:** 1 × 20 mm (0.79 in) M197 electric cannon (YOV-10D) or 4 × 7.62×51 mm M60C machine guns (OV-10D/D+)<br>**Hardpoints:** 5 fuselage and 2 underwing with provisions to carry combinations of rockets, missiles and bombs | |

Comparisons of the performances of five database aircraft are displayed in figure 4. All of the fixed wing aircraft meet the requirements specified for combat and ferry range, as well as service ceiling. Based on these comparisons, MAVERICC's aircraft is likely to have a maximum speed of 250-320 knots, and a rate of climb of 3000-3200 ft/min like the turboprop aircraft in the database such as the Wasp and OV-10 .

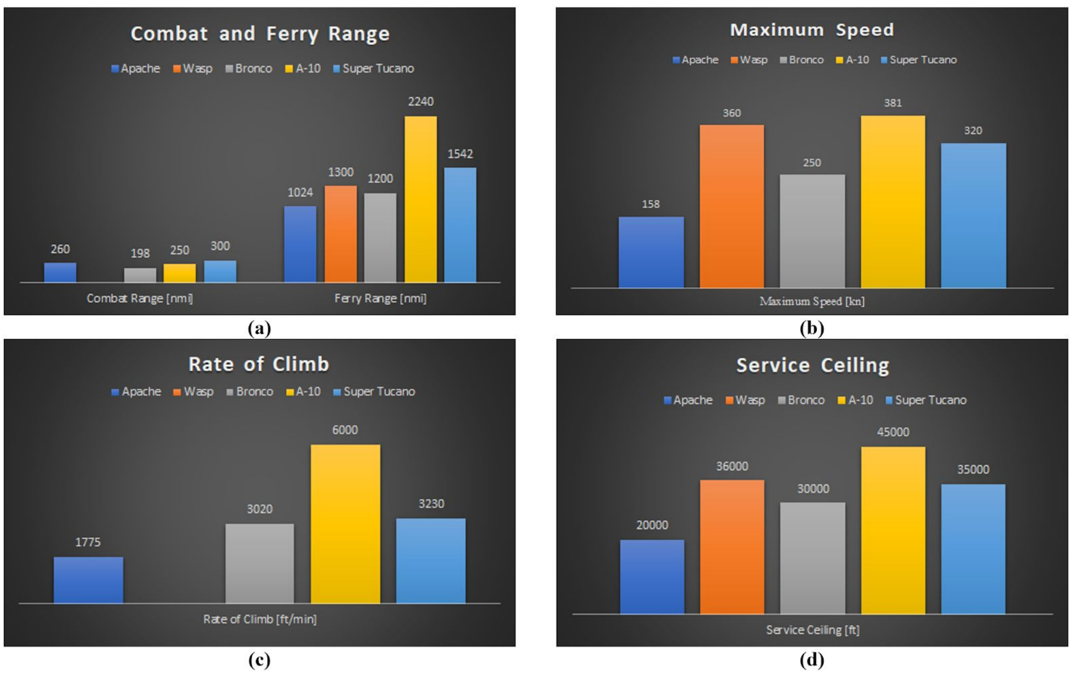
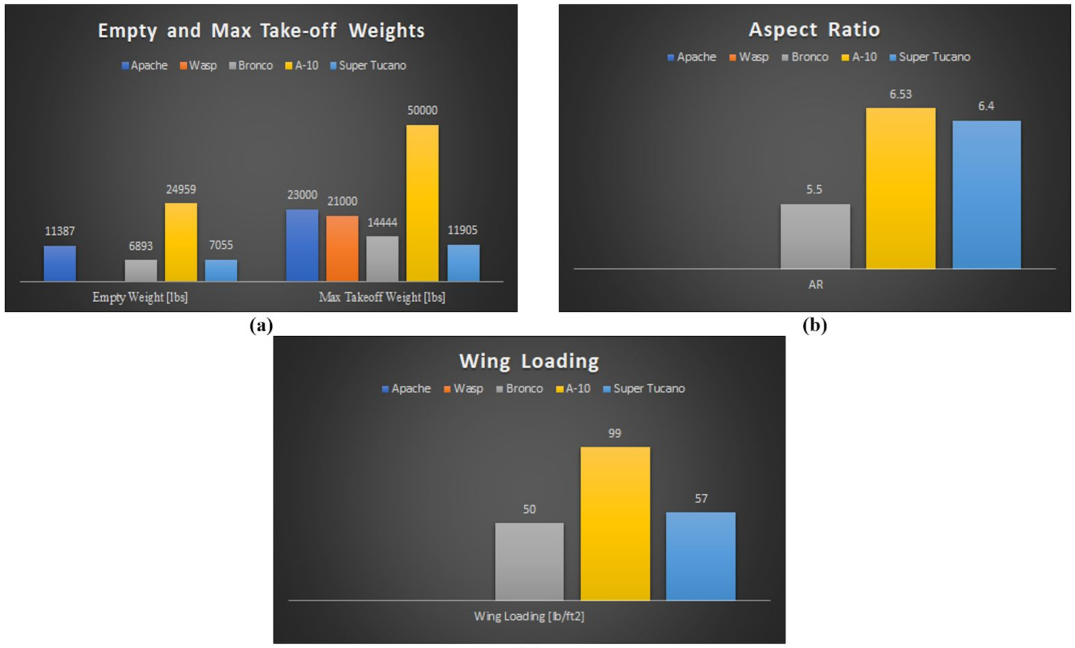



