Herbert Wertheim
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# The Boeing Constrictors


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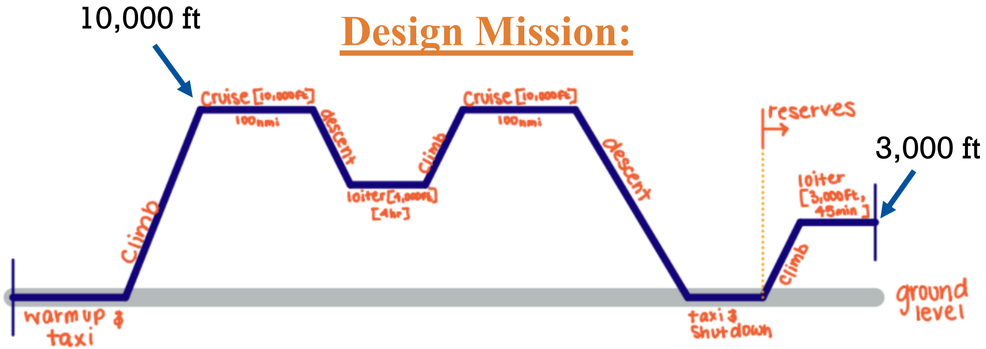
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

**Objective:** Create an austere field light attack aircraft that can provide close air support to ground forces

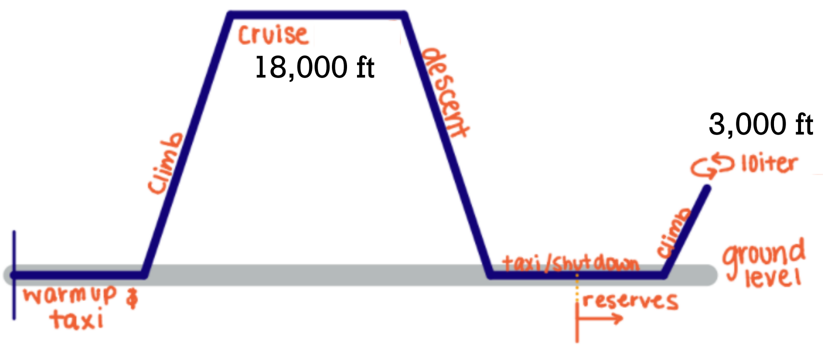
## Requirements:

- ≤ 4,000 ft for takeoff and landing
- 3000 lbs of armament
- Integrated gun for ground targets
- Service life of 15,000 hours over 25 years
- Service ceiling ≥ 30,000 ft
- Two crew members with zero-zero ejection seats
- Reasonable cost for design

## Design Mission:




## Ferry Mission:



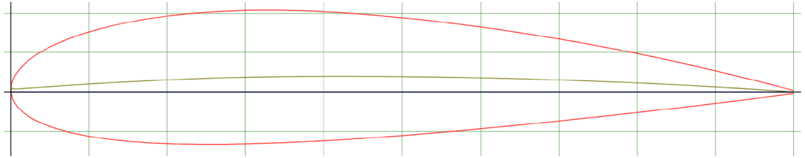
# Wing Design

## Airfoil

| Airfoil Selection | | | NACA 4412 | | | NACA 2215 | | | NACA 2417 | | | NACA 63-415 | | | NACA 63-218 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Objective | Weighting | Parameter | Mag. | Score | Value | Mag. | Score | Value | Mag. | Score | Value | Mag. | Score | Value | Mag. | Score | Value |
| Zero AOA Drag Coeff. | 0.225 | N/A | 0.00546 | 10.0 | 2.3 | 0.00621 | 8.79 | 1.98 | 0.00572 | 9.55 | 2.15 | 0.00680 | 8.03 | 2.00 | 0.00588 | 9.29 | 2.09 |
| Cruise Lift to Drag ratio | 0.35 | N/A | 88.54 | 1.66 | 0.58 | 34.23 | 4.30 | 1.44 | 43.13 | 3.41 | 1.19 | 50.35 | 2.92 | 1.02 | 29.68 | 4.96 | 1.59 |
| Stall AOA | 0.275 | Degrees | 19.4 | 9.24 | 2.54 | 20.1 | 9.57 | 2.63 | 21.0 | 10.0 | 2.75 | 20.0 | 9.52 | 2.62 | 19.0 | 9.05 | 2.49 |
| Zero AOA Moment Coeff. | 0.15 | N/A | -0.1053 | 3.28 | 0.49 | -0.0345 | 10.0 | 1.5 | -0.0525 | 6.57 | 0.98 | -0.0786 | 4.39 | 0.66 | -0.0386 | 8.94 | 1.34 |
| Overall value | | | | | 5.86 | | | 7.55 | | | 7.58 | | | 6.30 | | | 7.51 |

- Study of airfoils of various light attack aircraft
  - A2D Skyshark with the NACA 4412
  - T-6 Texan with the NACA 2215
  - A-1 Skyraider with the NACA 2417
- Xfoil is used to generate values for NACA airfoils
  - Simulations based on a $Re = 7.67 \times 10^6$
- NACA 2417 chosen as design airfoil
  - Lowest drag coefficient at zero AOA
  - Highest stall AOA


