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Design and Optimization of a Ground Attack Aircraft

Abdus Samad Shohan[1], Md. Inzamim Khan[2], Adnan Shahriar[3],
Group Captain Md. Abdus Salam[4]

[1, 2, 3]*(Department of Aeronautical Engineering, Military Institute of Science & Technology, Dhaka-1216,*
[4] *(Professor & Head, Department of Aeronautical Engineering, Military Institute of Science & Technology, Dhaka-1216,*

Abstract: *Fighter and Attack aircrafts represent some of the most exciting machines in the sphere of military power because of their design, speed, and weaponry. The sheer diversity of this category of aircraft, their evolution through military history, and the modern race to produce the most advanced and lethal fighter and attack aircraft yield a great deal of information and generates more interest than any other category of military aircraft. A design of a ground attack aircraft meeting the given requirements is presented in this paper. Design requirements were selected from market analysis. The most suitable requirements for aircraft design, extracted from market analysis were: range: 1,080 nm, maximum Mach number: 0.65, ceiling: 45,000 ft., payload: 16,000 lb., load factor: ranging from +4 to -3. The aircraft is capable of carrying one crew member. The aircraft is designed to follow a certain mission profile. This mission profile contains the flight segments like taxing, take-off, climb, cruise, descend, attack and landing. The basic disciplines of aircraft design like aerodynamics, propulsion, engineering design, flight dynamics and management skill were carried out during the design process.*

Keywords: *Aircraft design, Aerodynamics, Thrust, Figure of merit analysis, Mission Profile.*

I. Introduction

An attack aircraft (also called a strike aircraft or attack bomber) is a tactical military aircraft that has a primary role of carrying out airstrikes with greater precision than bombers, and is prepared to encounter strong low-level air defenses while pressing the attack. The complete aircraft design is accomplished through three basic phases, conceptual, preliminary and detail design. Gantt chart, an effective form of project management control device, is used to present a design project overview, as a mean of informing management of project status. Initially, in conceptual design phase, configuration of the basic components of aircraft such as wing, tail, propulsion system, fuselage, landing gears are selected through figure of merit analysis. The selected configurations, through figure of merit analysis are low wing, H-tail, airfoil shaped fuselage, turbofan engine and tricycle landing gears. A conceptual sketch is presented at the end of conceptual design phase featuring the selected configurations of major components. Next, in preliminary design phase, the basic parameters e.g., maximum take-off weight, wing area, engine thrust or power were estimated. These parameters were optimized in such a way so that they fulfill all the requirements imposed by stall speed, maximum speed, take-off speed, rate of climb & ceiling. The estimated maximum take-off weight was 45,450(lb.), engine thrust 17,726(lb.), wing area 522(ft^2). In detail design phase, design requirements were established through carrying out functional analysis for all the major components of aircraft. All design activities were presented through design flowchart for each of the major components. Detail design of wing involves airfoil selection, determination of number of wings, wing incidence, aspect ratio, taper ratio, sweep angle, twist angle, dihedral angle. Detail design of tail involves both the design of horizontal and vertical tail. Both the cases involve airfoil selection, determination of tail incidence, aspect ratio, taper ratio, sweep angle, dihedral angle. Detail design of fuselage involves cockpit and other internal segments design. Similarly, propulsion system design comprises of engine type selection, number of engines, engine location and installation. Landing gear design involves selection of landing gear configuration, geometry and determination of aircraft's center of gravity. A final check was carried out at the end of detail design of each major component and subsequent adjustments were applied where required.

