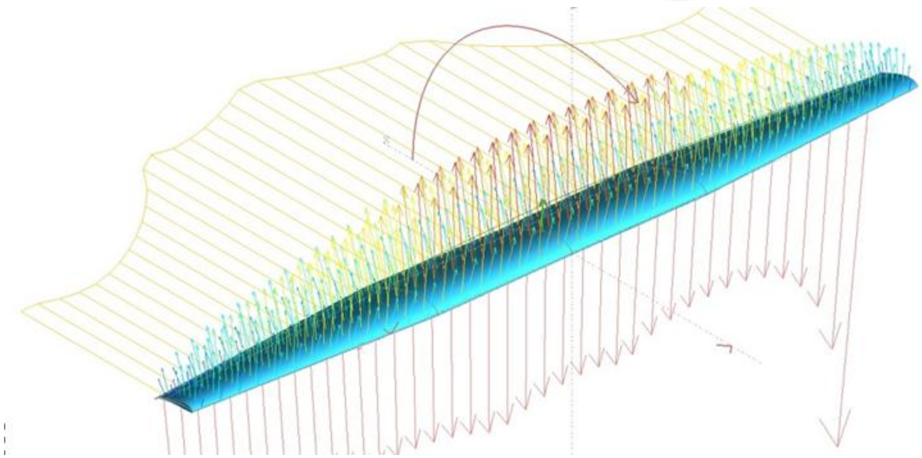
Aero Design



Group 10

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Outline

- Project Specifications
  - Airplane guidelines
  - Flight guidelines
  - Scoring
- Project Design
  - Wing
  - Tail Boom
- Calculations
  - Performance
  - Weight
  - Fuselage sizing
    - Length, Width, Height
  - Drag
- Material Selection
  - Aircraft
  - Payload
- Cost Analysis
- Summary

- Summary
- Product Specifications
- Design
  - Wing
  - Tail Boom
- Concepts & Selection
- Materials
- Calculations? Need or replace with Concept analysis?
- Concept Analysis
  - Aerodynamics
  - Stability & Control
  - Performance
  - Structural Analysis
  - Estimated Weight
  - Costs
- Manufacturing Procedure
- Environment, Health & Safety

Project Specifications (Competition Rules–Regular Class)

- **Aircraft Dimension Requirement**
  - Maximum combined length, width, and height of **225 inches**
- **Gross Weight Limit**
  - No more than fifty five pounds (**55 lbs.**) with payload and fuel.
- **Engine Requirements**
  - Single unmodified O.S 61FX
- **Aircraft must make one full 360° loop of the field**
  - **Disqualification** if flown into "No Fly" zones x2
- **Aircraft must land within specified landing zone**
  - Multiple passes of field is allowed
  - No "touch and go" landings

Competition Field

Competition Assessment

Final Flight Score = i x (Best Flight Score)

$i = 1 + (Ao - 40\%) \times .25$

Target A_o for Regular Class 2012 will be 40%

$$A_o = \frac{[\text{Successful Flight Round}]}{[\text{Successful Flight Round}] + [\text{Missed Flight Round}]}$$

$$FS = RAW + PPB + EWB - TP$$

$$RAW = W \times 4$$

RAW = Raw Weight Score
PPB = Prediction Point Bonus
EWB = Empty Weight Bonus
TP = Total Penalty Points

W = Weight Lifted in Pounds

$$PPB = 20 - (P_{Predicted} - P_{Actual})^2$$

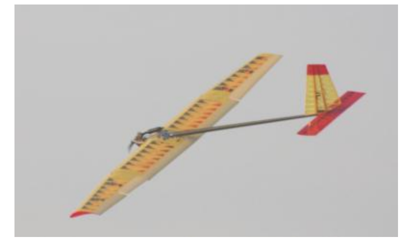
$P_{Predicted}$ = Predicted Payload
P_{Actual} = Actual Payload

Conceptual Options

Flying Wing

Standard

Minimalist



Canard

Bi-Plane

Design Decision Matrix

		Standard Design		"Flying Wing" Design		Minimalist Design		Canard Wing Design		Bi-Plane Design	
Selection Criteria	Weight	Rating	Weighed Score	Rating	Weighed Score	Rating	Weighed Score	Rating	Weighed Score	Rating	Weighed Score
Potential Lift	20%	7	1.4	9	1.8	8	1.6	8	1.6	7	1.4
Potential Drag	10%	4	0.4	8	0.8	9	0.9	2	0.2	3	0.3
Durability	15%	9	1.35	5	0.75	3	0.45	7	1.05	7	1.05
Cost	10%	5	0.5	5	0.5	8	0.8	3	0.3	4	0.4
Ease of Manufacture	5%	5	0.25	6	0.3	8	0.4	4	0.2	4	0.2
Potential Flight Score	40%	8	3.2	6	2.4	7	2.8	7	2.8	7	2.8
	100%		7.1		6.55		6.95		6.15		6.15

Tail Booms

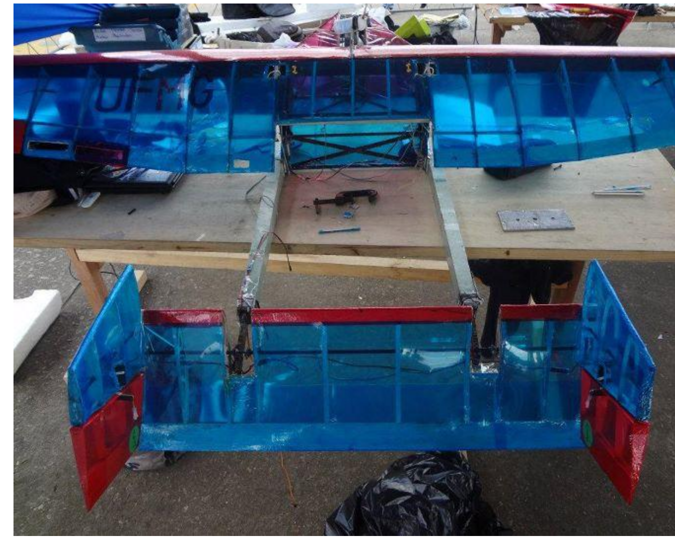
http://www.me.mtu.edu/saeaero/images/IMG_1215.JPG

Conventional:

- Commonly used in commercial passenger aircraft as cargo area
- Design
  - Flush with fuselage
- Strength:
  - Good torsion resistance
- Weight:
  - Heavier weight in comparison to other options of tail booms.

