

# Final Presentation for the Morphing Wing Design Team

**Desta Alemayehu**  
**Mathieu Leng**  
**Ryan McNulty**  
**Michael Mulloy**  
**Ryan Somero**  
**Cyril de Tenorio**



# The goal for this semester was to build a R/C airplane with a morphing wing



[NexGen, 2004]

The wings will be able to morph to loiter, maneuver, dash, and landing

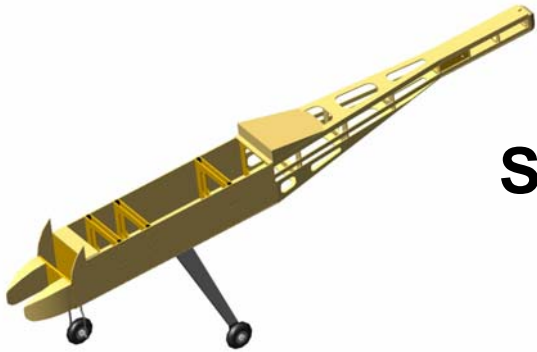
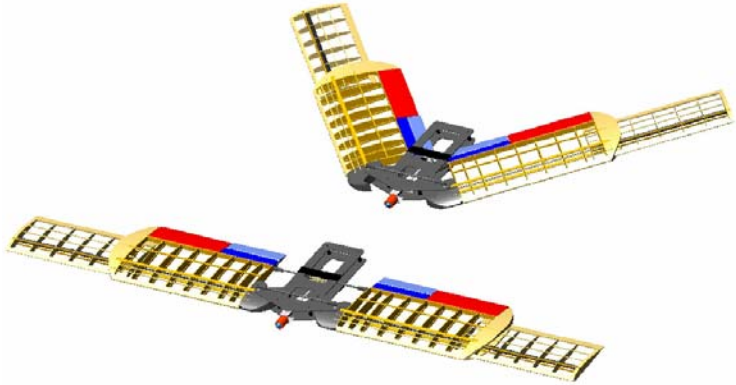
This will be accomplished with chord, sweep, and span changes

Last semester's results help our team in the design process



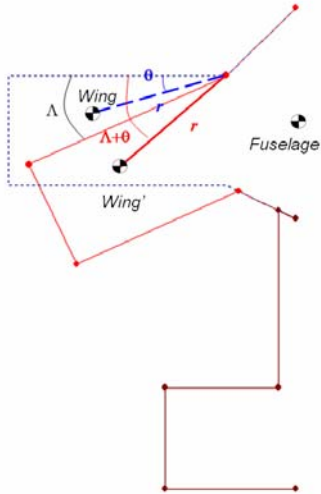
# The work presented identifies the process used to design and build a morphing aircraft

**Actuation**



**Sizing and structures**

**Aerodynamics**

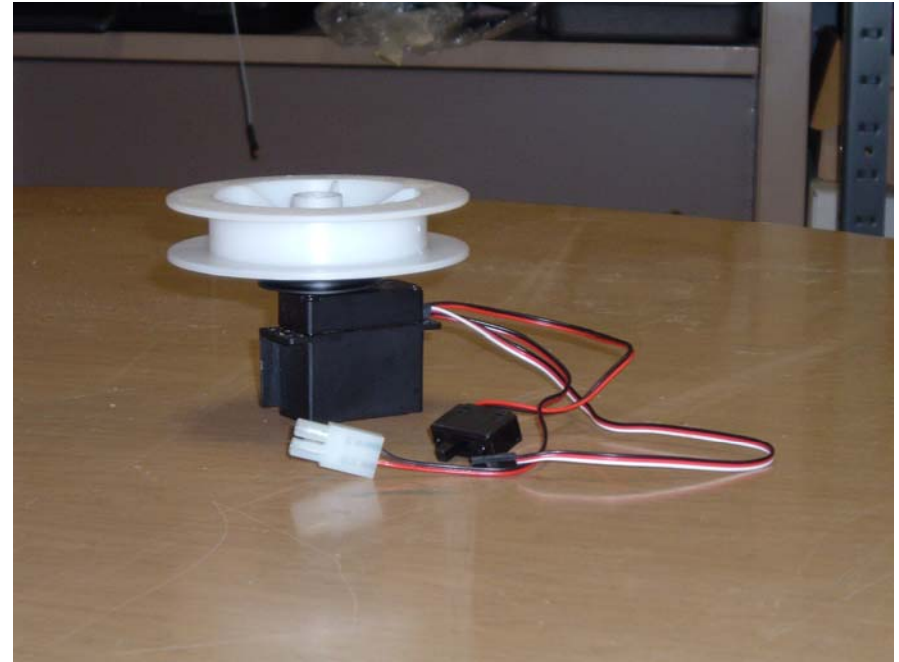


# The span extension is operated using a pull-pull method actuated by a winch servo and fishing line

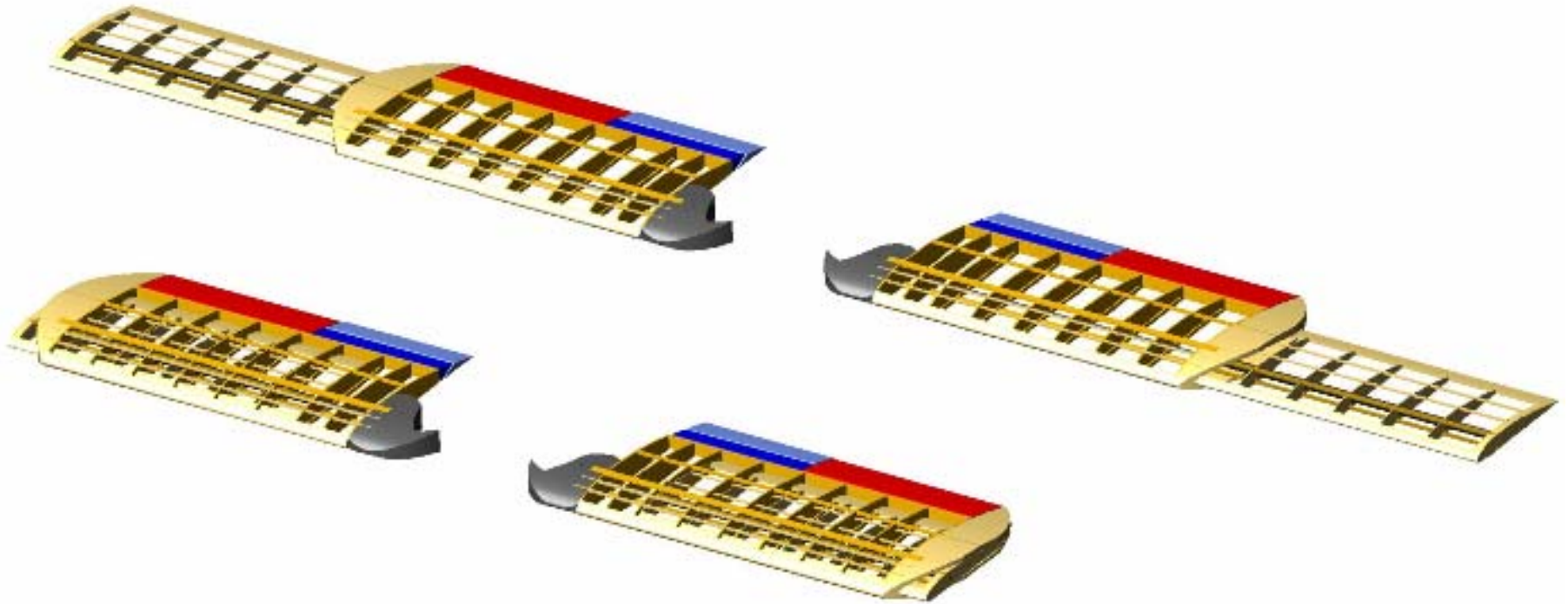
**A large control horn is counter wrapped with fishing line**

**When rotated, one line unwraps while the other winds up**

**Which ever side winds up pulls the extension in or out of the wing**



The span extension is operated using a pull-pull method actuated by a winch servo and fishing line