**Figure 4 Comparison of Aircraft Performance: (a) Combat and Ferry Range, (b) Maximum Speed, (c) Rate of Climb, (d) Service Ceiling.**

Comparisons of the aircraft's general characteristics are displayed in figure 5. Based on these comparisons, MAVERICC's aircraft will likely have a maximum takeoff weight of approcimately 15,000 lbs, similar to the 14,000 to 23,000 lbs weight of twin engine turboprop aircraft in the database. Additionally, MAVERICC's aircraft will likely have a wing loading between 50 and 60 lb/ft2 similar to the turboprop aircraft in the database.



(c)

**Figure 5 Comparison of Aircraft Characteristics: (a) Empty and Max Takeoff Weights, (b) Aspect Ratio, (c) Wing Loading.**

## V. Initial Concept

### A. Design Alternatives Analysis

The aircraft in the reference database represent a range of design features. The features considered, including the reasoning behind the final choices, are described below.

1) Fuselage and Engine Configuration

A twin boom, twin engine design was chosen over a single engine and single fuselage design to improve survivability through redundancy and to allow for a larger aircraft, capable of carrying a larger payload. Strengths of a twin boom design are a redundant vertical stabilizer in case one is damaged. Potential weaknesses of a twin boom design are that the booms are less stiff then a traditional fuselage, thus requiring additional structuring, and increased drag. Strengths of a twin engine design include engine redundancy, the easier installation of nose mounted weaponry. Two engines provide a counter rotating configuration to balance the torque and P-factor, thus eliminating a yawing moment from the propellers.

2) Wing Placement

A high wing design was chosen over a mid or low wing in order to facilitate austere field performance. The high wing increases propeller ground clearance and allows the engines to be mounted away from dust and debris. These features protect the aircraft and it's engines from potential hazards of a semi-prepared runway. A high wing also provides the crew members a clear field of view for takeoff, landing and identifying of ground targets. The high wing design also allows for a laterally stable aircraft without the use of a dihedral, improving it's qualities as a gun platform.

3) Tail Configuration

A horizontal stabilizer mounted at the top of the vertical stabilizers as opposed to the bottom was chosen in order to increase the efficiency and responsiveness of the horizontal stabilizer. The strength of a horizontal stabilizer mounted high on the tail is that it moves this surface out of the wake of the wings, thus improving pitch control, and improving performance at low speeds. Additionally, if a rear gun is chosen to be added later in the design, the high tail allows for better visibility and field of fire. The weaknesses of a high tail design are that it requires a stronger, heavier structure and that it introduces the possibility of a “deep stall”, a very dangerous condition from which it is extremely difficult, if not impossible to recover.

