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Design and Optimization of a Multi-Role Fighter Aircraft

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Abstract

Multi-role fighter aircraft is one of the latest innovations of science and technology. A multi-role fighter aircraft carrying one pilot that covers a range of 2000 NM with a maximum Mach number of 2 has a maximum ceiling of 65000 ft. is designed in this paper. The aircraft has to materialize a certain mission profile. The basic disciplines of aircraft design like aerodynamics, propulsion, engineering design, flight dynamics, performance and management skill are carried out during the design process. In addition to, the complete aircraft design is accomplished through three basic phases like conceptual, preliminary and detail design. A conceptual sketch is presented at the end of conceptual design phase featuring the selected configurations of major components. In the preliminary design phase, the basic parameters, e.g., maximum take-off weight, wing area, engine thrust or power are estimated. A final check is carried out at the end of the detail design of each major component and subsequent adjustments are applied where required.

Keywords: Aircraft design, Aerodynamics, Thrust, Conceptual design, Figure of merit analysis (FOM), Mission Profile

I. Introduction

Aircraft design is a scientific art and essentially an advanced branch of engineering design. Intellectual engineering and assumptions are required for designing aircraft. Now-a-days multirole fighter has become the most dominating aircraft in battle field. It has different roles in battle field. Primarily, it is designed for air to air combat against other enemy aircraft and secondarily for air to ground attack or air to surface attack. It establishes air superiority over the battle field. This paper illustrates about the design and optimization of multi-role fighter aircraft. Design of an aircraft follows the sequence of conceptual design, preliminary design and detail design chronologically. A mission profile and requirements are given for design the aircraft. This paper covers all of the phases of designing an aircraft by using the system engineering approach.

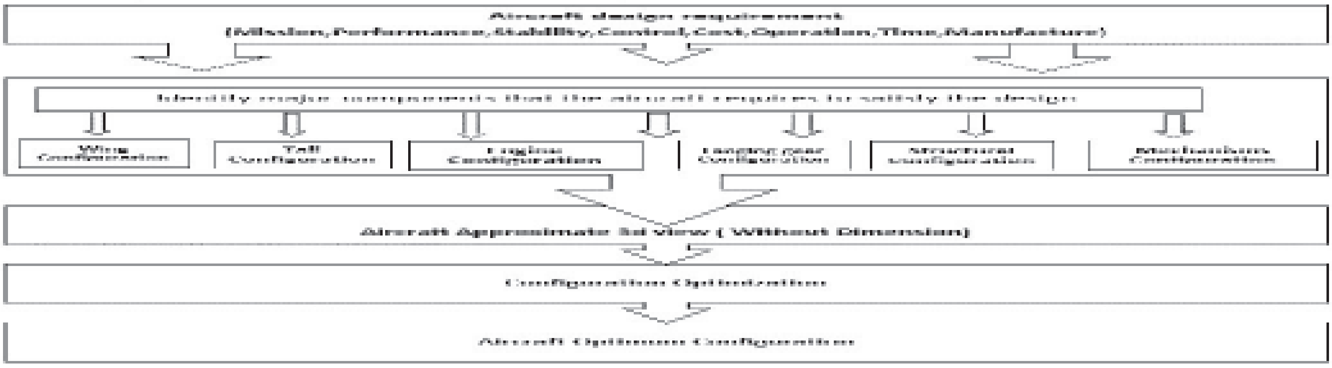

Figure 1: Conceptual Design Flow Chart

II. Conceptual Design

Initially in the conceptual design phase, configurations of the basic components of aircraft such as wing, tail, propulsion system, fuselage, landing gear were selected through a figure of merit analysis (M. H. Sadreay 2013) The selected configurations through a figure of merit analysis are high wing, conventional tail, turbofan engine, tricycle landing gear. At the end of conceptual design a good rough conceptual sketch is drawn.

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Table 1: Design Requirements

Parameters	Minimum Requirements
Range	3700 km 2000 NM
Max Mach	2
Ceiling	65000 ft.
Payload	6200 lb.
Load Factor, n	+9, -3
Crew	1

Initial Design Layout

The actual aircraft design effort usually starts with conceptual sketch. This is the "back of a napkin" (D. P. Raymer *et al;* 2010) drawing of aircraft legend and gives a rough idea of what the aircraft looks like. The initial design, layout begins with a good conceptual sketch.

