EAS4710 – Group 6 - Spring 2021

Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

G8-R Austere Field Light Attack Aircraft

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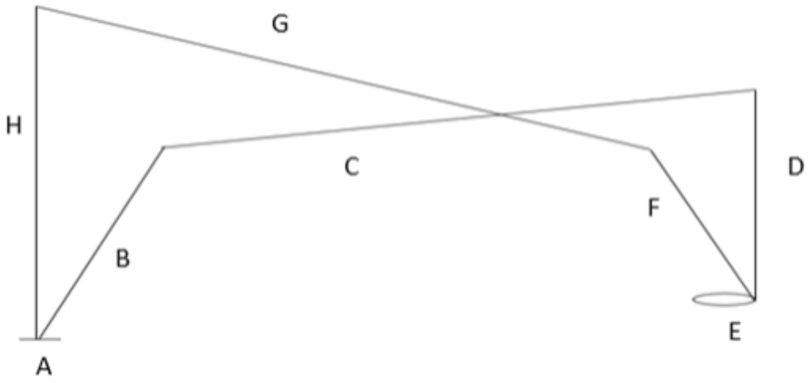
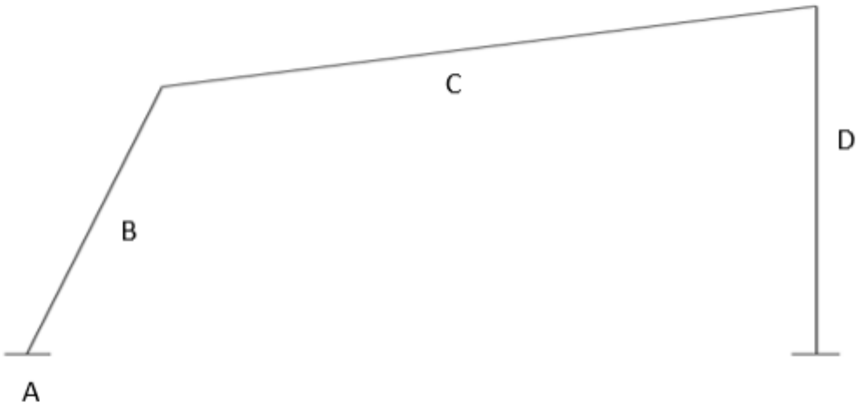
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Design and Ferry Missions



DESIGN MISSION

A – Warm Up, Takeoff
B – Climb [≥10,000 ft]
C – Cruise [100 n mi]
D – Descent [to 3,000 ft]
E – Loiter [4 hours]
F – Climb [≥10,000 ft]
G – Cruise [100 n mi]
H – Landing and Shutdown



FERRY MISSION

A – Warm Up, Takeoff
B – Climb [≥18,000 ft]
C – Cruise [900 n mi]
D – Descent, Landing

Design requirements

- 15,000 hours / 25 years service
- ≥ 30,000 ft service ceiling
- Two-person crew
- Takeoff and landing over 50ft obstacle in ≤ 4000 ft
- Takeoff altitude up top 6000 ft in semi-prepared runways
- Up to 3000 lbs payload

G8-R

Specifications	
Engine Type	Pratt & Whitney PT6A-68 1250 hp
Propeller	91 in 5-blade Harzell ASC-II
Grossweight	11,823 lb
Wing Airfoil	NACA 6413
Wingspan	46 ft
Wing Area	333 ft^2
Fuelcapacity	Wing 180 Gal – Auxiliary 80 Gal
Radar	AirMaster C compact all-in-onesystem
Armaments	MK-82 / GBU-12 Bombs AIM-9L Missile

Performance	
Max Speed	350 kt
Cruise Speed	272 kt
Takeoff Distance	3050 ft
Landing Distance	2585 ft
Cruise Range	1008 NM
Endurance	16.8 hours

Similar Aircraft

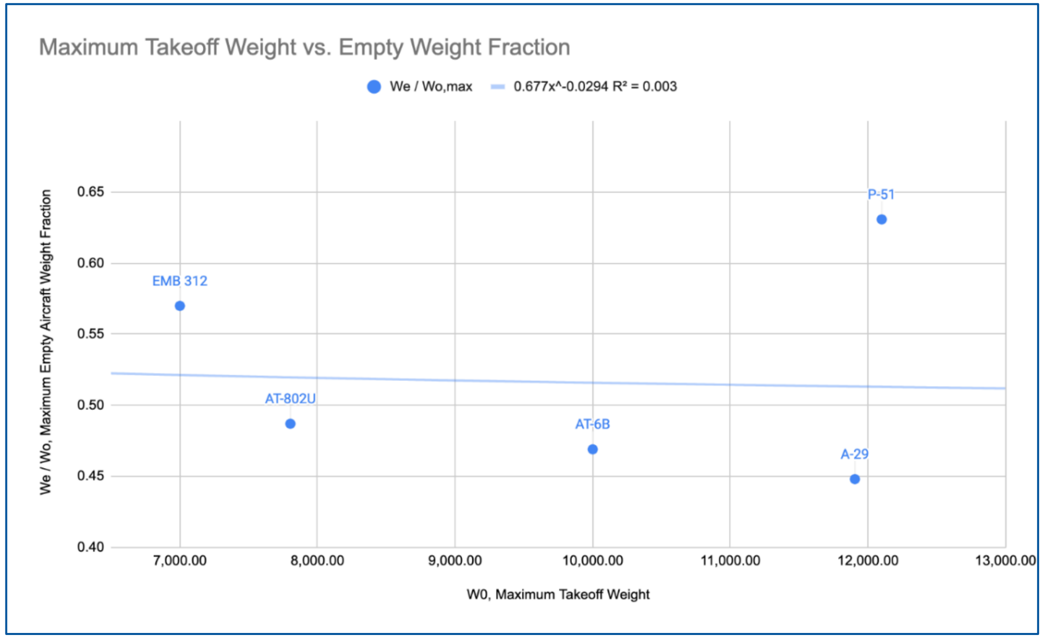
Parameter	A-29	P-51	T-6	EMB 312	AT-802U
Empty Weight (lbs)	11905	7635	4690	3390	7803
Max W_e/W_0	0.448	0.631	0.469	0.57	0.487
Wing Area (ft^2)	208.82	233	179	209	401
Cruise Speed (ft/sec)	474.3	530.9	469.3	401.9	280.1

Preliminary Sizing

- Takeoff Weight
  - Design Mission ~ 14300 lbs
  - Ferry Mission ~ 8000 lbs
- L/D Ratio ~ 14.9
- T/W ~ 0.175
- W/S ~ 55.7 psf

Designweightcalc.m MATLAB Code

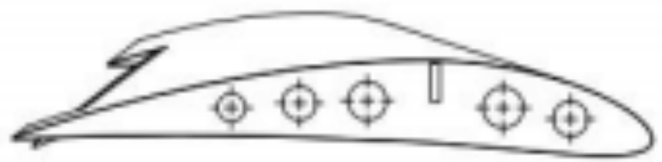
```
function [LD,takeoffgrossweight] = Designweightcalc(initialguess,Wcrew,Wpayload,range,endurance,path)
        %Calculates the design takeoff gross weight given the weight of the crew,
        %payload, endurance during loitering periods, range during cruise periods.
        %Constants of .985, .995, .970 used for weight fraction of climb, descent,
        %and takeoff respectively. LD ratio, SFC, and cruising velocity are
        %calculated within function for only 1 similar aircraft (A-29).
        Wold = 100000;
        range = range*6076.12; %convert to feet for the cruise period
        %Using velocity value from A-29 specs for cruising speed
        V = 474.275; %ft/s speed during cruise [2]
        A = 0.677; %A constant obtained from curve fitting of similar aircraft
        C = -0.0294; %C constant obtained from curve fitting of similar aircraft
        emptyfrac = A*initialguess^C; %Calculate We/W0 for initial guess
        b = 11.14; %Wing span for A-29 in m [2]
        S = 19.4; %Wing area for A-29 in m [2]
        AR = b^2/S; %Wing aspect ratio for A-29, dimensionless value
        Wetted_Area = 3.5; %Wetted area ratio estimated from Fig 3.6 in [10]
        Wetted_AR = AR/Wetted_Area; %Calculate wetted aspect ratio
        KLD = 11; %KLD constant for retractable prop aircraft given in [10]
        LD = KLD*sqrt(Wetted_AR); %L/D ratio calculated from eq. 3.12 in [10]
        SFC_loiter = .6 / 3600; %hrs to sec; obtained from table 3.4 for turboprop [10]
        SFC_cruise = .5 / 3600; % hrs to sec; obtained from table 3.4 for turboprop [10]
        endurance = endurance *3600; %hours to seconds endurance for the loiter
        wi_loiter = exp(-endurance*SFC_loiter/(LD*.866)); %LD*.866 for turboprop a/c during loiter [10]
        wi_cruise = exp(-range*SFC_cruise/(V*LD)); %Constant LD for turboprop a/c during cruise [100]
        if path == 1
        %mission path for the design – refer to Fig. 1.
```



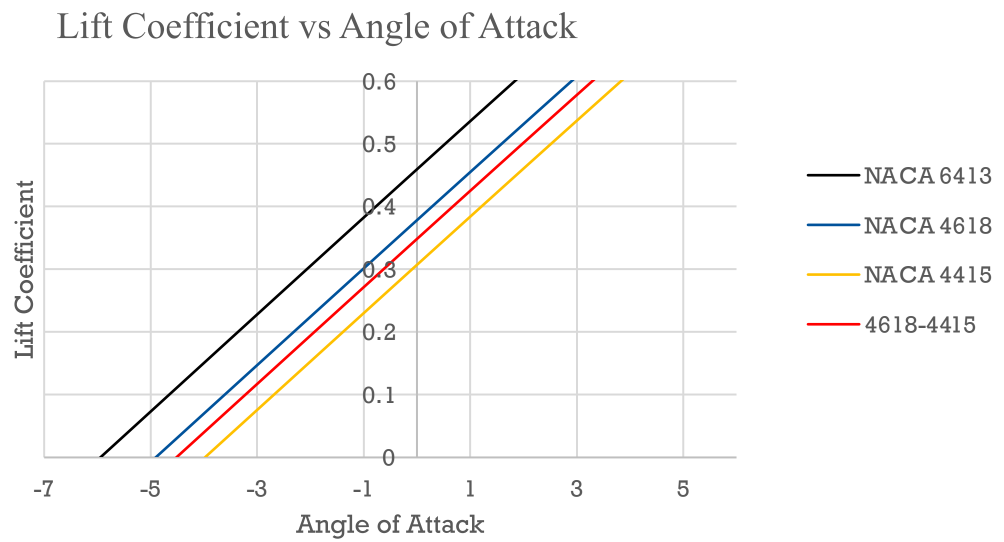
Airfoil Selection

<u>Process</u>

- Find Ideal and maximum lift coefficient.
- Perform trade analysis.
- Compare desired aerodynamic Characteristics.
- Interpolate airfoils to create the ideal fit.



