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CONCEPTUAL DESIGN & TAKE-OFF WEIGHT ESTIMATION OF ATTACK FIGHTER AIRCRAFT

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Abstract- *Aircraft design includes three important phases; conceptual design, preliminary design & detail design. This paper deals with the conceptual design & a part of preliminary design (maximum take-off weight estimation) of an attack fighter aircraft. Conceptual design includes the initial configurations of the aircraft from recent trends & historical observations. Preliminary design phase includes calculation of maximum take-off weight, wing loading & engine thrust for the aircraft. In this paper conceptual design & the calculation of maximum take-off weight are done. In case of calculating maximum take-off weight, weight loss due to bomb drop is considered which is absent in general aircrafts.*

Keywords: Conceptual design, Preliminary design, Aircraft design

1. INTRODUCTION

Attack fighter aircraft design varies from normal aircraft designing. The purpose & mission profile of the fighter aircraft is quite different from that of the normal transport, commercial or trainer aircraft. It includes weight drop, more controllability than stability due to its basic purpose & complex the mission profile. Conceptual design provides the very basic considerations for the aircraft design. Preliminary design includes calculation of maximum take-off weight and engine thrust. In this paper, we completed the conceptual design and calculation of maximum take-off weight for given mission profile. Conceptual designing was done by considering both historical data and recent trends. In case of calculating maximum take-off weight, we had to consider the attack segments where weight loss occurred due to bomb drop. Our task was to design an attack fighter aircraft for the following conditions:

Table 1: Mission requirements

Parameters	Minimum Requirements
Range	1150 km Or, 620 nm
Maximum Mach No.	.62
Ceiling	42000 ft
Payload	15000
Load Factor	+9 -3
Crew	1

Mission profile for this is given below:

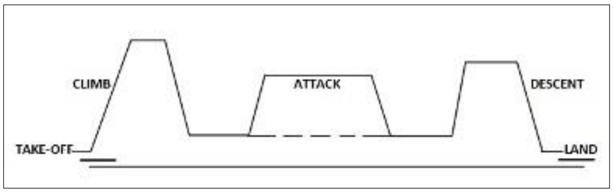

Fig.1: Mission profile

2. CONCEPTUAL DESIGN

Figure of merit analysis was used to find the appropriate configuration.

WOM means Weight of merit. Better option was marked by a higher value. This value ranges from 5 to 10.

2.1 Selection of Wing Type

Table 2: Selection of wing

Option		Mono-plane	Bi-plane	Delta wing
Criteria	WOM (%)			
Weight	30	8	6	7
Aerodynamics	30	7	8	6
Control & Stability	20	7	5	6
Manufacturability	20	9	8	7
Total	100	770	700	650

(Sample calculation: for monoplane, total value =30*8+30*7+20*7+20*9=770)

2.2 Selection of Tail Type

Table 3: Selection of tail

Option		Inverse T tail	V tail	H tail
Criteria	WOM (%)			
Weight	30	6	7	7
Aerodynamics	30	8	7	8
Control & Stability	20	8	6	7
Manufacturability	20	7	7	7
Total	100	720	680	730

2.3 Selection of Landing Gear Type

Table 4: Selection of landing gear

Option		Quad-cycle	Tri-cycle	Conventional
Criteria	WOM (%)			
Weight	30	8	9	8
Aerodynamics	30	7	8	9
Control & Stability	20	8	9	7
Manufacturability	20	7	8	8
Total	100	750	850	810

2.4 Selection of Power plant Position

Table 5: Selection of power plant position

Option		Fuselage mounted	Below wing
Criteria	WOM (%)		
Weight	30	7	7
Aerodynamics	30	8	7
Control & Stability	20	8	7
Manufacturability	20	7	8
Total	100	750	720

2.5 Final Selection

Table 6: Final selection of different items

Item	Selected Option
Wing type	Mono-plane
Tail type	H tail
Landing gear	Tri-cycle
Power plant position	Fuselage mounted

3. PRELIMINARY DESIGN

Preliminary design includes weight estimation and calculation of wing loading and engine thrust. Here, we'll solve only the weight estimation part. To accomplish this, we divided the mission profile into 20 different segments. For calculating maximum take-off weight, we considered the fuel weight fraction for different segments. For some of the segments, we got the value directly from historical data [1]. For other segments, where bomb drop is not included, we considered Breguet Range equation to find fuel weight ratio for those segment [2]. For the rest of the segments including weight drop, we considered breguet range equation as well as, weight drop related calculation to find the fuel weight ratio for those segments.

