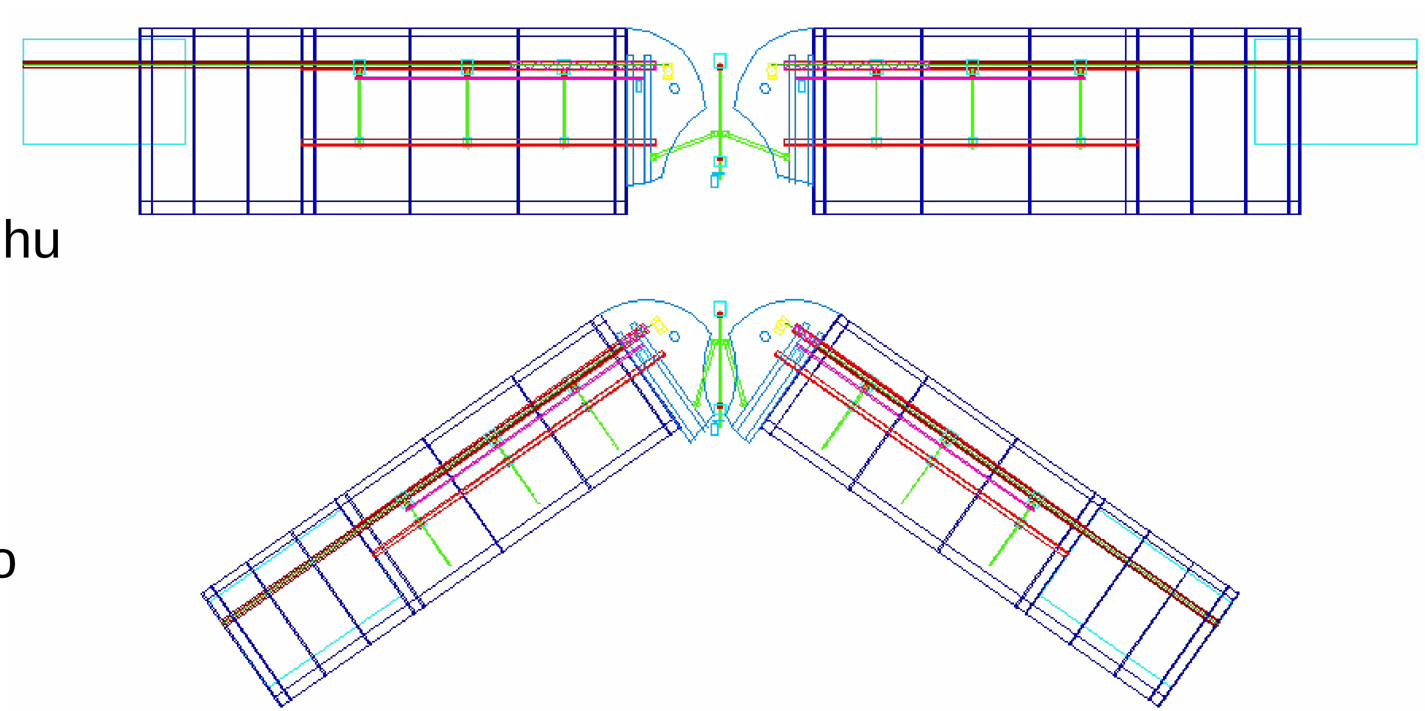
End of Semester Project Summary for the Morphing Wing Design Team



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Request for Proposal (RFP) from the Center for Intelligent Materials Systems and Structures

Design and build a morphing wing aircraft which can operate in four configurations

The four configurations are Dash, Maneuver, Loiter, and Landing

Similar to the aircraft currently being developed by NextGen.

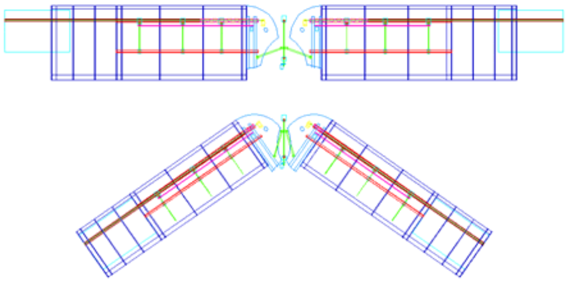
Four configurations from NextGen design [NextGen, 2004]

The work presented identifies the process used to design, build and test a morphing wing

Full scale wing model

Airfoil shape models

Results and conclusions



Three important factors drove the design and construction of the wing

Feasibility

1. **Weight**
2. **Actuation / structural arrangement**
3. **Aerodynamics**
4. **Structures**
5. **Flight Controls**

Time

1. **Design**
2. **Constructions**
3. **Testing**

Due to time constraints alternative methods of morphing were not considered.