Pipe:

- Used in model aircraft and small helicopters
- Design:
  - Best done with carbon fiber (not permitted)
- Strength:
  - Low torsion resistance
- Weight:
  - Lightest weight design



Twin Boom:

- Design:
  - Greatly affects fuselage design
- Strength:
  - Great torsion resistance
  - High stability
- Weight:
  - Highest weight compared to other booms

Tail Design – Decision Matrix

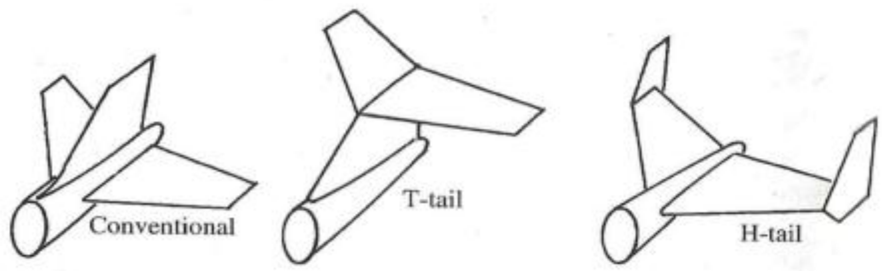
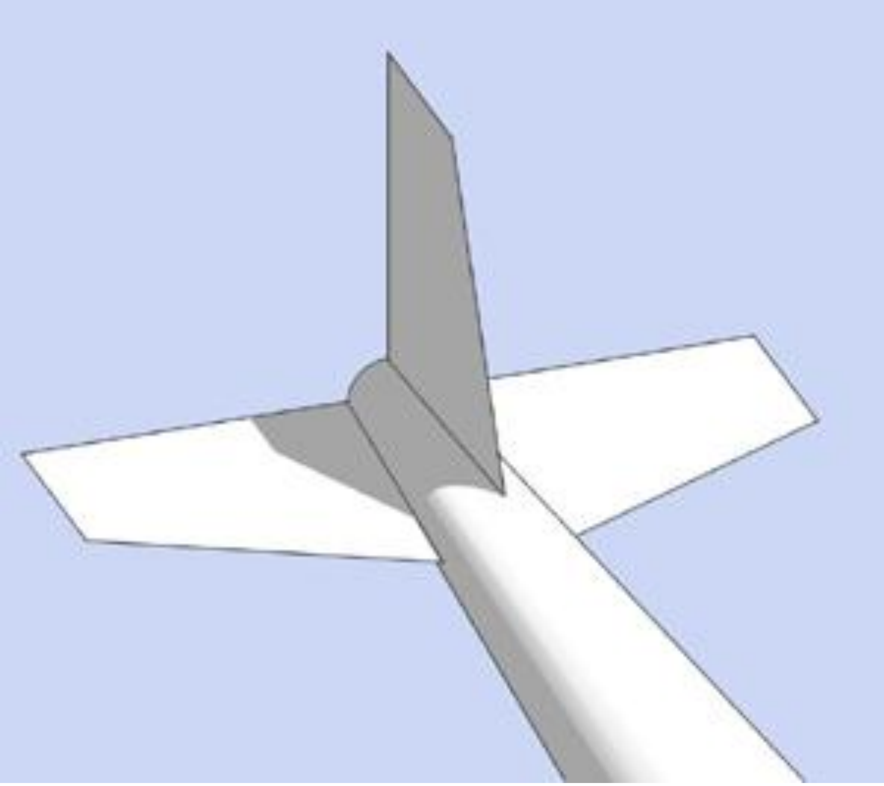


Figure of Merit	Weighting Factor	Conventional	T-tail	H-tail
Drag	0.20	3	2	1
Ease of Build	0.10	5	3	2
Maneuverability	0.15	3	4	5
Stability	0.35	4	4	5
Weight	0.20	4	4	3
Total	1.00	**3.75**	3.5	3.5

Tail Design – Conventional

http://me-wserver.mecheng.strath.ac.uk/group2007/groupj/design/airframe/lower/image/conventionals.jpg



- Roots of both stabilizer attached to fuselage
- Effectiveness of vertical tail is large

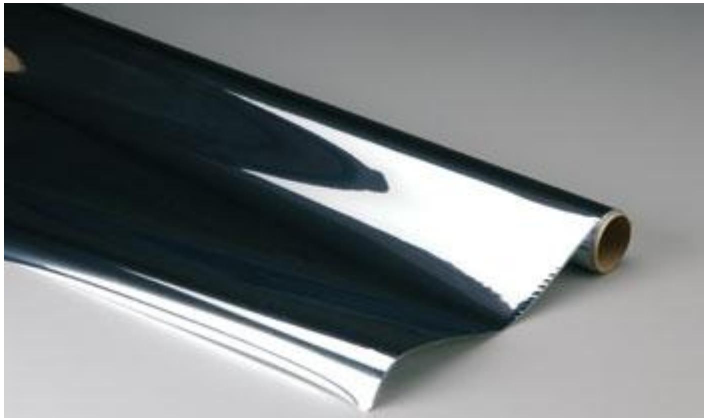
Materials Selection

- FRP (fiber-reinforced plastics) <u>not allowed</u>

http://cdn.dickblick.com/items/333/01/33301-8301-1-3ww-l.jpg

Balsa Wood Construction

Monokote Shrinking Wrap



http://www.monokote.com/colors/topq0209b.jpg

Payloads

- With an approximated payload $W_{payload} = 35\ lbm \approx 16\ kg$ we can approximate the volume of the payload based on densities of various common metals and their corresponding cost, and decide on a material for the payload.

Material	Density (gm/cm^3)	Cost (USD/kg)	Volume (in^3)	Cost (USD)
Steel Alloy	7.85	0.5	123.414	7.94
Stainless Alloy	8	2.15	121.1	34.13
Gray Cast Iron	7.3	1.2	132.712	19.05
Copper Alloy	8.5	3.2	113.976	50.8

- From this analysis our payload will likely be Steel

*Data selected from Callister 7th edition

Manufacturing Procedure

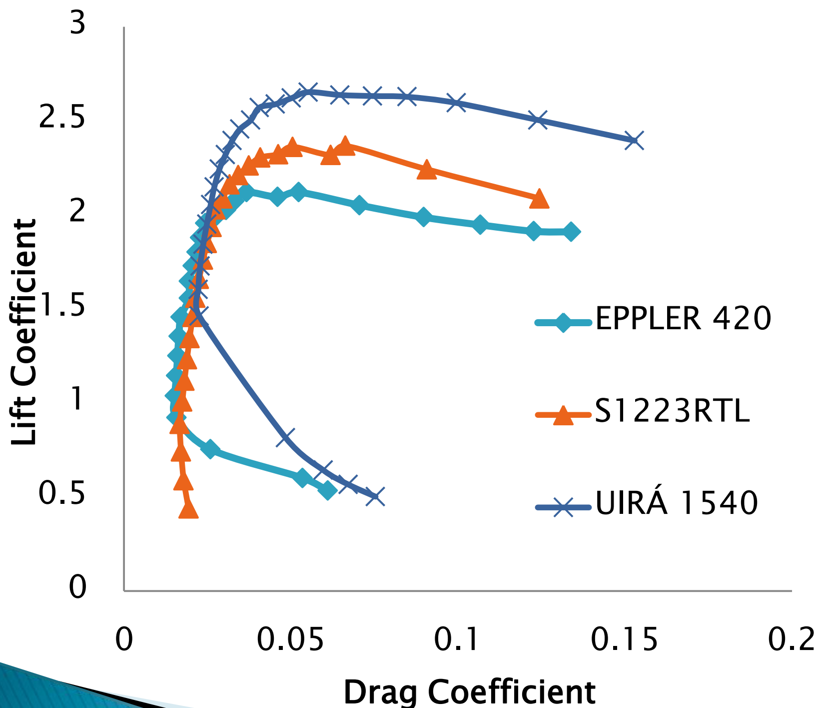
- CNC cutting for airfoil ribs, fuselage ribs, and stabilizers
- As many as 3 prototypes in event of crash
- Most lightweight construction methods possible

