AIAA 2021 Undergraduate Austere Field Light Attack Aircraft

Aircraft Sizing Report

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I. Nomenclature

R	=	Range ft
V	=	Velocity ft/s
C	=	Specific fuel consumption lb/hr lbf
L/D	=	Lift to drag ratio
W_i	=	Weight of the aircraft at the beginning of ith leg
W_0	=	Ramp weight lbs.
W_f	=	Fuel weight lbs.
W_c	=	Crew weight lbs.
W_e	=	Empty weight lbs.
W_p	=	Payload weight lbs.
e	=	Oswald span efficiency
K	=	trailing-edge (TE) nondimensional angular deflection rate

II. Introduction

The objective of the project is to design a light attack aircraft that can operate from short, austere fields near front lines to provide close air support (CAS) to ground forces at short notice. As determined by the AIAA request for proposal, the fighter jet should be operated at infrastructures near frontline, able to reach the war zone via a short cruise, ready to provide CAS with air to ground weaponry during an extended loiter and head back to the base of operation. For the mission the aircraft is required to carry 3000 lbs. of armament, integrated gun for ground targets and preferably rail-launched missiles and 500 lbs. of bombs. With the requested payload the fighter jet should be about to take off and land over a 50 ft obstacle in less than 4000 ft at up to 6000 ft density altitude. This design report focuses on the sizing of the aircraft that would carry out the outline of aircraft's dimensions and weight that meets the driven requirement.

III. Sizing Methodology

In Table 1 below the requirements that will define the sizing are shown. The weapon of choice for sizing purpose is M61 Gun with 500 round of ammunition, 2 AGM-65 Maverick air to surface missile on top of the default 3000 lbs. armament. This combination fire power will give the light attack aircraft fire power that it needs to keep up with its heavier competitors.

Type	Requirement
Payload	2 Crew (400 lbs.) + M61 Gun and Ammunition (550 lbs.) + 2 AGM-65 Missile (1000 lbs.) + Armament (3000 lbs.)
Range	900 n mi (Ferry mission)
Reserve	Climb to 3000 ft and loiter for 45 minutes
Mission Profile	
Warm Up / taxi	5 minutes
Take Off	Austere field, 50 ft obstacle, less than 4000 ft
Climb	To cruise altitude
Cruise	100 n mi
Descent	To 3000 ft, within 20 minutes of the initial climb
Loiter	On station, four hours, no store drops
Climb	To cruise altitude
Cruise	100 n mi
Decent / Landing	Austere field, 50 ft obstacle, less than 4000 ft
Taxi / Shutdown	5 minutes

Table [1]. Requirements and Mission Profile

The mission segments, or the legs, will be analyzed to determine the weight fraction, the weight ratio of the aircraft at the start of a leg to that at the end of that leg. While we will rely on historical data for the weight fraction at any segments other than Climb and Cruise.

$$R = \frac{V}{C}\frac{L}{D}\ln(\frac{W_{i-1}}{W_i})$$

$$E = \frac{L/D}{C}\ln\left(\frac{W_{i-1}}{W_i}\right)$$

According to Raymer 3.7 3.8, the weight fraction for loiter and range segments can be estimated from the designed cruise velocity, L/D ratio and specific fuel consumption of the aircraft which will be discussed later. The weight fraction for the entire mission W_x/W_0 will be estimated by the equation defined below. The fuel fraction of the aircraft can be derived assuming 6% allowance for reserve and trapped fuel, according to Raymer.

$$\frac{W_x}{W_0} = \prod \frac{W_{i-1}}{W_i}$$

$$\frac{W_f}{W_0} = 1.06(1 - \frac{W_x}{W_0})$$

In steady of using historical data for analysis, the weight, size and aerodynamic property of the aircraft will be obtained by tuning a seed aircraft to meet our needs. Here the sizing method provided by the example in Raymer in chapter 5 will be modified to accommodate the methodology adopted.

$$W_0 = W_c + W_p + W_f + W_e$$

$$W_f = \frac{W_p + W_c}{1 - \frac{W_f}{W_0} - \frac{W_e}{W_0}} - W_p - W_c - W_e$$

MRW is broken down into crew, payload, empty weight and fuel weight. While the crew, payload and empty weight will be defined by the mission and dimension input, the fuel weight is left to be determined with the second equation. Clearly, the second equation defines fuel weight as a function of itself which allows us to run a regression on fuel weight to solve for it. Note that there is a requirement on the BFL of 4000 ft, therefore the regression must be run under such constraint.

Last but not the least, the sizing will start with the regular mission. Since the regular mission is considered to be the more demanding one, the sized aircraft from the regular mission will be validated by the ferry mission. The design will be considered successful if it is capable of both regular and ferry mission.

IV. Similarity Analysis

The main consideration for picking a seed aircraft are the capability to take off and land at runway less than 4000 ft with payload similar to what we have defined from RPF. The second consideration is the ferry range of 900 n mi. From the cost and effectiveness perspective, the aircraft with minimum size and powerplant that accomplishes similar mission will be a good candidate for the purpose. Here some existing aircrafts from the same class are examined in the table below.

