NORTHERN ARIZONA UNIVERSITY

The Wright Stuff

UGRADS Technical Presentation

April 26, 2013

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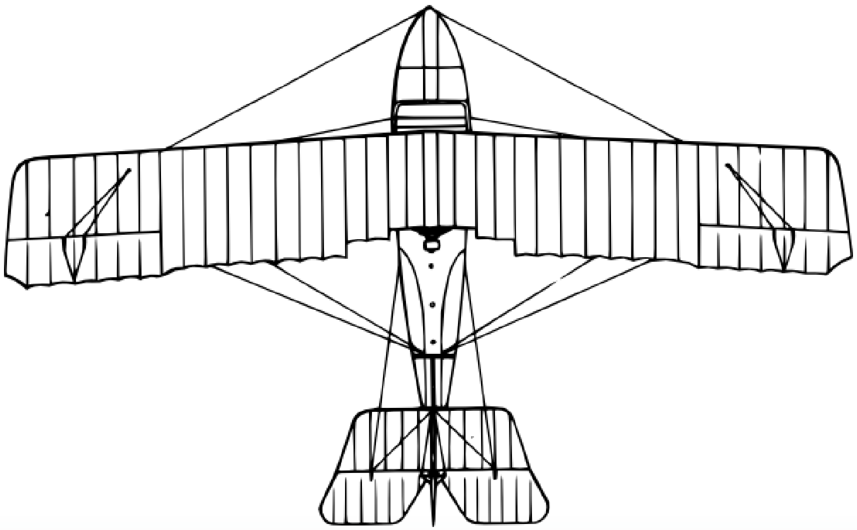
Agenda

- Competition Overview
- Team Process
- Budget
- Configuration Selection
- Preliminary Analysis
- Performance Analysis
- Flight Testing
- Competition Objectives & Results
- Lessons Learned



Competition Overview

- **Customer**
  - Society of Automotive Engineers (SAE)
- **Project**
  - Aero Design West Competition
  - Self-motivated, self-funded project
  - Test of individual and group capabilities

Problem Statement

- **Needs Identification**
  - Current remote controlled aircraft do not carry sufficient payload
- **Goals**
  - Introduce precision manufacturing techniques into RC aircraft design
  - Maximize the payload capacity of an aircraft within the requirements laid out by SAE

Design Constraints

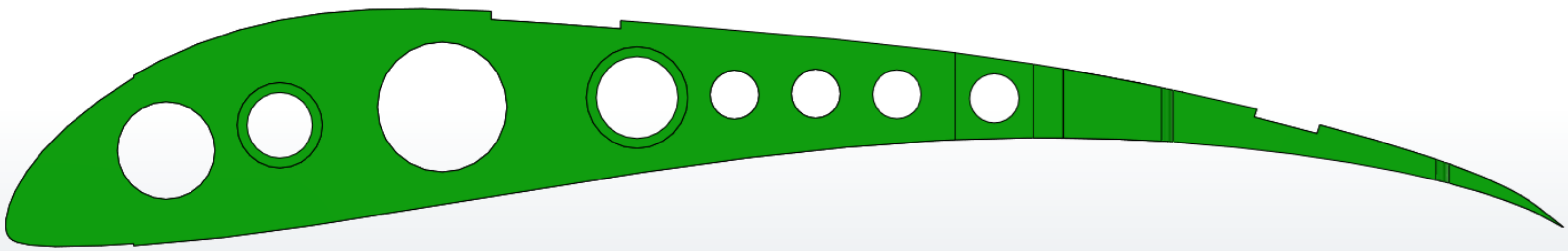
- **Mission Objectives**
  - Technical Presentation
  - Flight Demonstration
- **Design Limitations**

Design Limitations

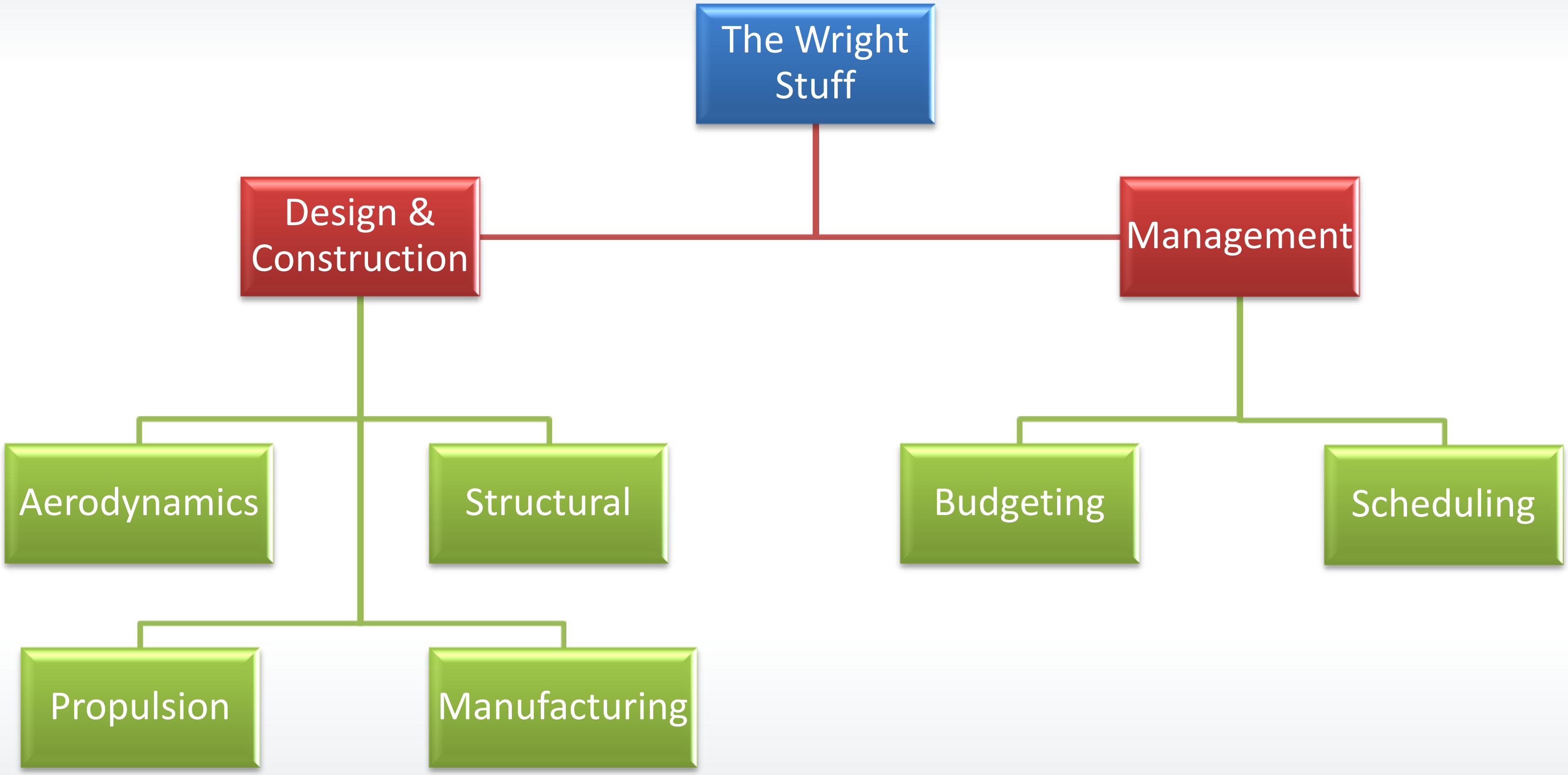
R1	**Aircraft must lift from the ground within a take-off distance of 200 feet**
R2	**Aircraft must successfully complete one 360 degree circuit of the field**
R3	**Aircraft must touch down and land within 400 feet**
R4	**Aircraft must remain intact during takeoff and landing**
R5	**Aircraft shall not exceed a combined length, width and height of 225 inches**
R6	**Aircraft may not weigh more than 65 pounds with payload and fuel**
R7	**Aircraft components may not consist of any fiber-reinforced plastic or lead**
R8	**Either an O.S. 61FX or a Magnum XLS-61A engine must be used**