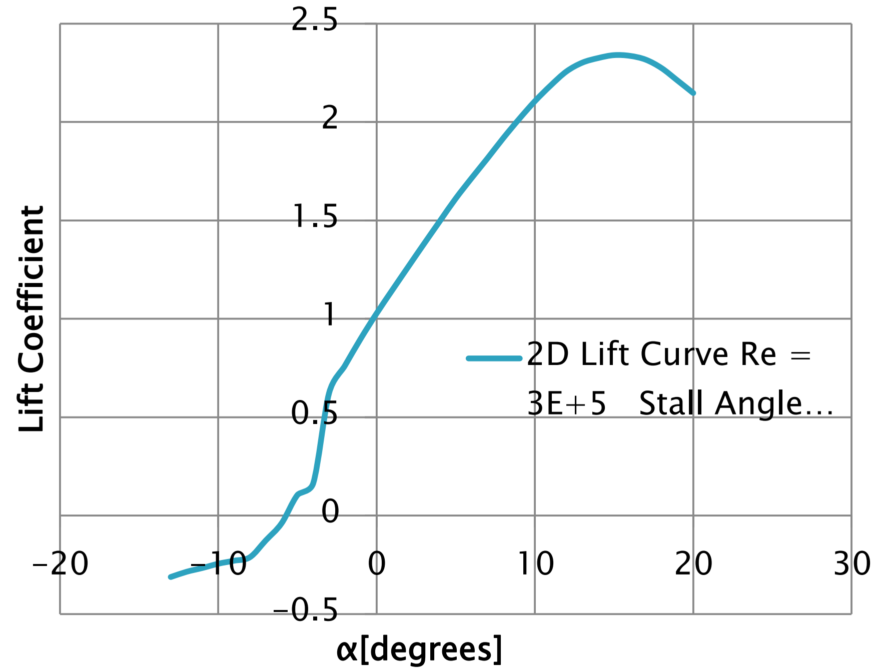
Cost Analysis

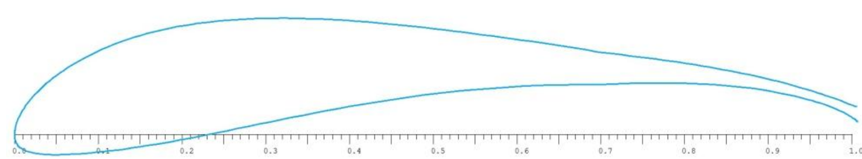
Item	Description	Quantity	Cost
Engine	Magnum xls 61	1	$99
Balsa Wood	Structure of aircraft, various lengths and shapes	~50 ft.	$100
Monokote	Skin around structure	~50 sq. ft.	$60
Servos	Controls flaps (elevator, aileron, rudder, etc.)	5	$125
Fuel Tank	Holds fuel within fuselage	1	$5
Battery	Powers servos and receiver	1	$15
Radio and receiver	Radio controller for the plane and the receiver to send control functions to servos	1	$0
Miscellaneous Items	Wheels, pushrods, hardware, engine mounts, propeller	TBD	$75-$150
Shipping	Will be Shipping supplies from high fly hobbies located in Daytona Beach, FL	2-3	$14.95(per box)
Total		*estimate	*$509-$600

Wing Profile

- Knowing the MTOW, we find $C_{L_{Design}} = 1.94$
- According to the literature(Abbot), the vortex effects decrease 20% of the aircraft`s lift coefficient.







Airfoil data calculate for Cl_max

Lift Coefficient = 2.34
Drag Coefficient = 0.048
L/D = 48.8
Moment Coefficient = -0.202

Wing Design

•The software utilized was the Cea-*VLM (vortex lattice method)*

• Several iterations were made varying:

  • *Wingspan*
  • *Wing root and chord*
  • *Taper ratio and its position*

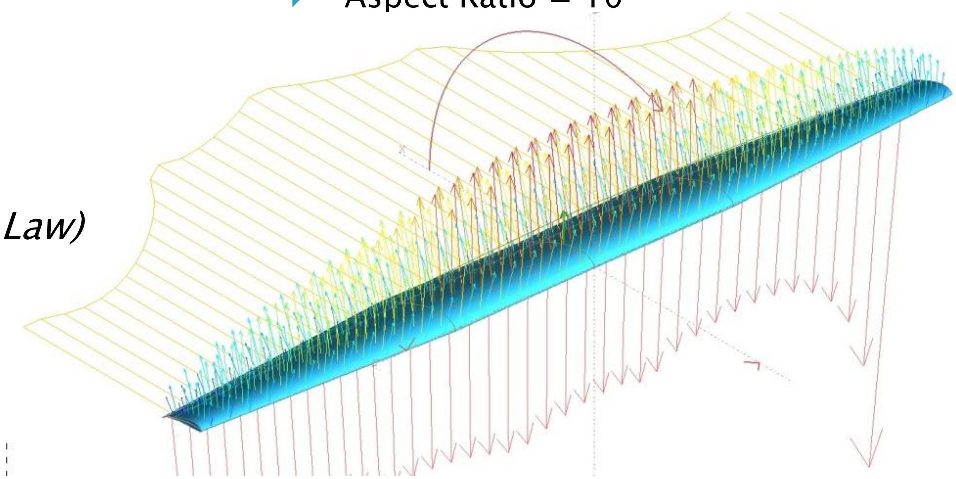
• considering it's consequences to:

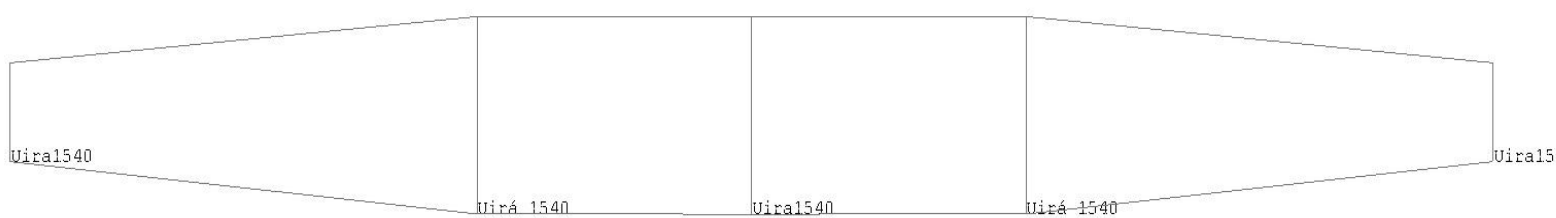
  • *Wing weight (estimated via the Cubic Law)*
  • *Wing lift and drag*