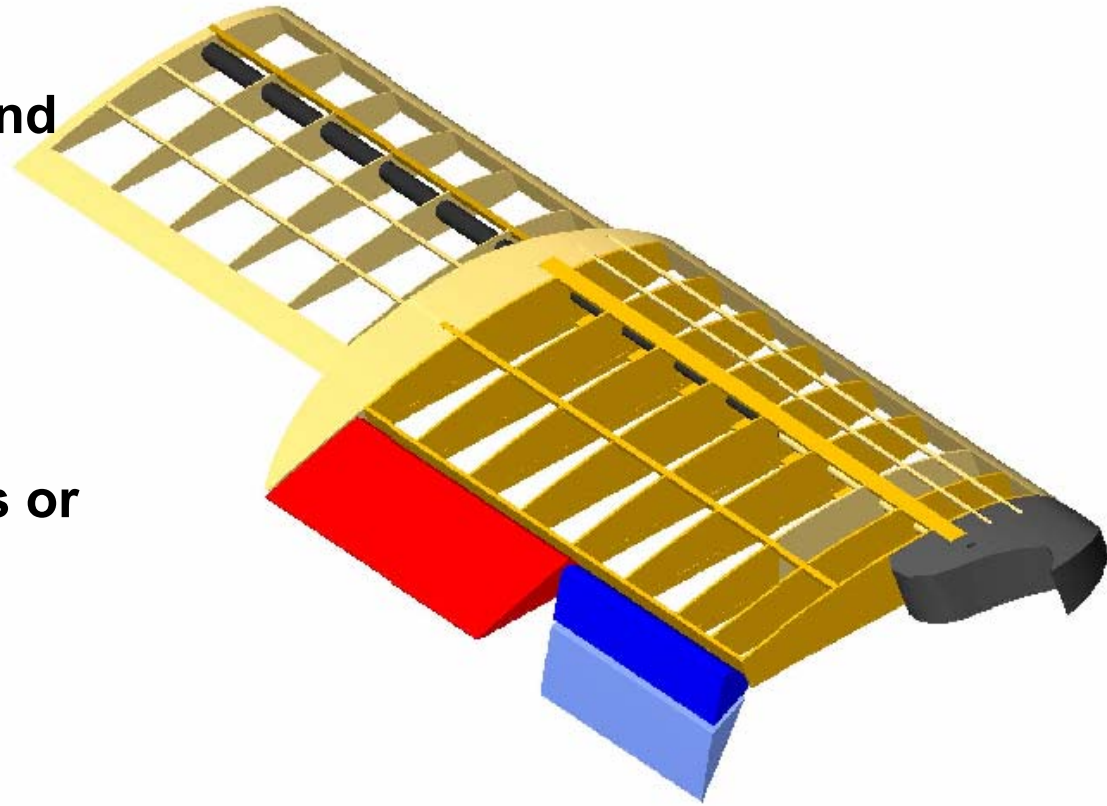


# The change in camber is produced by a flap that is actuated by a servo

The flap rotates downward and increases the camber

A servo moves a flexible pushrod in or out

The flexible pushrod extends or retracts the fowler flap

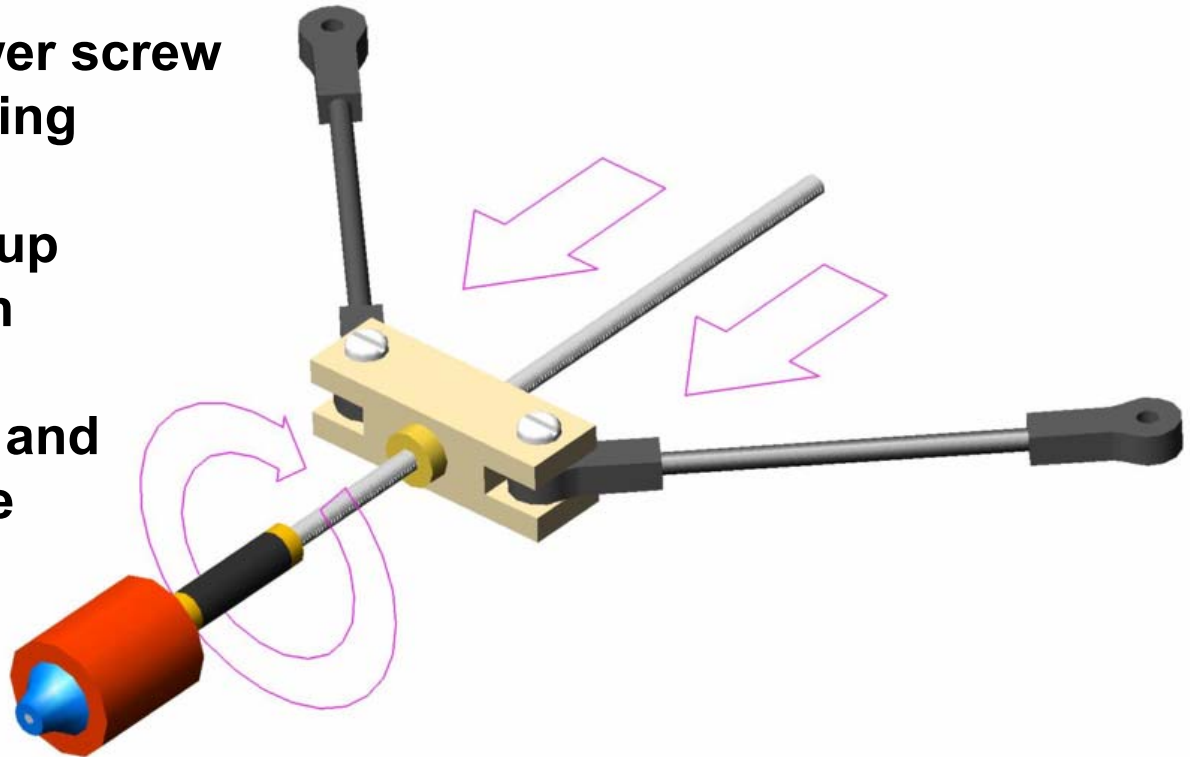


# The sweep is actuated by a motor driven power screw

A DC motor drives a power screw through a Hooke's coupling

A transverse nut travels up or down the screw length

Push rods retract, rotate and increase the sweep angle



# The electric motor was sized using power screw equations

The approximated maximum load on the power screw was 20 lbs

$$T_{raise} = \frac{Fd_m}{2} \left( \frac{l + \pi f d_m}{\pi d_m - fl} \right)$$

If the screw was self locking no holding torque would be required

$$\pi f d_m > l$$



[[www.towerhobbies.com](http://www.towerhobbies.com)]

Power Screw Calculations	
Screw Specifications	
Axial Load (lb)	20
Mean Diameter (in)	0.25
Lead (in)	0.0625
Friction Factor	0.1
Screw Material	Stainless Steel

Torque Results	
Total Torque to Raise (ft-lb)	0.037712076
Total Torque to Lower (ft-lb)	0.004221103
Efficiency (%)	43.96109015
Self Locking	YES

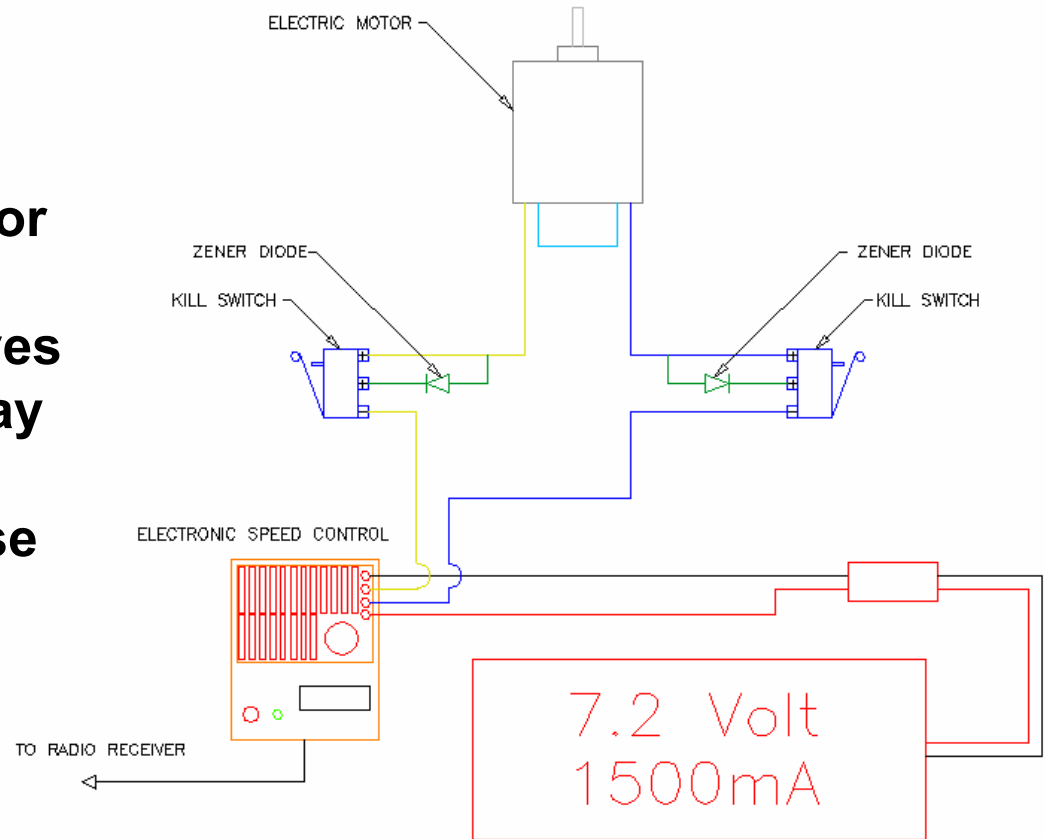
Total Torque to Raise (N-mm)	51.13071005
Total Torque to Lower (N-mm)	5.723047151

# The sweep actuation electrical system is made possible through use of Zener Diodes

An electronic speed controller regulates the speed of the motor

Zener diodes act as check valves allowing current to flow one way

This allows the motor to reverse direction with the kill switches engaged



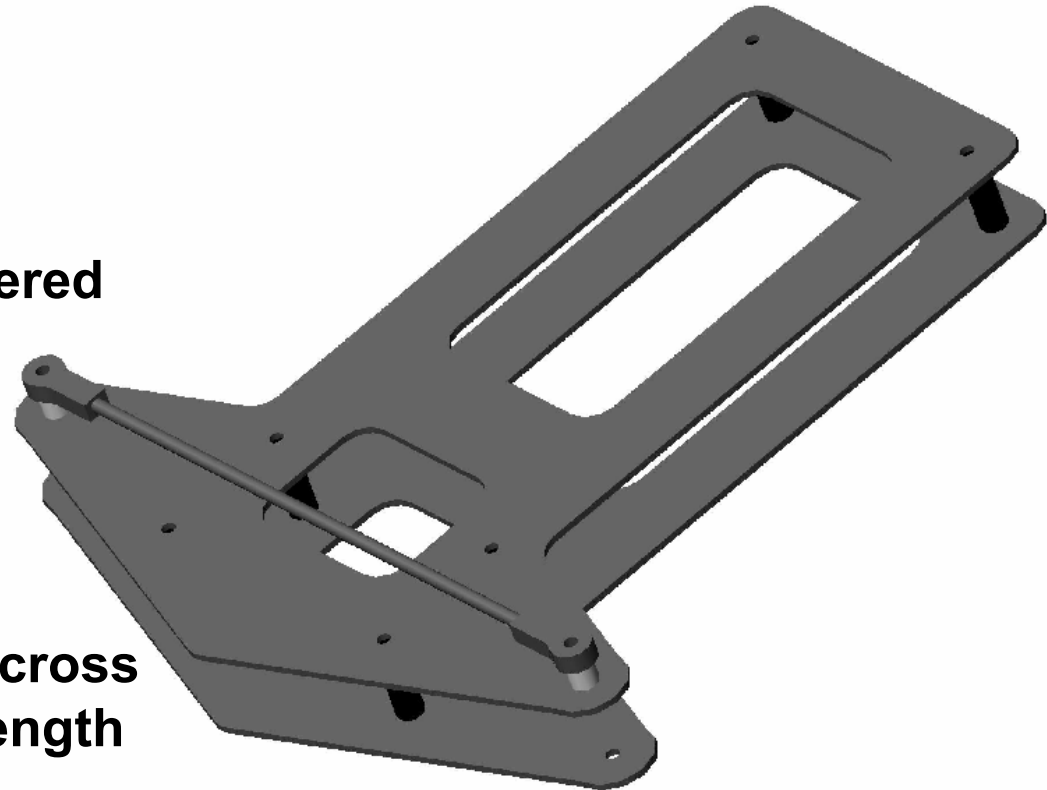
# The core of the sweep actuation is located within the carbon fiber wing box