Team Process

- Design Philosophy
  - Sound conceptual design
  - Thorough engineering analysis
  - Precision manufacturing techniques

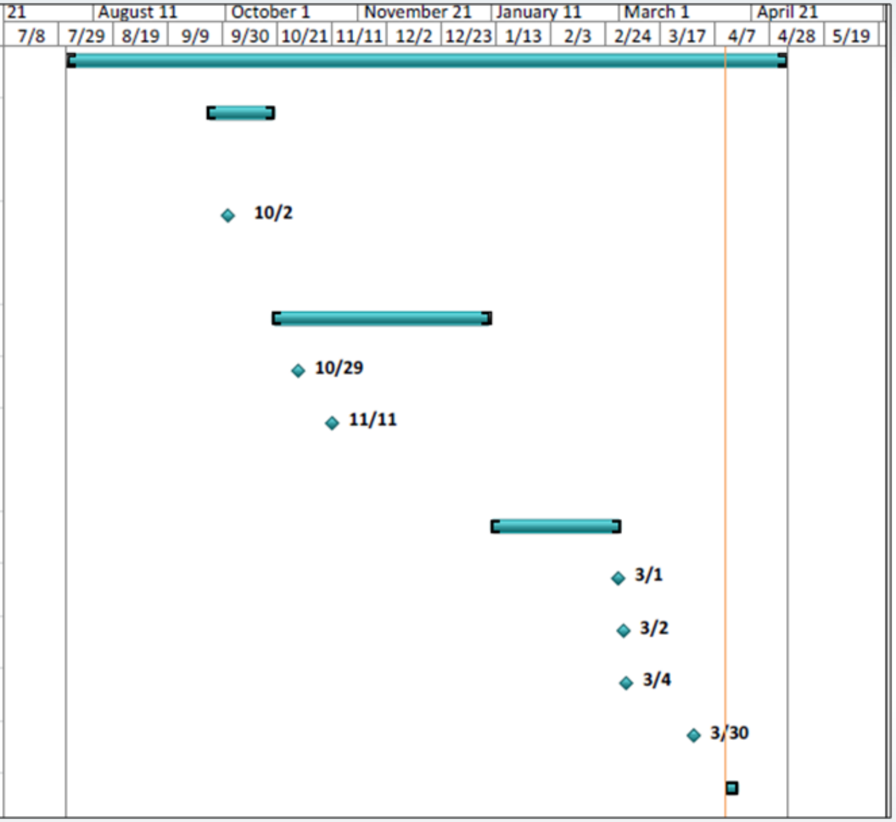


Team Process



Team Process

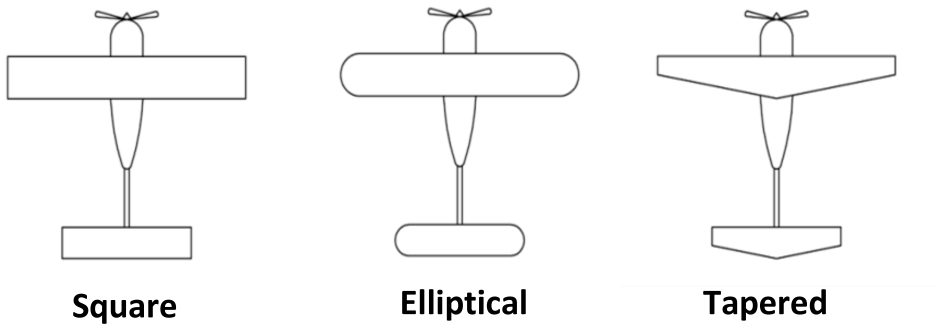
Task Name	Start	Finish
Senior Design	Wed 8/1/12	Sat 5/4/13
Conceptual Design Phase	Mon 9/24/12	Fri 10/19/12
Register for Competition	Tue 10/2/12	Tue 10/2/12
Preliminary Design	Fri 10/19/12	Thu 1/10/13
Meet Fundraising Goal	Mon 10/29/12	Mon 10/29/12
Preliminary Design Review	Sun 11/11/12	Sun 11/11/12
Construction	Fri 1/11/13	Fri 3/1/13
Critical Design Review	Fri 3/1/13	Fri 3/1/13
Flight Test	Sat 3/2/13	Sat 3/2/13
SAE Report Due	Mon 3/4/13	Mon 3/4/13
Flight Test 2	Sat 3/30/13	Sat 3/30/13
SAE Aero Competition	Thu 4/11/13	Mon 4/15/13



Budget & Expenses

Building Budget	$1,835
Travel Budget	$2,250
Competition Budget	$870
Total Budget	**$5,000**
Expenses	$4901
Remaining Budget	**$98.57**