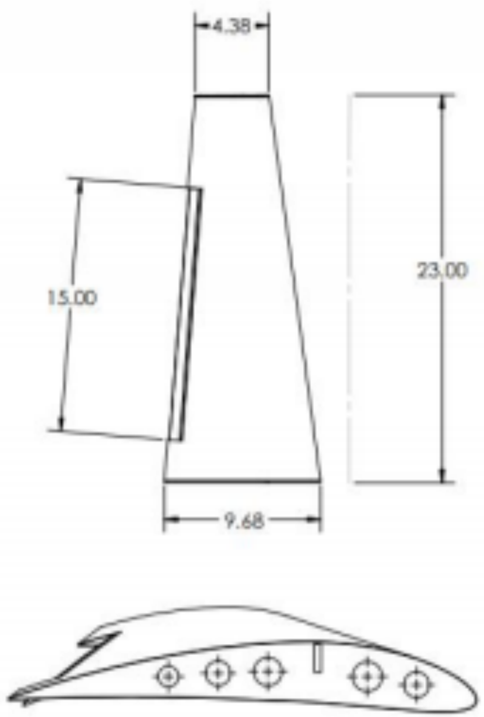
NACA6413



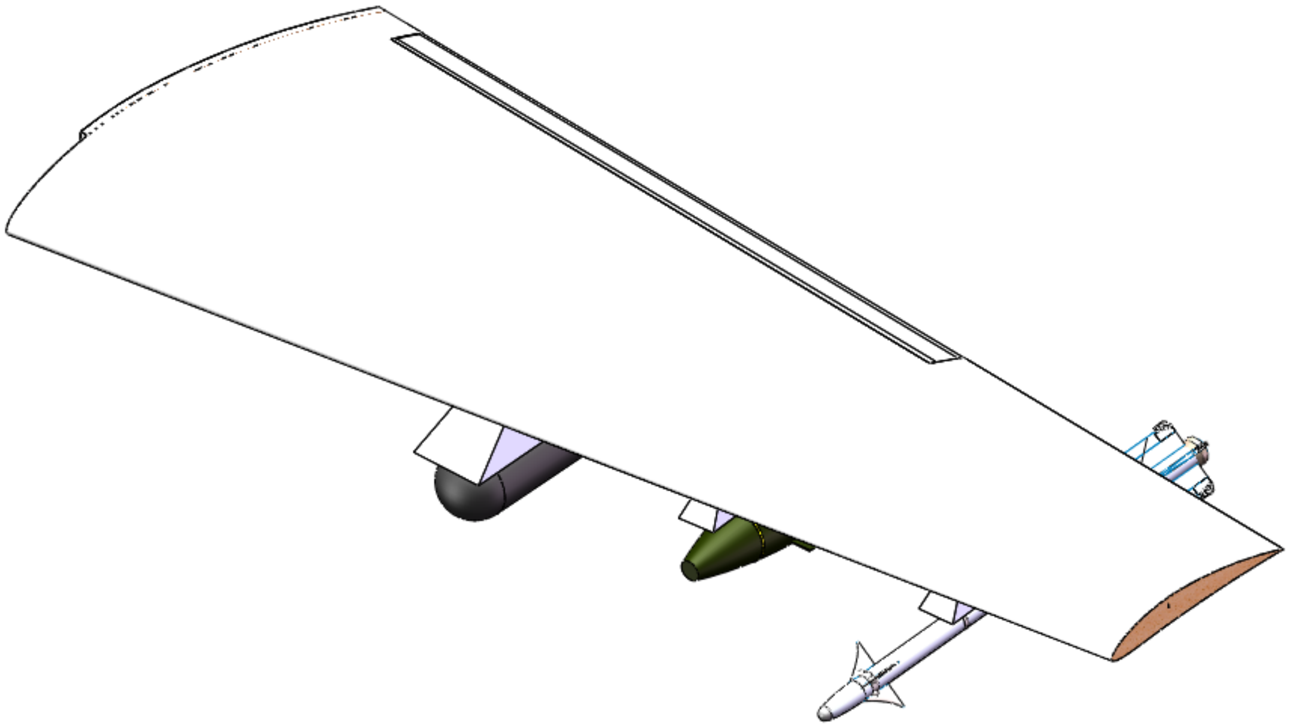
<u>XFOIL Analysis</u>

- XFOIL was used to perform a comparative analysis of reference airfoils over a range of angles of attack.
- Trade study airfoils were chosen from similar aircraft.
- Once results were found, the airfoils were interpolated and then re-analyzed.
- The NACA 6413 fit best with requirements for our design.

Wing Development



NACA6413



3D wing analysis performed using the inviscid xflr5 solver

xflr5

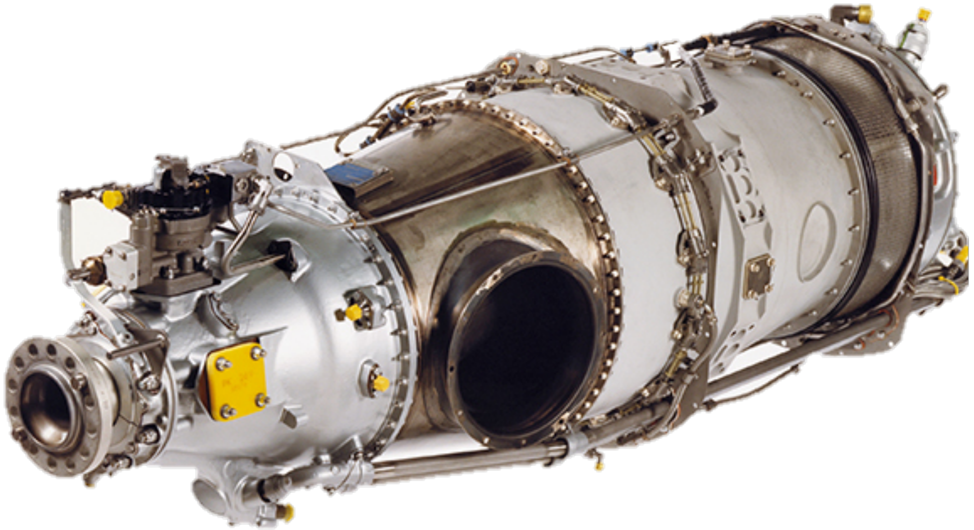
Propulsion System

Engine

Predesign Considerations

- Austere field performance
- Takeoff distance <4000ft
- High subsonic speeds not required
- Reliability
- Fuel consumption
- Operations and maintenance cost

PT6A-68C 1600shp Turboprop



Propeller: 91-in 5-blade Hartzell ASCII

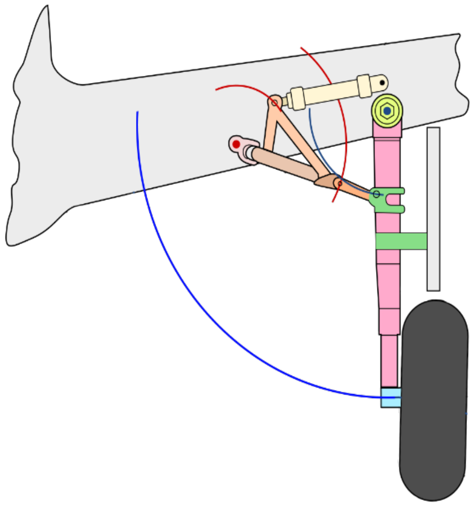
Advantages

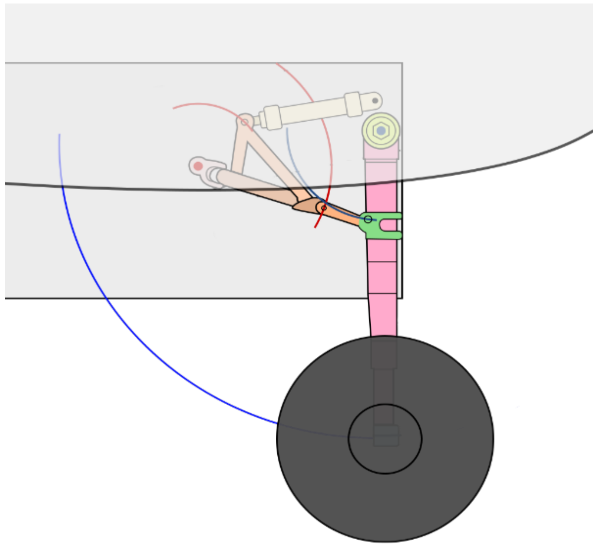
- Advanced Structural Composite
- Thinner and stiffer airfoil design
- Fly-over noise reduction
- Vibration reduction (Foam core, extra blades)
- Replaceable leading edge erosion shield
- 10% improved takeoff acceleration
- 2-5 kt cruise speed increase