The wing box was cut from 1/8" plywood

One side of each plate was covered with carbon fiber

The plates are separated by 1 1/2" long PVC spacers

A carbon fiber rod was added across the pivot points to increase strength



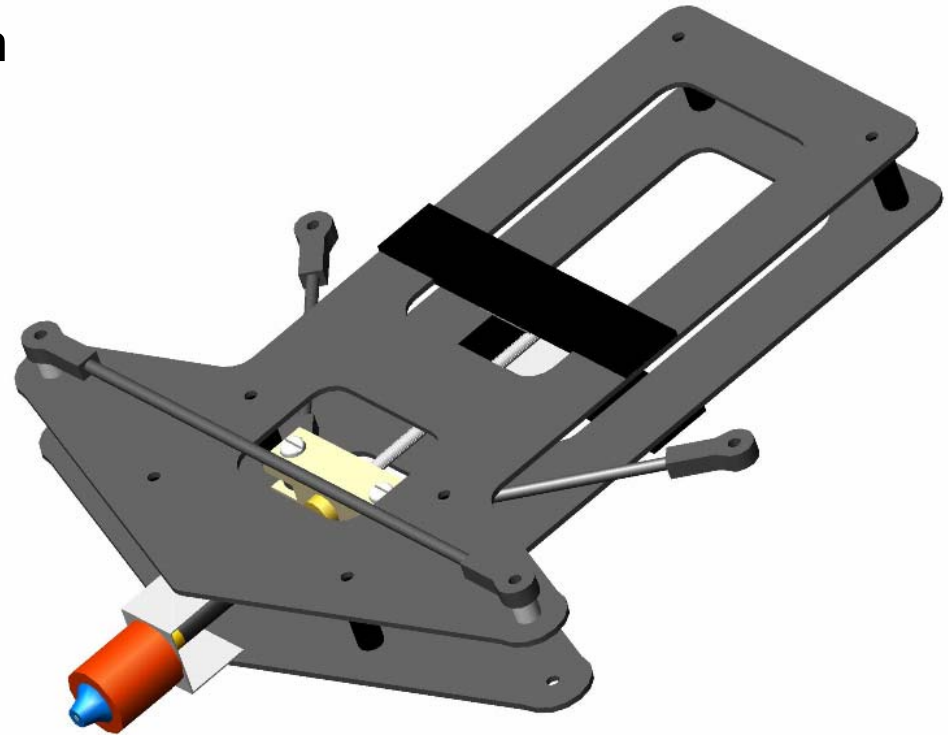
# The wing box and power screw are combined to form the sweep mechanism

The motor mounts were made from prefabricated sheet metal

The transverse nut travels 6 1/2" to sweep the wing a full 45°

With the motor running at 1200 RPM it takes 5.5s to sweep

The carbon fiber plates are connected with nylon bolts



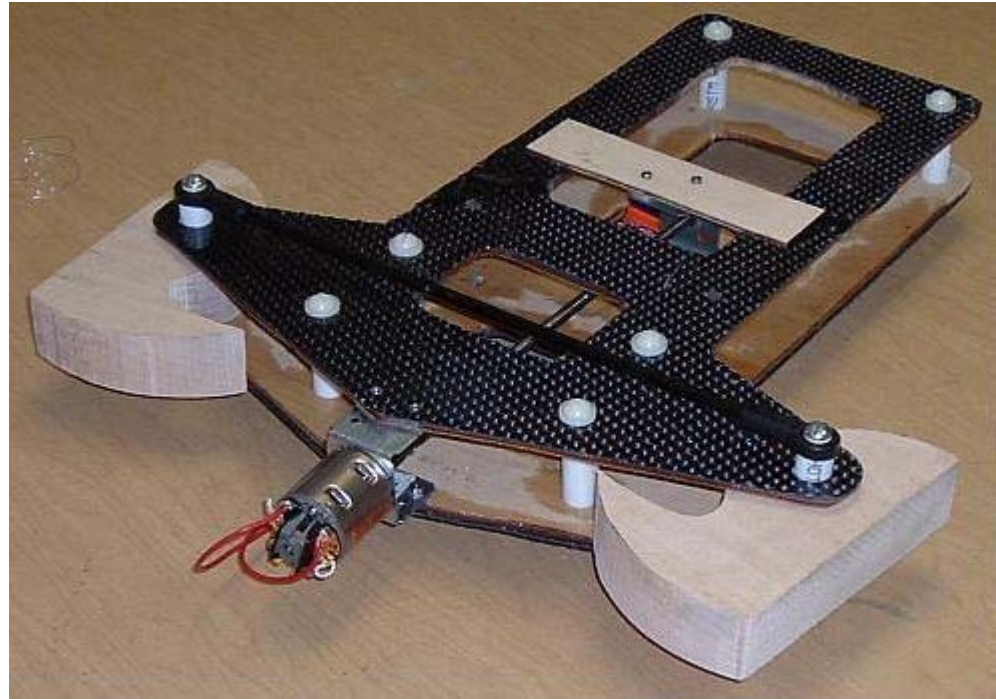
# The wing box and power screw are combined to form the sweep mechanism

The motor mounts were made from prefabricated sheet metal

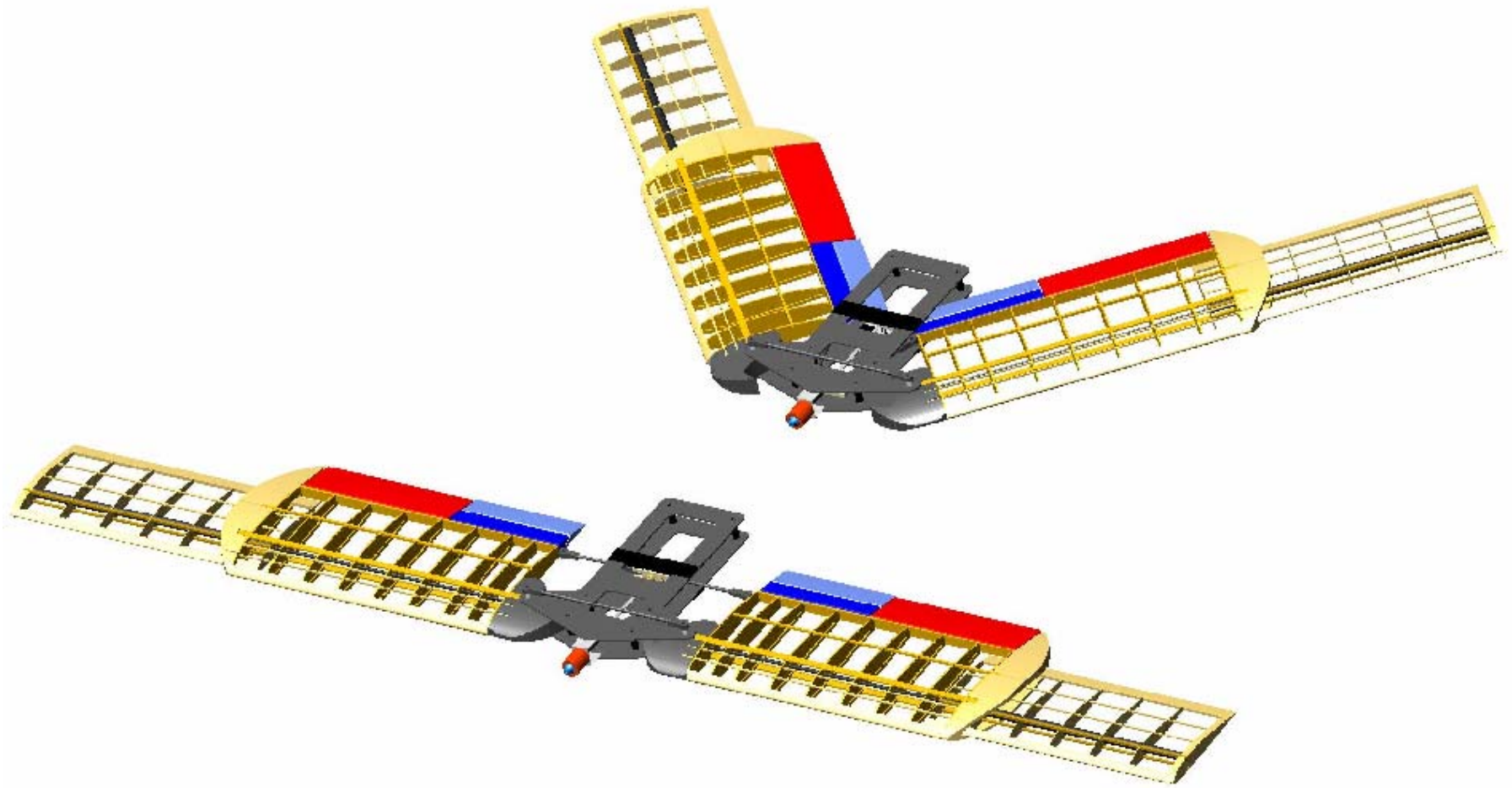
The transverse nut travels 6 1/2" to sweep the wing a full 45°

With the motor running at 1200 RPM it takes 5.5s to sweep

The carbon fiber plates are connected with nylon bolts



**After final assembly the wing can sweep back to a maximum angle of 45 degrees**



# The aircraft was divided into seven components to estimate the total weight.

The seven components which make up the aircraft are:

1. Propulsion
2. Main wing
3. Fuselage and tail
4. Landing gear
5. Radio control system
6. Actuation system
7. Instrumentation system

The weight of each component is estimated by obtaining the weight of each part which make up the component. If the weight of a part can not be obtained, an estimation was made using a similar part.