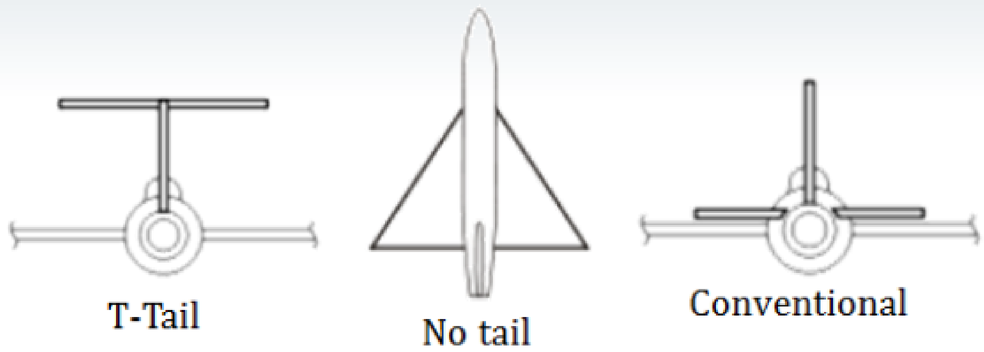
Configuration Selection



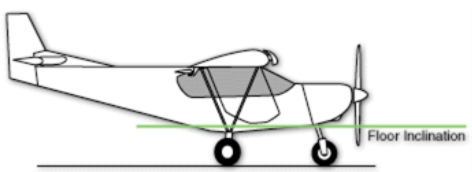
- Wing
  - Hybrid square/elliptical
  - High placement
  - Aspect Ratio = 7.5
  - Dihedral
  - Acrylonitrile Butadiene Styrene (ABS) additive manufactured ribs

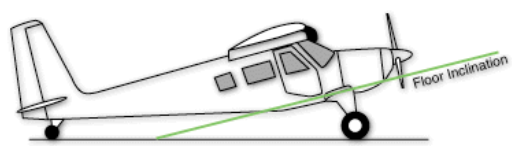
Configuration Selection

- Tail
  - Conventional
  - Minimize weight without sacrificing stability



- Landing Gear
  - Tail Dragger
  - High propeller clearance
  - Induces natural angle of attack
  - Minimizes weight





- Propulsion Installation
  - Front mounted
  - Induces desired center of gravity
  - “Clean” air intake

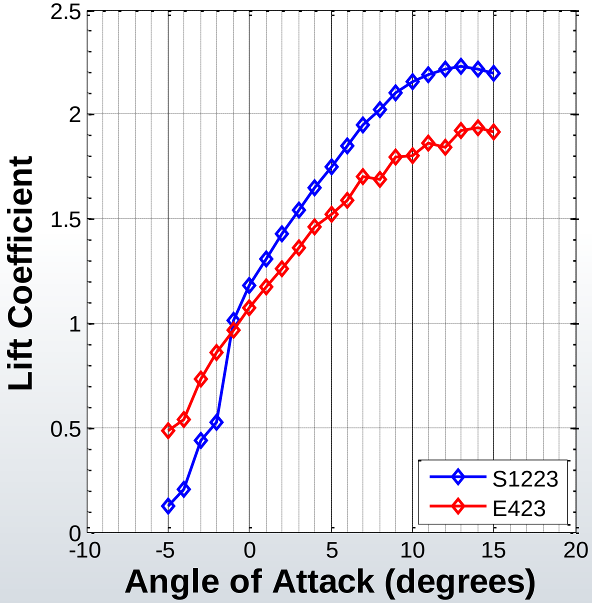
Preliminary Analysis

- Based on legacy documentation [3]
  - Airfoils: E423 and S1223
  - Traveling velocity = 30 ft/s
  - Re = 200,000
  - Elevation = 800 ft
  - Air density = 0.0023 slug/ft^3
  - Total plane weight = 35 lb

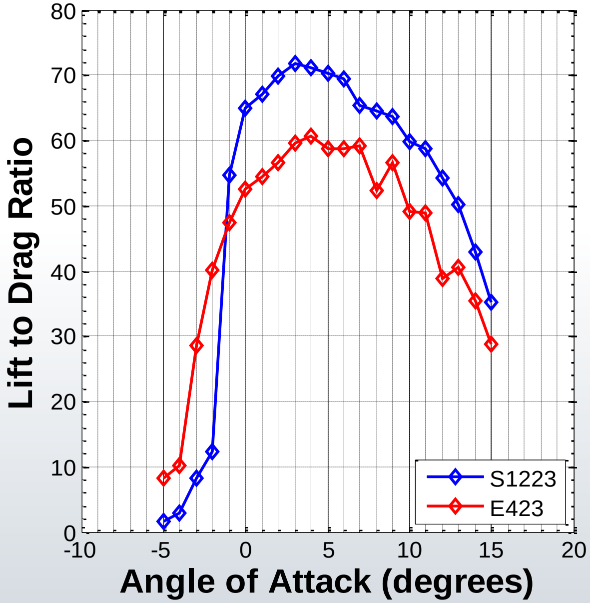
Preliminary Analysis

- XFOIL [4] Comparison between Selig 1223 and Eppler 423
- L/D ratio up to 15% higher for S1223
- Optimal L/D ratio at approximately 5°
- c_L ranges between 1.2 and 1.5

Lift Coefficient Comparison



Lift-to-Drag Comparison



Vehicle Sizing

- Wing Sizing (Airplane Width)
  - Input assumed values for c_L, ρ, and V into below equations [5]

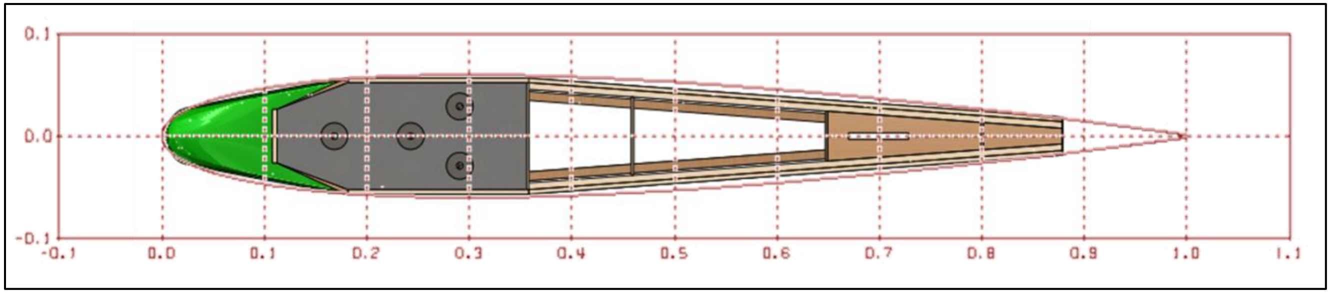
$$L' = c_L \times \frac{1}{2} \times \rho \times V^2 \times chord$$

$$L = L' \times wingspan$$

  - Iterate chord and wingspan values until desired result is met
    - Lift matches target airplane weight (35 lb)
    - Aspect ratio is acceptable (7.5)

Vehicle Sizing

- Fuselage Sizing (Airplane Length)