Table1. Design requirements

Parameters	Minimum Requirements
Range	2000 (km)
Max. Mach	0.65
Celling	45,000(ft.)
Payload	16,0000(lb.)
Load Factor	+4 & -3
Crew	01

1.1 Mission Profile:
This mission profile was chosen considering most military and general aviation data.

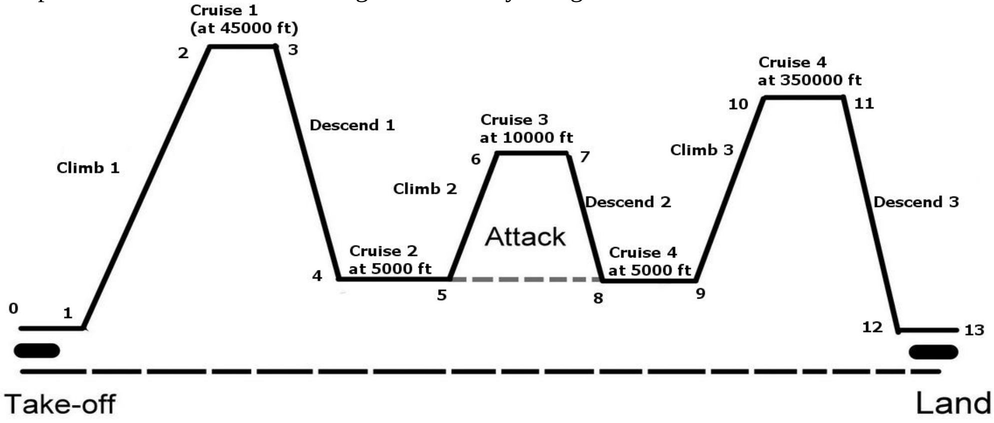

Fig 1: Mission Profile.

II. Conceptual Design

To begin determining aircraft configuration, a variety of aircraft components are generated. Then a FOM analysis is used to select competitive configurations for future considerations. FOM analysis is used to select the aircraft sub-system.

Table2. Selection of Component Configuration

Components	Selected configuration
Plane	Mono plane
Fuselage	Bullet
Wing	Low wing
Propulsion	High by-pass turbo fan
Empennage	H-tail
Landing gear	Tricycle

2.1 Conceptual Sketch:
A rough sketch which is known as conceptual sketch was first drawn as initial sketch.

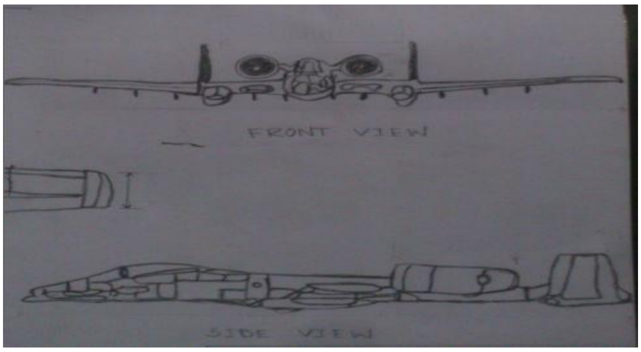

Fig.2 Initial Sketch.

III. Preliminary Design

Preliminary design is performed in two steps:
Step 1: Estimation of aircraft maximum take-off weight.
Step 2: Determination of wing area and engine thrust simultaneously**.**

Table 3. Iteration for Close Range of Guessed Take –off Weight and Calculated Take-off Weight

$W_{TO\text{-}guessed}$(lb.)	W_f (lb.)	W_e(lb.)	$W_{TO\text{-}calculated}$ (lb.)
50,000	10,600	21,000	47,800
48,900	10,366	20,535	47,101
48,000	10,176	19,205	45,581
46,790	9,920	19,760	45,880
46,335	9,823	19,593	45,616
45,975	9,716	19,460	45,406

Table 4. Layout data

Take-off Weight (W_{TO})	**45,450(lb.)**
Empty Weight (W_e)	19,500(lb.)
Fuel Weight (W_f)	9,800(lb.)

Table 5. Summary of preliminary design

Parameter	**Value**
Take-off Weight(W_{TO})	45,450(lb.)
Surface Area (S)	522(ft.)
Thrust (T)	17,726(lb.)