Note: Part names followed by \* indicate weight estimations

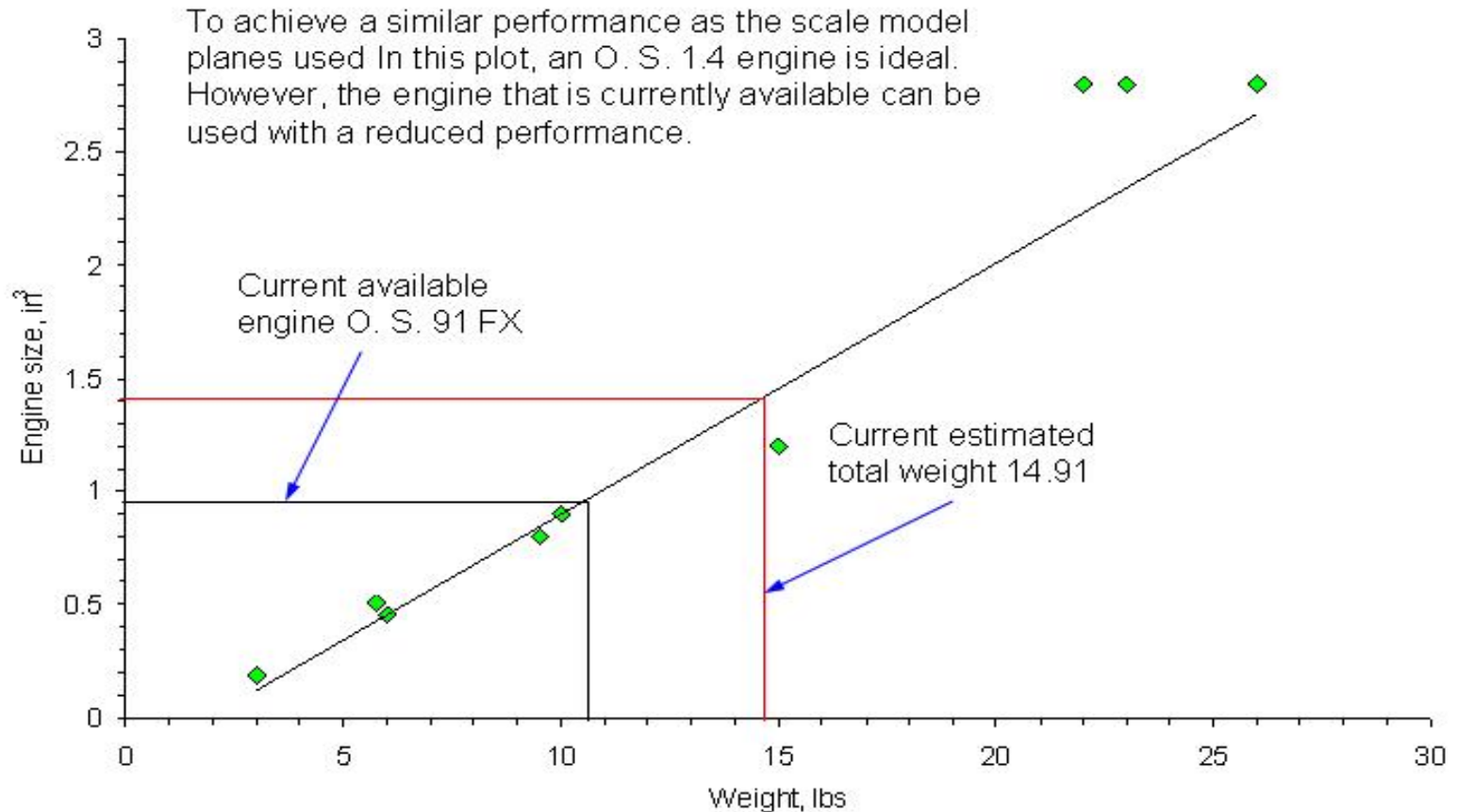
# The estimated total aircraft weight was between 12.91 – 14.91 lbs

<b>Propulsion</b>	<u>3.65</u>	lbs
<b>Main wing</b>	<u>3.63</u>	lbs
<b>Fuselage and Tail</b>	<u>1.56</u>	lbs
<b>Landing gear</b>	<u>1.41</u>	lbs
<b>Radio control system</b>	<u>1.13</u>	lbs
<b>Actuation System</b>	<u>1.53</u>	lbs
<b>Instrumentation System</b>	<u>2.00</u>	lbs

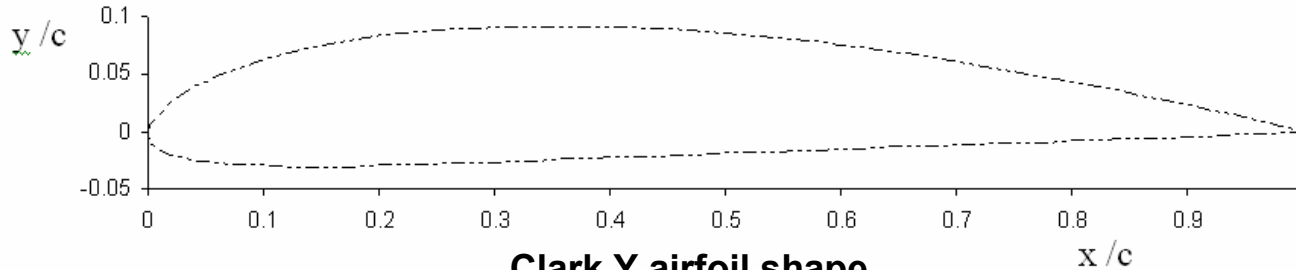
**The total aircraft weight varies depending on the use of the instrumentation system for data acquisition.**

# Aircraft engine sizing based on data for existing aircraft

Engine size vs. Weight



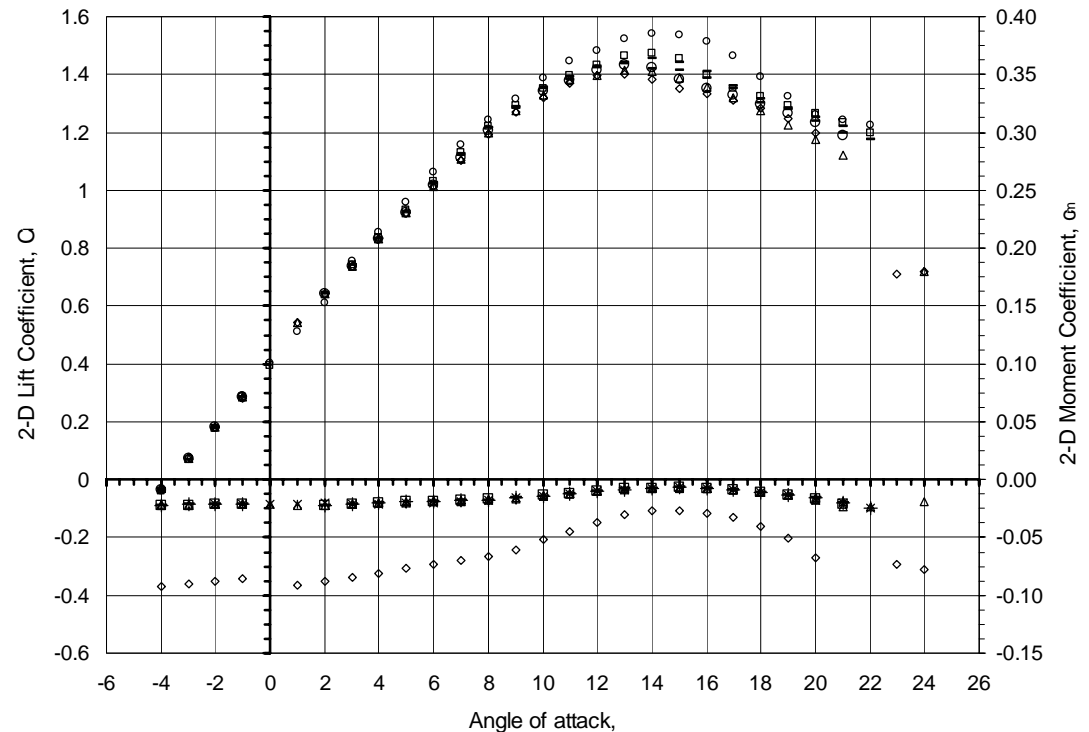
# Wing airfoil and geometry selection



The Clark-Y airfoil was chosen for its flat lower surface.

## Geometric properties of the Clark-Y airfoil

Chord	$c$
Maximum camber	$0.03435 c$
Location of max camber	$0.42 c$
Maximum thickness	$0.117 c$
Location of max thickness	$0.29 c$
Circumference	$2.04 c$
Circumference to Chord ratio	$2.04 c$



2-D CL and CM curves for the Clark-Y airfoil

# The wing dimensions were calculated based on specific goals and constraints

Goals, requirements and constraints:

Take-off speed range: 30 – 35 mph

Take-off velocity equation:

$$V_{LO} = 1.2V_{stall} = 1.2\sqrt{\frac{2W}{\rho_{\infty}SC_{L,max}}}$$

where:  $W = 14.91$  lb (from weight estimation)

$C_{L,max} = 1.3$  (estimation based on WT data + flap effect)