• this process was monitored by the:

  • *Oswald 's factor*

- Wing span = 2.7 m
- Root Chord = 0.32m
- Tip Chord = 0.16 m
- M.A.C = 0.28 m
- Tip Twist = - 2 degrees
- Wing Area = 0.728 m^2
- Aspect Ratio = 10

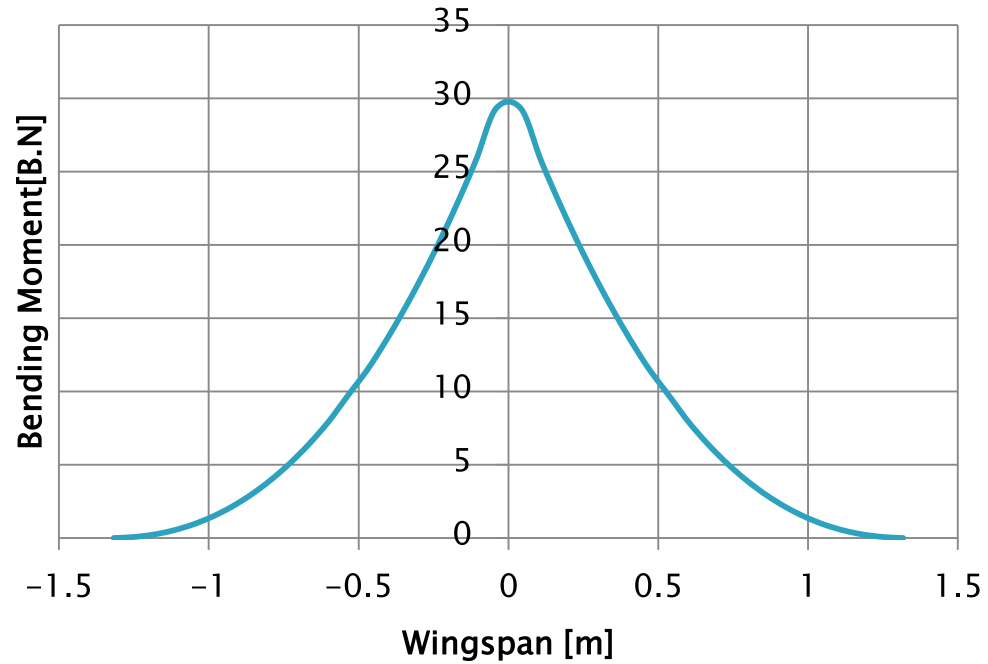


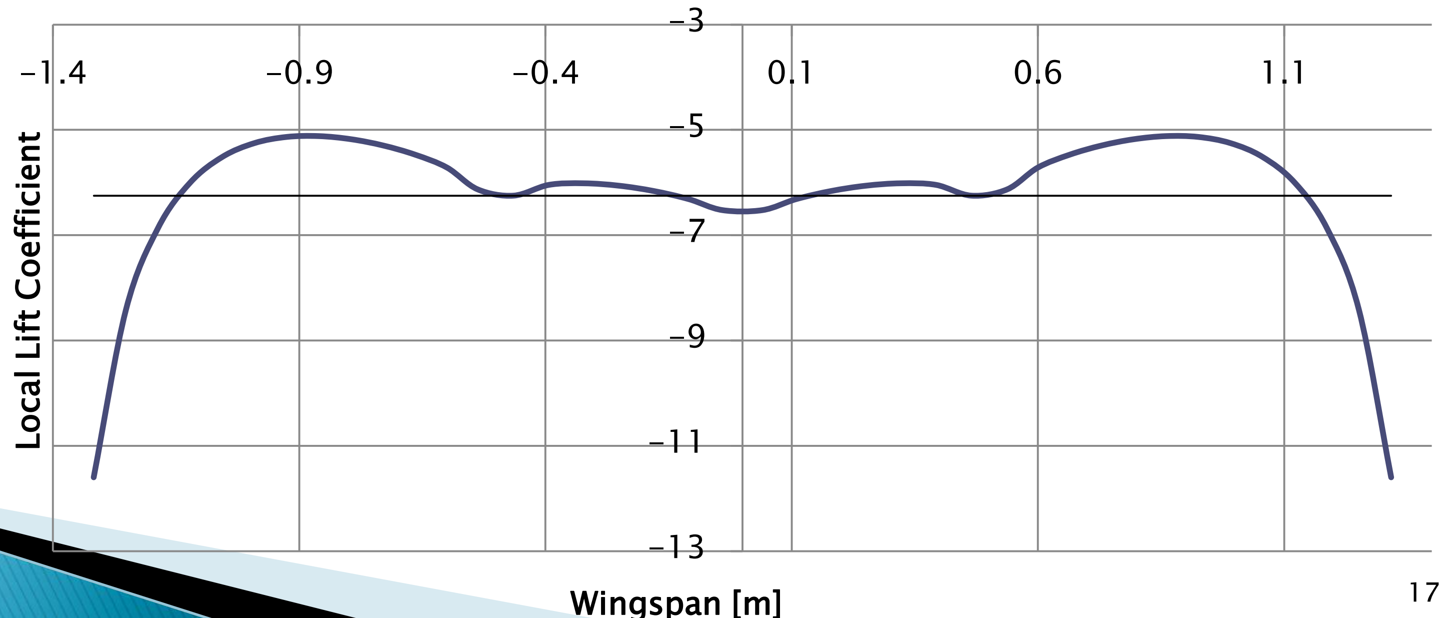


Wing Loads

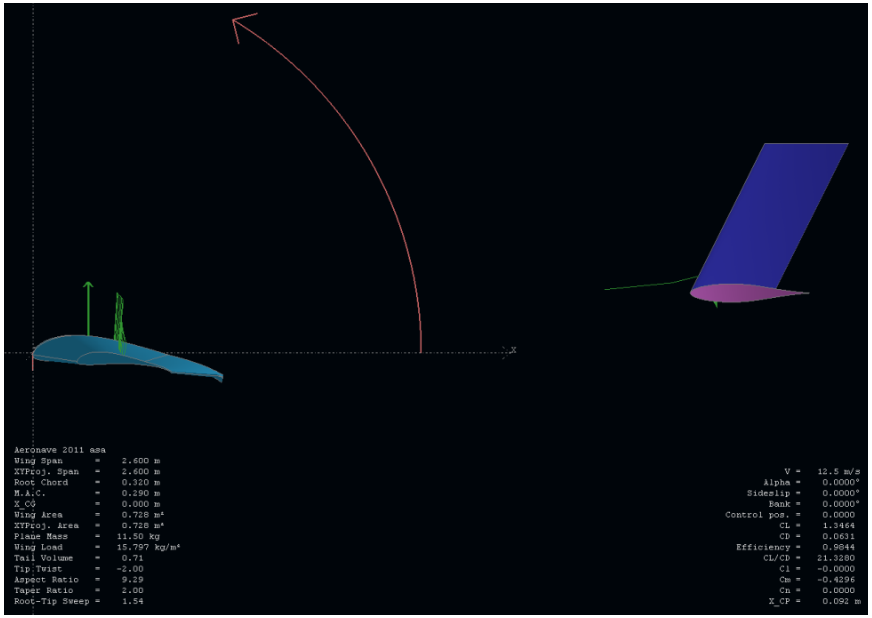
•The wing loads were estimated utilizing the methodology proposed by Schrenk