A-1 Skyraider, a historical operator of the NACA 2417 airfoil

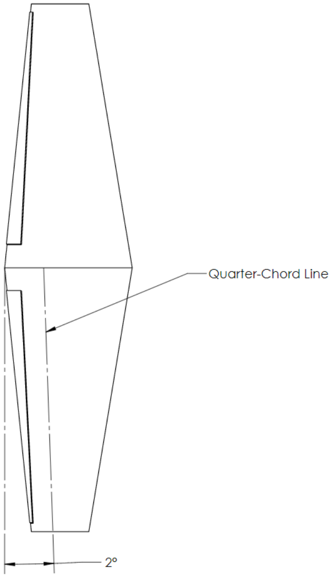


Side profile of a NACA 2417 airfoil

# Wing Design

## Wing Specifications

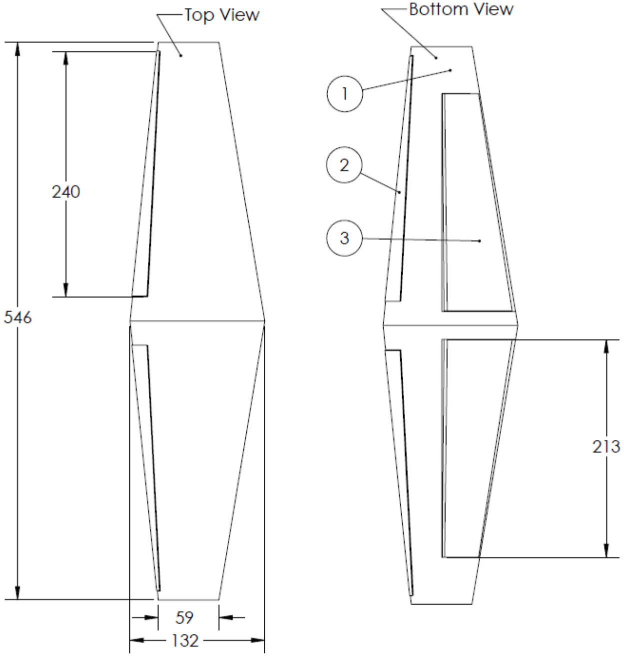
- Trapezoidal Wing
- Wingspan = 45.49 ft
- Aspect Ratio = 5.7
- Reference Area = 362.97 $ft^2$
- Incidence angle = 1°
- Taper Ratio = 0.45
  - Root Chord = 11 ft
  - Wingtip Chord = 4.95 ft
- Leading Edge Slats
- Trailing Edge Kruger Flaps




Sweep: 2°

Twist: 3°

| ITEM NO. | QTY. | PART/ASSEMBLY NAME |
|---|---|---|
| 1 | 1 | Wing Structure |
| 2 | 1 | Leading Edge Slats |
| 3 | 1 | Kruger Flaps |




Various Wing Dimensions, Shown in inches

# Wing Design

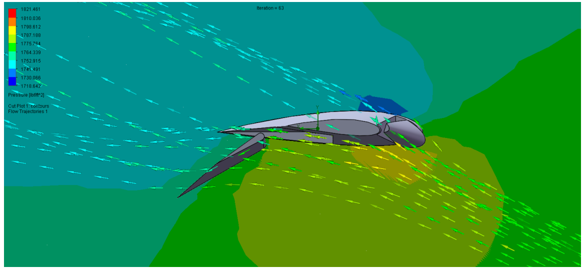
## Lift Generation

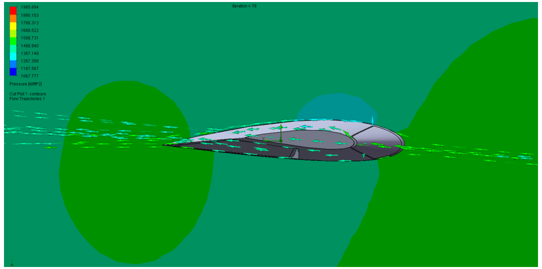
- Solidworks Flow Simulation used to analyze wing performance during 3 segments of flight: Takeoff, Cruise, and Landing
- Generate coefficient of lift of the wing for each segment
  - Takeoff = 1.21
  - Cruise = 0.33
  - Landing = 1.24
- Aircraft can sustain a landing velocity of 194.89 ft/s

VALUES FOR DIFFERENT FLIGHT SEGMENTS

| Value Type | Take-off | Cruise | Landing |
|---|---|---|---|
| Lift (lbf) | 20,116 | 21,433 | 16,989 |
| Angle of Attack (°) | 20 | 4 | 25 |
| Air Velocity (ft/s) | 215 | 450 | 194.89 |
| Air density (slug/ft$^3$) | 0.001987 | 0.001756 | 0.001987 |
| Wing Reference Area (ft$^2$) | 362.97 | 362.97 | 362.97 |

Table showing lift generation of the wing for each segment of flight



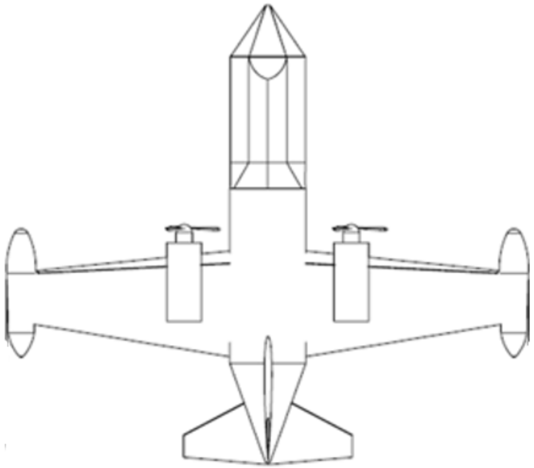


Solidworks Flow Simulation pressure distribution with and without high lift devices