3.1 Maximum Take-off Weight Estimation

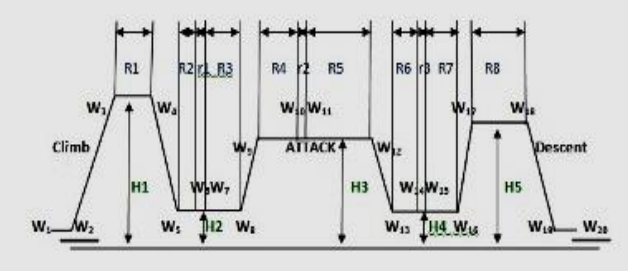

Fig.2: Detailed mission profile for attack fighter aircraft

Assumptions:
H1= 42000 ft
H2= 2000 ft
H3= 25000 ft
H4= 2000 ft
H5= 35000 ft
R1= 250 km = 820210 ft
R2=100 km = 328084 ft
r1= 10 km = 32808.4 ft
R3= 90 km = 295276 ft
R4=150 km = 492126 ft
r2=10 km = 32808.4 ft
R5=140 km = 459318 ft
R6=100 km = 328084 ft
r3=10 km = 32808.4 ft
R7=90 km = 295276 ft
R8=200 km = 656168 ft
Weight of the crew = 200 lb

Here, r1, r2, r3 is the distance the aircraft passed while bomb dropping. Fuel weight fraction in this small range is assumed to have a value of 1.

Assumption of payload:

Table 7: Assumption of payload

Payload type	Weight (lb)
Fixed	9000
Droppable in 1st case	2750
Droppable in 2nd case	500
Droppable in 3rd case	2750
Total	15000

Calculation of fuel-weight fraction for different segments and maximum take-off weight:

i. For this segment, fuel weight fraction is directly obtained from historical data [1]. So,

$W_2/W_1 = 0.99$

ii. For this segment, fuel weight fraction is directly obtained from historical data [1]. So,

$W3/W2 = 0.98$

iii. $W4/W3 = e^{-[(R \text{ x } SFC)/(0.866 \text{ x } L/D \text{ x } V_{alt})]}$ …….. (1)

Now,
In this case, R = R1 = 820210 ft, SFC is found from historical data [3]. SFC = 1/3600 lbs/lbs/s
Assume, L/D = 15 because, the highest mach is quite low and the value of L/D is larger for lower values of Mach number.
Here, H = H1 = 42000 ft,
So,
velocity $a = (\gamma R'T)^{1/2}$
$= (1.4 \text{ x } 287 \text{ x } 216.650) = 295.04$ m/s = 967.73 ft/s

here, γ & R′ are fixed reference value. T is the temperature at 42000 ft, which is obtained from standard atmospheric temperature & pressure chart.
Now,
V_{alt} = a x Mach No.
= (967.73 x 0.62) ft/s = 600 ft/s

So, $W4/W3 = e^{-[(820210 \text{ x } 1/3600)/ (0.866 \text{ x } 15 \text{ x } 600)]} = 0.97$

iv. For this segment, fuel weight fraction is directly obtained from historical data [1]. So,

W5/W4 = 0.99 [1]

v. $W6/W5 = e^{-[(R \text{ x } SFC)/(0.866 \text{ x } L/D \text{ x } V_{alt})]}$

In this case, R= R2 = 328084 ft, SFC = 1/3600 lbs/lbs/s
L/D = 15 (assume)
Here, H = H2 = 2500 ft
So,
velocity $a = (\gamma R'T)^{1/2}$
$= (1.4 \text{ x } 287 \text{ x } 283.2) = 337.33$ m/s =1106.44 ft/s

here, γ & R′ are fixed reference value. T is the temperature at 2500 ft, which is obtained from standard atmospheric temperature & pressure chart.
Now,
V_{alt} = a x Mach No.
= (1106.44 x 0.62) ft/s =686 ft/s
So,