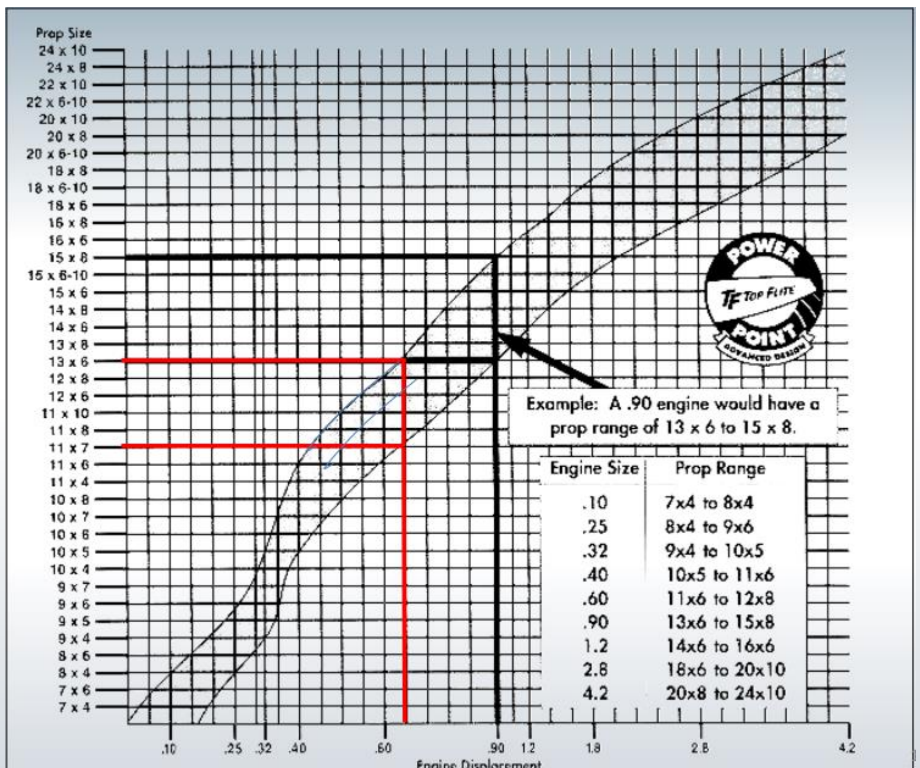
  – Mimic the profile of a NACA 0012 [6]

Vehicle Sizing

- Landing Gear Sizing (Airplane Height)
- Results
  - Width = 90 in
  - Length = 56 in
  - Height = 17 in
  - Total = 90 + 56 + 17 = **163 inches < 225 inches**

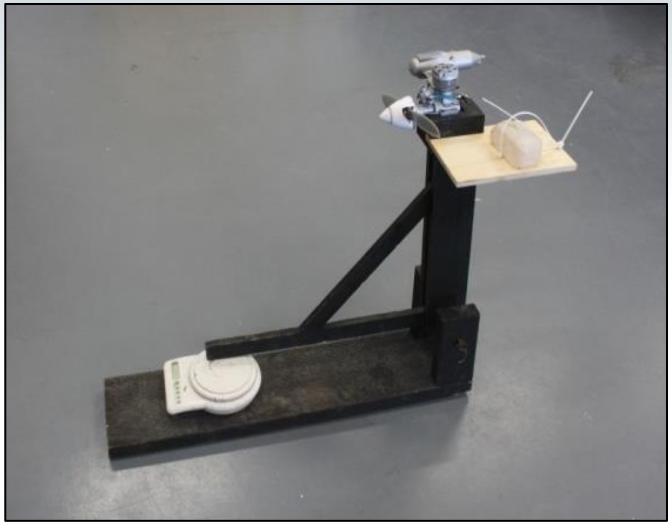
Propulsion

- Magnum XLS-61A engine selected per SAE requirements
- Propeller manufacturer guidelines for choosing diameter range [6]



Propulsion

- Static thrust testing
- 14X4 provided the most static thrust
  - Seemed to stress the engine a bit
- When in motion, the thrust will decrease
- 14X4 propeller will be used

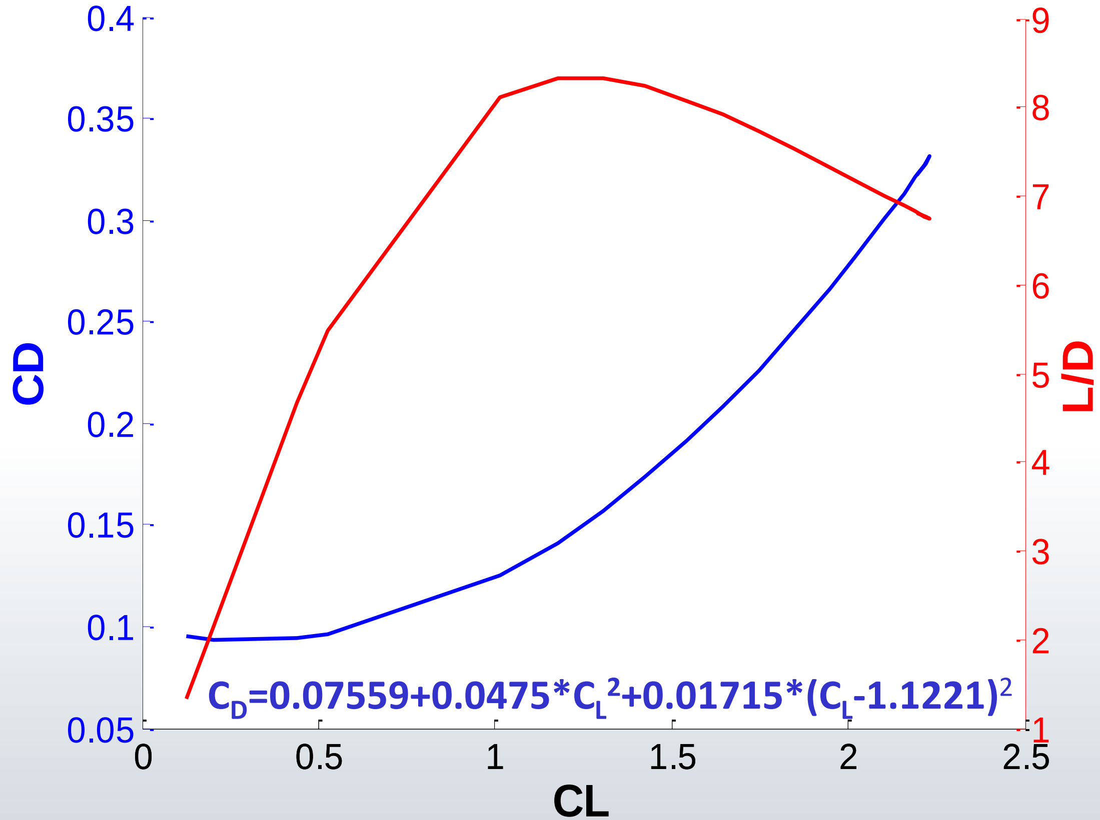


Propeller	RPM	Thrust (lb)
11X7	11,400	5.51
12X7	10,000	5.22
13X4	10,500	7.28
14X4	9,300	8.16