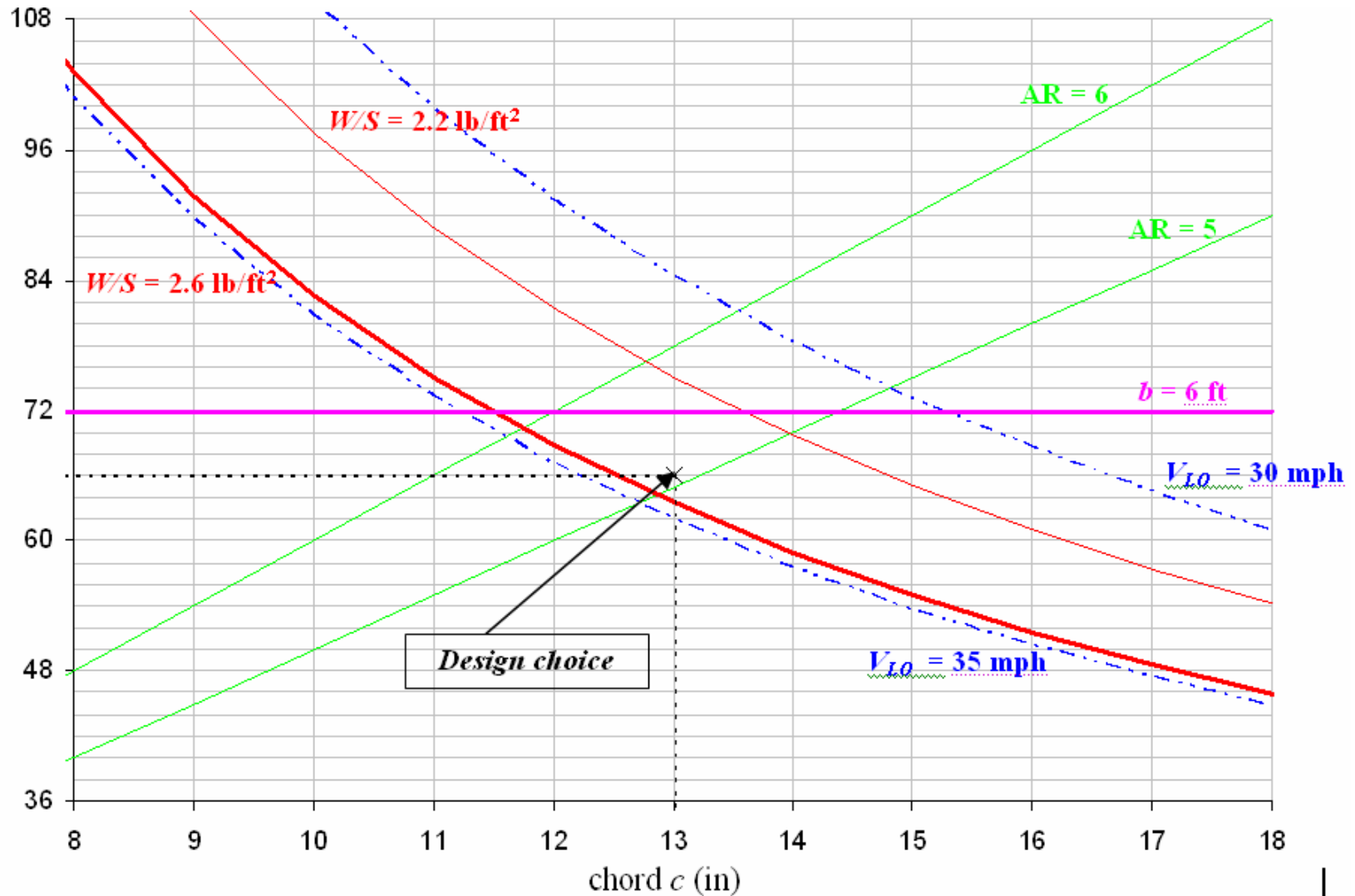
Aspect ratio  $\sim 5, 6$        $AR = b^2/S$

Wing loading limit:  $W/S < 2.6$  lb/ft<sup>2</sup>

→ Result: span  $b = 5'6''$  , chord  $c = 13''$  which gives:

$$V_{LO} = 33.9 \text{ mph} ; AR = 5.08 \text{ and } W/S = 2.50 \text{ lb/ft}^2$$

# The wing dimensions were calculated based on specific goals and constraints



# The span extension was designed to achieve a high aspect ratio for loiter configuration

- **Constraint:** chord of extension  $c_e$  limited to 8.625 in (66% of the the wing chord) by space necessary for ailerons, flaps and structure
- **Objective:** 50% increase in span or more likely  $AR_l \sim 9$

$$AR_l = \frac{b_l^2}{S_l} = \frac{[(1+x)b]^2}{bc + xb(0.66c)} \Rightarrow \frac{(1+x)^2}{1+0.66x} = \frac{AR_l}{AR}$$

**solving for x with  $AR_l/AR = 9/5.08$  gives :  $x = 0.56$**

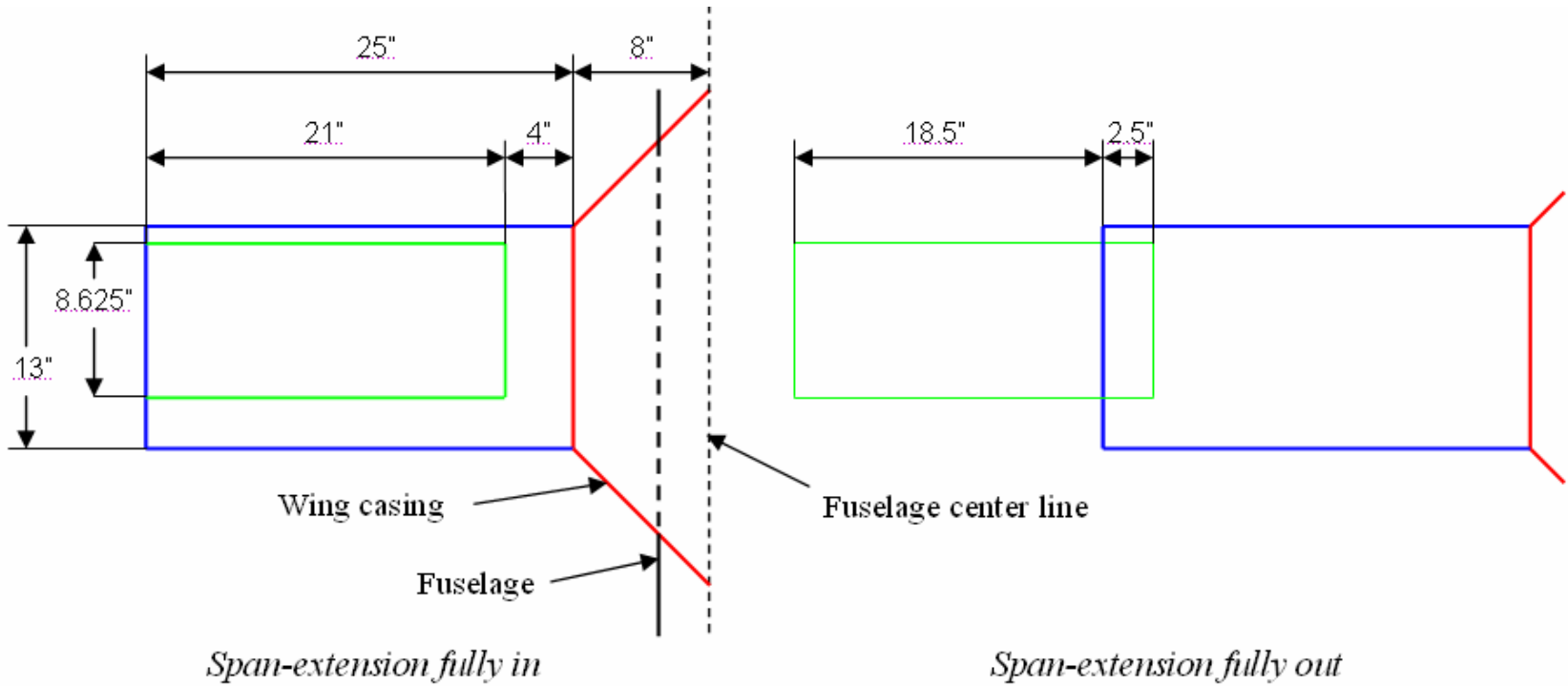
**→  $b_l = 8'7''$  → span increase: 56% , AR increase: 77%**

**Result: extension dimension:  $c' = 8.625''$  and  $b' = 21''$**

**– when fully extended: 18.5'' out and 2.5'' in**

**– when fully retracted: 4'' free space for actuations**

# Resulting wing dimensions

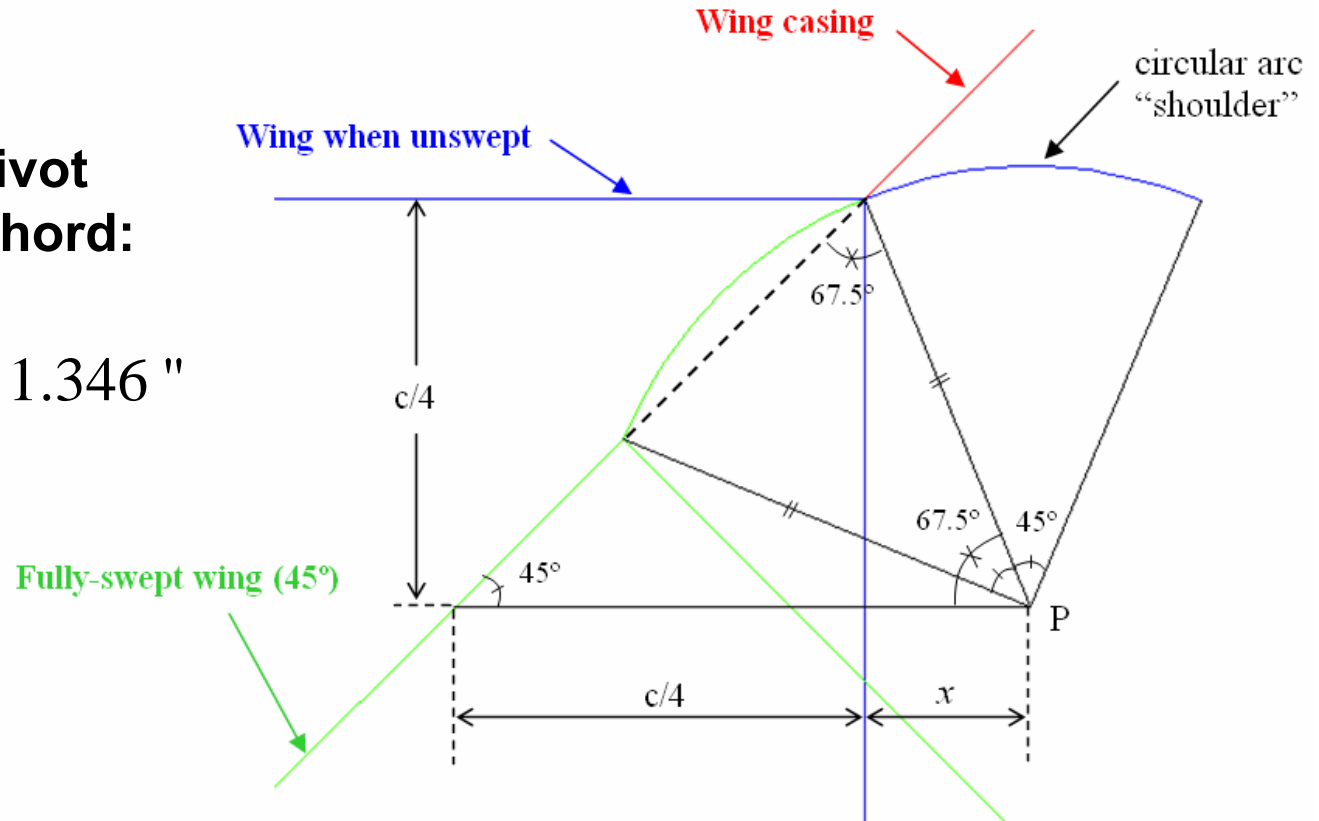


	Wing Area $S$ (in <sup>2</sup> )	Span $b$ (in)	Mean Geometric Chord $c'$ (in)	Aspect Ratio $AR$	Mean Aerodynamic Chord $c_a$ (in)
Span-extension fully in	858	66	13	5.08	13
Span-extension fully out	1177.1	103	11.43	9.01	11.81