IV. Detail Design

4.1 Wing Design

A wing should produce enough lift to carry out the entire mission requirement and have enough strength to carry fuel, payload and engine. In conceptual design phase a monoplane and low wing was selected. According to mission requirement a NACA-2415 airfoil that yield an ideal lift co-efficient of 1.1 and a net maximum lift co-efficient of 1.5 was selected.

Table 6. Final summary of wing design

Parameter	**Value**
Leading Edge Sweep Angle ($\wedge_{LE}$)	13^0
Quarter Chord Sweep Angle ($\wedge_{c/4}$)	10^0
Tip Chord (C_t)	3.54(ft.)
Root Chord (Cr)	11.8(ft.)
Surface Area (S)	522(ft^2.)
Span(b)	68(ft.)
Aspect Ratio (AR)	8.8
Taper Ratio (λ)	0.3
Incidence Angle (i_w)	9^0
Take-off Angle of Attack ($\alpha_{TO\text{-}wing}$)	8^0
Dihedral Angle	7^0
Twist Angle of Attack (α_{twist})	-3^0
Fuselage Setting Angle	1^0
Location of Wing (Y)	13.95(ft.)
MAC	8.4(ft.)
Flap Span(b_f)	40.8(ft.)
MAC of Flap(C_f)	1.68(ft.)

Airfoil: NACA-2415 (naca2415-il)
Reynoldsnumber: 1,000,000
MaxCl/Cd: 102.23atα=5.75°
Description: Mach=0Ncrit=9
Source: Xfoil prediction
Download polar: xf-naca2415-il-1000000.txt

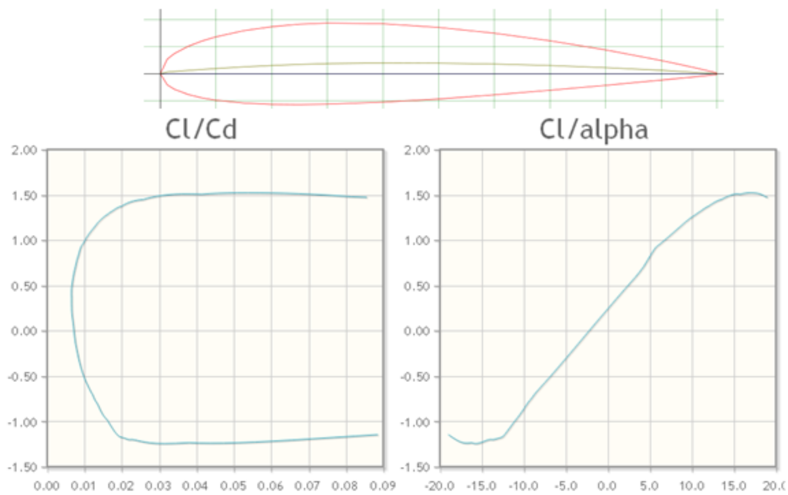

Fig 3: NACA-2415 aerofoil and its performance curves.

4.2. Tail Design

'H' tail is selected so that hot exhaust gases coming from the engine can be hidden from rudder detection. Forward horizontal tail is selected which is conventional. For 'H' tail vertical tail will be symmetric so designing one vertical tail is enough. It's required to select a symmetric and thinner than wing airfoil for both vertical and horizontal tail. As wing airfoil thickness is 15% so 6% thinner airfoil (NACA 0009) is selected for both vertical and horizontal tail.

Table7. Summary of tail design

Parameter	Horizontal Tail	Vertical Tail
Surface Area (S)	170 (ft^2)	115.9 (ft^2)
Sweep Angle (∧)	13^0	13^0
Dihedral Angle	7^0	0^0
Aspect Ratio	4	1.4
Taper Ratio	0.9	0.3
Angle of Attack	-2.3^0	0^0
Downwash Angle	7^0	0^0
Incidence Angle	3.7^0	2^0
Span(b)	26(ft.)	7.35(ft.)
Root Chord (C_{root})	10(ft.)	8(ft.)
Tip Chord (C_{tip})	9(ft.)	2.4(ft.)
Mean Aerodynamic Chord(C)	9.5(ft.)	5.7(ft.)