$W6/W5 = e^{-[(328084 \text{ x } 1/3600)/ (0.866 \text{ x } 15 \text{ x } 686)]} = 0.9898$

vi. In bomb dropping phase, fuel-weight fraction is equal to 1 [4]. So,

W7/W6 = 1

vii. $W8/W7 = e^{-[(R \text{ x } SFC)/(0.866 \text{ x } L/D \text{ x } V_{alt})]}$

In this case, R= R3 = 295276 ft , SFC = 1/3600 lbs/lbs/s
L/D = 15 (assume),
Here, H = H2 = 2500 ft
So,
velocity $a = (\gamma R'T)^{1/2}$
$= (1.4 \text{ x } 287 \text{ x } 283.2) = 337.33$ m/s = 1106.44 ft/s
here, γ & R′ are fixed reference value. T is the temperature at 2500 ft, which is obtained from standard atmospheric temperature & pressure chart.
Now,
V_{alt} = a x Mach No.
= (1106.44 x 0.62) ft/s = 686 ft/s

So, $W8/W7 = e^{-[(295276 \text{ x } 1/3600)/ (0.866 \text{ x } 15 \text{ x } 600)]} = 0.9895$

But, this value should be corrected due to bomb dropping [5].
Now,
Fuel weight fraction up to this part =0.99 x 0.98 x 0.97 x 0.99 x 0,9898 x 1 = 0.9222
Therefore, just prior to the bomb drop,
weight = (15000 x .9222) lb = 13833 lb
Immediately after bomb drop,
weight = (13833 – 2750) lb = 11083 lb
The weight ratio of after & before bomb drop is = (11083/13833) = 0.85
So, the corrected value of

W8/W7 = [1-(1 - 0.9895) x 0.85] = 0.991

viii. Fuel weight fraction for this segment was assumed by comparing with the fuel-weight fraction for climb [1]. So,

W9/W8 = 0.98

ix. $W10/W9 = e^{-[(R \text{ x } SFC)/(0.866 \text{ x } L/D \text{ x } V_{alt})]}$

In this case, R= R4 = 492126 ft, SFC is found from historical data [3]. SFC = 1/3600 lbs/lbs/s
L/D = 15 (assume),
Here, H = H3 = 25000 ft
So,
velocity $a = (\gamma R'T)^{1/2}$
$= (1.4 \text{ x } 287 \text{ x } 238.62) = 309.67$ m/s = 1015.98 ft/s
here, γ & R′ are fixed reference value. T is the temperature at 25000 ft , which is obtained from standard atmospheric temperature & pressure chart.
Now,
V_{alt} = a x Mach No.
= (1015.98 x 0.62) ft/s = 629.91 ft/s

So,

$W10/W9 = e^{-[(492126 \times 1/3600)/ (0.866 \times 15 \times 600)]} = 0.983$

x. In bomb dropping phase, fuel-weight fraction is equal to 1 [4]. So,

$W11/W10 = 1$

xi. $W12/W11 = e^{-[(R \times SFC)/(0.866 \times L/D \times Valt)]}$

In this case, R= R5 = 459318 ft , SFC = 1/3600 lbs/lbs/s [3]
L/D = 15 (assume),
Here, H = H3 = 25000 ft
And, $a= (\gamma R'T)^{1/2} = (1.4 \times 287 \times 238.62)$ = 309.67 m/s = 1015.98 ft/s
here, γ & R′ are fixed reference value. T is the temperature at 25000 ft, which is obtained from standard atmospheric temperature & pressure chart.
Now,

V_{alt} = a x Mach No.
= (1015.98 x 0.62) ft/s = 629.91 ft/s
So,

$W12/W11 = e^{-[(459318 \times 1/3600)/ (0.866 \times 15 \times 600)]} = 0.9837$

But, this value should be corrected due to bomb dropping [5].
Now,
Fuel weight fraction up to this part = 0.9222 x .991 x .98 x .983 x 1 = 0.896
Therefore, just prior to the bomb drop, weight = [(15000-2750) x .896] lb = 10976 lb
Here, 15000-2750 = 12250, is the weight of total payload, after the 1st bomb drop.
Immediately after bomb drop,
weight = (10976 – 500) lb = 10476 lb
The weight ratio of after & before bomb drop is = (10476/10976) = 0.954
So, the corrected value of