# The pivot point location was determined to align the wing LE with the casing at maximum sweep

Distance from pivot point P to root chord:

$$x = \frac{c/4}{\tan(67.5^\circ)} = 1.346''$$



Also from geometry, the distance from the root TE for 45° sweep to the root chord line for 0° sweep is:  $d = 7.289''$

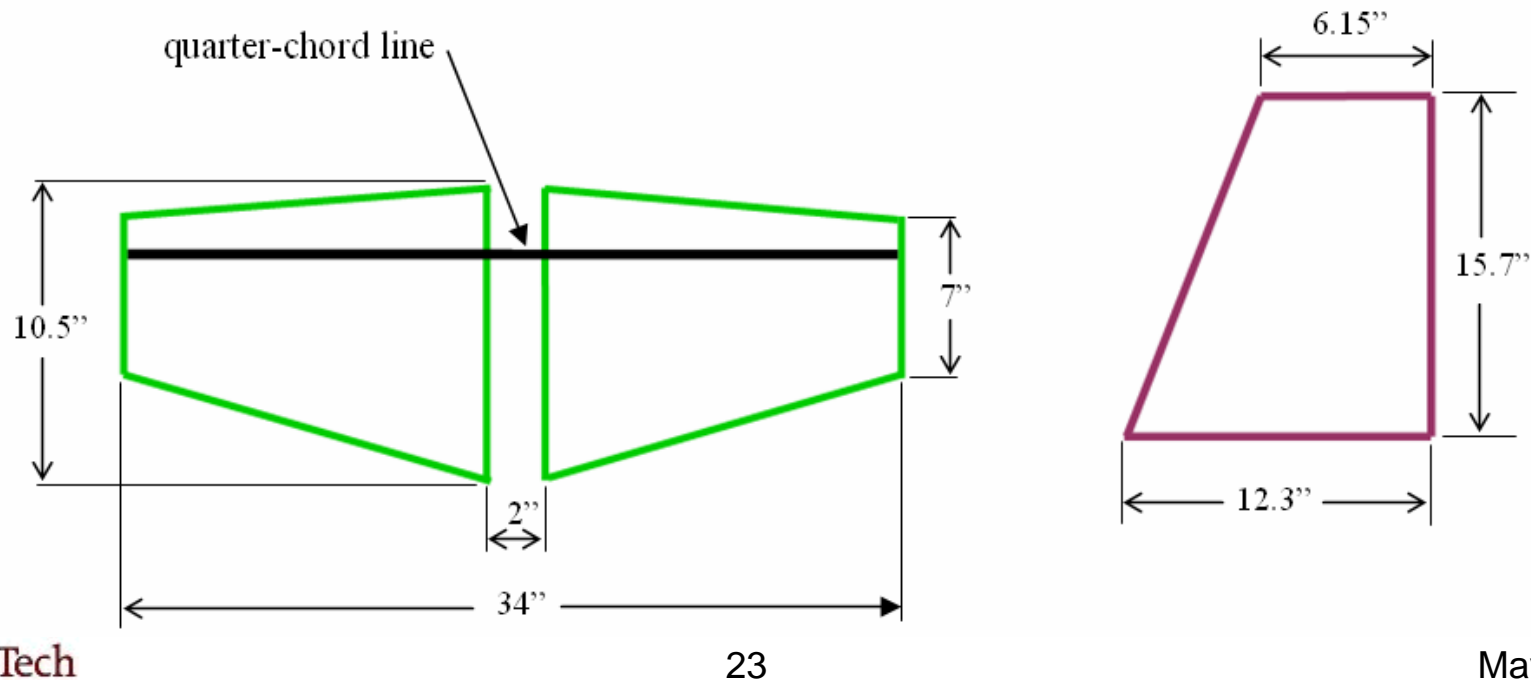
→ thus we opted for a wing casing width of 16''

# Tail sizing was based on empirical techniques and refined by stability analysis

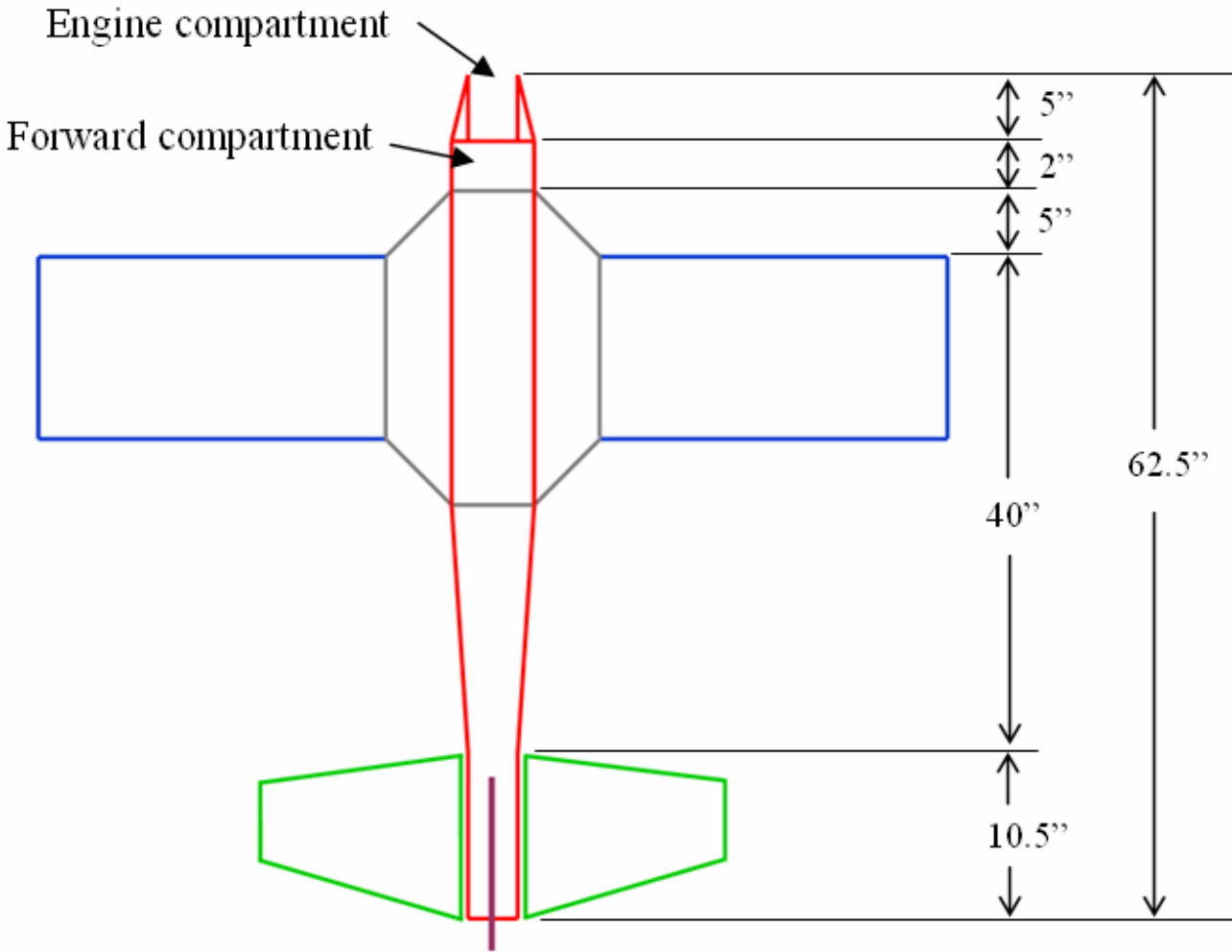
- An initial estimation of the tail size was obtained using the “tail volume coefficient” method given by Raymer:

$$S_{VT} = c_{VT} b_w S_w / L_{VT} \quad S_{HT} = c_{HT} \bar{c}_w S_w / L_{HT}$$

- The results were refined using VLMprojective: 50% increase in span or more likely  $AR_1 \sim 9$