Cost ($5,000 budget)

The following are the project goals for the year

Fall 2004

1. **Design the morphing wing and build semi-span of the wing for testing in the wind tunnel.**
2. **Show that the wing can morph under aerodynamic load**
3. **Prove the concept is feasible for implementation on a model airplane**

Spring 2005

1. **Implement the morphing wing design on a model airplane**
2. **Conduct flight testing to validate design**

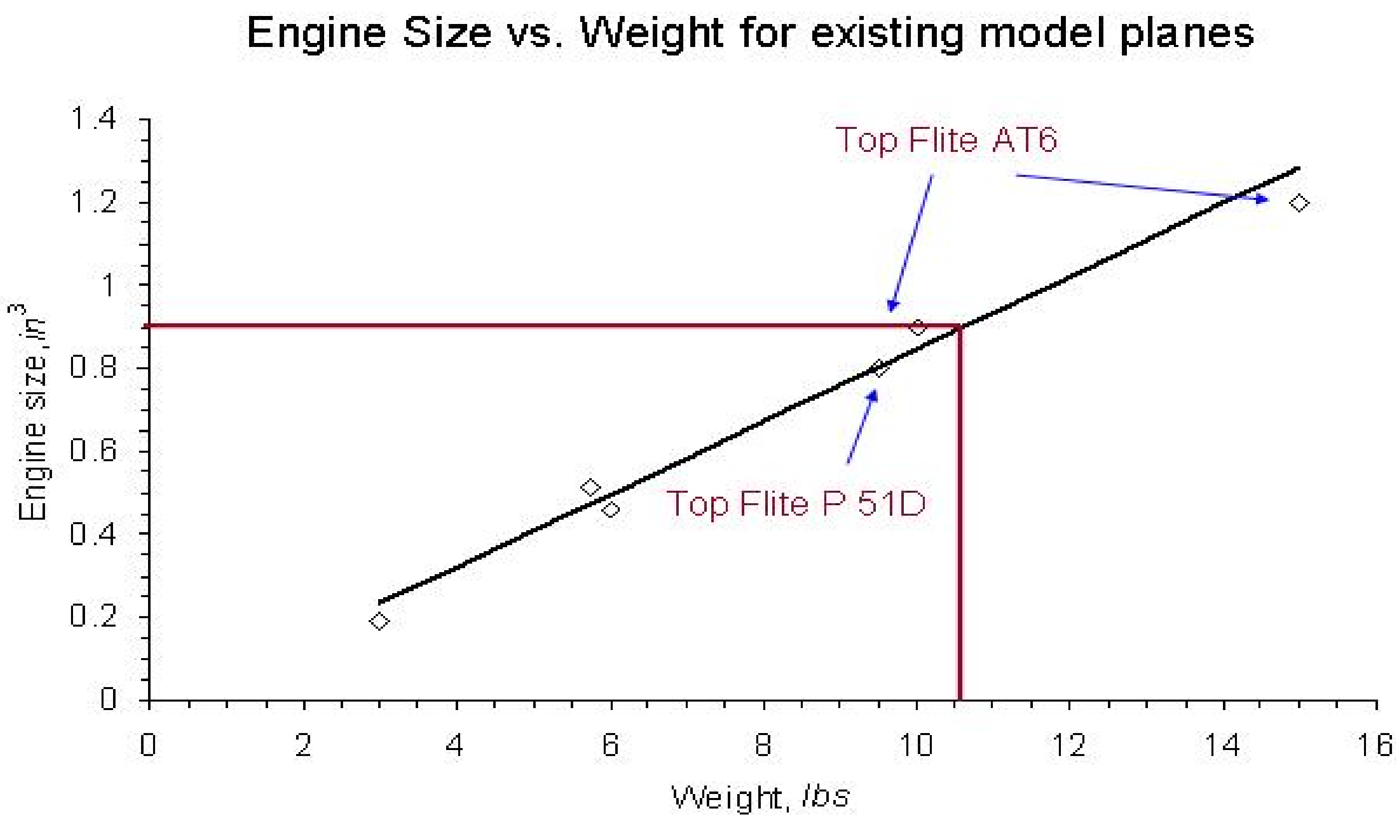
The total estimated weight for the aircraft was 13.97 lbs.

The initial weight estimation was done by categorizing the parts needed for construction into five components

The weight for each part was acquired from the manufacturer

COMPONENT	WEIGHT
Propulsion Weight	3.65 lbs
Landing Gear Weight	1.41 lbs
Wing Weight	3.40 lbs
Fuselage and Tail Weight	3.26 lbs
Payload Weight	2.25 lbs
Total Weight	13.97 lbs

The weight estimate was compared to existing model air planes

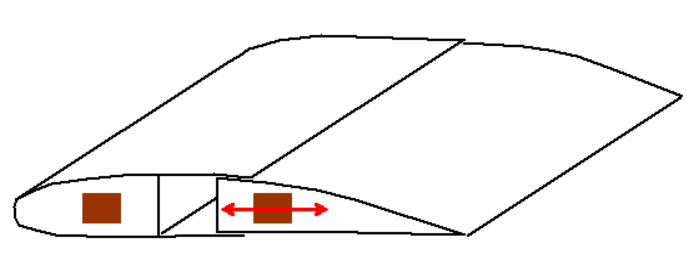


Total weight for the model airplane should be close to 10 -11 lbs.