4) Engine Type

Turboprop engines were chosen because they best compete with attack helicopters in terms of performance. Turboprops are more fuel efficient at low speeds compared to turbofans. Given this aircraft will mainly serve in a ground attack role, efficiency is considered more important than speed. In addition, turboprops have better performance at lower altitudes, making them the ideal choice for a light-ground-attack aircraft. The drawbacks of turboprops are that these engines are less efficient at higher speeds and at higher altitudes. Thus, the aircraft will not be able to attain as great of a velocity or altitude compared to a turbofan, but given the mission is to mainly stay low and attack ground targets, the turboprop better meets mission requirements.

5) Armament Placement

Placement of the armament on external hard points as opposed to an internal bombay was chosen in order to minimize complexity. Using external hardpoints provides versatility for a range of weapons and stores to be carried. These include rocket pods, gun pods, ECM & ESM pods, as well as external fuel tanks. Additionally, hardpoints do not require moving bay doors, or the allocation of internal fuselage space. The weakness of external hardpoints is that they increase aircraft drag.

6) Armament Loadout

The loadout outlined below is only a thoughtful selection of possible armaments for this aircraft, but it represents a wide mission range. Listed here are the armaments chosen specifically for project Top Gun. First, there is the AGR-20A (APKWS) which is a conversion of a Hydra unguided rocket. Each rocket weighs around 32 lbs, can travel about 1.2-6.8 miles at a speed of Mach 2.9, and comes in pods of 19. Next we have the AGM-114 Hellfire missile. This missile weighs around 100 lbs, can travel about 5 miles at a speed of Mach 1.3, and comes in a pack of 4, while expensive and a poor choice against unarmored targets, the Hellfire will provide the aircraft with the ability to engage and effectively eliminate armored threats.. The GBU-39 small diameter bomb can utilize either GPS or laser guidance, enabling it to strike both fixed and moving targets. The small diameter bomb also has the advantage of many different, mission specific warheads. These warheads include an anti-personnel, anti-moving armor, low collateral damage anti-structure, laser and GPS guided options. Each bomb weighs around 250 lbs. The primary guns on this aircraft will be the M61 20mm Vulcan rotary cannon mounted in the nose, and the M230 30mm chain gun mounted with a 180 degree swivel on the rear of the plane, giving it a large field of view. The Vulcan has a rate of fire of 6,000 rounds per minute, weighs 202 lbs, and costs around $275,000. The M230 has a rate of fire of about 625 rounds per minute, weighs 130 lbs, and has an unknown cost.

6) Integrated gun

A two gun design was chosen in order to increase the versatility of the aircraft. The two guns chosen were a 20mm vulcan cannon located in the nose of the aircraft, and a 30mm chaingun located in the rear of the fuselage. The 20mm provides the high rate of fire needed in order to effectively strafe ground targets, while the 30mm provides a more powerful round and more precise targeting. The advantage of this design is that it allows for the use of less expensive ammunition to engage ground targets, as opposed to more expensive missiles. The disadvantage of this design is the large number of rounds needed to be carried, as well as the complexity and additional cost associated with implementation of a moveable turret located at the rear of the aircraft.

## B. Concept Configuration

Based on the design alternatives, an initial concept design drawing was created as shown in Fig. 6. The parameters of this design were heavily influenced by the North American Rockwell OV-10 Bronco as this aircraft was seen by the team as a simple design that met most of the design requirements. All dimensions in the drawing are in feet and inches.