•In a later analysis this data will be used to size the wing spar by using finite element methods



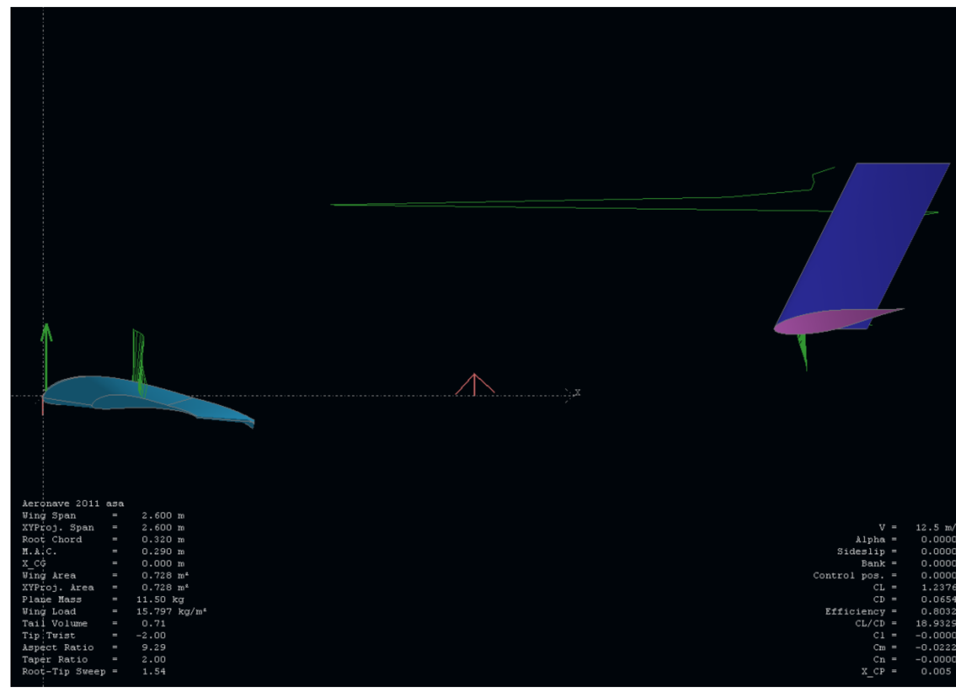


Stability – Tail Design



- Initial elevator design
- Zero lift airfoil, 0 degree angle of attack
- Large pitching moment coefficient: -0.4296

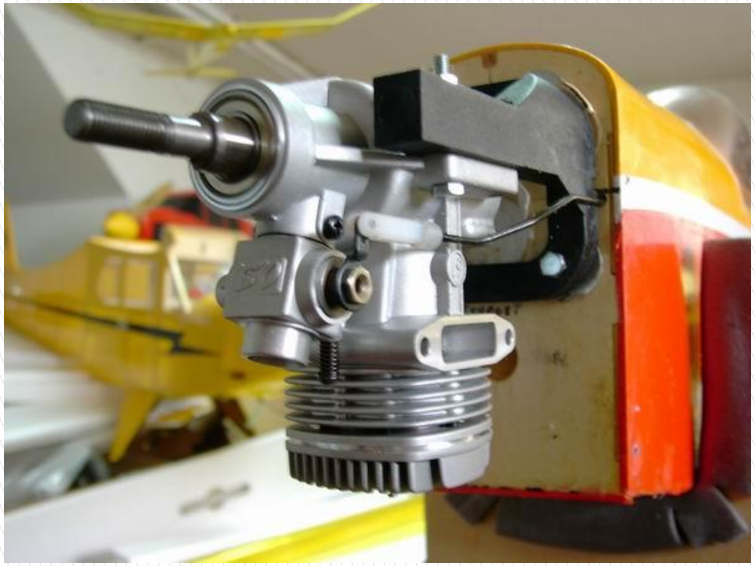
- Revised elevator design
- Zero lift airfoil, -9 degree angle of attack
- Minimal pitching moment coefficient: -0.0222
    - Also a negative lift airfoil can be used



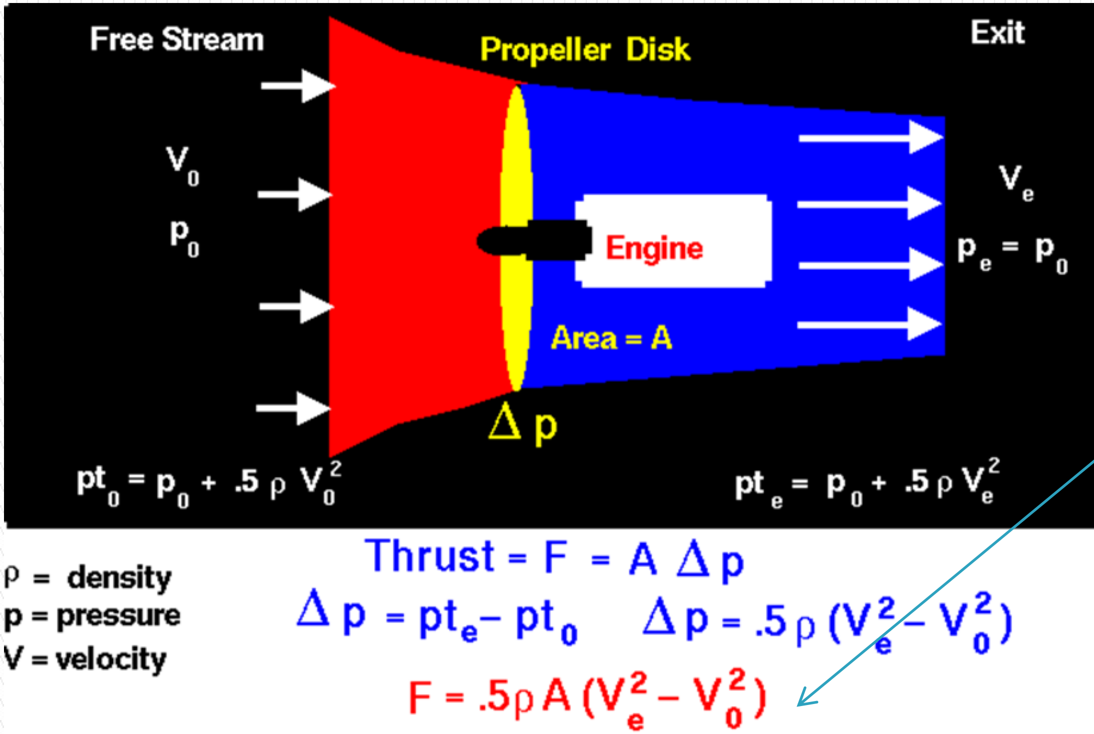
Performance– Engine

- OS 61 FX
  - Suggested fuel tank cap: 350cc
    - 12-13min flight
  - Displacement: 9.95cc (0.607cu.in.)
  - Bore : 24.0mm (0.945 in.)
  - Stroke: 22.0mm (0.866 in.)
  - Practical RPM: 2k~17k rpm
  - Power output: 1.9 bhp @ 16k rpm
  - Weight: 550g (19.42 oz.)