Performance Analysis

- Drag Estimation

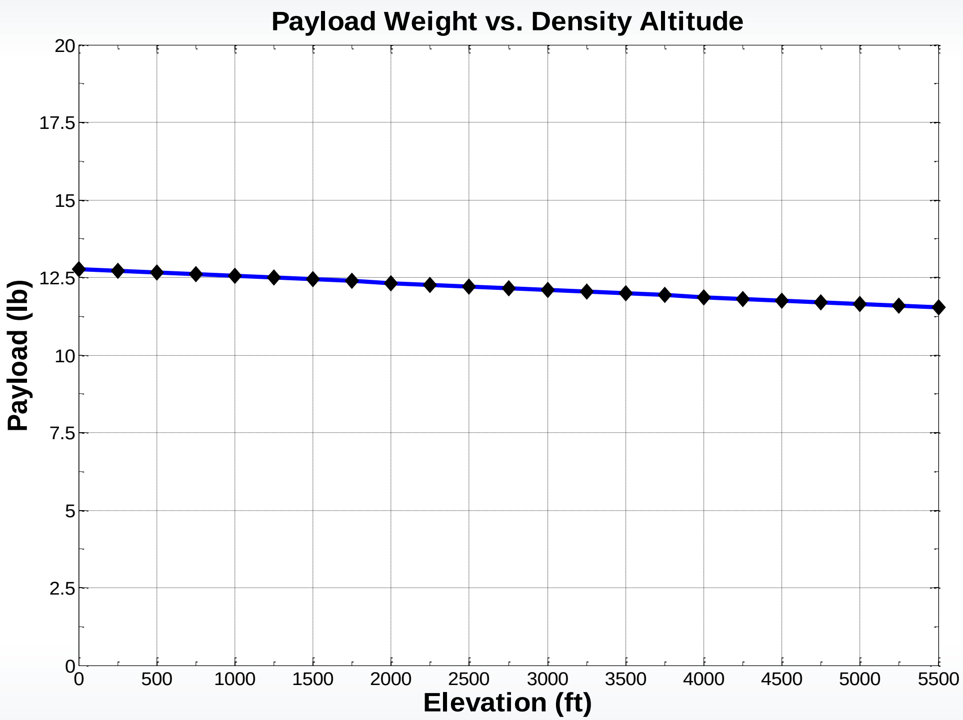
$$C_D(C_L) = \sum C_{D_{min}} + K' C_L{}^2 + K''^{\left(C_L - C_{L_{min}}\right)^2} \text{ [7]}$$



Performance Analysis

- Takeoff Performance

$$s_{LO} = \frac{1.44W^2}{g\rho_\infty S C_{L_{max}}\{T-[D+\mu_r(W-L)]_{ave}\}} \text{ [5]}$$



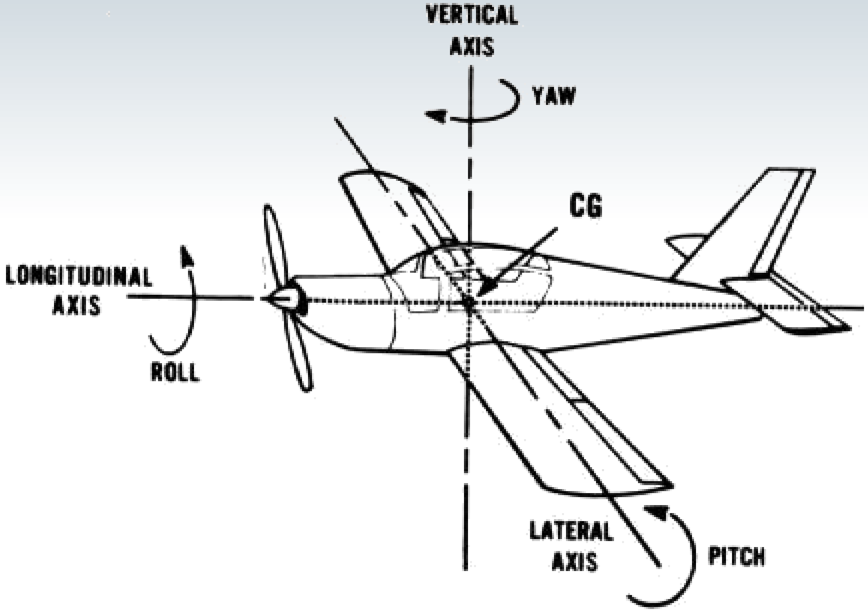
$$\boldsymbol{W_{max} = 12.78 - (2.273 \times 10^{-4})h}$$

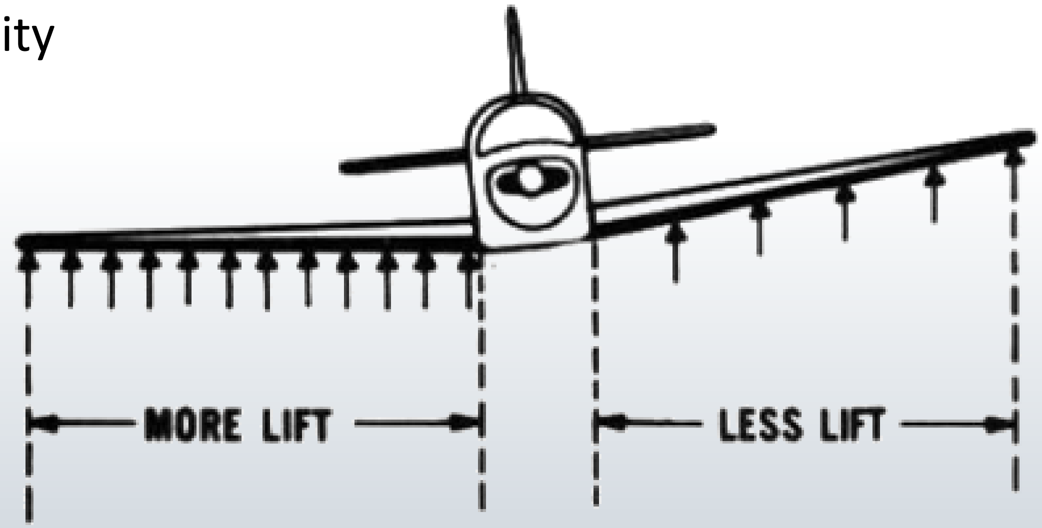
$$\boldsymbol{W(800\ ft) = \boxed{12.60\ lb}}$$