Conceptual Sketch

Conceptual sketch is the rough sketch which includes approximate wing and tail geometries, fuselage shape and the location of other major components such as engine, landing gear, cockpit, fuel tanks, etc. Final concept of aircraft featuring high wing, conventional tail, Turbofan engine and tricycle landing gear. By using rough hand sketch (J. Nawar *et al;* 2014) initial sketch is drawn.

Figure 2: Conceptual Sketch

III. Preliminary Design

In the preliminary design phase, fundamental aircraft parameters such as aircraft maximum take-off weight (MTOW), wing area (S) and engine thrust (T) are determined. It starts with initial design sizing.

Initial Design Sizing

Initial design sizing is the most important calculation in aircraft design. It consists of 2 steps. (M. H. Sadreay 2013)

- Aircraft Maximum take-off weight (MTOW) calculation
- Determination of wing area (S) and Engine thrust (T) Simultaneously.

Maximum take-off weight (MTOW) is calculated by using the following equations:

$$W_{TO} = \frac{W_{Crew} + W_{Payload}}{1 - \frac{W_{Empty}}{W_{TO}} - \frac{W_{Fuel}}{W_{TO}}} (1)$$

According to design requirement of multirole fighter aircraft, one crew member approximate weight of 200 pounds and payload weight 6200 pounds are considered. Fuel fraction is calculated based on the weight fraction of different mission segments using approximate fuel consumption of the engine and the aerodynamic characteristic of aircraft.

Empty weight is calculated by using the following Equations:

$$\frac{W_{Empty}}{W_{TO}} = aW_{TO} + b(2)$$

Where values of 'a' and 'b' are taken from historical data table (M. H. Sadreay *et al;* 2013)

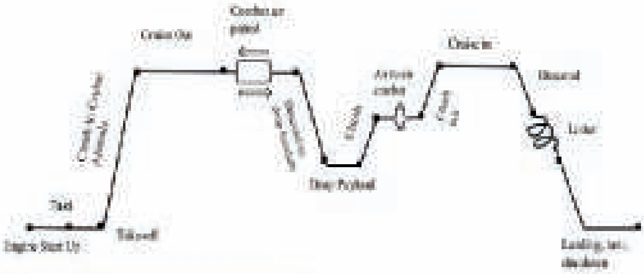


Figure 3: Mission profile

Table 2: Mission segments weight fractions (Historical data) (D. P. Raymer *et al;* 2006)

Mission Segment	Weight Fraction
Warmup and takeoff	0.970
Climb	0.985
Landing	0.995

Wing Area and Engine Sizing

The calculation of wing area and engine sizing in the preliminary design phase depends upon aircraft performance requirement such as stall speed, maximum speed, maximum rate of climb

(ROC), take-off run and aircraft ceiling (M. H. Sadreay chen, 2013) A matching plot curve is drawn for these performance requirements and an optimum design point is found from this matching plot curve. From this design point, corresponding values of wing loading (W/S)and thrust loading (T/W)are found. These Values are used to calculate the wing reference area (**S**) and engine thrust (T). The equations are:

Wing reference area, $S=W_{TO}/(W/S)$(3)
Engine Thrust ,$T= W_{TO}*(T/W)$ (4)

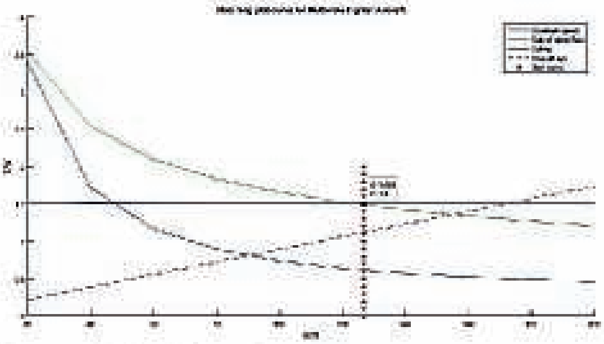


Figure 4: Matching plot curve

Table 3: Preliminary design summary

Maximum take –off weight, W_{TO}	**45440.359 lb.**
Thrust Loading, $\frac{T}{W}$	1.5
Wing Loading, $\frac{W}{S}$	126.8416
Thrust, T	68160.53 lb.
Wing area, S	358.24 ft^2

IV. Detail Design

In Detail design, phase aircraft wing, tail (both horizontal tail and vertical tail), fuselage, propulsion system and landing gear system are designed one by one chronologically.