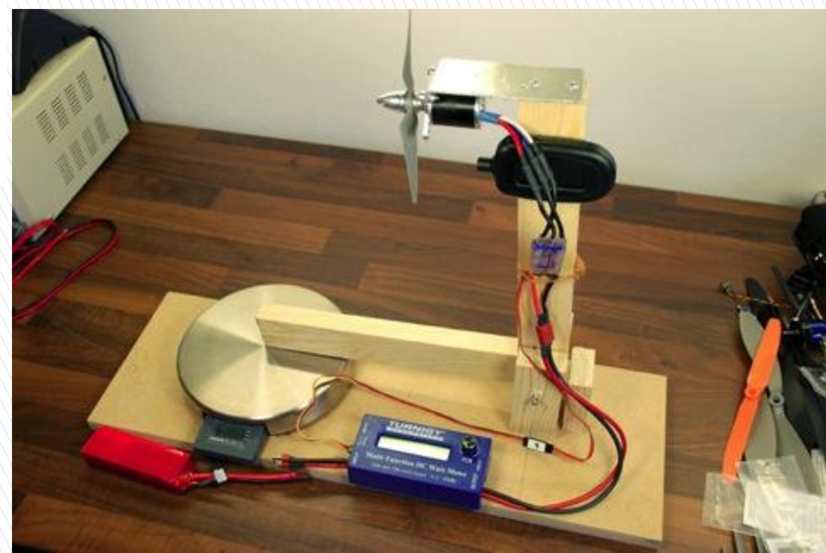
- Deliver reliable and efficient power to propel the aircraft.
  - In the form of thrust with the help of a propeller.



Performance– Thrust



- Thrust is required to propel aircraft
  - Requires energy (from engine) to produce thrust
  - Force of thrust generated by engine & propeller
  - Experimentally determine thrust:
    - Thrust stand
  - Give accurate static thrust ratings for motor and propeller combinations



Thrust-to-Weight Ratio

- The thrust-to-weight ratio is a fundamental parameter for aircraft performance
  - Acceleration rates
  - Climb rates
  - Max/min speeds
  - Turn radius
- Higher T/W will accelerate more quickly, climb more rapidly and achieve higher max speed
- Using a max take-off distance of 200 feet, a reference T/W was calculated,
  - $\frac{T}{W} = \frac{1.21*6.03}{32.2*0.002377*2.34*200} \approx 0.204$
- The thrust required at take-off was calculated using *Aximer*
  - TR = 5.83 lbf
- The thrust available at take-off is expressed by,

$$\text{TA} = \frac{n_{prop}*P}{V_\infty}$$

  - TA = 15.19 lbf
- The aircraft will have enough force to thrust the 35 pound payload into flight.

Power Available/Required

- Assuming 85% efficiency of motor shaft power, the power available is 1.615 hp.
- The PR is important when computing what the output needs to be for a given altitude and velocity
  - The motor performance is fixed
  - Other factors must be adjusted to compensate

$$P_R = \frac{T}{W} * W_o * V$$

$$P_R = 0.204 * 47lbs * 55.71\frac{ft}{s}$$

$$= 534.15\frac{lb*ft}{s}$$

- Converting to horsepower yields a value of 0.971hp
  - The motor is sufficient enough to create thrust for the max payload of 35 pounds

Propellers

- Transfer mechanical energy from shaft into thrust.
- Propeller drag is a loss mechanism
  - Robing engine of net power output…thrust.
  - Efficiency increases as propeller size increases
    - Requires increased ground clearance and low tip speeds.
    - Optimize with diameter, pitch and blade count

$$D = 22 * hp^{0.25}$$

- Propellers can be sized according to HP of the engine (2-blades eqn)
  - Results in 25” diameter
    - Formula unsuitable for small scale RC
- Propellers recommended
  - Sport: 12x6-8, 13x6-7
  - Aerobatic: 12x9-11

Propeller Selection

- Measuring various makes and models of propellers could be useful.
  - Build thrust stand

Recommended Sport Props				
Diameter (in)	Pitch (in)	RPM	ST (lb)	C.t
12	6	11675	8.48	0.029
12	7	11100	7.66	0.026
12	8	10600	6.99	0.024
13	6	10500	9.44	0.033
13	6	10500	8.91	0.031
13	7	10000	8.57	0.03

- Recommended sport propellers were analyzed with *ThrustHP*
  - Allows varying inputs of propeller (diameter, pitch, blade count, make)
  - Approximate and record the RPM to reading close to 1.9bhp *0.85=1.62bhp
  - Some useful outputs:
    - Static thrust

$$C_t = \frac{T}{\rho n^3 D^5}$$

Wing Loading

- Weight of the aircraft divided by the area of reference wing
  - Stall speed
  - Climb rate
  - Turn performance
  - Take-off & landing distances

- If W/S is reduced, the wing becomes larger but may add to both weight and drag adversely
- W/S must be optimized together with T/W

- Wing Loading Values
  - At takeoff – 8.63 psf
  - At cruise altitude of 3000 ft – 5.99 psf

- Stall speed is directly determine by wing loading and is a major contributor to flying safety