# Powerplant Layout

## Twin Tractor Turboprop

- Turboprop- efficient at low speed/altitude
- Twin engines, one on each wing
- Smaller moment than nose-mounted engine
  - Higher maneuverability, greater load flexibility
- Engine-out survivability
- Increased cross-wind resistance



# Powerplant

## PW123 by Pratt and Whitney

- Design:
  - Calculated horsepower-to-weight ratio = 0.1418
  - Req'd shaft horsepower = 3505
  - PW123 shp output = 2400
    - Twin output = 4800 shp
  - Weight = 900 lbs
  - SFC = 0.52 lbs/hp
- Proven Reliability:
  - PW100 series in service since 1984
  - Used around the world in civil and military fleets

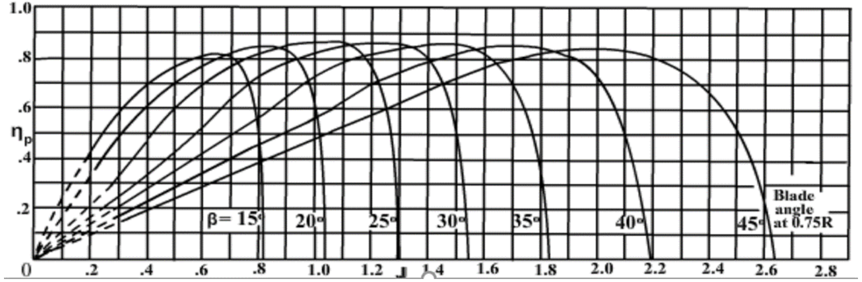
EADS Casa C-295 aircraft featuring PW100 series powerplant

Embraer EMB-120 aircraft featuring PW100 series powerplant

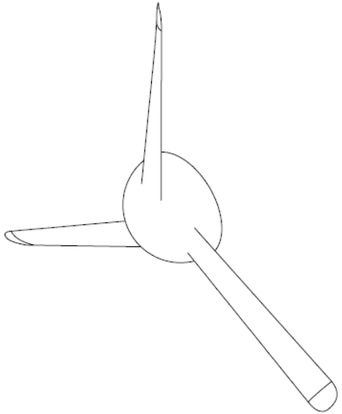
# Propellor Design

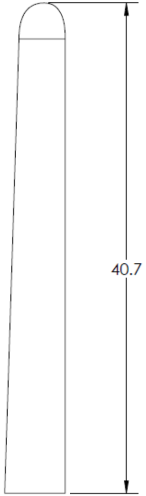
## Custom 3-Blade Design

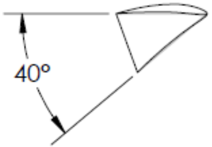
- NACA 6409 airfoil
- 40° twist angle
- 1.71 advance ratio
- 6.79 ft diameter
- High propellor efficiency – 85%
  - Calculated req'd efficiencies: 50.9% takeoff, 29.8% cruise