  - Iterative MATLAB code solves for airplane weight for a sweep of air density values
  - After subtracting the empty airplane weight, the payload weight is found

Stability

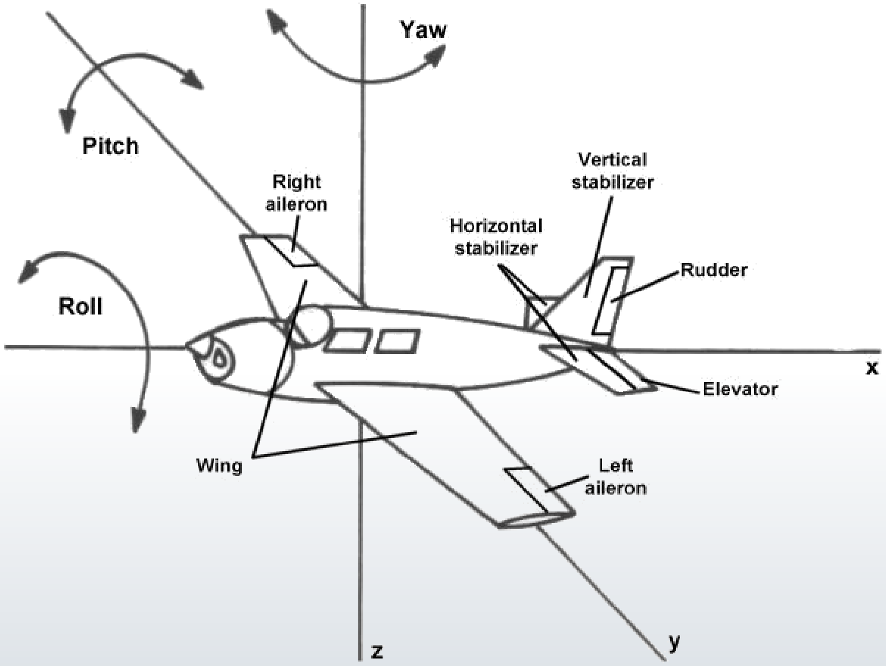
- Pitch
  - V_H of 0.3-0.6 is needed [8]
  - Our $V_H = 0.55$
- Roll
  - Dihedral angle of 3° provides spiral stability





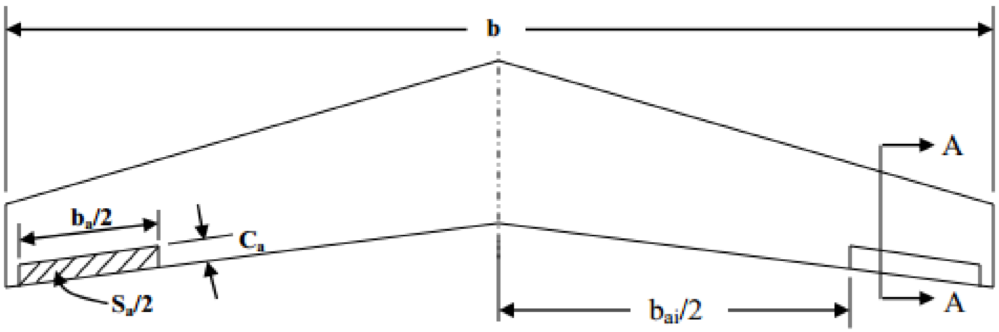
Control

- Control Surfaces
  - Based on ratios between wing/stabilizers and respective control surface
    - Planform Area (S)
    - Total Span (b)
    - Chord Width (C)



Control

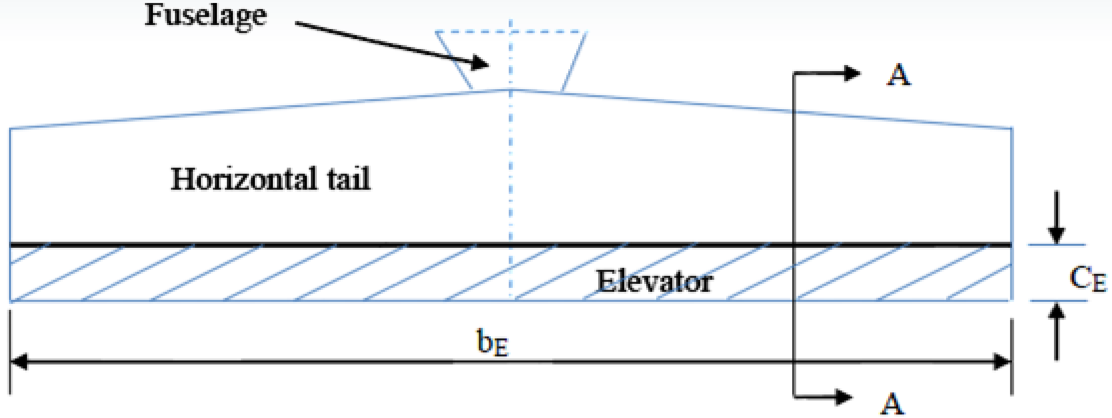
- Aileron



	Typical [9]	Actual
S_a/S	0.05-0.1	0.11
b_a/b	0.2-0.3	0.38
C_a/C	0.15-0.25	0.29
δ_{Amax}	$\pm 30°$	$\pm 25°$

Control

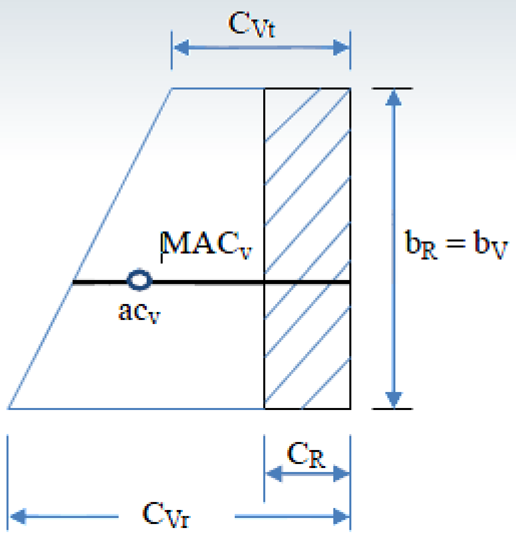
- Elevator



	Typical [9]	Actual
S_E/S_h	0.15-0.4	0.26
b_E/b_h	0.8-1	1
C_E/C_h	0.2-0.4	0.39
δ_{Emax}	$\pm 20°$	$\pm 20°$

Control

- Rudder



	Typical* [9]	Actual
S_R/S_V	0.19-0.24	0.28
C_R/C_V	0.2-.25	.37
δ_{Rmax}	$\pm 30°$	$\pm 20°$