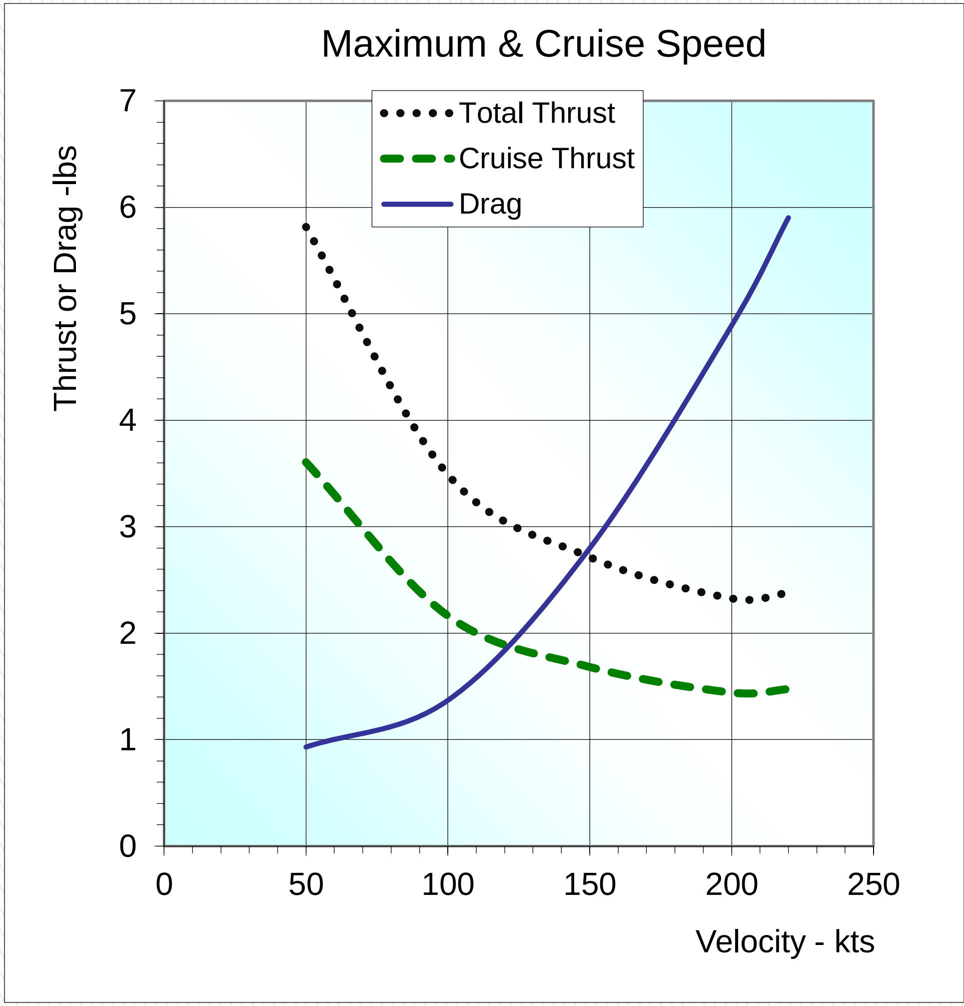
- Using the wing loading value at cruise altitude one can calculate the stall velocity

  - $V_{stall} = (\frac{W}{S} * \frac{2}{\rho C_L})^{0.5}$

  - Stall Speed = 46.43 fps

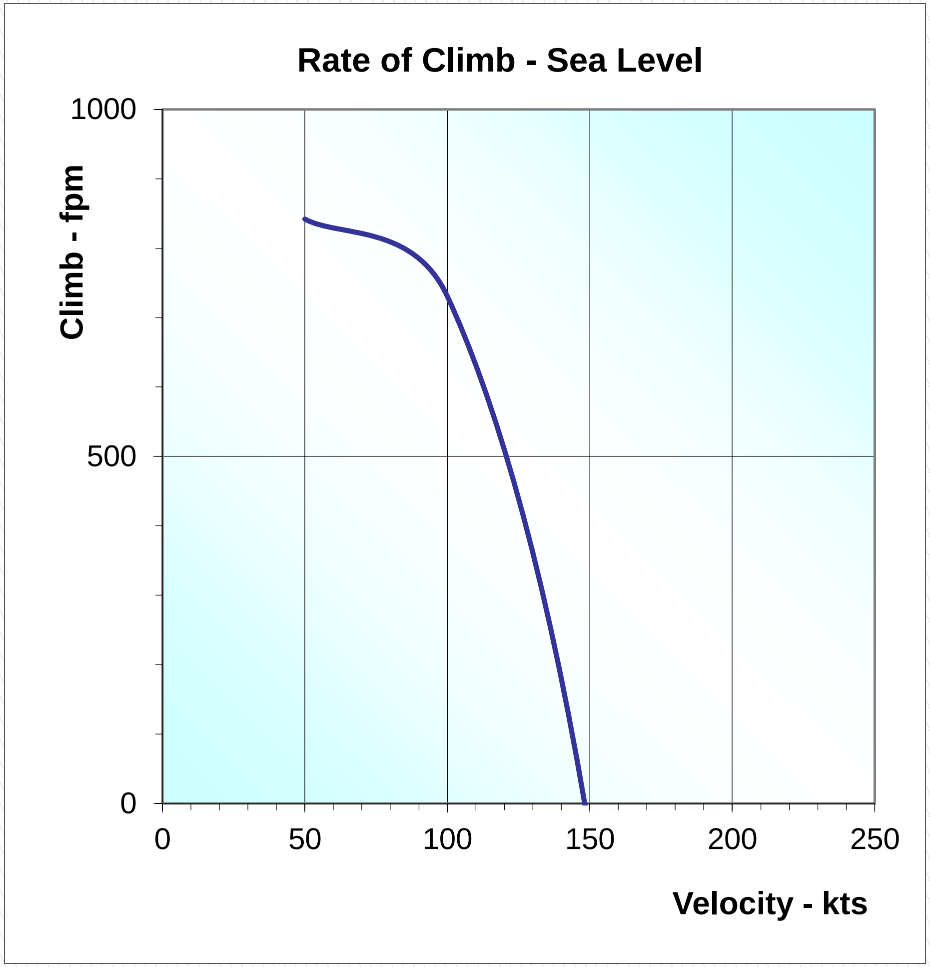
Thrust vs. Cruise Speed

- The thrust initially begins at a large value but decreases with increasing velocity
  - Weight and dynamic pressure decrease
- At cruise altitude thrust becomes equal to weight thus, no additional thrust is needed to cause motion
- Drag tends to increase with increasing velocity because the Reynolds number is becoming more turbulent yielding more drag effectively