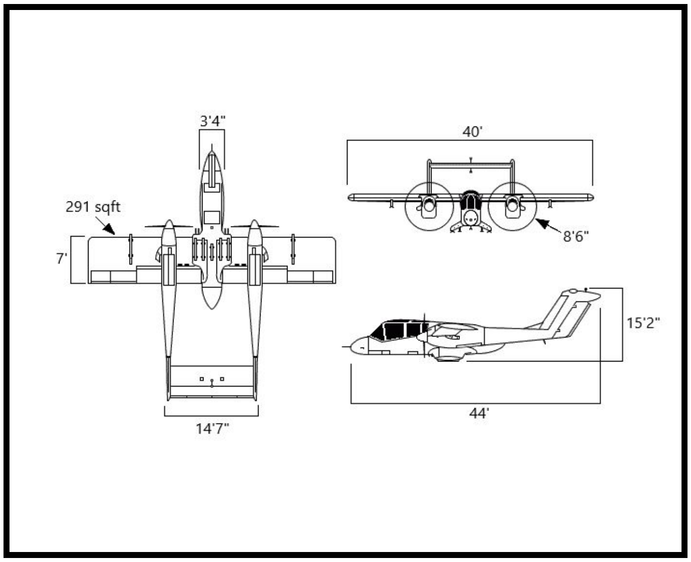



**Figure 6 Initial Concept Drawing.**

## C. Proposed Weapons Load

When calculating the total weight for our armed aircraft, including its 1,000 rounds of 20mm ammo, 1,200 rounds of 30mm ammo, 1 rocket pod, 1 pack of hellfire missiles, and 2 small diameter bombs we get 3,635 lbs of armaments, excluding the pylon racks. Finally, the aircraft will be equipped with an AN/ALE-47 countermeasures system. This system contains both flares and chaff and comes at a cost of $1,100-$1,500 per reload. This loadout was chosen due to its flexibility in performing any strafing or bombing runs required by the ground troops.

The package outlined above is by no means the extent of this aircraft's capability, as it will remain compatible with most armaments currently employed by the U.S. Armed Forces. These other options could include unguided bombs, dumb rockets, JDAM's, or even anti-aircraft or anti-radiation missiles.

## D. Initial Concept Performance

For proof of concept, and because the ideal design was an airframe of similar design, all wing geometry had been initially benchmarked on the specifications of the OV-10 Bronco and the chosen airfoil's data, which is of similar specifications as the Bronco's (Ref [7]). The team's design intended to use a modern set of turboprop engines for propulsion, which in this case has been represented by the PT6A-68 in use in aircraft such as the Embraer Super Tucano. All calculations were made in MATLAB. The PT6A-68's shaft power and specific fuel consumption are publicly available (Ref [12]). Table 3 summarizes the initial concept; however, thrust had to be manually calculated using Equation (1) (Ref [8]).

$$T_A = \frac{P_A}{V_\infty} = \frac{\eta_{prop} P_{engine}}{V_\infty} \tag{1}$$

Thrust available is a function of power available and flight speed. Power, available at altitude, is a function of density is given by

$$P_{A,alt} = P_{A,SL} \frac{\rho}{\rho_{SL}} \tag{2}$$

Because the turbine engine operates exclusively at subsonic speeds, thrust provided by the turbine itself is assumed to be 0. Aerodynamic calculations have been excluded to save space, but are included in the MATLAB code. The results of these calculations are shown in Table 3.

**Table 3. Calculated Wing Geometry and Cruise Conditions for the Initial Design Concept.**

| | |
|---|---|
| **Airfoil** | NACA 64(2)-415 |
| $\alpha_{L=0}$ **[deg]** | -3 |
| $a_0$ **, airfoil [deg$^{-1}$]** | 0.11 |
| **Chord (** $c$ **) [ft]** | 7 |
| **Wing Span (** $b$ **) [ft]** | 40 |
| **Planform Area (** $S$ **) [ft$^2$]** | 292 |
| **Aspect Ratio** (AR) | 5.48 |
| **Span Efficiency Factor (** $e$ **)** | 0.8853 |
| $a$ **, finite wing [deg$^{-1}$]** | 0.0778 |
| **Angle of Attack (cruise) [deg]** | 3 |
| **Zero Lift Drag Coefficient (** $c_{D0}$ **), body** | 0.005 |
| **Lift Coefficient (** $C_L$ **)** | 0.4669 |
| **Induced Drag Coefficient (** $C_{Di}$ **)** | 0.0143 |
| **Drag Coefficient (** $C_D$ **)** | 0.0268 |