Performance

- 1490 lbs of thrust (1390 lbs required)
- 80% efficiency

Landing Gear: Retractable Tricycle Nose Gear Setup with Oleo Shock Absorber





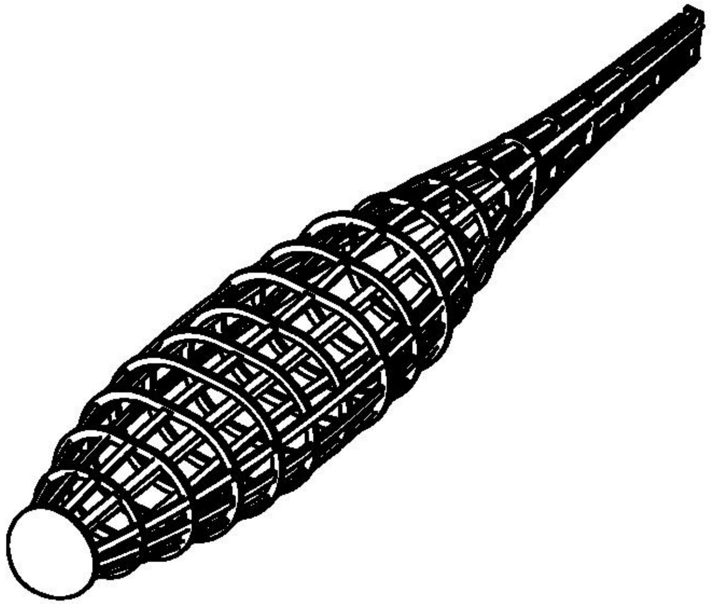
Wheel Location	Adjusted Maximum Loading	Tires
Nose gear	6076 lbs	7.50-14 8-ply 27.75-in 87 psi
Main gear	7941 lbs	11.00-12 10-ply 32.2-in 60 psi

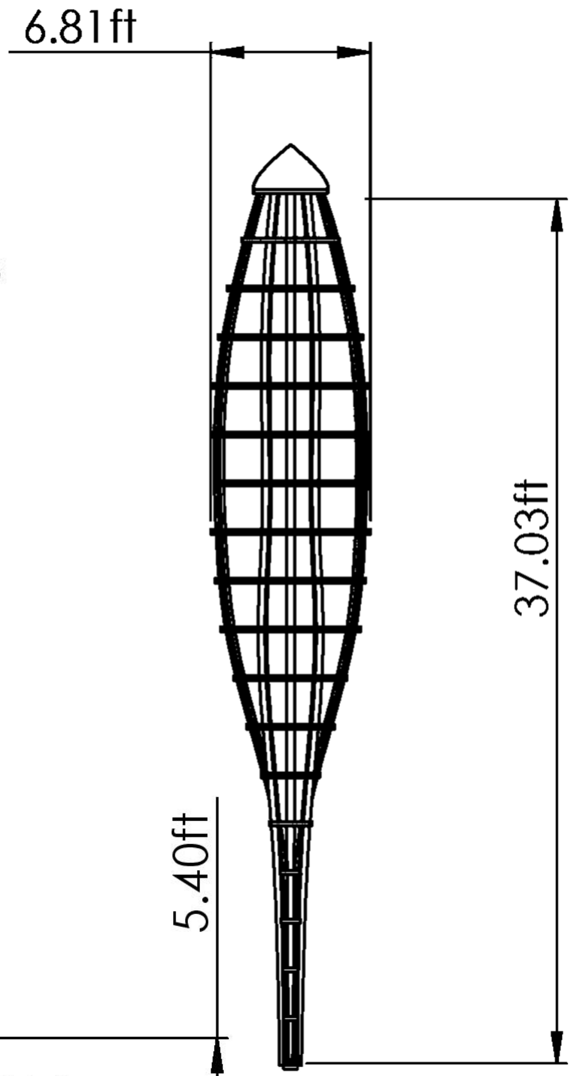
Rear and front gear hydraulic retraction mechanism

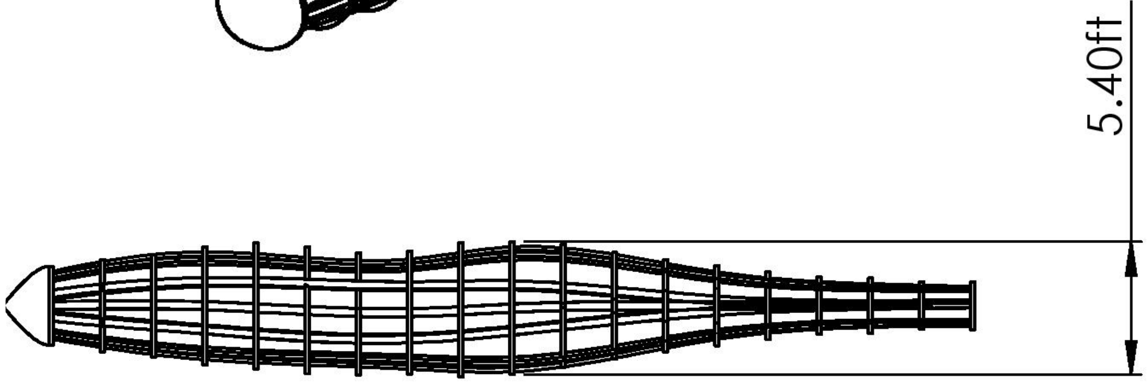
Fuselage Design

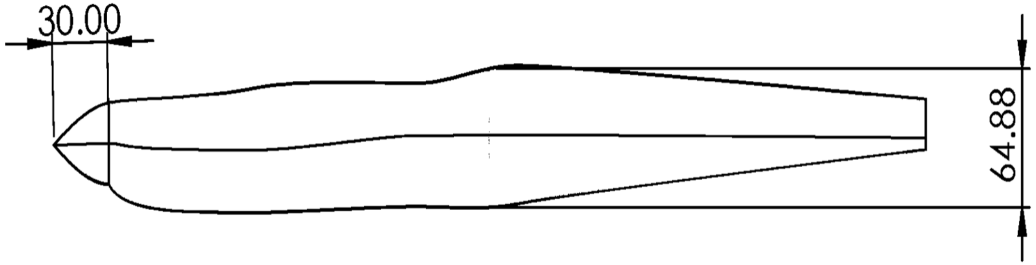
<u>Semi-Monocoque Structure</u>

- Provides structural integrity needed for military operations and low weight.
- Combination of longerons and frames. Trade studies used to find the distance between each frame.
- 7075-T6 Aluminum used for Longerons and Frames.
- Stringers also used prevent tension and compression from bending.
- 2024-T4 Aluminum used for the skin.



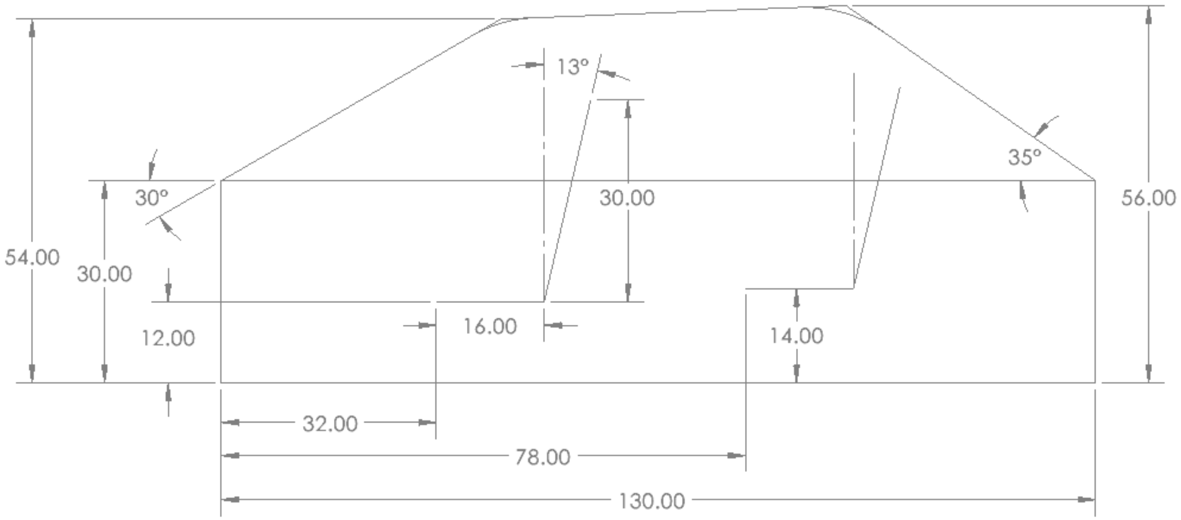






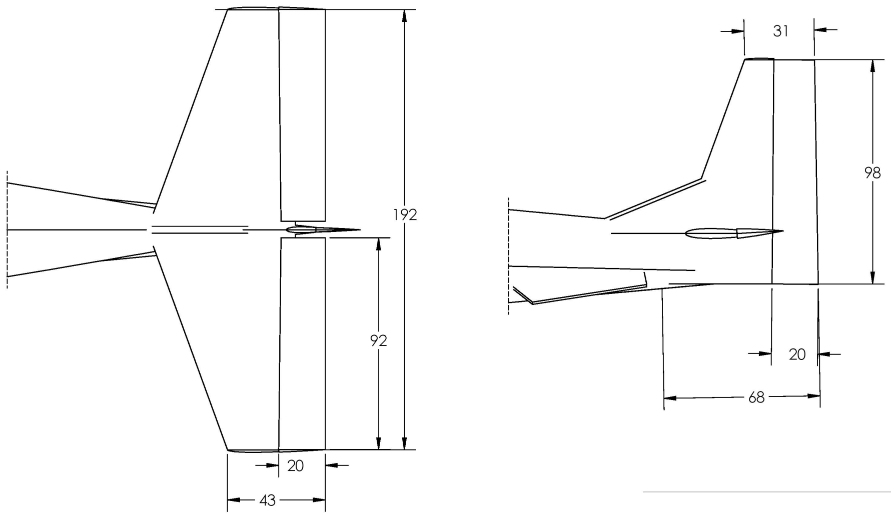
Crew Station Design

- 13-degree setback angle to accommodate ejection seats
- Optimized for sitting height of 44 inches
- 130" L x 48" W