Wing design

Wing is considered as the most important components of aircraft. A fixed wing aircraft can't fly without it. In wing design stage, wing airfoil and high lift devices (HLD) are selected and other wing geometries are calculated.

Airfoil Selection

Airfoil is considered as the heart of the airplane. The airfoil affects the cruise speed, take-off and landing distances, stall speed and other aerodynamic efficiency during all phases of flight (D.P. Raymer, 2006) In this paper, ideal lift coefficient and maximum lift coefficient for multi-role fighter aircraft are calculated. The values of ideal and maximum lift coefficient are 0.21169 and 1.94 respectfully. By using these values, NACA 6-series airfoil 632-215 is selected from maximum lift coefficient vs. ideal lift coefficient curve (M. H. Sadreay, 2013) The 2nd digit represents the chord - wise position of the minimum pressure in tenths of a chord. The 3rd digit represents the ideal lift coefficient in tenths. The last two digits represent the maximum thickness to chord ratio. For 652-215 airfoil, maximum thickness to chord ratio is 15%. From airfoil database (M. H. Sadreay, 2013) airfoil maximum camber 1.1% is at 50% chord. Chamber airfoil increases lift and reduces drag and also produces lift at zero AOA. The airfoil drag polar curve is drawn by using xflr5 *XFLR5* software for different Reynolds number.

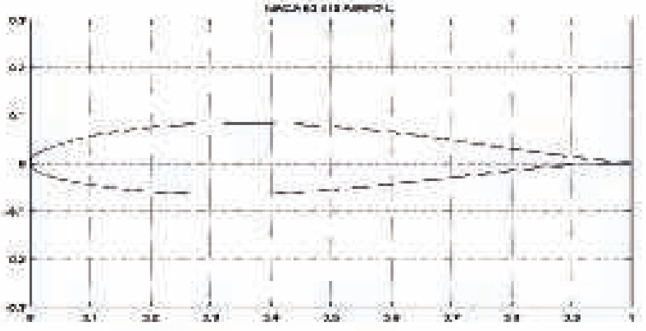


Figure 5: NACA 632-215 airfoil

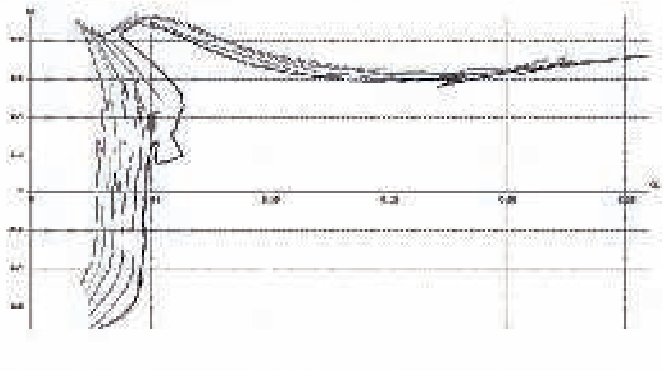


Figure 6: Airfoil Drag polar for diff. Reynolds num.

Wing high lift devices (HLD)

Plain flap positioned at trailing edge of wing and leading edge flap (M. H. Sadreay, 2013) positioned at leading edge of the wingare selected for the design of fighter aircraft in this paper. HLD increase lift coefficientat both take-off and landing.

Wing Geometries

Analyzing historical wing configurations of different aircraft; monoplane, high wing, wing taper, twisted and swept back configuration are selected for the desired aircraft in this paper. Other values of wing geometries are given below:

Table 4: Wing geometries

Parameters	Value	Parameters	Value
Aspect ratio, AR	3	Wing span,b	32.78 ft.
Taper ratio, λ	0.27	Wing effective span, b_{eff}	19.886 ft.
Wing twist, α_{twist}	-2	Mean Aerodynamic chord, C	11.92 ft.
Wing leading edge sweep, $\wedge_{LE}$	62	Root Chord, C_{root}	15.50 ft.
Wing Area, S	358.24 ft^2	Tip Chord, C_{tip}	4.18 ft.