Empty weight was assumed to be the same as the North American OV-10 Bronco with the minimum armament weight from the RFP applied. Initial parameters were tested with 1000 pounds of fuel, which is slightly more than the Bronco itself can carry. Empty weight in the final design is expected to be larger as the engines will add weight along with most design inclusions, such as the integrated cannon. Profile drag was estimated based on figures relating to larger aircraft, and future research will be necessary to ascertain the accuracy of the estimation made here. Some of these parameters are detailed in Table 4.

**Table 4. Performance Parameters for the Initial Design Concept.**

| | |
|---|---|
| **Empty Weight [lb]** | 7000 |
| **Armament Weight [lb]** | 3000 |
| **Fuel Weight [lb]** | 1000 |
| **Engine** | Pratt & Whitney PT6A-6B |
| **Engine Equivalent Power [shp]** | 1600 |
| **Propeller Efficiency [η]** | 0.9 |
| **Specific Fuel Consumption** | 0.54 |
| **Endurance [hrs]** | 3.67 |
| **Range at 10,000ft [nmi]** | 532 |
| **Max Rate of Climb at Sea Level [kts]** | 70.42 |

Thrust required and power required were calculated assuming steady level flight as shown in Equations (3) and (4) (Ref [9]). The aircraft in its current assumed configuration is more than capable of cruising above 30,000 ft, the minimum requirement. Currently, propeller thrust is more of a performance constraint than turbine delivered shaft power, as the propeller's efficiency factor reduces thrust generated by the turbine itself. A wingspan increase in future designs will have positive downstream effects toward improving general performance of the aircraft. The trust required is calculated using equation 3.

$$T_R = D_R = C_{D0} + C_{Di} = C_{D0} + \frac{C_L^2}{\pi * AR * e}\ ,\ where\ C_L = \frac{W}{\frac{1}{2}\rho_\infty V_\infty S} \tag{3}$$

Power required is calculated using equation 4.

$$P_R = T_R V_\infty \tag{4}$$

Range, endurance, and rate of climb were not calculated with any specific operation in mind, but it is recognized that these are important parameters that will impact other aspects of the design (Ref [10]). Calculations made for endurance and range are assuming payload is expelled. The mentioned wingspan increase will improve these statistics, along with other airframe design changes. Endurance will have to be increased to meet loiter time goals, and range at proposed cruise altitudes will need to improve as well. With the loss of efficiency from power transfer to the propeller, performance is further hampered. Therefore, in order for the Concepts of Operations to be met, many aerodynamic improvements will need to be made. The option of increased fuel capacity may alleviate some of these issues through added fuel tank volume or, as a last resort, additional drop tanks. Regardless, these initial figures show promise for the team's design in its early stages, especially with the plentiful opportunities of improvement on Bronco.