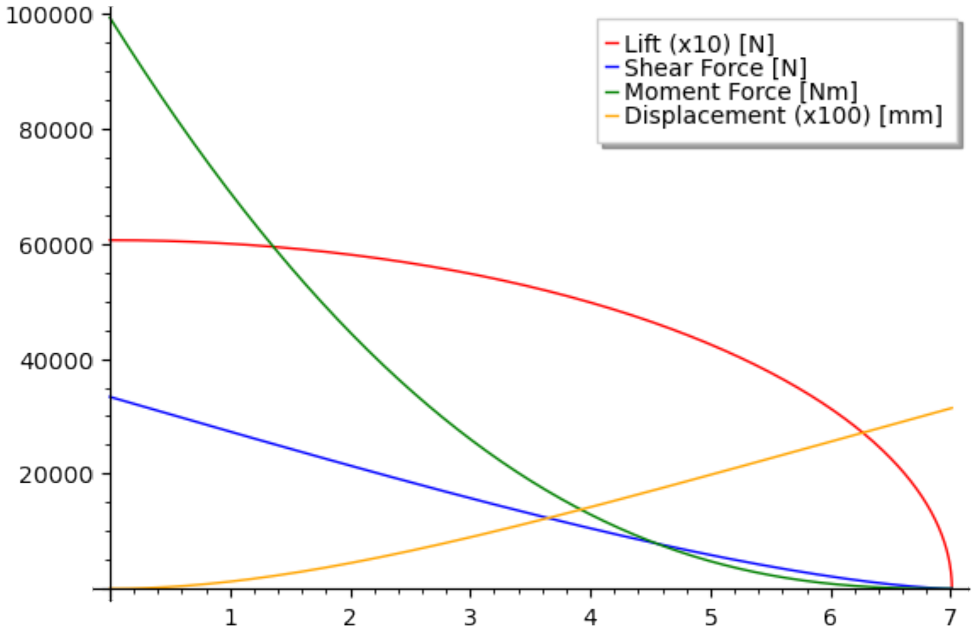
Tail Design

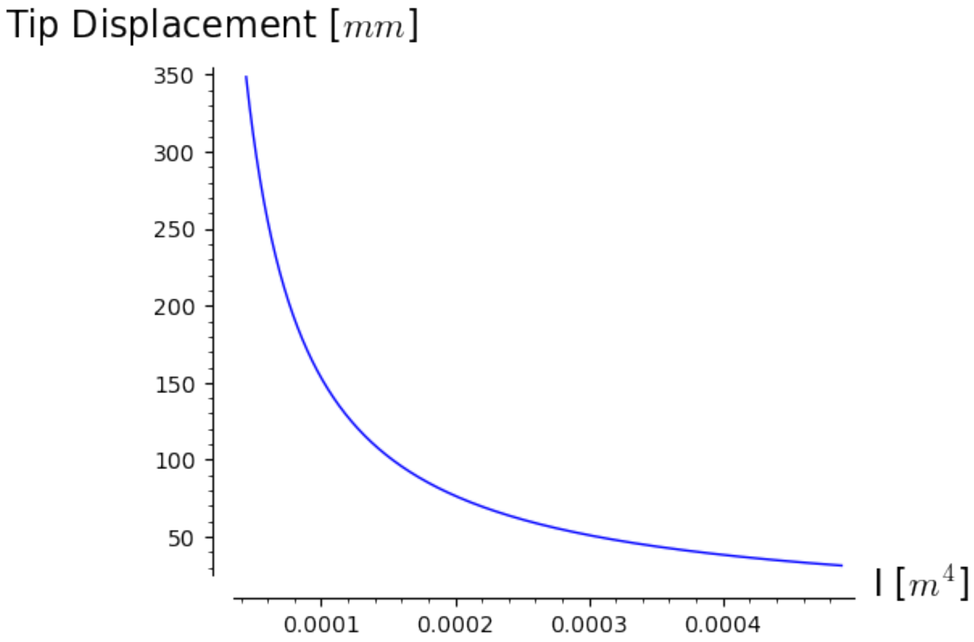
- Simple tail design oriented around ease of manufacturing while providing adequate stability.
- $S_{HT} = \frac{c_{HT}\bar{C}_w S_w}{L_{HT}}$ $S_{VT} = \frac{c_{VT} b_w S_w}{L_{VT}}$
- Trade study and historic data used for other parameters in tail design.
- The tail is located 23.5ft aft of the center of gravity, 60% of the fuselage length.
- Two ventral fins are used to provide lateral stability and spin recovery.
- A dorsal fin to improve the effectiveness at high angles of sideslip.



Design Aspect	Horizontal Stabilizer Values	Vertical Stabilizer Values
Chord	*4.5 ft*	*3.25 ft*
Span	*16 ft*	*8.15 ft*
Reference Area	*72.00 ft²*	*26.5 ft²*
Aspect Ratio	*3.55*	*1.89*
Sweep Angle	*0 deg.*	*20 deg.*
Taper Ratio	*0.5*	*0.43*