Tail Design

The aircraft tail means horizontal tail (H.T) and vertical tail (V.T). For stability and control purposes, aircraft tail is required. Both H.T and V.T are designed in tail design step. For desired fighter aircraft, conventional tail configuration is selected by analyzing historical tail configuration. Both the H.T and V.T are tapered and swept back. For both H.T and V.T tail symmetry airfoil is selected. The 3rd digit of the airfoil shows that airfoil is symmetric. Tail geometries are given below:

Table 5: Tail geometries

Horizontal Tail geometries		**Vertical Tail geometries**	
Parameters	Value	Parameters	Value
H.T airfoil	NACA 63_2-012	V.T airfoil	NACA 63_2-012
H.T volume coefficient, V_H	0.2	V.T volume coefficient, V_V	0.07
Optimum tail moment arm, l_{opt}	18.63 ft.	Optimum tail moment arm, $l_{v.t}$	18.63 ft.
H.T area, $S_{H.T}$	42.023 ft^2	V.T area, $S_{V.T}$	44.12 ft^2
H.T Aspect ratio, $AR_{H.T}$	2	V.T Aspect ratio, $AR_{V.T}$	1.5
Taper ratio, $\lambda_{H.T}$	0.3	Taper ratio, $\lambda_{V.T}$	0.4
Leading edge sweep angle, $\wedge_{LE}$	62 (swept back)	Leading edge sweep angle, $\wedge_{LE}$	55
H.T span, $b_{H.T}$	9.166 ft.	V.T span, $b_{V.T}$	8.135 ft.
H.T effective span, b_{eff}	6.13 ft.	V.T effective span, b_{eff}	8.135 ft.
Mean aerodynamic Chord, $C_{H.T}$	4.583 ft.	Mean aerodynamic Chord,$C_{V.T}$	5.42 ft.
H.T root chord, C_{root}	6.429 ft.	V.T root chord,C_{root}	7.29 ft.
H.T tip chord, C_{tip}	1.9288 ft.	V.T tip chord, C_{tip}	2.916 ft.

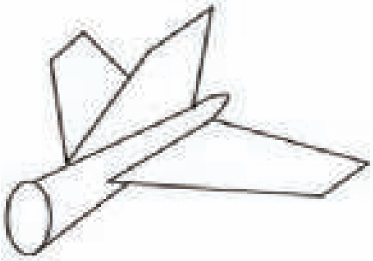


Figure: 7. Conventional Tail

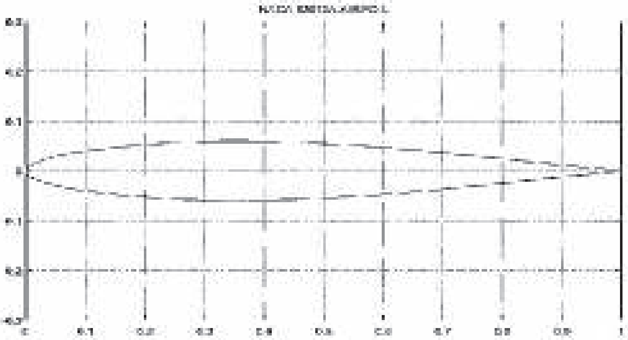


Figure: 8. Tail Airfoil

Fuselage Design

A single fuselage with a single deck configuration is selected for minimizing weight and drag. For multi-role fighter aircraft, in this paper, the designed fuselage length is 50 ft. Here fuselage nose length is 8 ft. and rear section length is 7ft. Calculation of fuselage diameter depends on the fuselage optimum length to diameter ratio (slenderness ratio) and other aerodynamic parameters and fuselage internal arrangement. Taking fuselage length to diameter ratio (L_f/D_f) 10.3, (M. H. Sadreay, 2013) desired aircraft diameter becomes 4.854 ft.

Propulsion System Design

In the preliminary design phase, calculated total thrust required is 68160.53 lb. Such amount of thrust is not produced by a propeller driven engine. Besides, in design requirement, Mach number is 2. So low bypass turbofan engine will be good for higher thrust and better fuel efficiency. Two turbofan (low by-pass ratio) GE/Rolls-Royce F136 engine is selected for the multirole fighter aircraft. The engine is buried inside the wing and fuselage and inlet located under the wing.

Landing Gear Design

Most commonly used landing gear arrangement for fighter aircraft is "Tricycle landing gear". In this arrangement, main gear is aft of the aircraft most aft Centre of gravity (C.g) and the nose gear is in front of aircraft most forward C.g. Distance between main gear and the nose gear (wheel base) is 28.564 ft. and distance between two wheels of main gear (wheel track) (M. H. Sadreay 2013) is 10.2543 ft. Nose gear carries 20% of the total weight of aircraft and rest of weight is carried by main landing gear.