	EW	Max Thrust	Payload	Range
KAI FA-50	14264 lbs.	11930 lbf	8250 lbs.	999 n mi
Aermacchi MB-339A	6779 lbs.	4400 lbf	4001 lbs.	1140 n mi
Fairchild Republic A-10	24969 lbs.	18130 lbf	16000 lbs.	2240 n mi

Table 1. Similar aircraft performance

Attack aircraft of three sizes are present in the chart. While A-10 and FA-50 provides great range and payload carrying capability, they are just a bit too big for our purpose. Aermacchi MB-339 is the successor of MB-326, a very successful jet trainer that sells to more than 10 countries for its light weight, cost effective design. MB-339 has been flown as an attack aircraft in two conflicts of relatively small size (Eritrean-Ethiopian War, Falklands War), very similar conditions to the one described by RFP.

V. Constraint and Trade Studies

A. Constraint Diagram

With the methodology described in previous section, an excel sheet is built for the iterative procedure which carry out optimal parameter from seed input and guesses. Specifically, the sizing chart takes in requirements, seed parameters and starting guesses of the design parameters. Then it applies the sizing equations from Raymer to update the design parameters until it converged.

To narrow the design space, the constraint diagram is produced. The constrain is enforced by the requirements in following ways:

1. Take off in less than 4000 ft.
2. Landing in less than 4000 ft.
3. Cruising 0.5 Mach at 20000 ft.
4. 30-degree Climb angle.

Given the requirements, the white region between the red region is the derived valid design space.

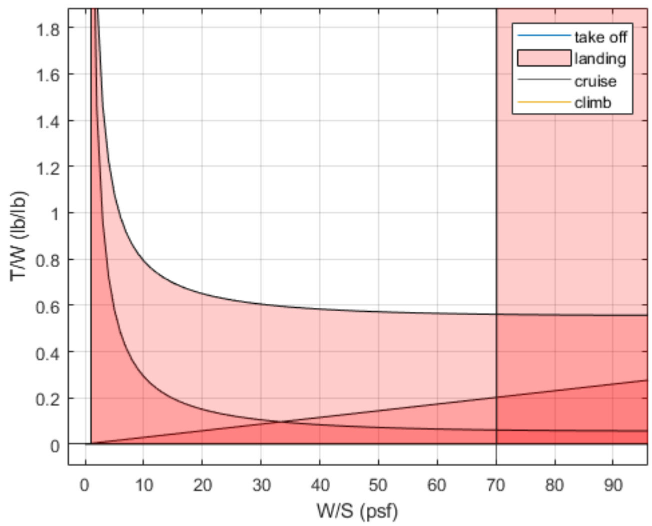

Figure 1. Constraint Chart for Valid Design region

B. Trade Study

The goal of the sizing is to achieve the requirements with minimum empty and fuel weight possible. These qualifications ensure that the aircraft achieves minimum unit cost and has the best fuel economy for the mission. In the chart below the effect of wing area and aspect ratio on the ramp weight is illustrated. The seed aircraft, when asked to carry 5350 lbs. of payload for the mission, does not meet the desired landing field length and service ceiling requirement. Changes are needed to be made for improvements.

A larger wing provides more lift and is essential for increased fuel capacity. With increased lift, aircraft may require less thrust to take off and acquire higher L/D for cruise and loiter. The effect of larger wing area is clearly illustrated in the sizing chart. It reduces thrust required significantly and fuel needed for the reasons mentioned.

A higher aspect ratio contributes to the performance by reducing the induced drag. It helped to increase L/D further during cruise and loiter, saving approximately 300 lbs. of fuel.

The seed aircraft, MB-339A is equipped with a plain flap. Given that we are incorporating a much bigger wing, a revised flap mechanism such as Fowler or Slotted flap could be used to boost the C_L at takeoff and landing. Similar to a bigger wing, the aircraft benefit from this design by reducing thrust needed to takeoff and lower approach speed at landing phase.

The last improvement is drawn from an improved T/W IPPS. Currently the seed aircraft is equipped with an Armstrong Siddeley Viper turbofan which has a thrust to weight ratio of 4.9:1. As engine technology evolves, we are opened up to wider range of engine choices. Aermarcchi M-346 is powered by 2 Honeywell F124 turbofan which provides a thrust to weight ratio of 5.3:1. An optimized turbofan reduces the weight of the power plant while providing same and even better thrust available for the aircraft.

The aircraft after improvements yield the following performance.

MZFW	13220 lb
Fuel Capacity	6800 lb
Payload	5350 lb
TOFL	4000 ft
LFL	3921 ft
Service Ceiling	> 40000 ft

Table 2. Key performance

VI. Conclusion

The 2021 AIAA RFP asks for a light attack aircraft that is capable of close air support from airbase located near the frontline. The sizing practice starts with an existing aircraft whose dimensions are analyzed for trade-offs and are fine tuned to meet the requirements driven by the RFP. The resulted conceptual aircraft has shown considerable improvement from the seed aircraft in its designed mission with cost and effectiveness in mind.

References

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