# After the analysis the final fuselage dimensions could be determined



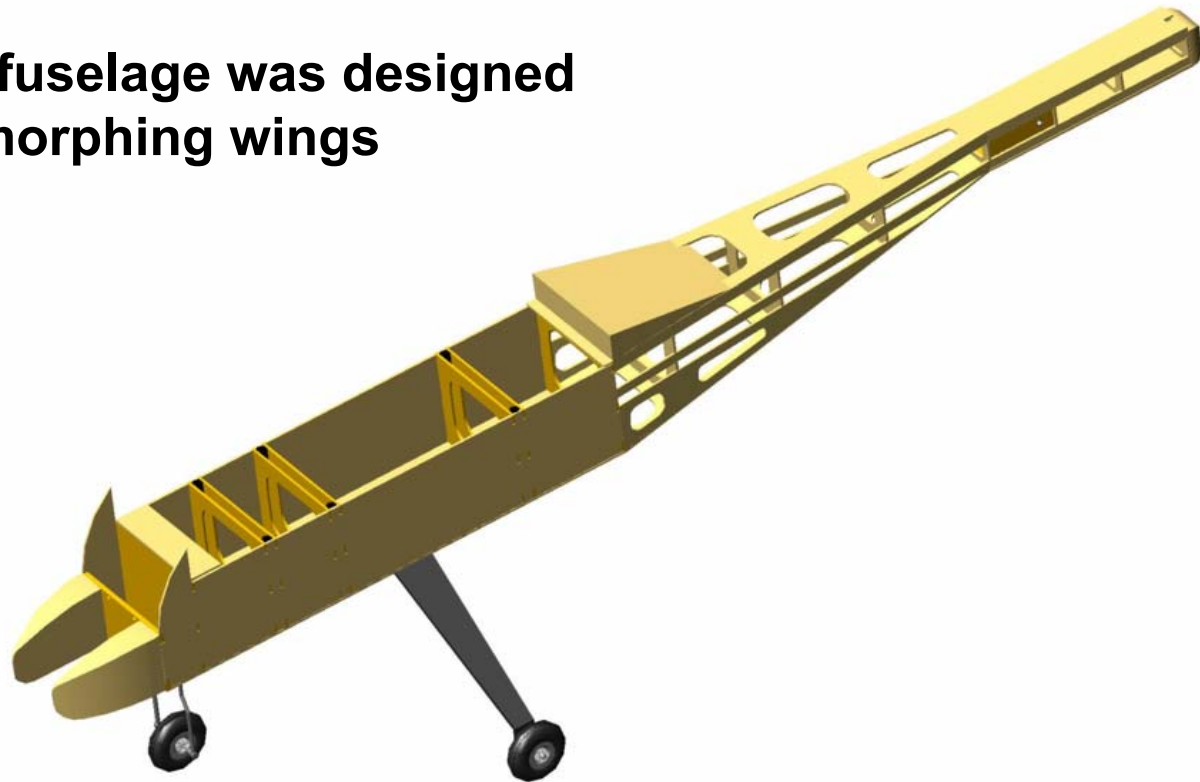
# **An all-moving tail was chosen to trim the backward shift of the aerodynamic center in sweep**

- **The all-moving tail provides a tremendous down load necessary to balance the aircraft in its swept configuration**
- **The other control surfaces were sized based on historical guidelines**
  - **the aileron extends from about 50% to 90% of the wing span, has a span of 14” and a chord of 3” (23% of the wing chord)**
  - **the rudder is 40% of the tail chord, begin at the side of the fuselage and extends all the way to the tip of the tail**

# The fuselage was designed to support the wing, the tail, the landing gear and the engine

The main purpose of a conventional fuselage is to carry cargo

In this case the fuselage was designed to support the morphing wings

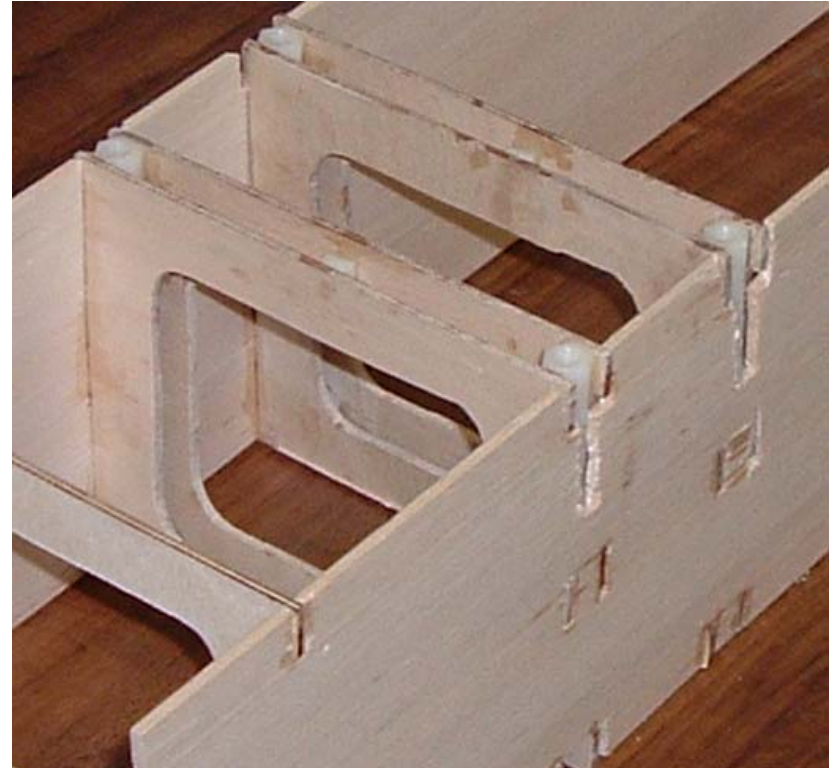


# The wing was supported by a series of three bulkhead pairs

The bulkhead pairs were connected by nylon bolts

These bolts also attached the wing box to the fuselage

The forward, center and aft bulkheads used 6, 7 and 4 nuts respectively



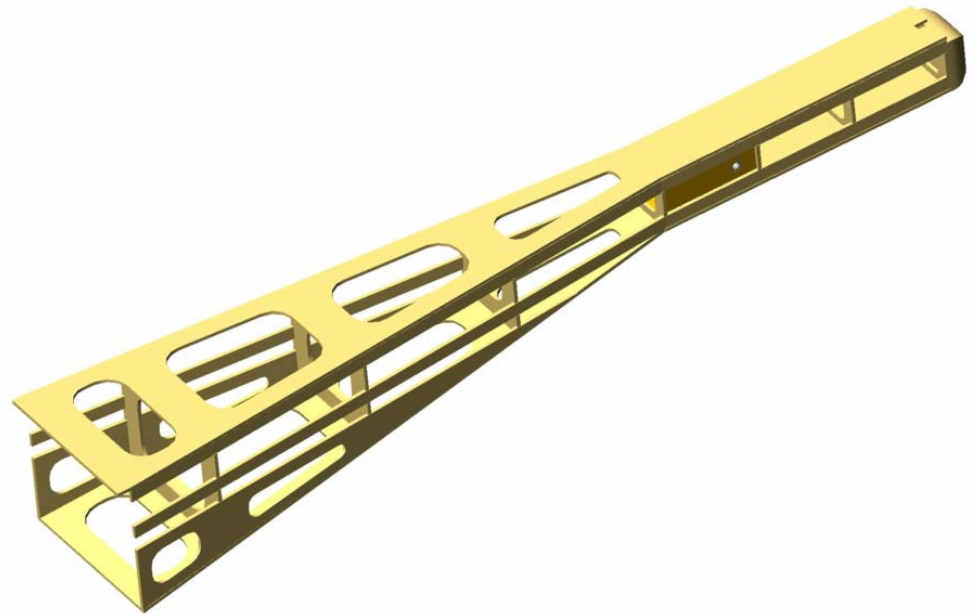
# The tail loads were carried by the aft fuselage

Four balsa bulkheads support the aft fuselage

The loads are transferred between the bulkheads by 1/8 inch balsa sheets and sticks

The tail is connected to the fuselage by a 1/4 inch carbon fiber rod

The rod passes through two 1/8 inch balsa sheets positioned 2 inches apart



# The landing loads were carried by the baseboard and the landing gear

The landing loads are shared by the baseboard and the gear

The corners of the main gear are reinforced to provide greater shock control

The main landing gear was attached --- in. from the nose

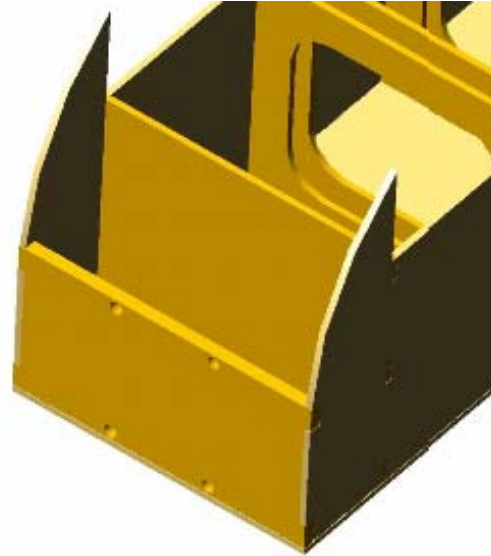


# The engine loads were carried by the firewall

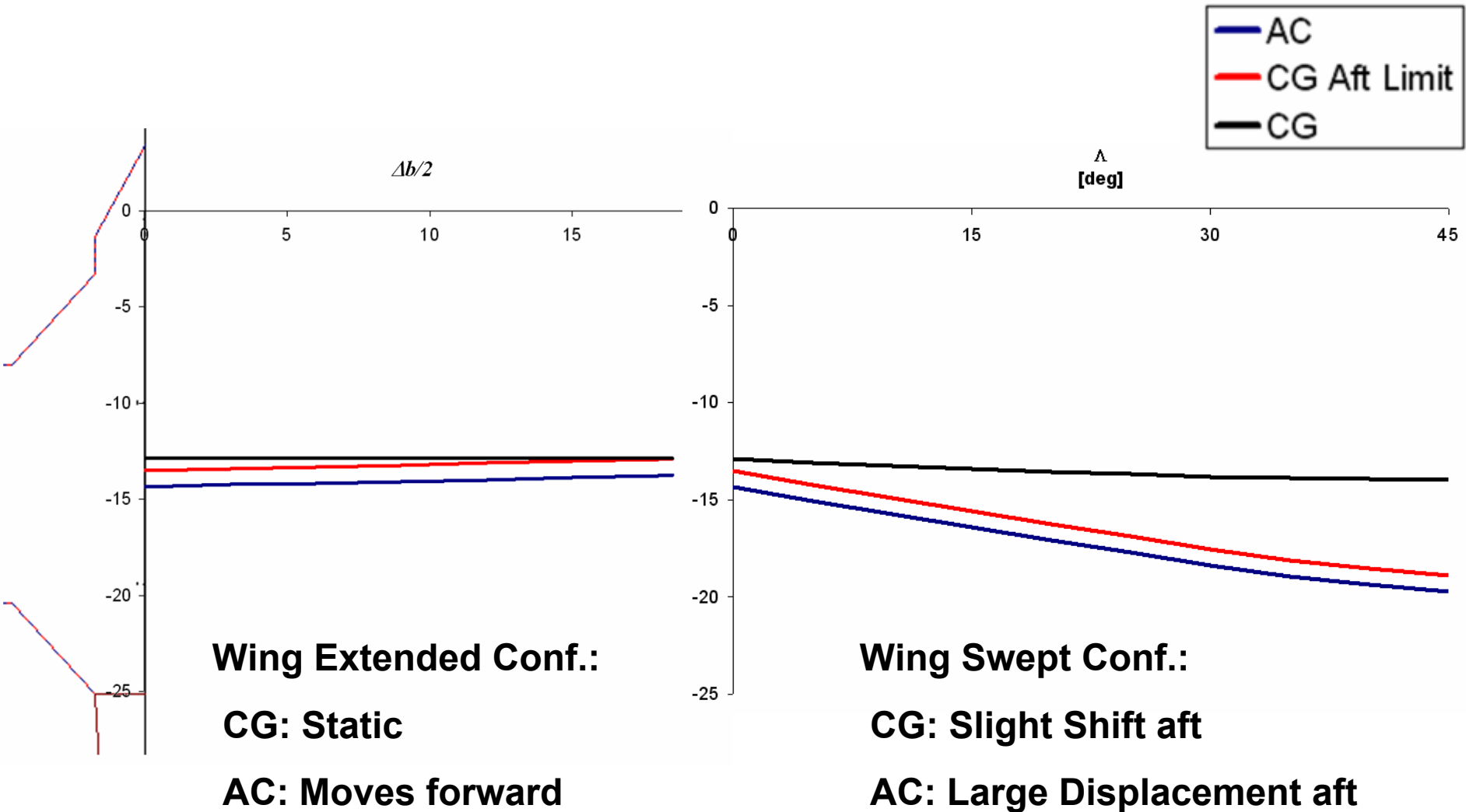
The engine mount was attached to the firewall by four 1/8" bolts