Advance ratio vs Propeller efficiency for various blade twists





# Fuel Tank Design

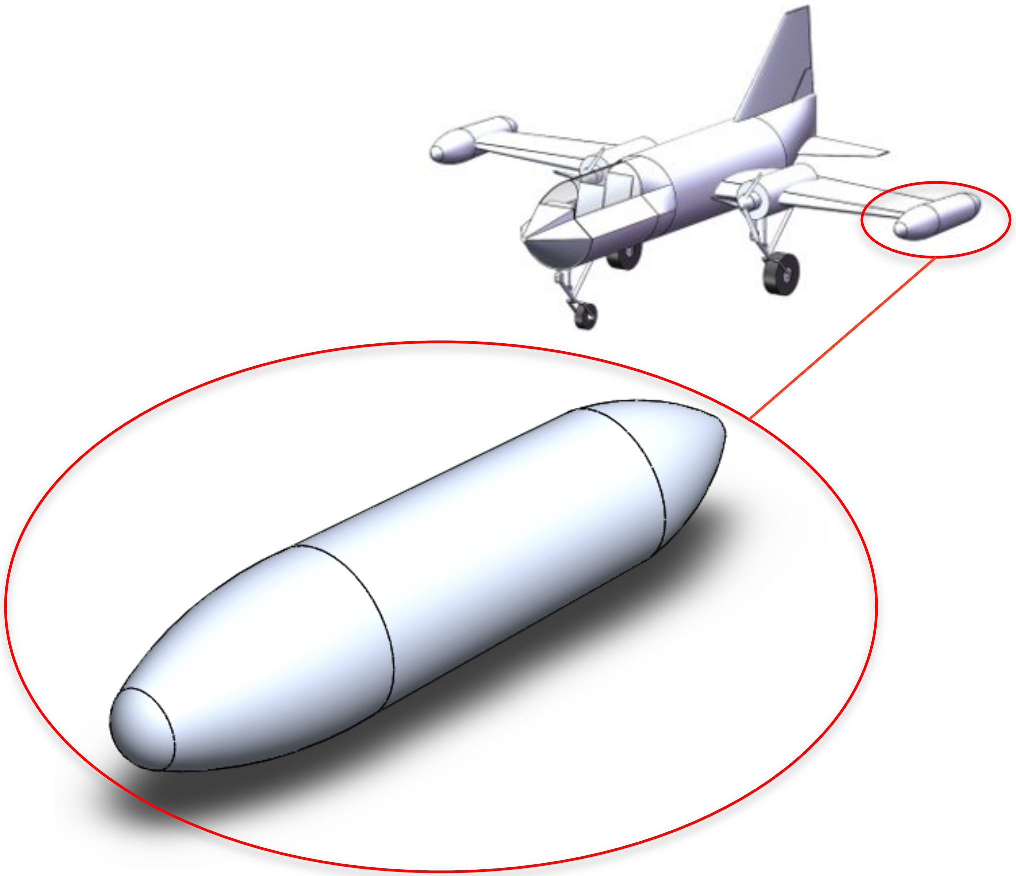
## Jet A-1 Fuel

- Fuel Density = 6.468 lb/gal to 7.01 lb/gal
- Weight difference in design mission = 4,177 lbs
- Total fuel amount = 646 gal
- *Note:* Fuel includes foam additives to prevent fire hazards, requiring the tanks to carry around 685 gal of fluid (fuel & foam)

# Fuel Tank Design

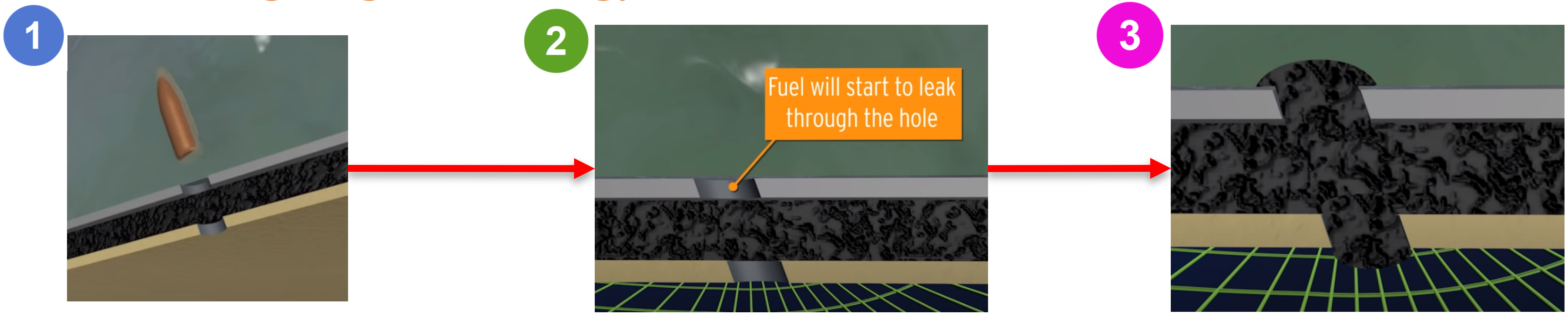
## Wing-tip Tanks

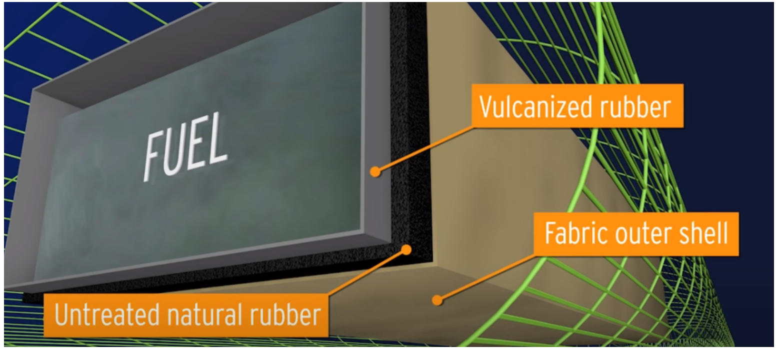
- Fluid Amount = 170 gal for each tank
- Weight w/o fuel = 173 lbs for each
- Weight with fuel = 1289.6 lbs for each
- Material = Aluminum 6063-T6
- Thickness = 6 gauge or 0.204 in.
- Req'd inner volume = 39,270 $in^3$
- Inner Volume = 43,799.562 $in^3$
- Outer Volume = 45,519 $in^3$