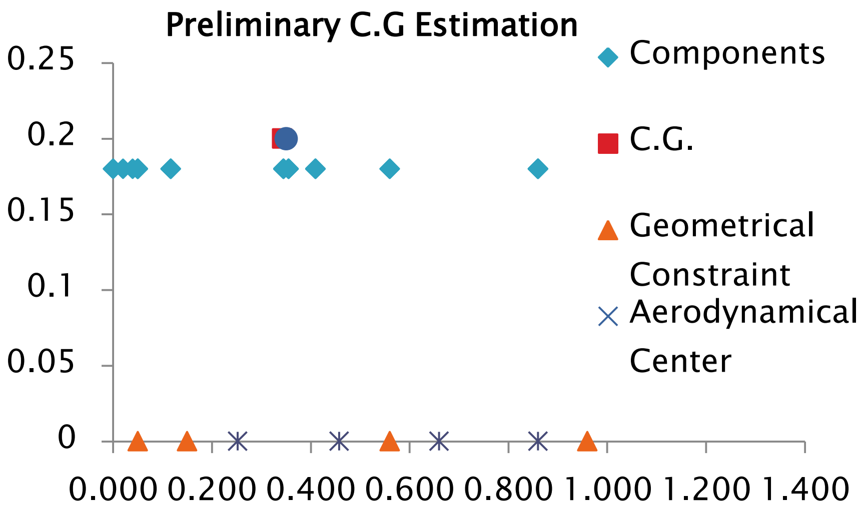


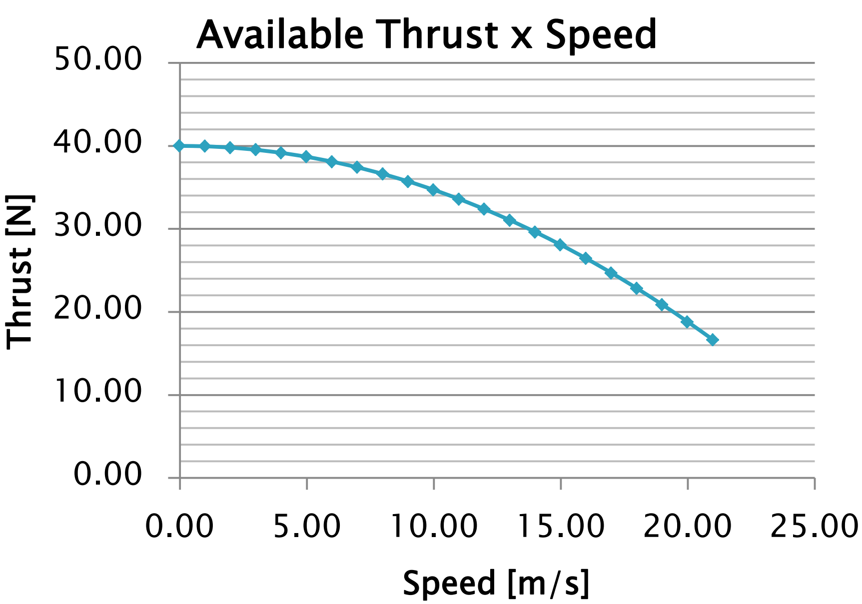
Climb Rate

- The rate of climb (RC) is the rate at which an aircraft can safely and effectively change altitudes
- Using *Aximer* the predicted climb rate with standard flight conditions at cruise velocity was calculated to be
  - RC = 12.543 ft/s



Performance Calculations

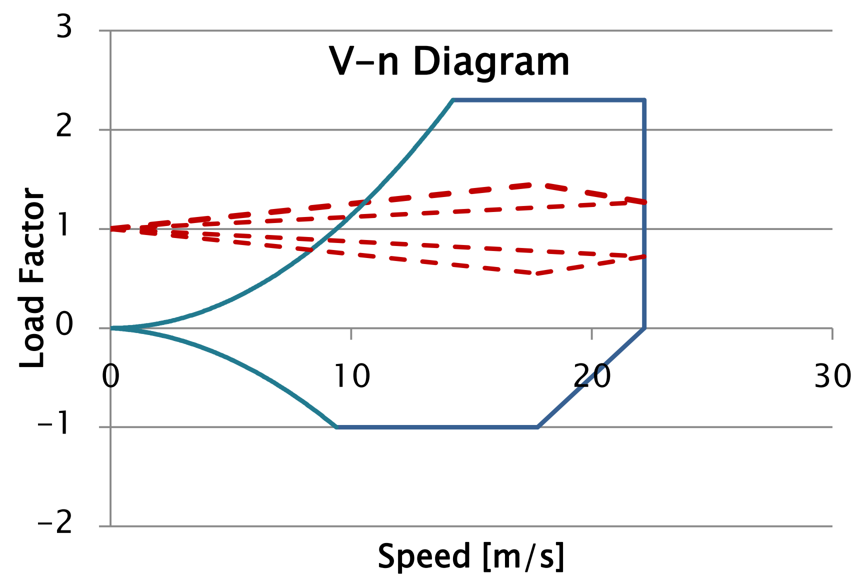




- The components will be positioned according to the overall effect that they have on C.G.
- The V-n Diagram gives an overview of the flight envelope by relating its velocities to the load factor that the aircraft will undergo under that speed.

Performance Parameters

Climb Angle	5.1670	degrees
Rate of Climb	0.1920	m/s
Vstall	10.6832	m/s



Takeoff Gross Weight

- $W_o = W_{payload} + W_{fuel} + W_{empty}$
  - $W_{payload}$ can assume a value of about 35.3 lbs which was the max payload of last year's 1st place aircraft
  - W_{fuel} can be determined using the following givens and relations:
    - Given:
      - $\rho_{fuel} = 1.1371\ g/cm^3$; $V_{tank} \approx 350\ cm^3$; $g = 9.81\ m/s^2$
      - $W_{fuel} = \rho_{fuel}\ x\ V_{tank}\ x\ g \approx 3.904\ N \approx$ 0.8777 lbs
  - W_{empty} can be estimated using a minimum ratio of 0.2 (W_e / W_o)
    - $W_o = \frac{W_{payload}}{1 - \frac{W_{fuel}}{W_o} - \frac{W_e}{W_o}} = \frac{35.3}{0.8 - \frac{0.8777}{W_o}} \cong$ 45.22 lbs
    - $W_e = W_o - W_{payload} - W_{fuel} =$ 9.0423 lbs
      - $W_o \leq 55$ lbs

Fuselage – Sizing

- Utilizing a spreadsheet CG and Sizing analyzer we were able to determine the sizing of the fuselage based on the wing dimensions
  - $Length = 0.7*\text{Wingspan} = 6.20\ \text{ft}$
- Average diameter can be calculated using a fineness ratio (FR) of 10 and the length of the fuselage
  - $FR = \frac{L}{D_{avg}}$ $D_{avg} = \frac{6.20}{10} = 7.44\ \text{in}$ (circular)
- If the cross section is noncircular, the height and width can be attained using the relation,
  - $D_{avg} = \frac{H+W}{2}$ If we set H = 2W for clearance purposes
  - W = 4.96 in H = 9.92 in (rectangular)

Fuselage – Drag Calculations

- Wetted Area Estimation (blunt body)
  - *Circular Fuselage*: $A_w = 2\pi r(r+h)$
    - $A_w \approx$ 12.682 ft^2
  - *Rectangular Fuselage*: $A_w = 2(wh + lw + lh)$
    - $A_w \approx$ 16.061 ft^2
- Drag Estimation

$$F_d = qA_wC_f$$

Assume: q = 1.0665 lb/ft^2 Re = 300,000 (laminar)

- ***Circular Cross Section***
  - $F_d = \left(1.0665\frac{lb}{ft^2}\right)(12.682ft^2)\left(\frac{1.328}{\sqrt{300{,}000}}\right) = 0.0328\ lbf$
- ***Rectangular Cross Section***
  - $F_d = \left(1.0665\frac{lb}{ft^2}\right)(16.061ft^2)\left(\frac{1.328}{\sqrt{300{,}000}}\right) = 0.0415\ lbf$

Environment

- Magnum xl 61 engine uses 10% nitro methane ($4CH_3NO_2 + 3O_2 \rightarrow 4CO_2 + 6H_2O + 2N_2$)
- Over the course of the semester it is estimated we will use a little over 4 gallons of nitro methane
- This translates to about 4 lbs of CO_2 "green house gas"
- The average passenger car produces this amount in under 5 miles
- Insignificant amount of pollution

Safety

- Always keep fingers clear of a running engine
- When revving up, hold engine from vertical stabilizer, not behind engine or on wing leading edge
- Always refuel the aircraft in a well ventilated area
- Keep fuel away from outside ignition sources
- All members of team keep an eye on the flying aircraft at all times
- Never fly more than one plane at a time
- When possible, wear hardhats when in the fly zone

QUESTIONS?