W12/W11 = [1-(1 - 0.9837) x 0.954] = 0.9844

xii. Fuel weight fraction for this segment was assumed by comparing with the fuel-weight fraction for descent [1]. So,

W13/W12 = 0.99

xiii. $W14/W13 = e^{-[(R \times SFC)/(0.866 \times L/D \times Valt)]}$

In this case, R= R6 = 328084 ft, SFC = 1/3600 lbs/lbs/s
L/D = 15 (assume),
Here, H = H2 = 2500 ft
Now, $a= (\gamma R'T)^{1/2} = (1.4 \times 287 \times 283.2)$ =337.33 m/s =1106.44 ft/s
here, γ & R′ are fixed reference value. T is the temperature at 2500 ft, which is obtained from standard atmospheric temperature & pressure chart.
Now,
V_{alt} = a x Mach No.
= (1106.44 x 0.62) ft/s =686 ft/s
So,

$W14/W13 = e^{-[(328084 \times 1/3600)/ (0.866 \times 15 \times 686)]} = 0.9898$

xiv. In bomb dropping phase, fuel-weight fraction is equal to 1 [4]. So,

W15/W14 = 1

xv. $W16/W15 = e^{-[(R \times SFC)/(0.866 \times L/D \times Valt)]}$

In this case, R= R7 = 295276 ft , SFC = 1/3600 lbs/lbs/s [3]
L/D = 15 (assume),
Here, H = H2 = 2500 ft
Here, $a= (\gamma R'T)^{1/2} = (1.4 \times 287 \times 283.2)$ = 337.33 m/s = 1106.44 ft/s
here, γ & R′ are fixed reference value. T is the temperature at 2500 ft, which is obtained from standard atmospheric temperature & pressure chart.
Now,
V_{alt} = a x Mach No.
= (1106.44 x 0.62) ft/s = 686 ft/s

So, $W16/W15 = e^{-[(295276 \times 1/3600)/ (0.866 \times 15 \times 600)]} = 0.9895$

But, this value should be corrected due to bomb dropping [5].
Now,
Fuel weight fraction up to this part =0.896 x 0.9844 x 0.99 x 0.9898 x 1 = 0.864
Therefore, just prior to the bomb drop,
weight = ((15000-2750-500) x .864) lb = 10152 lb
Here, (15000-2750-500) lb = 11750 lb is the weight of payload after the 1st & 2nd bomb drop.
Immediately after bomb drop,
weight = (10152 – 2750) lb = 7402 lb
The weight ratio of after & before bomb drop is = (7402/10152) = 0.73
So, the corrected value of

W8/W7 = [1-(1 - 0.9895) x 0.73] = 0.992

xvi. Fuel weight fraction for this segment was assumed by comparing with the fuel-weight fraction for climb [1]. So,

W17/W16 = 0.98

xvii. $W18/W17 = e^{-[(R \times SFC)/(0.866 \times L/D \times Valt)]}$

Now,
In this case, R = R8 = 656168 ft, SFC = 1/3600 lbs/lbs/s [3],
L/D = 15 ; Here, H = H5 = 35000 ft,
Here, $a= (\gamma R'T)^{1/2} = (1.4 \times 287 \times 218.810)$ = 296.51 m/s = 972.55 ft/s

here, γ & R' are fixed reference value. T is the temperature at 35000 ft, which is obtained from standard atmospheric temp. & pressure chart.