*Empirically derived

Control

- Servo Sizing
  - Torque Equation

$$T(oz - in) = 8.56x10^{-6}\left(\frac{C^2V^2Lsin(S_1)}{\tan(S_2)}\right) \text{ [10]}$$

C = Control Surface Chord

V = Max Velocity

L = Control Surface Length

S_1 = Maximum Control Surface Deflection

S_2 = Max Servo Deflection

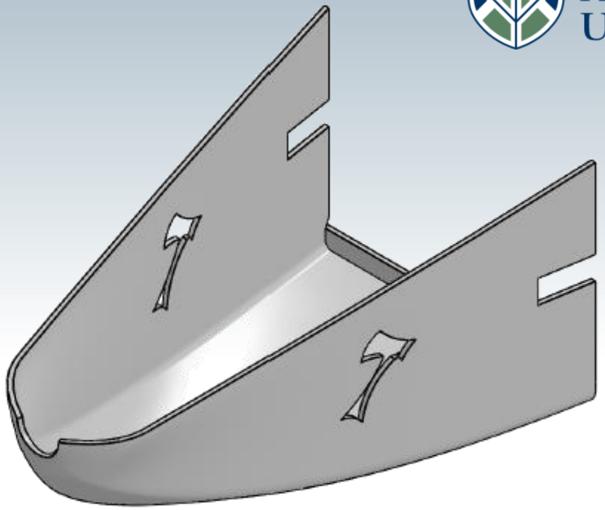
	Calculated (oz-in)	Actual (oz-in)
Aileron	31.4	42.0
Elevator	28.7	42.0
Rudder	47.27	72.0

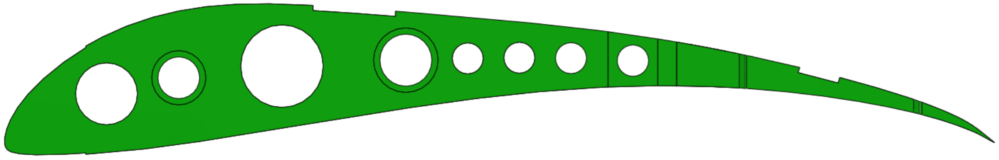
Weight Buildup

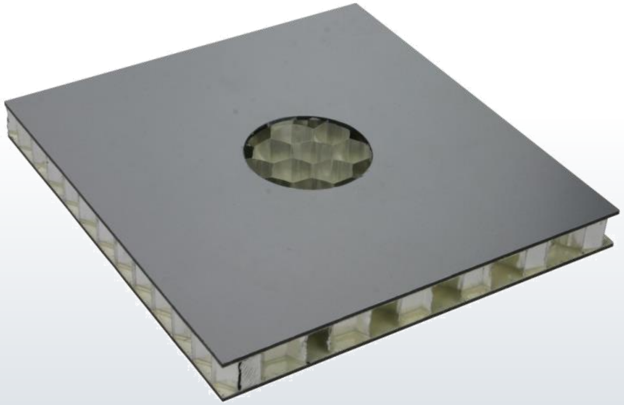
- Initial weight estimate = 10 lb
- Final airplane weight = **10 lb**
- Use of commercial-grade Al honeycomb as fuselage centerpiece
- Cut holes in stabilizers, bulkheads, and ribs to reduce weight
- Center of Gravity was placed at 22% of the wing chord
  - Slightly forward from standard 25% approximation
  - Highly-cambered airfoil [11]

Materials

- Acrylonitrile Butadiene Styrene (ABS)
  - Used for ribs, cowling, and ailerons
  - 3D printed for precise manufacturing and customization
- Aluminum Honeycomb
  - Connection point between fuselage, wings, landing gear, and payload
  - High strength-to-weight ratio





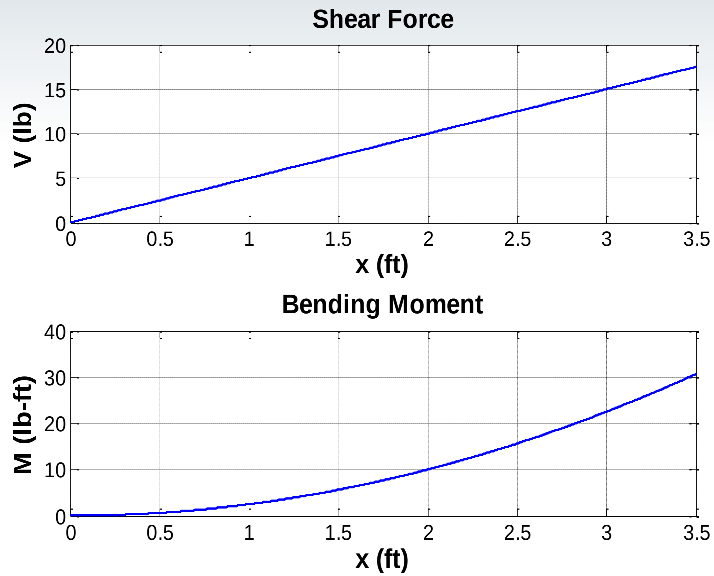


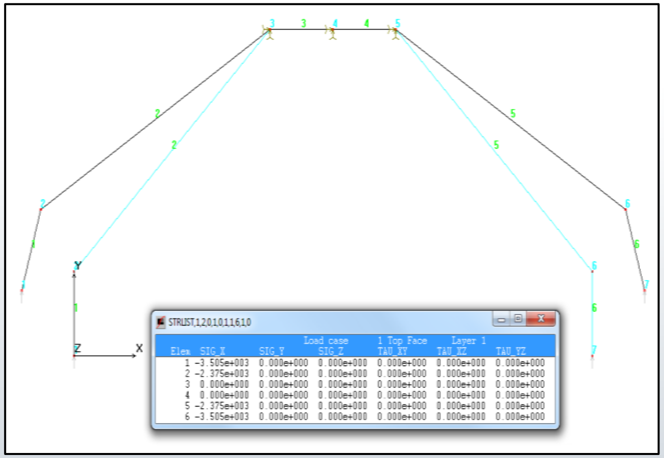
Stress Analysis

- Spars

  -Treated as cantilevered beam with distributed load

- Landing Gear
  - Utilized COSMOS FEA software





Elem	SIG_X	SIG_Y	SIG_Z	TAU_XY	TAU_XZ	TAU_YZ
1	-3.505e+003	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
2	-2.375e+003	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
3	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
4	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
5	-2.375e+003	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
6	-3.505e+003	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000