4.3 Fuselage Design

According to design requirements a fuselage with following parameters is designed.

Table8. Summary of fuselage design

Parameters	Value
No. of pilot	01
Required Volume for fuel	5.3(m^3)
Length of fuselage	49(ft.)
Maximum Diameter of fuselage	5(ft.)
Length of nose section	7.5(ft.)
Length of rear section	3(ft.)
Upsweep angle	17^0

4.4 Propulsion System Design

For subsonic attack aircraft high by-pass turbofan engine is the best option. From preliminary design, required thrust is 17,726(lb.). Now searching through engine manufacturer's catalog's it was found that TF34 of GE aviation can give 9,065(lb.)/per engine. So total thrust = (2*9,065) = 18,130(lb.) which fulfills the target thrust of 17,726(lb.).Engine is placed at rear fuselage because under the wing payload is attached for mission requirement. To avoid hot exhaust gas of engine it's placed over fuselage with pylons. This eliminates the wing interference effects of wing mounted engines. Aft mounted engines tend to move the CG aft which requires shifting the entire fuselage forward relative to the wing.

Table9. Performance Specifications (Sea level/standard day) [3]

Parameters	Value
Thrust	9,065(lb.)
Length	100(in.)
Maximum diameter	49(in.)
Dry weight	1,440(lb.)
Pressure ratio	21:1
Specific fuel consumption	0.371

4.5 Landing Gear Design

An aft mounted engine allows a short landing gear which in terms reduces the weight of the aircraft. From conceptual design the best landing gear configuration is tricycle. Retractable landing gear is best option because it has low drag arrangement.

Table10. Landing gear parameters

Parameters	Value
Landing gear height	6(ft.)
Distance between the main gear and aircraft CG	5.75(ft.)
Tip back angle	26^0
Wheel base	20(ft.)
Wheel track	10(ft.)

Max^{m} load on nose gear during landing	16,810(lb.)
Max^{m} load on main gear during take-off	42,926(lb.)

V. Aircraft Weight Distribution

The weight calculation is about 85%-95% accurate, since it employs a rather more sophisticated empirical approach.

Table11. Aircraft weight distribution

Component Name	Weight (lb.) [2]	CG distance from aircraft nose (ft.)[ ]
Fuselage	2,500	19.6
Wing	2,450	25
Horizontal tail	720	44
Vertical tail	535	44
Main landing gear	350	28.5
Nose landing gear	50	8.5
Fuel system ,electric and avionics	2,000	10
Payload-1(under wing)	10,000	20
Payload-2(front fuselage)	6,000	15
Pilot and suits	220	8.5
Fuel	9,800	27(excepted to be around wing)
Engine	3,000	35
Total	37,625	

Here, $\Delta W = W_{TO} - W_{Total}$ =45,450-37,625 =7,825(lb.)

So, more fuel or payload can be added in future for mission requirement. And optimization can be done to reduce maximum take-off weight (W_{TO}) of the aircraft. Now from the above table the calculated location of aircraft CG is listed below:

Table12. Position of CG

Parameters	Value (%of mean aerodynamic chord of wing airfoil)
Most forward location of CG	22%
Most Aft location of CG	52%
CG range	30%

Recommended longitudinal CG location range is 15-30% of mean aerodynamic chord for subsonic fighter aircraft. So our design is OK in longitudinal stability [1].

VI. Comparison With Similar Aircraft

Table13. Comparison with similar aircraft

Parameter	A-10 Thunderbolt II [4]	Designed aircraft
Crew	01	01
Fuselage length	53(ft.)	49(ft.)
Wing span	57(ft.)	68(ft.)
Take-off weight	50,000(lb.)	45,450(lb.)
Wing loading	99(lb./ft^2)	87(lb./ft^2)
T/W	0.36	0.39

From the above comparison it is observed that both the aircraft has almost same fuselage length and crew number. But the designed aircraft has a reduced take-off weight of 5,050(lb.) where wing span is only increased by 11(ft.).So it is noteworthy success in design.