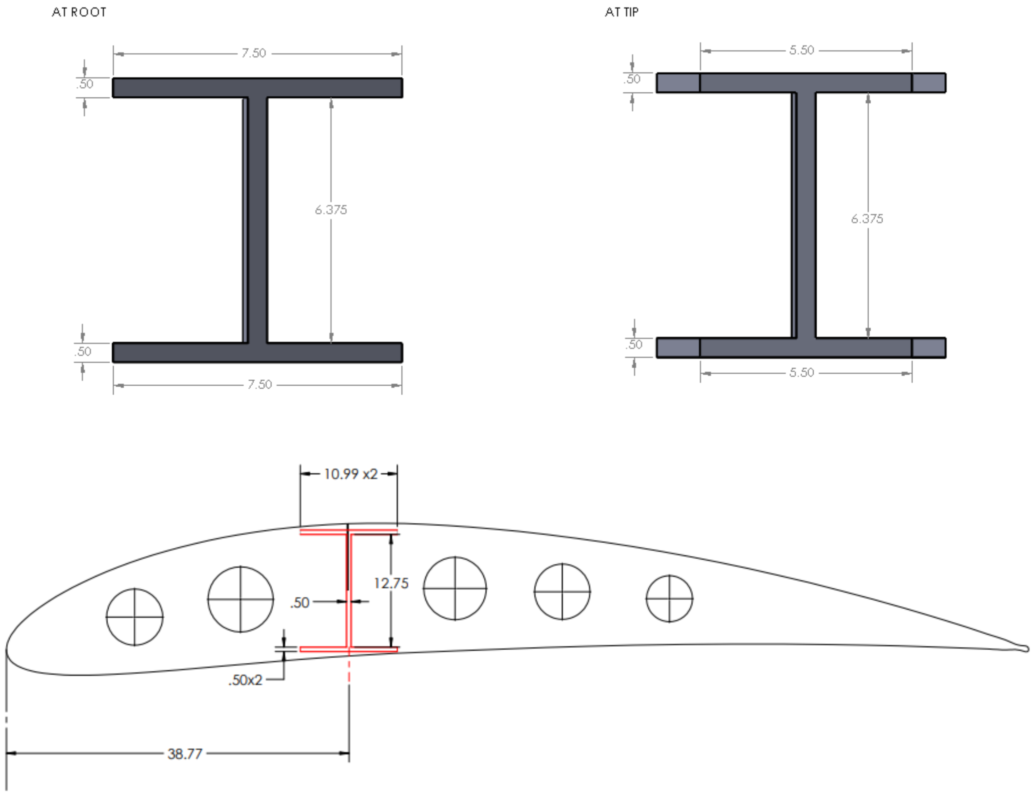
Wing Structure

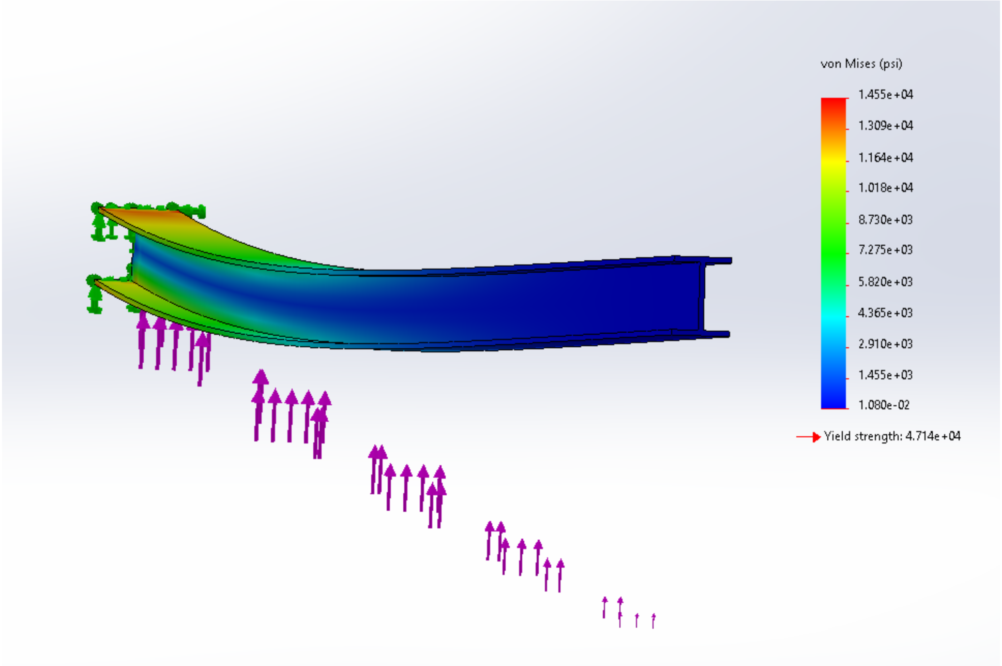




Preliminary Euler Beam Analysis

Wing Structure



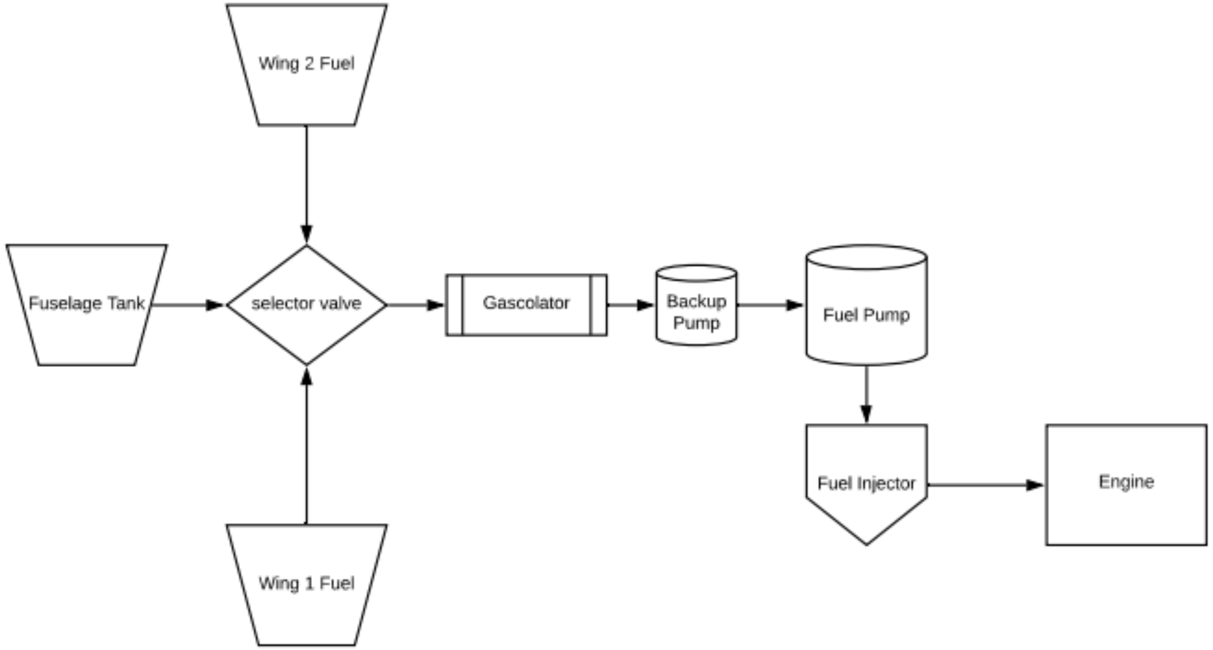


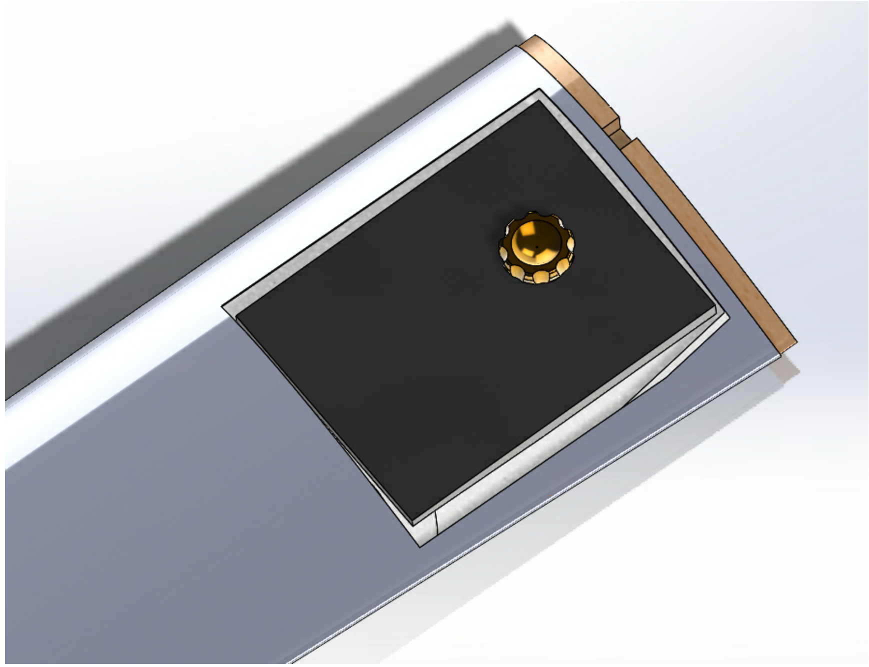
FEM Analysis

N=4 During Cruise

Fuel System

- Bladder tanks: Wings 180-Gal
- Auxiliary self-sealing tank: 80-Gal fuselage

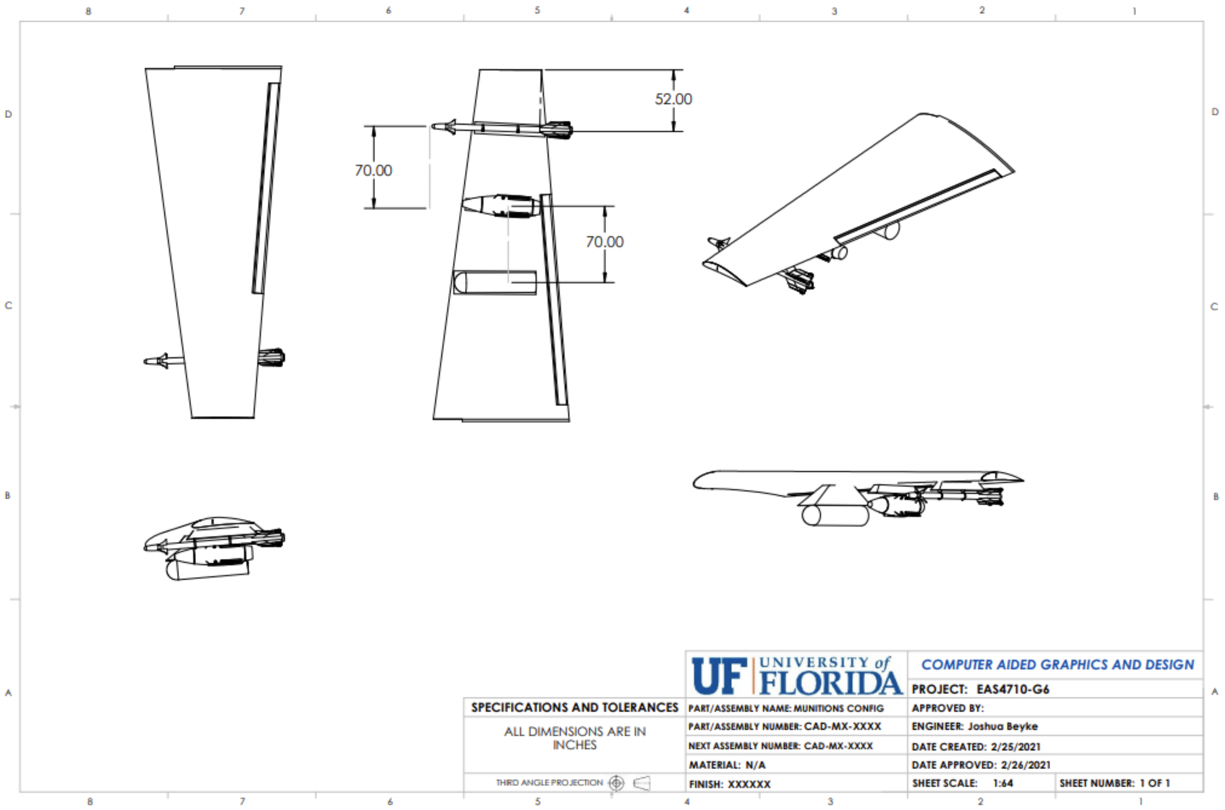




Fuel bladder representation under wing

Weapons/Armaments

WING WEAPON CARRIAGE			
Munition	**Weight (lbs)**	**Length**	**Height**
HMP400 Pod	197 (empty) 305 (loaded)	76.4”	17.1”
AIM-9L Missile	188	119”	5”
MK-82 Bomb	500	87.4”	10.75”
GBU-12 Bomb	510	128”	10.7”



M621 Air to Ground Integrated Gun

- 750 rpm fire rate
- 20x102 mm ammunition
- 250 rounds of ammunition storage
- Pod weight of 245 pounds
- Loaded weight of 377 pounds