The firewall was made from a 1/4" plywood sheet

The firewall was attached to the baseboard, a 1/8" plywood sheet, as well as to the 1/8" balsa siding



# As the wing morphs the AC and CG location move



**Wing Extended Conf.:**

**CG: Static**

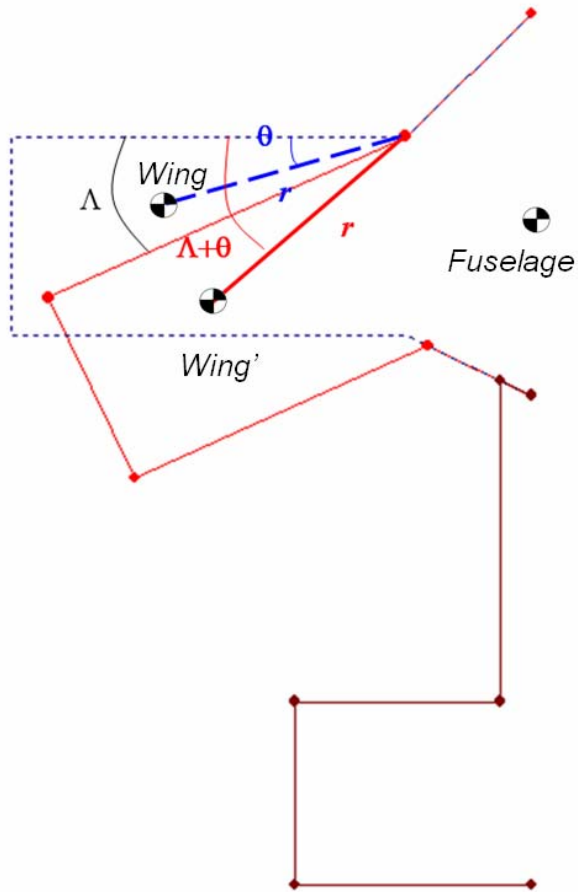
**AC: Moves forward**

**Wing Swept Conf.:**

**CG: Slight Shift aft**

**AC: Large Displacement aft**

# The mass of the swinging wing induces the displacement of the CG



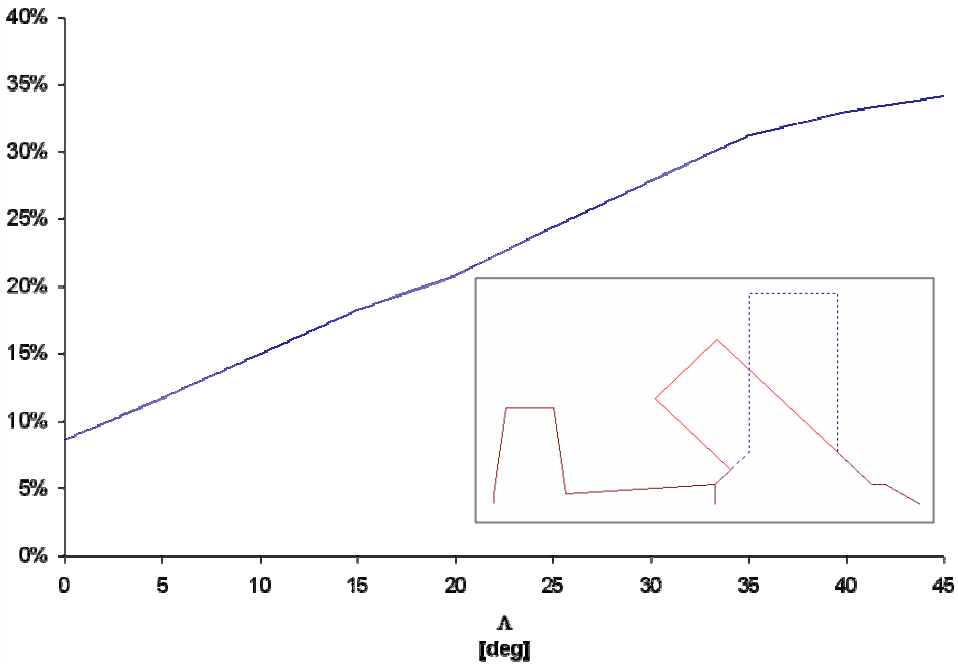
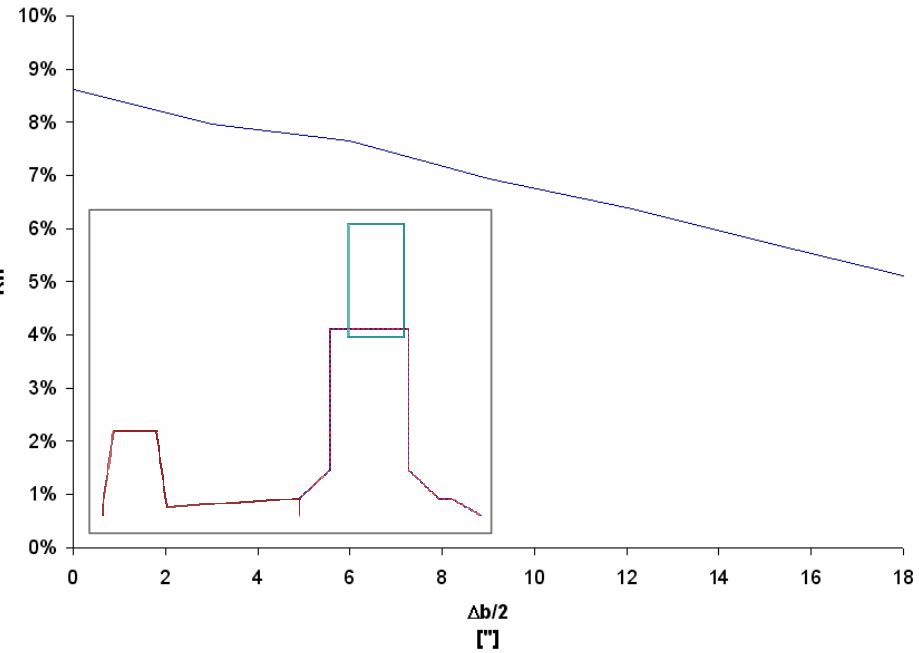
The locus of wing CG is displaced due to the rotation of the wing

$$x_{cg}(\Lambda) = \frac{x_{fuselage} \times m_{fuselage}}{m_{total}} + \frac{[x_{w0} + r(\sin(\Lambda + \theta) - \sin(\theta))] \times m_{wing}}{m_{total}}$$

# The morphing wing alters longitudinal stability characteristics

In the loiter configuration the aircraft will reach its least stable state

In dash configuration the aircraft will become heavily stable



# The wing was designed to limit the negative impact on longitudinal stability

<b>Wing design Characteristic</b>	<b>Impact on Stability</b>
<ul style="list-style-type: none"><li>• Outboard pivot point</li></ul>	<ul style="list-style-type: none"><li>• Lower AC displacement by keeping a section of the wing static</li></ul>
<ul style="list-style-type: none"><li>• Wing Heavy (Relative to fuselage)</li></ul>	<ul style="list-style-type: none"><li>• This characteristic induced by the extension increases the CG displacement</li></ul>

# Fuselage and tail design decisions were driven by the stability constraints

<b>Driving Stability Characteristic</b>	<b>Design Decision</b>	<b>Effects</b>
Displacement of AC in sweep	<ul style="list-style-type: none"> <li>• Large wing/tail distance</li> </ul>	<ul style="list-style-type: none"> <li>• Increased level arm for longitudinal control</li> <li>• Lower forces required by HT to trim.</li> </ul>
Important static margin in sweep	<ul style="list-style-type: none"> <li>• Full deflecting HT</li> <li>• Large HT surface</li> </ul>	<ul style="list-style-type: none"> <li>• Increased force range for control and trim</li> <li>• Capacity to balance moment induced by static margin in sweep</li> </ul>
Variable CG location	<ul style="list-style-type: none"> <li>• Fuel tank placed at 0 sweep CG location</li> </ul>	<ul style="list-style-type: none"> <li>• No effect in loiter and maneuver configuration</li> <li>• Positive effect in dash conf. (displacement aft of CG with fuel usage)</li> </ul>

**In conclusion, the aircraft will be flight ready by Wednesday morning**

**The fuselage is nearly complete**

**The control surfaces are built and ready to fly**

**The actuation must be added last**