VII. Drawing Package

SolidWorks2014 [6] was used as CAD tool. The detail drawings of the designed aircraft are presented below:

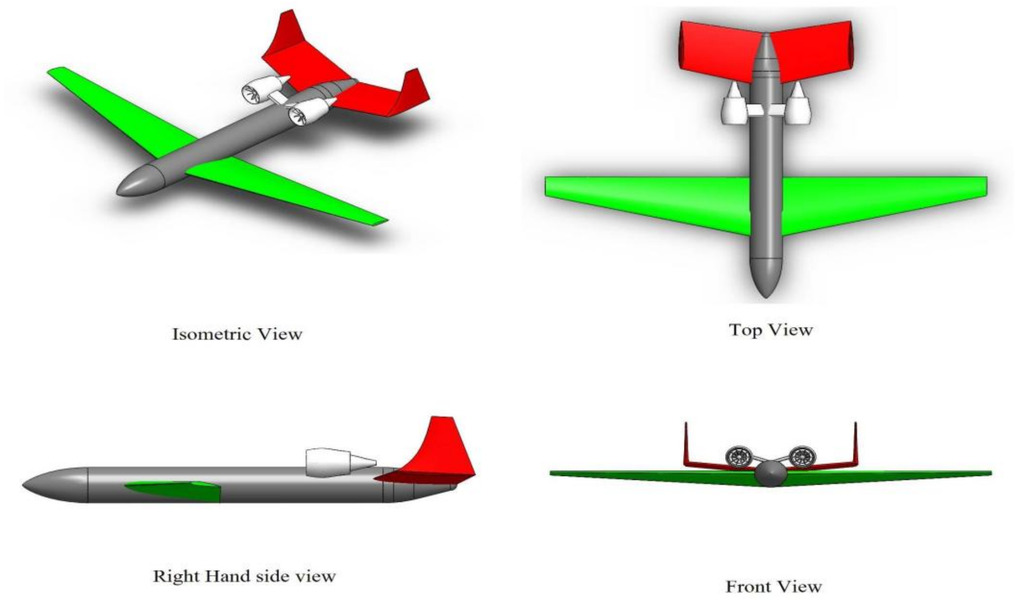

Fig4. CAD Drawing Of the Designed Aircraft

VIII. V-N Diagram

V-n diagram (also called the "Flight envelope") is a very important diagram for both the designers and the pilots which is actually a graph showing the limiting factors of design and flying. It shows stall region, corner velocity, maximum velocity, maximum and minimum load factor etc. As required maximum load factor $n_{max=}$ +4 and minimum load factor, $n_{min=}$ -3, considering 50% factor of safety, positive ultimate load factor = 4× 1.5 = 4.5. Negative ultimate load factor = -3×1.5 = -4.5. From this, corner

velocity $V^* = \sqrt{\frac{2n_{max}(\frac{w}{s})}{\rho(Cl_{max})}}$ =446.8ft/s.

The high speed limit velocity or never exceed velocity, V_{ne} =1.2×Vmax = 880.8 ft/s. V-n diagram for this aircraft is shown in *"Fig. 5"*.