Stealth Considerations

- Radar-absorbent paint used to absorb incoming radar signals and reduce radar detection
- Low IR reflectively paint to reduce infrared detectability
- Streamlined fairings to reduce aircraft noise outputted by extending landing gear and flaps

Subsystems

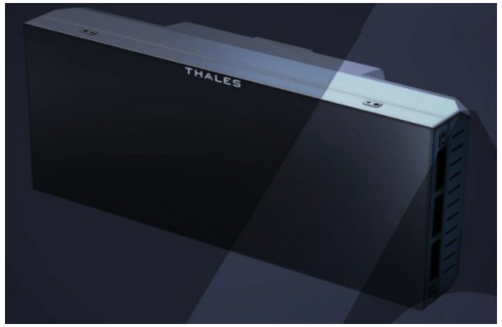
Electrical
- 115 VAC, 400Hz three-phase power source
- 28 VDC output to aircraft displays/instruments
- MIL-STD-704F compliant
- MPU (micro power unit) by Honeywell
- 28 VDC batteries (mainly for startup)

Pneumatic
- Environmental control system keeps avionics cooling and cabin pressurization stable
- Powered by the MPU when ground sources of power not available.
- Pressurized bleed air routed from engine through the Environmental Control Unit

AC normal operation characteristics - 400 Hertz

Steady state characteristics	Limits
Steady state voltage	108.0 to 118.0 Volts, RMS
Voltage unbalance	3.0 Volts, RMS maximum
Voltage modulation	2.5 Volts, RMS maximum
Voltage phase difference	116° to 124°
Distortion factor	0.05 maximum
Distortion spectrum	Figure 7
Crest factor	1.31 to 1.51
DC component	+ 0.10 to - 0.10 Volts
Steady state frequency	393 to 407 Hz
Frequency modulation	4 Hz
Transient characteristics	Limits
Peak voltage	±271.8 Volts
Voltage transient	Figure 3
Frequency transient	Figure 5

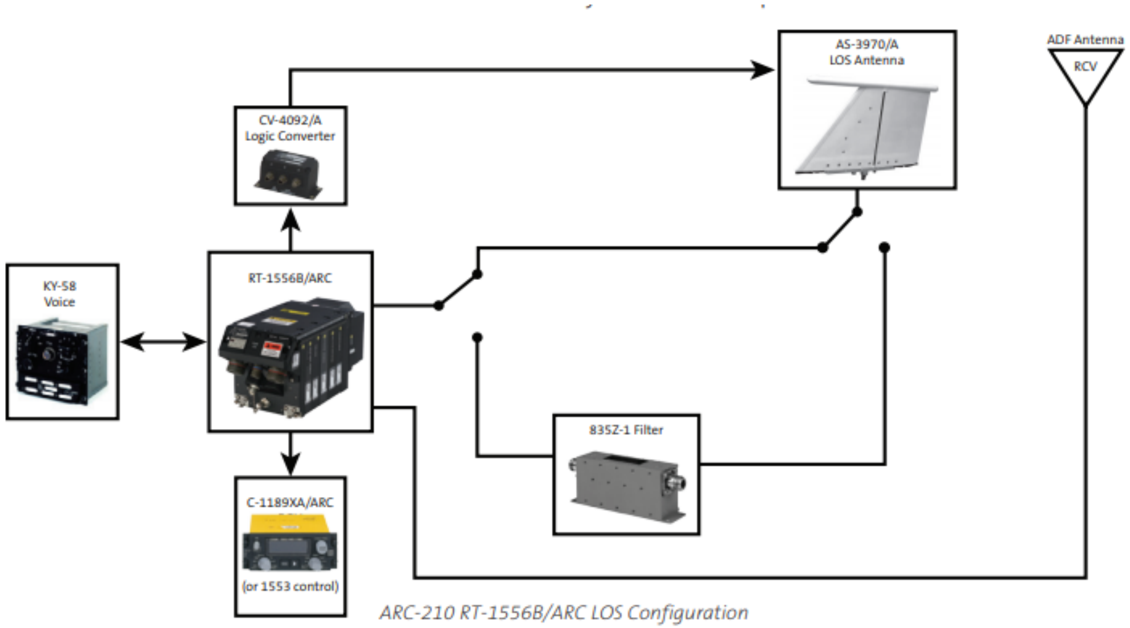
Radar
- Simplified into a single LRU, the AirMaster C system by Thales Group.
- Roughly 29.7cm x 42 cm , compact size



Radio
- AN/ARC-210 radio 30-941 MHz frequency range
- Communications security (COMSEC) functionality.
- Already used in US military aircraft

Flight Instruments
- Altimeters, airspeed/direction indicators, artificial horizons.
- Modern glass cockpit design
- Flight information accessed through Primary Flight Display (PFD)

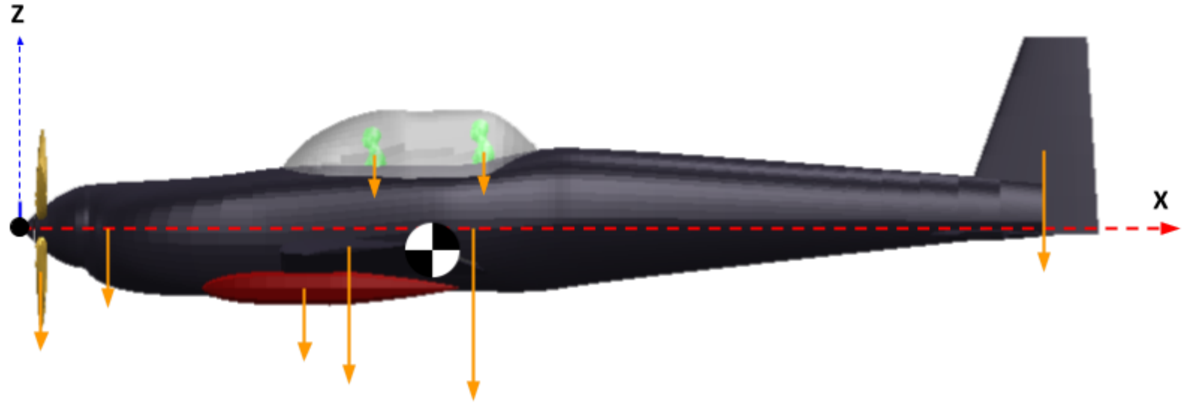
Navigational Aids
- GPS-Aided Inertial Navigation System (GAINS) from Raytheon
- Air data computer
- Marker Beacon



ARC-210 RT-1556B/ARC LOS Configuration

Weight Estimation

Aircraft Component (Sub-Component)	Weight (lbs)	X-Datum Distance (ft) (Measured from propeller tip)	Z-Datum Distance (ft) (Measured from propeller tip)
Engine	350	4.3	0
Wing	2062.04	13.16	-2
Fuselage	2100	~16.5	~0
Seats	400	15	2.08
Payloads	3000		
Fuel	1200	13.62	-1.8

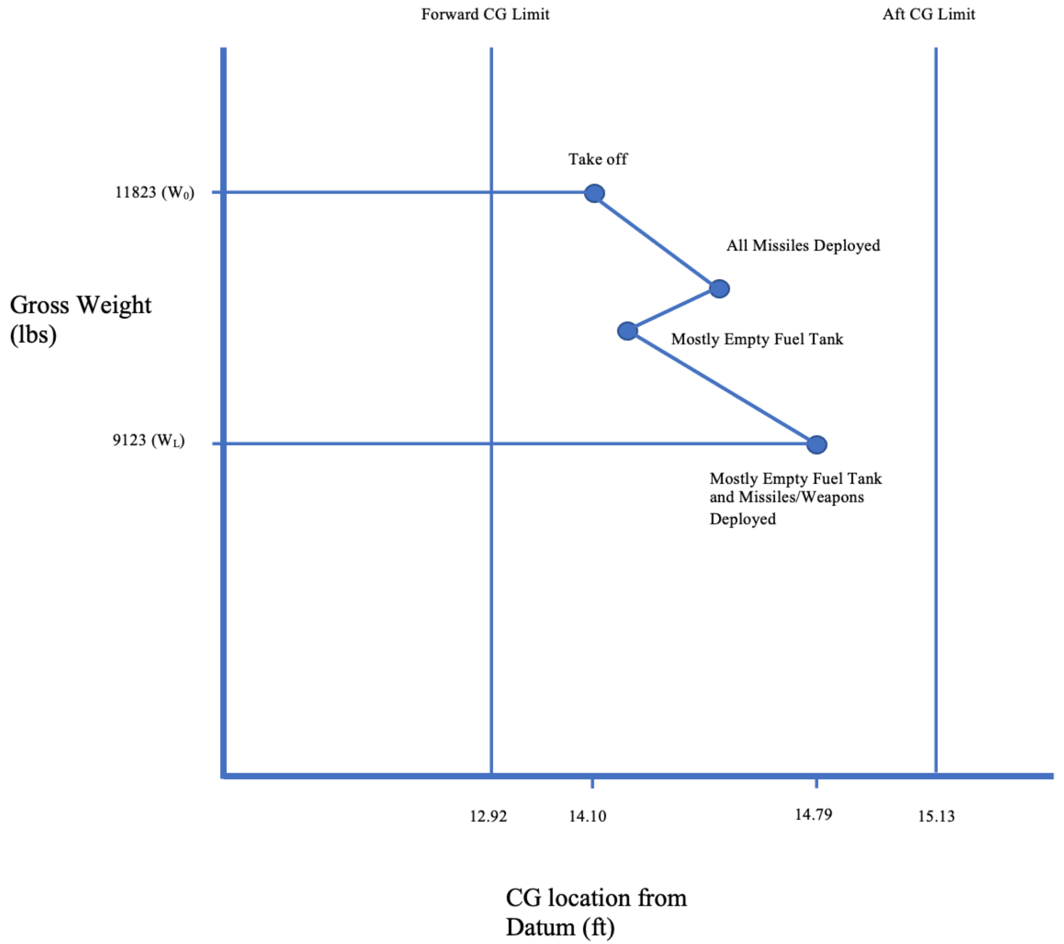


- Weights and distances are determined by one of the following:
  - i. OpenVSP
  - ii. SolidWORKS
  - iii. Textbook Weight Equations
  - iv. Online sources or similar aircraft
  - v. RFP