# Fuel Tank Design

## Self-sealing Bag Technology

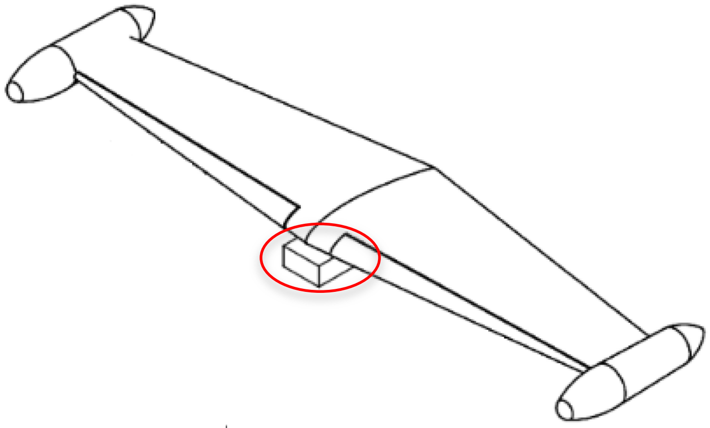


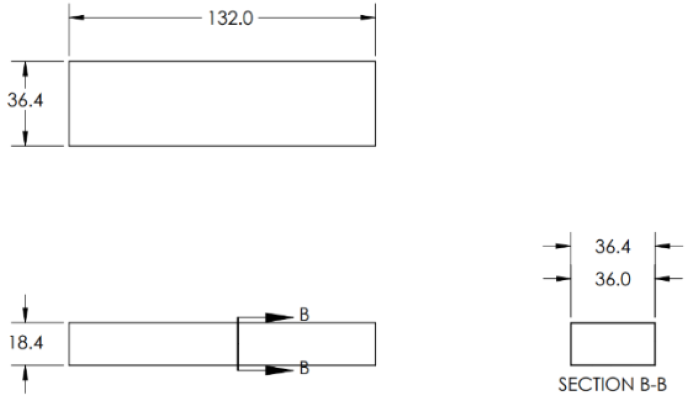



# Fuel Tank Design

## Fuselage Tank

- Location = Underneath the wing inside the fuselage
- Amount of fluid = 345 gal
- Req'd Inner Volume = 79,669 $in^3$
- Inner Volume = 85,406.4 $in^3$
- Outer Volume = 88,408.32 $in^3$
- Weight = 2218.65 lbs

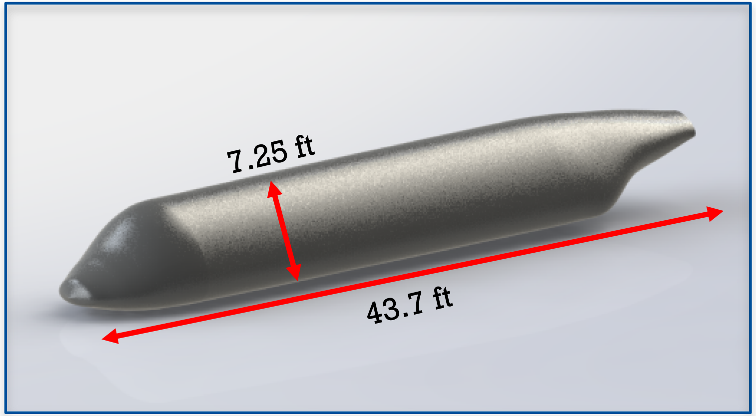




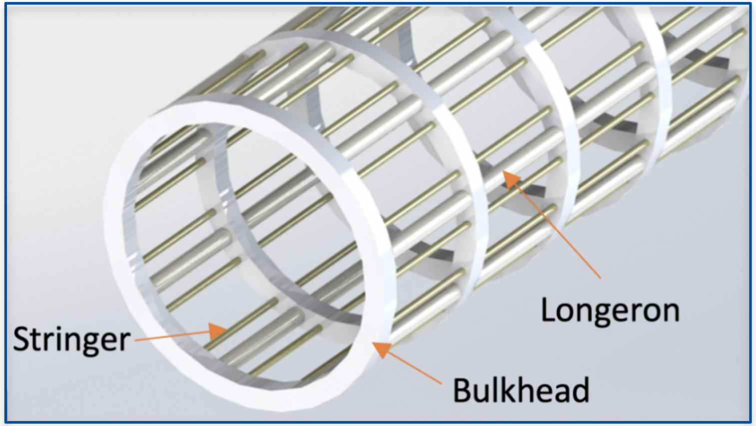
# Fuselage Design

## Fuselage Specifications

- Fitness Ratio = 6.02
- Empty Weight = 4601 lbs
- Volume = 1616 ft$^3$
- Aluminum 6063-T6, Tensile Yield Strength = 66.7 ksi
  - Skin, Stringers, Bulkheads
- Steel AISI 4130, Tensile Yield Strength = 31.0 ksi
  - Longerons



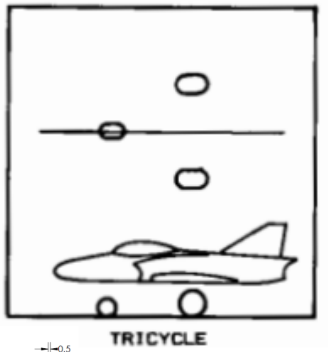

Semi-Monocoque Structure

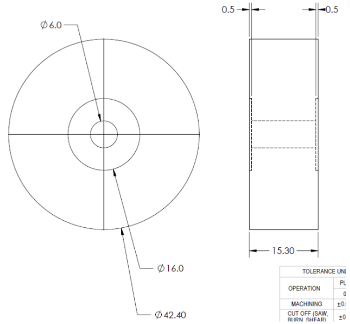


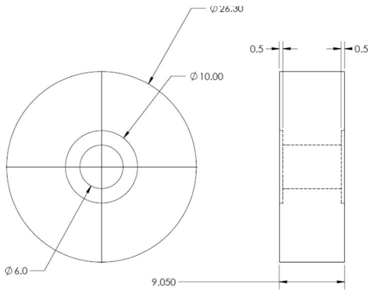
# Landing Gear

## Tires

- Tricycle Landing Gear
- Max tip back angle of 20°
- Nose gear 6ft forward of CG
- Main gears 1ft aft of CG
- Main gears 8ft away from centerline
- Nose tire D = 26.3 in W = 9.05 in Pressure = 41 psi
- Main tire D = 42.4 in W = 15.3 in Pressure = 53 psi