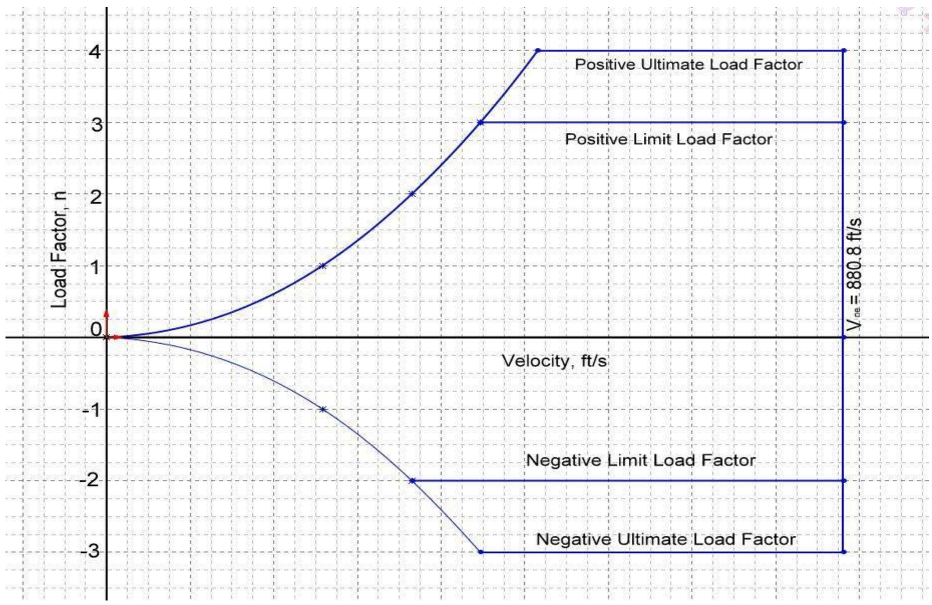

Fig 5: The V-n Diagram

IX. Ps Plots

Ps, the specific excess power or the excess power per unit weight of the aircraft is an important parameter that gives indication about the acceleration performance of the aircraft. Ps plots for different altitudes with respect to velocity for this aircraft is shown in "Fig. 6". It is seen that, for a specific altitude, Ps first increases with velocity, then reaches a maximum and finally decreases to zero as the velocity approaches Vmax for the aircraft.

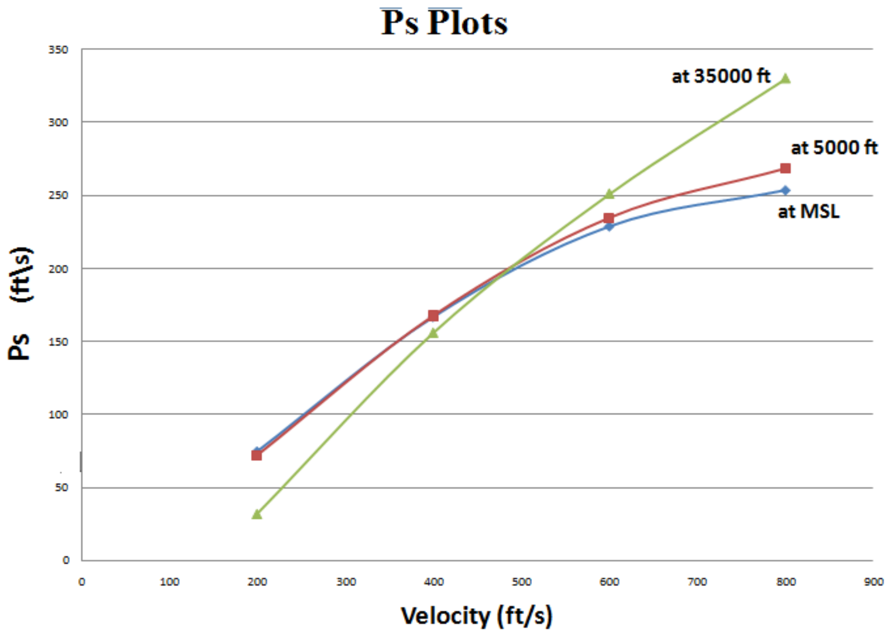

Fig 6: Specific excess power Vs velocity at different altitutes.

X. Conclusion

This work presents the design of a ground attack aircraft which is finally compared to the design of an existing ground attack A-10 Thunderbolt aircraft. It represents the entire conceptual design phase of a ground attack aircraft. From design experience, it can be concluded that, aircraft design is all about trade off and to have better performance many iterations and optimizations are needed.

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