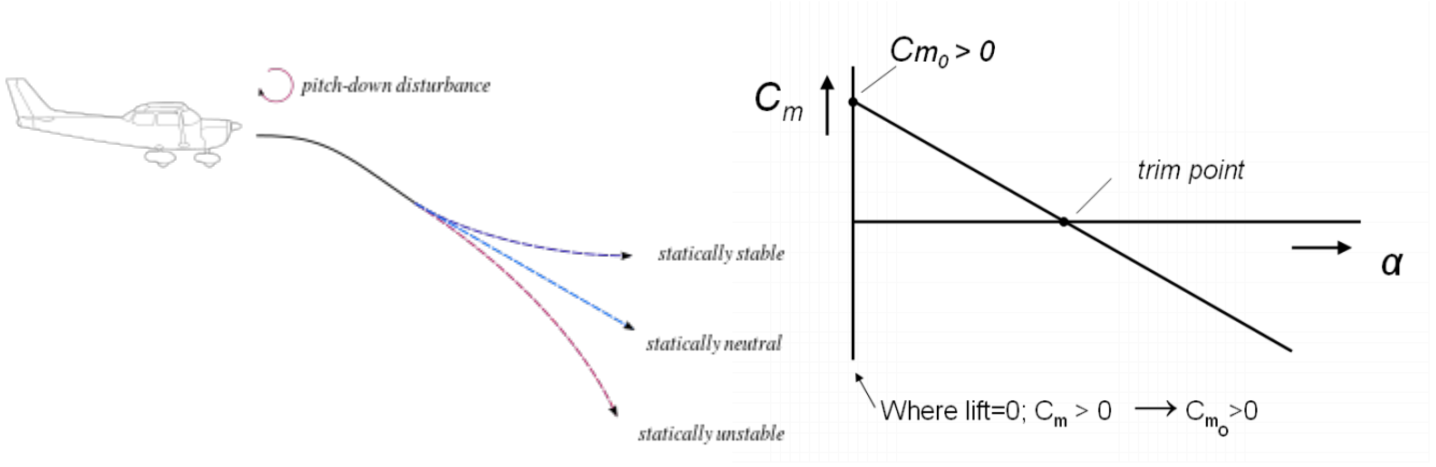
Center of Gravity Estimation

Loading Scenario	Gross Weight (lbs)	Center of Gravity About X axis (ft)	Center of Gravity About Z axis (ft)
Take Off	11823	14.10	-0.963
All Missiles Deployed	10323	14.65	-0.807
“Empty” Fuel Tank	10623	14.16	-0.868
“Empty” Fuel Tank and All Missiles Deployed	9123	14.79	-0.676

- The center of gravity is calculated for the Design Mission at 4 separate loading scenarios
- The center of gravity about the y axis is negligible
- The limits are determined by data and procedures used for similar aircraft



Longitudinal Stability Analysis

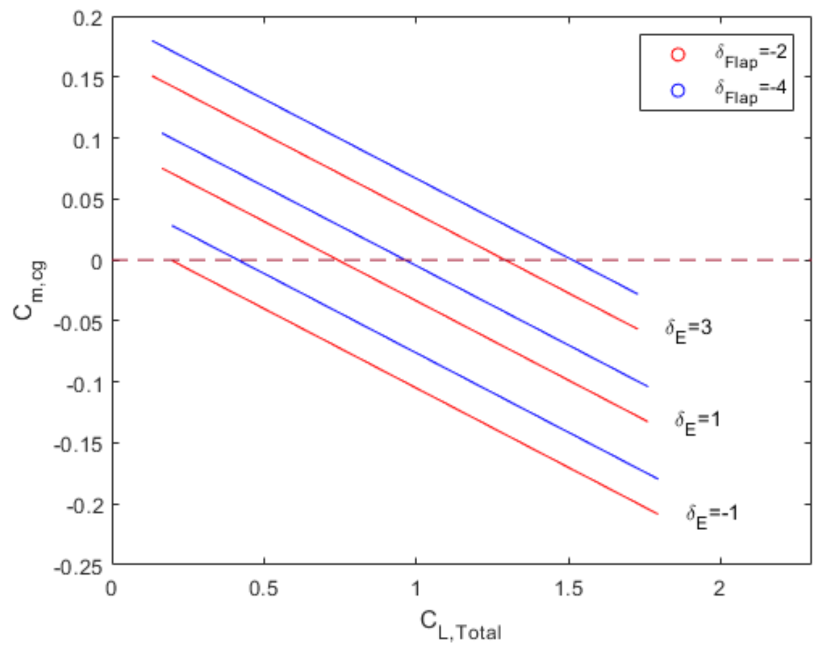


- Verify a negative C_{m_α}
- Verify a neutral point aft of CG
- Analyze trim conditions

$$C_{m_\alpha} = C_{L_\alpha}\left(\frac{X_{cg} - X_{acw}}{c}\right) + C_{m_{\alpha fus}} - \eta_h \frac{S_h}{S_w} C_{L_{\alpha h}} \frac{\partial \alpha_h}{\partial \alpha}\left(\frac{X_{ach} - X_{cg}}{c}\right) + \frac{F_{p_\alpha}}{qS_w}\frac{\partial \alpha_p}{\partial \alpha}\left(\frac{X_{cg} - X_p}{c}\right)$$

$$C_{m_{cg}} = C_L\left(\frac{X_{cg} - X_{acw}}{c}\right) + C_{m_w} + C_{m_{w\delta_f}}\delta_f + C_{m_{fus}} - \frac{q_h S_h}{qS_w} C_{L_h}\left(\frac{X_{ach} - X_{cg}}{c}\right) - \frac{Tz_t}{qS_w c} + \frac{F_p(X_{cg} - X_p)}{qS_w c}$$

$$\bar{X}_{np} = \frac{C_{L_\alpha}\bar{X}_{acw} - C_{m_{\alpha fus}} + \eta_h \frac{S_h}{S_w} C_{L_{\alpha h}} \frac{\partial \alpha_h}{\partial \alpha}\bar{X}_{ach} + \frac{F_{p_\alpha}}{qS_w}\frac{\partial \alpha_p}{\partial \alpha}\bar{X}_p}{C_{L_\alpha} + \eta_h \frac{S_h}{S_w} C_{L_{\alpha h}} \frac{\partial \alpha_h}{\partial \alpha} + \frac{F_{p_\alpha}}{qS_w}}$$



Lateral/Directional Stability Analysis

- Calculate yaw and roll moment derivatives
- Verify expected derivative values
- Trim analysis (crosswind landing)

Yaw moment derivative

$$C_{n\beta} = C_{n\beta w} + C_{n\beta fus} + C_{n\beta v}$$

$$C_{n_{\beta_w}} = C_L^2\left\{\frac{1}{4\pi A} - \left[\frac{\tan\Lambda}{\pi A(A+4\cos\Lambda)}\right] \times \left[\cos\Lambda - \frac{A}{2} - \frac{A^2}{8\cos\Lambda} + \frac{6(\bar{X}_{acw} - \bar{X}_{cg})\sin\Lambda}{A}\right]\right\}$$

$$C_{n_{\beta_{fus}}} = -1.3\frac{\text{volume}}{S_w b}\left(\frac{D_f}{W_f}\right)$$

$$C_{n_{\beta_v}} = C_{F_{\beta_v}}\frac{\partial\beta_v}{\partial\beta}\eta_v\frac{S_v}{S_w}(\bar{X}_{acv} - \bar{X}_{cg})$$

$\boldsymbol{C_{n_\beta}}$ = 0.129

Roll moment derivative

$$C_{l\beta} = C_{l\beta w} + C_{l\beta v}$$

$$C_{\ell_{\beta_w}} = \left(\frac{C_{\ell_{\beta_{wing}}}}{C_L}\right)C_L + (C_{\ell_\beta})_\Gamma + C_{\ell_{\beta_{wf}}}$$

$$(C_{\ell_\beta})_\Gamma = -\frac{C_{L_\alpha}\Gamma}{4}\left[\frac{2(1+2\lambda)}{3(1+\lambda)}\right]$$

$$C_{\ell_{\beta_{wf}}} = -1.2\frac{\sqrt{A}Z_{wf}(D_f + W_f)}{b^2}$$

$\boldsymbol{C_{l_\beta}}$= -0.166

Trim Analysis

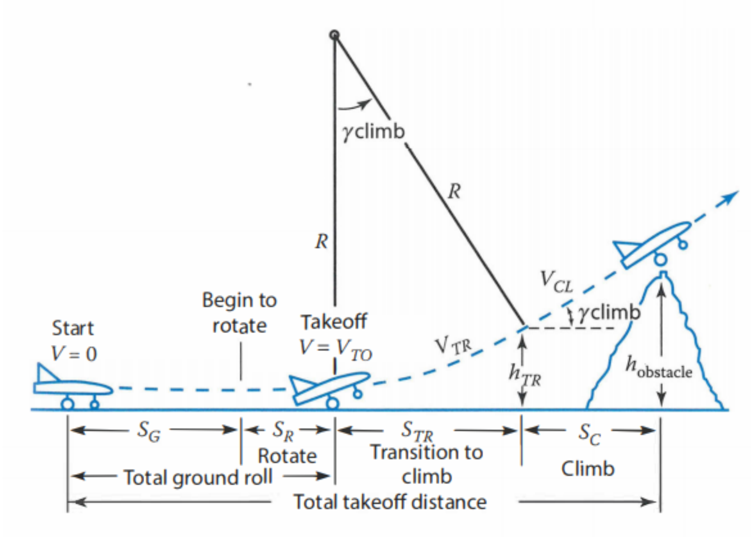
Goal: Maintain 11.5-degree side slip angle while using less than a 20-degree rudder deflection

$$C_n = \frac{N}{qS_w b} = C_{n_{\beta_w}}\beta + C_{n_{\delta_a}}\delta a + C_{n_{\beta_{fus}}}\beta + C_{n_{\beta_v}}\beta - \frac{T\bar{Y}_p}{qS_w} - \frac{D\bar{Y}_p}{qS_w} - \frac{F_p}{qS_w}(\bar{X}_{cg} - \bar{X}_p)$$