Now, V_{alt} = a x Mach No. = (972.55 x 0.62) ft/s = 603 ft/s

So, $W18/W17=e^{-[(656168 \times 1/3600)/(0.866 \times 15 \times 603)]} = 0.977$

xviii. Fuel weight fraction for this segment was obtained from historical data [1]. So,

W19/W18 = 0.99

xix. Fuel weight fraction for this segment was obtained from historical data [1]. So,

W20/W19 = 0.995

So, total fuel-weight fraction

W20/W1 =
[(W_2/W_1) X (W3/W2) X (W4/W3) X (W5/W4) X (W6/W5) X (W7/W6) X (W8/W7) X (W9/W8) X (W10/W9) X (W11/W10) X (W12/W11) X (W13/W12) X (W14/W13) X (W15/W14) X (W16/W15) X (W17/W16) X (W18/W17) X (W19/W18) X (W20/W19)]
= 0.8084

xx. Again, Maximum take-off weight can be estimated using the following equation [6]:

Wto=(Wcrew+Wpayload) / [1-(Wf/Wto)-(We/Wto)] (2)

Now, Wf/Wto = 1.05[1-W20/W1] = 0.2012

From eqn (2),
Wto = 15200/ (1-.2012-We/Wto)
Or, Wto = 15200/(0.7988-We/Wto)
Or, 0.7988Wto-We=15200

So, We =0.7988Wto-15200 (3)

xxi. Again, we used another equation containing empty weight to total weight ratio [7].

$We/Wto = AWto^{C}K$

Here, for this purpose, A= 2.34, C= -0.13, K=1 assuming fixed sweep aircraft [7].

So, $We/Wto = 2.34Wto^{-0.13}$
Putting value from eqn (3),

$(0.7988Wto – 15200)/Wto =2.34Wto^{-0.13}$
Or, $0.7988Wto - 15200 = (2.34Wto^{-0.13} \text{ X } Wto)$
Or, $0.7988Wto – 15200 = 2.34Wto^{(-0.13+1)}$
Or, $0.7988Wto – 15200 = 2.34Wto^{0.87}$
Or, $2.34Wto^{0.87} – 0.7988Wto + 15200 = 0$ (4)
We can find Wto by solving eq^{n} (4) .
This eq^{n} can be solved by putting different values of Wto ; and find a value of Wto, for which the L.H.S of eq^{n} iii becomes zero.

Table 8: Iteration to find Wto

Wto = (lb)	L.H.S of eq^{n} iii
43000	5989.76
45000	5406.35
50000	3922.88
55000	2406.92
60000	861.802
65000	-709.73
So, value of Wto lies in between 60000 & 65000 (according to bi-section method)	
62000	236.22
63000	-78.103
So, value of Wto lies in between 62000 & 63000 (according to bi-section method)	
62500	79.19
So, value of Wto lies in between 62500 & 63000 (according to bi-section method)	
62700	16.3
So, value of Wto lies in between 62700 & 63000 (according to bi-section method)	
62750	0.57
So, value of Wto lies in between 62750 & 63000 (according to bi-section method)	
62760	-2.57
So, value of Wto lies in between 62750 & 62760 (according to bi-section method)	
62752	-0.05.
So, value of Wto lies in between 62750 & 62752 (according to bi-section method)	
62751.5	0.101
So, value of Wto lies in between 62751.5 & 62752 (according to bi-section method)	
62751.8	0.0062045
So, value of Wto lies in between 62751.8 & 62752 (according to bi-section method)	
62751.81	0.00306
So, value of Wto lies in between 62751.81 & 62752 (according to bi-section method)	
62751.815	0.00015
So, value of Wto lies in between 62751.815 & 62752 (according to bi-section method)	
62751.8195	0.00007 ≈ 0 = R.H.S
So, Wto = 62751.8195	

So, Maximum Take-off weight is 62751.8195 lb.

4. CONCLUSION

Considering the given requirements the attack fighter aircraft will be a monoplane, H tail aircraft having a tri-cycle landing gear. The powerplant will be fuselage mounted. Maximum takeoff weight for the aircraft including bomb drop is 62751.8195 lb.

5. REFERENCES

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6. NOMENCLATURE

Symbol	**Meaning**	**Unit**
T	Temperature	(K)
P	Pressure	(Pa)
R	Range	(Feet)
SFC	Specific fuel consumption	(lbs/lbs/s)
L/D	Lift to drag ratio	Dimensionless
R'	Gas constant	(J/Kg K)
γ	Specific heat ratio	Dimensionless
Wto	Maximum take-off weight	(lbs)
We	Empty weight	(lbs)
Wf	Fuel weight	(lbs)