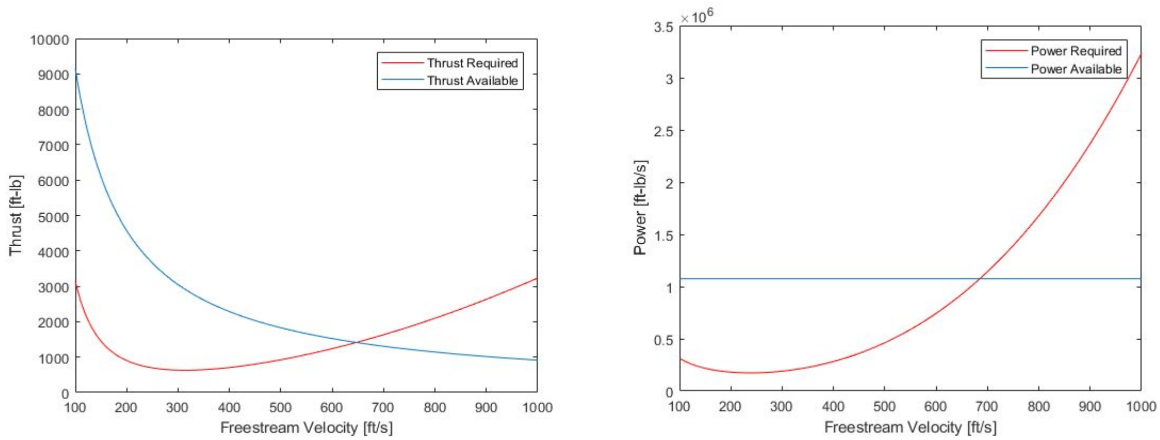



**Figure 7 Thrust and Power Curves at 10,000 feet.**

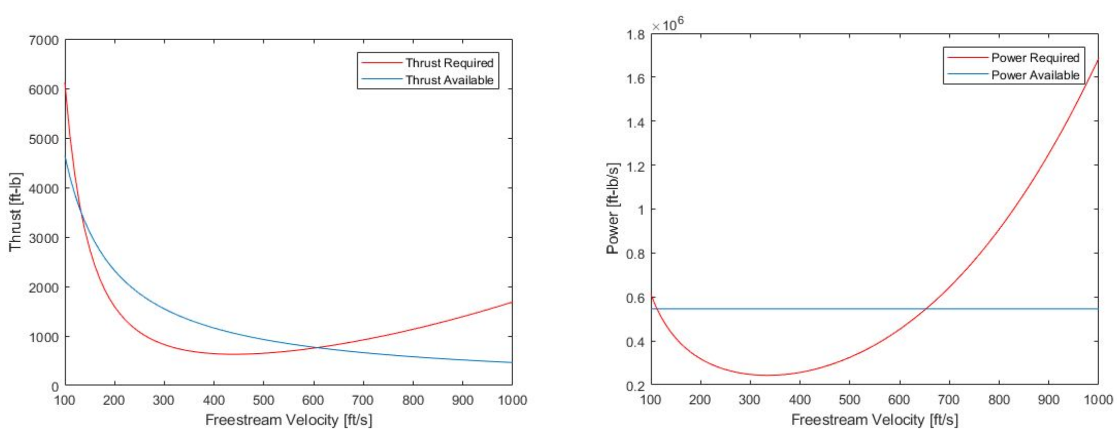



**Figure 8 Thrust and Power Curves at 30,000 feet.**

## VI. Future Design Process

For the next phase of the design process, the team will both re-evaluate the original parameters made for the initial design concept and attempt to incorporate new design ideas to add some complexity in hopes of improving efficiency. Some of these possible design ideas include retractable landing gear and a rear facing turret mounted canon. The parameters the team hopes to change in the future include the airfoil shape and overall weight. There also plans for more research to be done, this time to determine the correct structural materials to improve the aircraft's performance, to begin considering cost as a factor in the overall design plan, and to determine what sort of control systems and technologies should be implemented in the final design.

Included in our next phase is a more detailed cost analysis. With the original OV-10 Bronco valued at ~$80 million, adjusted for inflation, and the A-10 Thunderbolt at ~$90 million, also adjusted for inflation, the MAVERICC team expects to produce an aircraft within or below that production cost of $80 million. This will be achieved through using materials and components that perform well in the field, but remain cheap and easy to obtain in order to produce an aircraft that can be repaired with great ease while remaining on the front lines. This production cost would only be for the aircraft and will not include the price for fuel or ammunition, but will rather lay out the cost of materials, manufacturing, and the technology implemented.

## VII. Conclusion

While there are still many steps in the design process the team will have to take to improve upon the initial concept design, this initial concept design meets the basic requirements for a CAS aircraft. The team will move forward with adding more complex design features to improve the aircraft's efficiency, capability, and appeal.

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