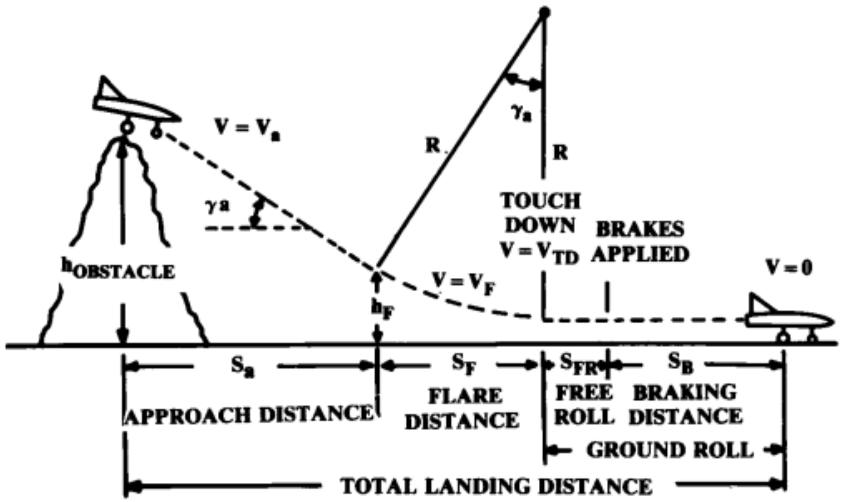
δ_r = -5.5 degrees

Takeoff/Landing Analysis

- Divided into ground roll, transition to climb, and climb (opposite order for landing)
- Calculations done at 6000ft altitude to satisfy design requirement

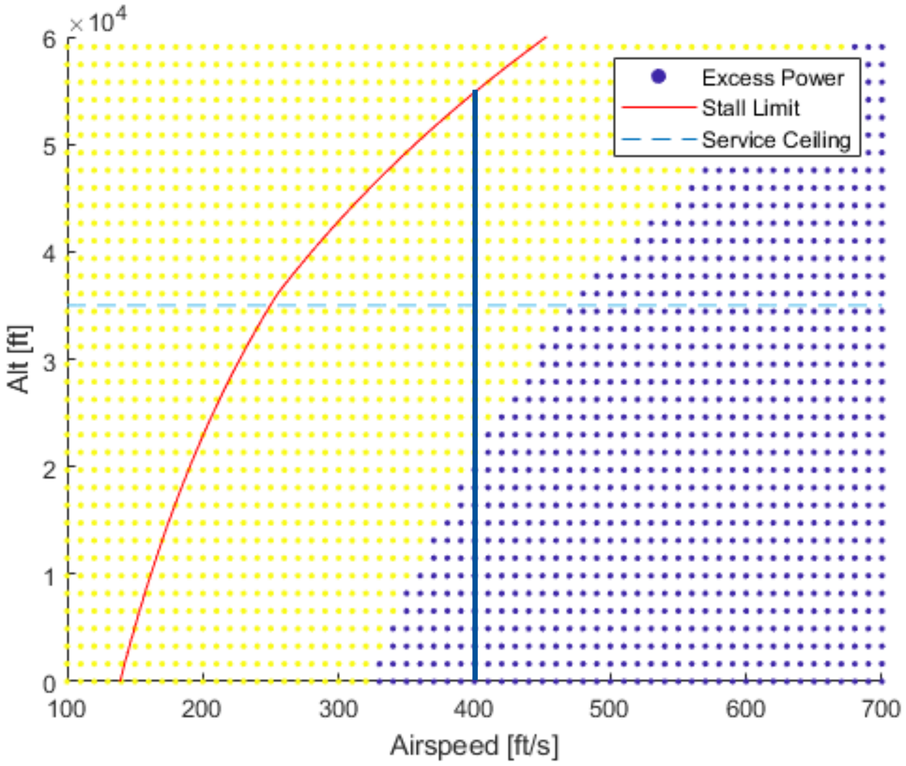


Ground Roll	1745.41 ft
Transition Distance	151.42 ft
Climb Distance	1153.35 ft
Total Takeoff Distance	3050.18 ft

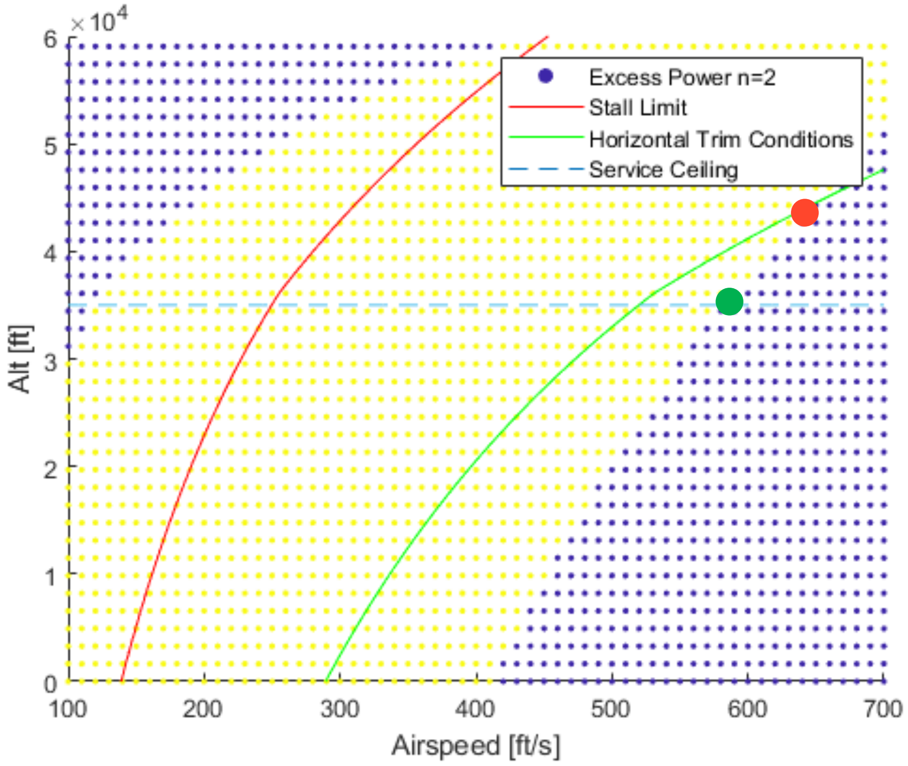


Approach Distance	616.01 ft
Flare Distance	251.89 ft
Ground Roll	1718 ft
Total Landing Distance	2585.9 ft

Performance Analysis



Takeoff Operating Envelope



Cruise Operating Envelope

Cost Analysis

G8-R Flyaway Cost

DAPCA IV Wrap Rates	
Engineering, R_E	$132.25
Tooling, R_T	$135.7
Quality Control, R_Q	$124.2
Manufacturing, R_M	$112.7

DAPCA IV Cost Model Estimates	
10 Aircrafts	$463.6 million
50 Aircrafts	**$933.2 Million**

G8-R Operating Costs

Maintenance Material Cost	**$120/FH (15.5%)**	
Maintenance Labor Cost	$225/FH (29.0%)	
Fuel Consumption Cost	$120/FH (15.5%)	
Military Crew Cost	$310/FH (40.0%)	
Total Operating Costs (One Aircraft)	$775/FH	**$930,000 per year**
Total Operating Costs (Fifty Aircraft)	$38,750/FH	$46,500,000 per year

Cost Estimation

RDT&E and Flyaway Costs – 50 aircraft Rand Dapca IV model Individual Contributors

Eng Hours	$H_E = 4.86W_E^{0.777}V^{0.894}Q^{0.163}$	**237.85 million**
Tooling Hours	$H_T = 5.99W_E^{0.777}V^{0.696}Q^{.263}$	**142 million**
Mfg Hours	$H_M = 7.37W_E^{0.82}V^{0.484}Q^{0.641}$	**276.4 million**
QC hours	$H_Q = .133H_M$	**40.5 million**
Devel Support Cost	$C_D = 45.42W_E^{0.630}V^{1.3}$	**24.5 million**
Fly Test Cost	$C_F = 1243.03W_E^{0.325}V^{0.822}FTA^{1.21}$	**6.23 million**
Mfg Materials Cost	$C_M = 11W_E^{0.921}V^{0.621}Q^{0.799}$	**37.3 million**
Engine cost	$969,000 / unit	**48.45 million**
Avionics cost	$6000/lb	**120 million**
Total		**933.2 million**