Flight Testing

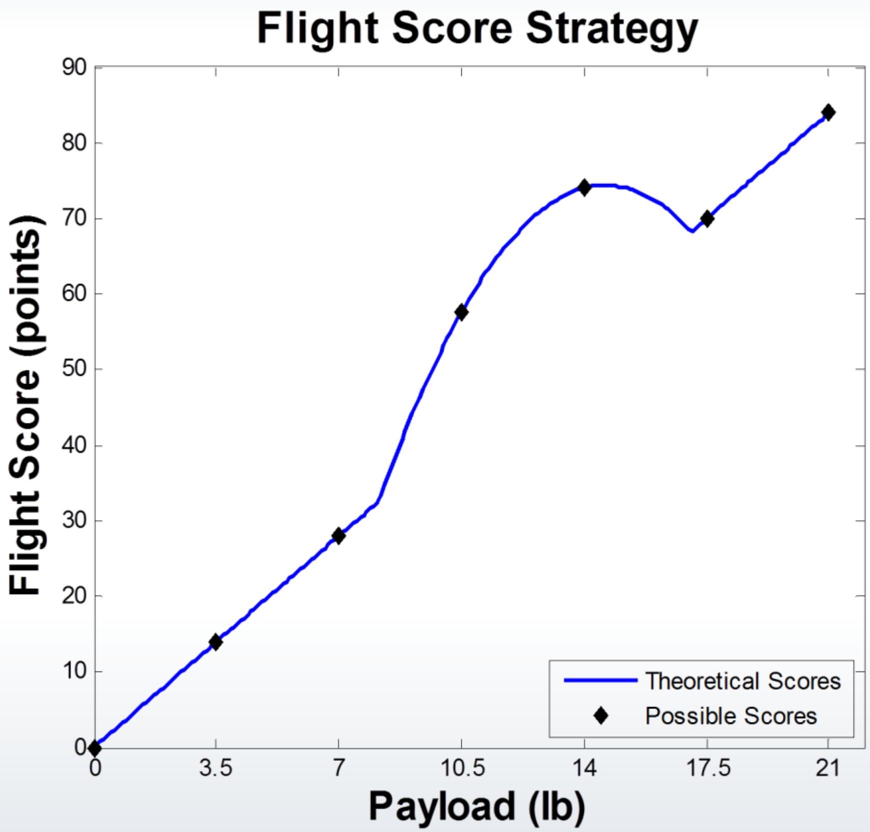
- Initial
  - Location
    - Flagstaff, AZ
  - Elevation
    - 7,000 ft
  - Inspired several design changes:
    - Larger horizontal stabilizer
    - Reduced angle of attack
    - Added dihedral angle
    - Propeller size increased

Flight Testing

- Final
  - Location
    - Leupp, AZ
  - Elevation
    - 4,400 ft
  - Multiple test flights with varying weights
    - Empty to 10.5 lbs

Competition Objectives

- Mission Strategy
  - Empty weight flight
    - 10 points
  - Flight with a load very near to prediction
    - FS + PPB = 74.0336
  - Empty flights for remainder to maximize Ao → i
    - i = 1.15



Competition

- Flight Results
  - Flight 1: Empty
  - Flight 2: 13.8lb
  - Flight 3: Empty
  - Flight 4: 6.9lb
  - Flight 5: 13.8lb
  - Flight 6: 6.9lb

Competition

- 1st place Technical Presentation
- 14th Overall Score

Lessons Learned

- Start design & build processes early
- Research fundamentals of aircraft design
  - Center of gravity location and aircraft stability
- Emphasize testing over conceptual perfection
- Problem Identification
  - Thorough understanding of aircraft components
  - Effective communication between pilot and crew
- Take advantage of allotted dimensions

Acknowledgements

- Pilot
  - Chuck Hebestreit

- Academic Advisors
  - Dr. John Tester
  - Dr. Tom Acker

And our sponsors…

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References

[1] “2013 SAE Aero Design Rules.” http://students.sae.org/competitions/aerodesign/rules/rules.pdf.

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[10] Gadd, Chuck. "Servo Torque Calculator." *Calculate Required Servo Torque*. N.p., n.d. Web. 04 Mar. 2013.

[11] Anderson, John. *Fundamentals of Aerodynamics*. 5th ed. New York: McGraw-Hill, 2011. Print.

Questions?

"The exhilaration of flying is too keen, the pleasure too great, for it to be neglected as a sport"

-Orville Wright

Performance Analysis

- Takeoff Performance

$$s_{LO} = \frac{1.44W^2}{g\rho_\infty S C_{L_{max}}\{T-[D+\mu_r(W-L)]_{ave}\}} \quad [5]$$

$$W = \sqrt{\frac{s_{LO}\, g\rho_\infty S C_{L_{max}}\{T-[D+\mu_r(W-L)]_{ave}\}}{1.44}}$$

$s_{LO} \equiv Takeoff\ Distance$

$W \equiv Airplane\ Weight$

$g \equiv Acceleration\ due\ to\ Gravity$

$\rho_\infty \equiv Air\ Density$

$S \equiv Wing\ Planform\ Area$

$C_{L_{max}} \equiv Maximum\ Lift\ Coefficient$

$T \equiv Static\ Thrust$

$D \equiv Total\ Drag$

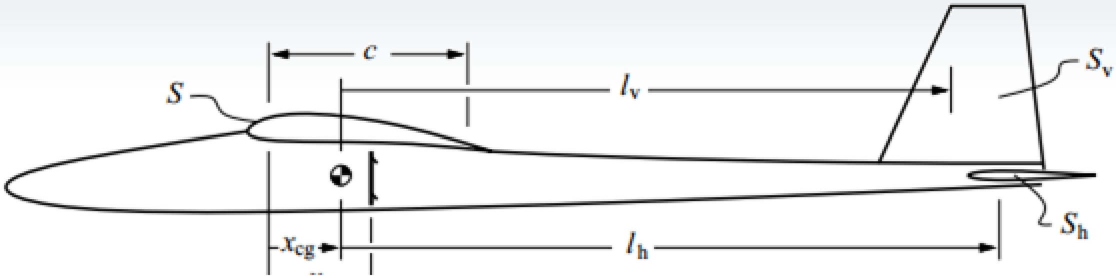
$\mu_r \equiv Rolling\ Friction\ Coefficient$

$L \equiv Total\ Lift$

- Iterative MATLAB code solves for airplane weight for a sweep of air density values
- After subtracting the empty airplane weight, the payload weight is found

Stability

- Longitudinal



$$V_H = \frac{S_H l_H}{Sc} \text{ [8]}$$

$V_H \equiv Tail\ Volume\ Ratio$

$S_H \equiv Horizontal\ Stabilizer\ Planform$

$l_H \equiv Horizontal\ Stabilizer\ Moment\ Arm$

$S \equiv Wing\ Planform$

$c \equiv Wing\ Chord$

  - V_H of 0.3-0.6 is needed [8]
  - Our V_H = 0.55

- Spiral
  - Dihedral angle of 3° provides spiral stability