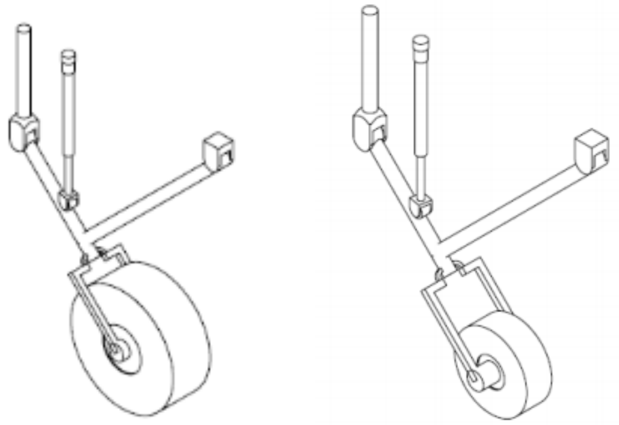



# Landing Gear

## Shock-Absorber

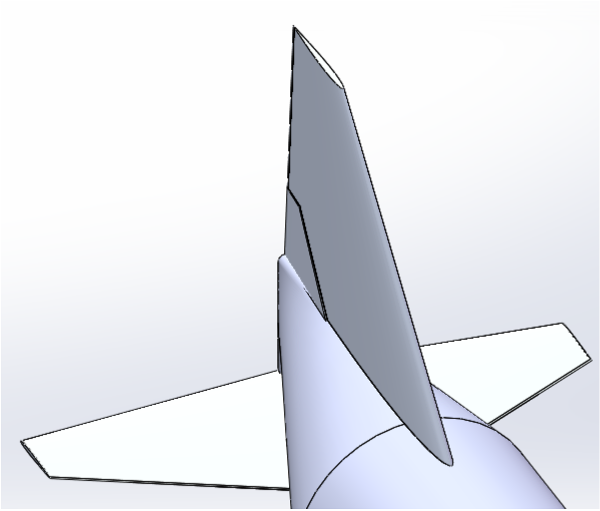
- Levered oleo shock strut
- Metered orifice oleo
- Oleo stroke = 14.3 in
- Oleo length = 4.17 ft
- Landing gear height = 10.11ft
- Nose oleo D = 1.81 in
- Main oleo D = 3.15 in
- Nose landing gear retracts rearwards
- Main landing gear retracts into engine fairing



# Tail Design

## Conventional Layout

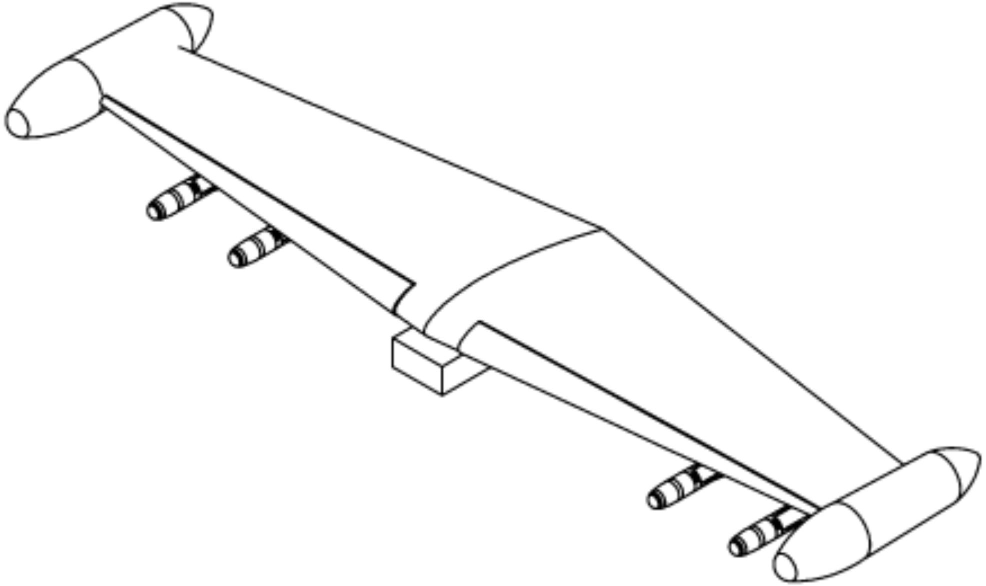
- Conventional layout- proven design
- Minimize manufacturing complexity/cost
- Horizontal tail in-line with wing
  - Avoids blanketing
- Horizontal span/reference area: 16.18 ft, 74.82 $ft^2$
- Vertical span/reference area: 7.78 ft, 60.51 $ft^2$