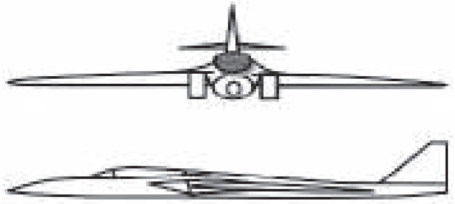


Figure 9: Engine inlet under wing

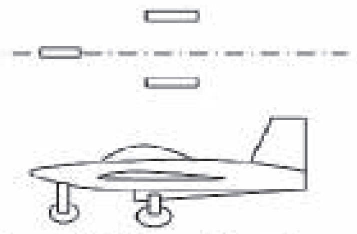
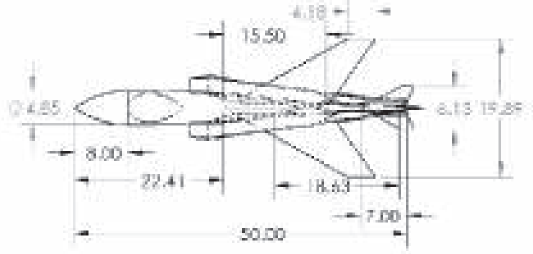


Figure 10: Tricycle Landing gear

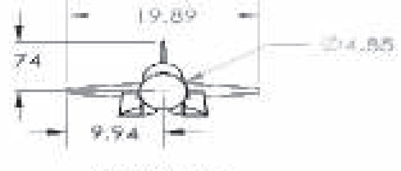
V. Final model of aircraft

After all the calculations and estimations, done in the preliminary and detail design phase a final model of aircraft is drawn with the help of Solid works (M. H. Sadreay, 2013) software package.

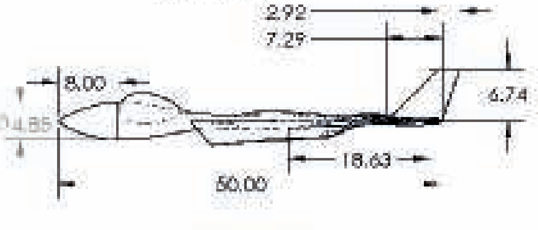


TOP VIEW

Isometric view



Front View



Right side view

Figure 11: Different views of the final model

VI. Structure and Material Selection

Aircraft structural material is selected in this section. Aerospace aluminum alloy is selected for the wing, H.T, V.T and fuselage structural construction material. Density of aerospace aluminum is 2711 kg/m^3 (M. H. Sadreay, 2013) Then, aircraft component weight is calculated. Calculated weight of wing, H.T, V.T, fuselage, landing gear, aircraft engine and fuel systems weights iare 12694.51 lb, 213.377 lb, 295.186 lb, 2293.07 lb, 3261.95 lb, 18829.75 lb, and 492.98 lb. respectively. So total weight of the aircraft is 44280.823 lb. with payload. Sincethe maximum takeoff weight (W_{TO}) of aircraft is 45440.35 lbin the preliminary design phase, sothe total weight of the aircraft is less than maximum takeoff weight, which is very effective for design.

VII. Conclusion

Comparing the designed aircraft with other similar aircraft, the take-off weight calculated in the preliminary design phase is reconcilable one. Airfoil chosen in wing design stage follows the design requirement.But the distance between main gear and nose gear exceeds optimum range. In this design, some requirements are fulfilled and some are not. However,the calculation of maximum take of weight in the preliminary design phase is a remarkable one from design and economic perspectives.

Nomenclature

W_{TO}: Maximum take off weight, lb.
W_{Fuel}: Fuel weight, lb.
W_{Empty}: Aircraft empty weight, lb.
H.T: Horizontal tail
V.T: Vertical tail
AOA: Angle Of attack, (degree)
HLD: High lift devices
n: load factor
Roc: Rate of climb, ft. /sec
C.g: Aircraft Centre of gravity

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UIUC Airfoil co-ordinate Database Web Site http://m-selig.ae.illinois.edu/ads/coord_database.html

XFLR5 Airfoil Analysis Software Website: http://www.xflr5.com/xflr5.htm

SolidWorks 2015 Software Web Site: http://www.solidworks.com