Conventional vertical/horizontal tail structure with control surfaces

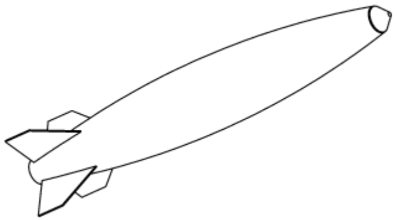
# Weapon Selection

- Primary role: attacking small ground targets
- 3000 lb. maximum payload
- Balance constraint
- Cruise speed of 400 ft/s
- External mounting via pylon
- No internal bombay required



# Loadout 1- Heavy Bomb Loadout

- 5 x Mk. 82 Large Diameter General Purpose bomb
- 3 mounted under the fuselage and 2 wing mounted
- Designed for fortified, static positions
- 2500 lbs of ordinance

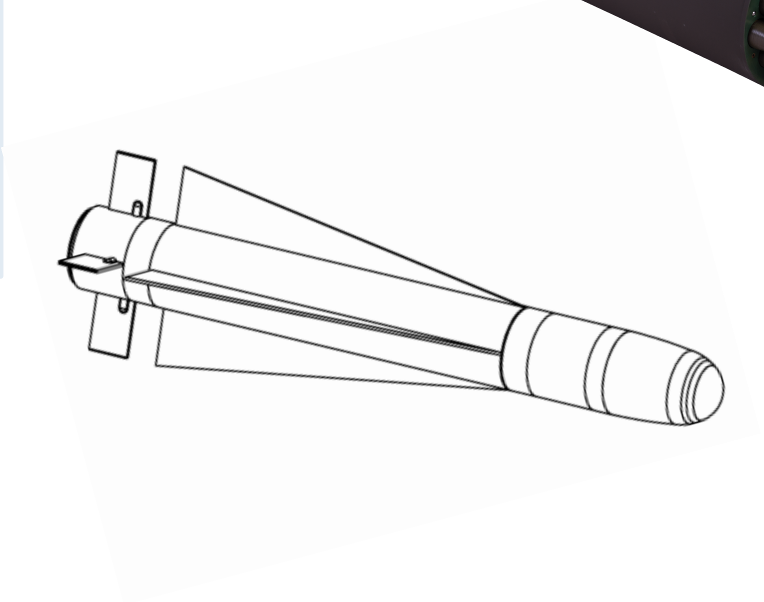


# Loadout 2-Mixed Bomb  Package

- Mk. 82 LDGP (fuselage mounted)
- GRU 61/a Bomb Carriages x2 each with 4 GRU 39B
- Greater number of targets
- 3160 lbs. of ordinance

# Loadout 3- Rocket Package

- AGM-65 Air-to-Ground IR Missile x4 (wing mounted)
- M261 Hydra Rocket Drum w/ 19 2.75” Hydra Rockets
- Ranged engagement with moving targets
- 3240lbs of ordinance



# Mounted Gun-Browning M2 0.50 caliber

- 500 rounds of ammunition
- Primary soft ground targets
- Secondary aircraft engagement
- Parts are commonly available

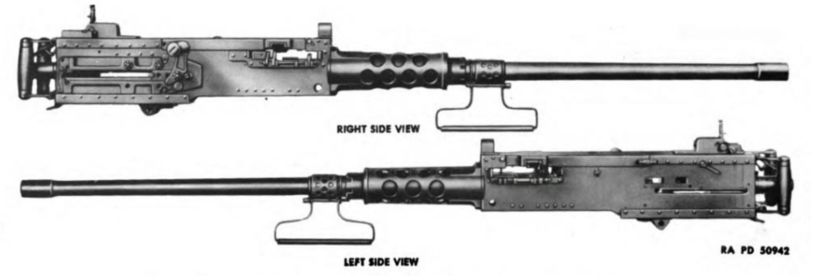


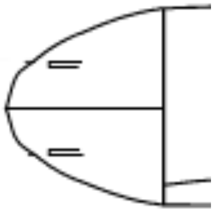

*Figure 7—Browning Machine Gun, Cal. .50, M2, Heavy Barrel, Flexible*

SPECIFICATIONS

| | | | | | |
|---|---|---|---|---|---|
| Weight of gun | — | 84 lb | Weight of barrel | — | 28 lb |
| Length of gun | — | $65\frac{1}{8}$ in. | Length of barrel | — | 45 in. |

CHECK LIST

Spade grip back plate (with bolt latch release and buffer tube sleeve assembly)
Front cartridge stop
Rear cartridge stop
R.H. rear cartridge stop assembly
Link stripper
Bolt latch and related parts
Trigger bar
Trigger bar pin assembly
Retracting slide group assembly
Front sight assembly
Rear sight group assembly
Barrel carrier assembly
Bolt stud

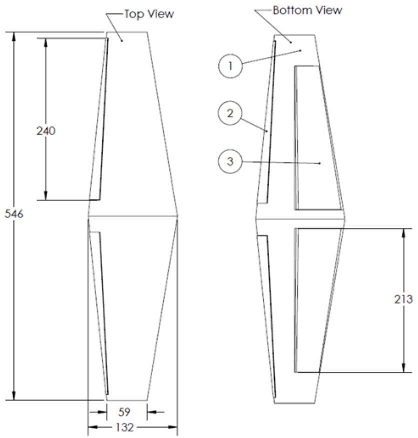


# Stealth Considerations

## Radar Detectability:

### General:

- Angled and swept surfaces
- Weapons



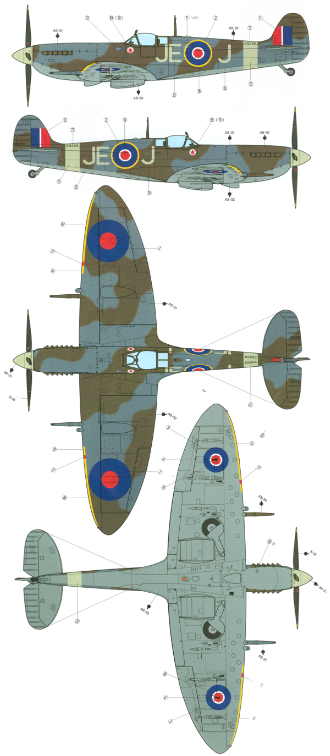

### Infrared:

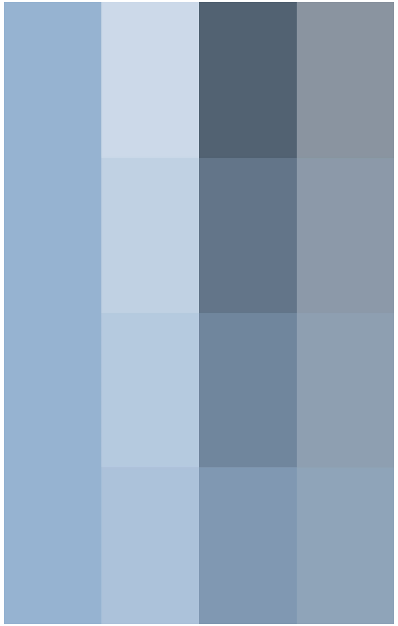
- Using a prop aircraft to reduce engine heat emissions
- Sun Glint

# Stealth Considerations

## Visual Detectability

- Reduced heat emissions from turboprop
- Paint
- Window Glint





## Acoustic Detectability

- Insulation
- Prop vs. Jet

# Cost

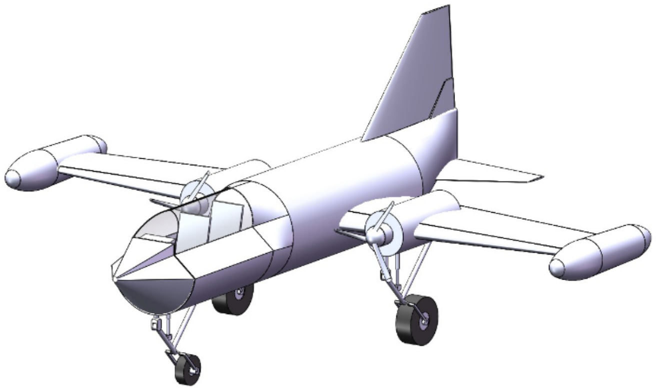
- Non-Recurring: $516.1 million
  - Engineering: $230.9 million
  - Military Airworthiness: $142.4 million
  - Tooling: $93.3 million
  - Manufacturing Costs: $49.5 million

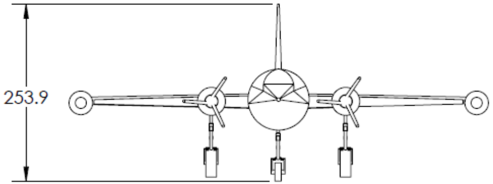
- Yearly Operation (1200 hrs): $369 million
  - Fuel: $9.7 million
  - Crew: $73.1 million
  - Maintenance: $286.2 million

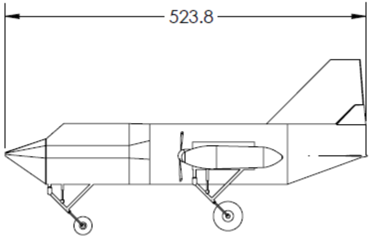
- Acquisition Cost (Fleet of 50): $11.16 billion
  - Engineering: $5.44 billion
  - Tooling: $2.2 billion
  - Manufacturing: $1.01 billion
  - Quality Control: $148 million
  - Engines: $98.8 million
  - Avionics $2.26 billion

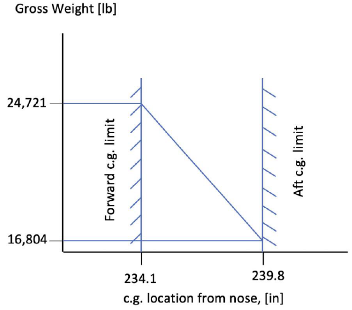
# Final Design

- Length: 43.65 ft
- Height: 21.16 ft
- Wingspan: 45.49 ft
- Gross Weight: 24,721 lbs
- Engines: 2 PW123 Turboprops
- Crew: 2 (with K-36 Zero-Zero Ejection Seats)
- Takeoff Distance: 3,653 ft
- Landing Distance: 3,999 ft
- Range: 1072 nm
- Service Ceiling: 47,683 ft
- Service Life: 30,000 hrs at 25 years (1,200 hr per year)
- Weapons
  - 3 weapons packages up to 3240 lbs
  - 2 .50 M2 Browning MGs imbedded into the nose





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