Three initial structural and actuation concepts were designed

Rotating Beam

Sliding Ribs



C-Socket

After the pros and cons were compared, the C-Socket design was selected

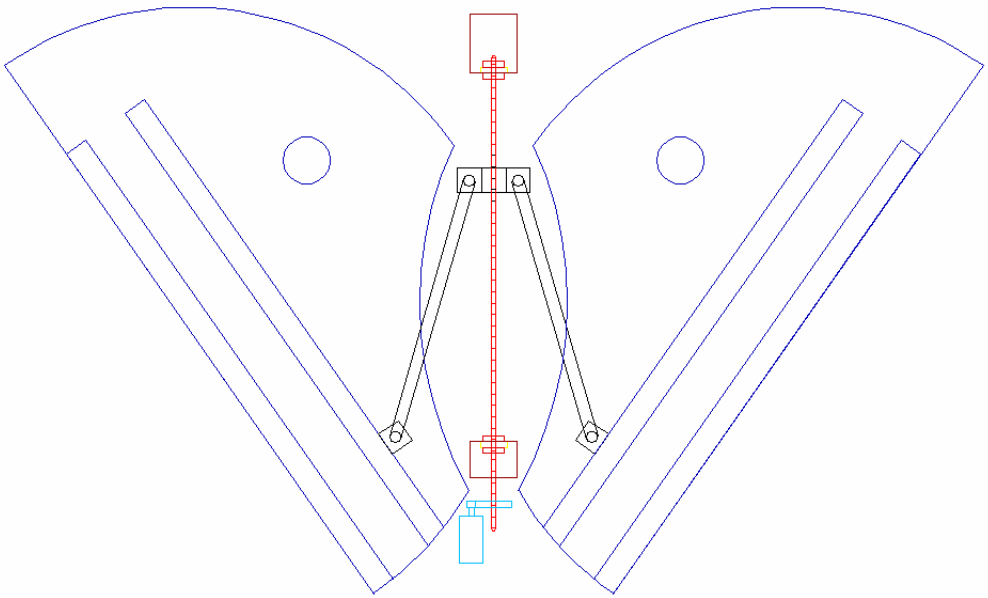
Rotating Beams		Sliding Ribs		C-Socket	
Advantages	**Limitations**	**Advantages**	**Limitations**	**Advantages**	**Limitations**
1) No mechanism inside the wing for actuation 2) Limited need of storage inside fuselage for sweep back	1) Difficulties to implement span change 2) Apparent complexity and time limitation for development	1) Guidance of the trailing ½ wing as it is moving, due to the sliding ribs support 2) Twist resistance at the level of the ribs	1) The beams have to be placed too close from the edges 2) Lack of confidence in the pin to support the loads due to twist 3) Holes in the wing in the deployed position	1) Possibility to place the main spar at ¼ chord 2) Available space at mid-chord. 3) Span, Chord, and sweep changes can be implemented with this design	1) Twist only supported by the screw mechanism

Sweep actuation consists of a motor driven power screw

An electric motor drives a power screw

A transverse nut travels up the screw length

Push rods retract and increase sweep

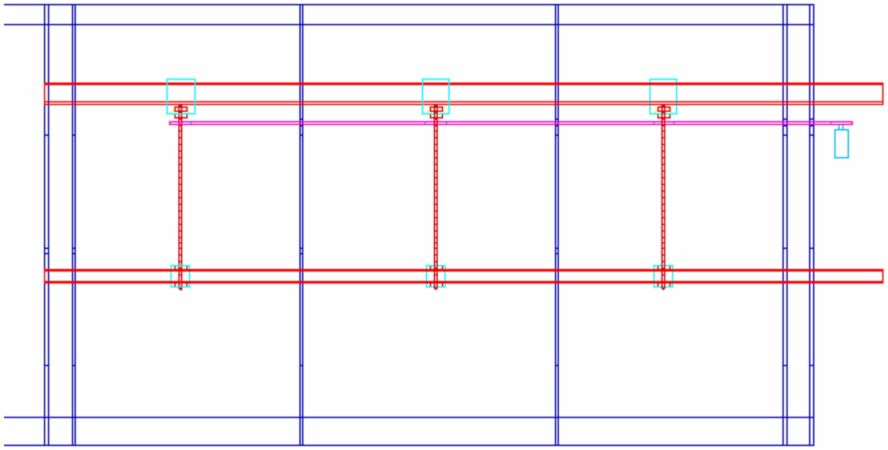


Chord change actuation consists of chain driven power screws

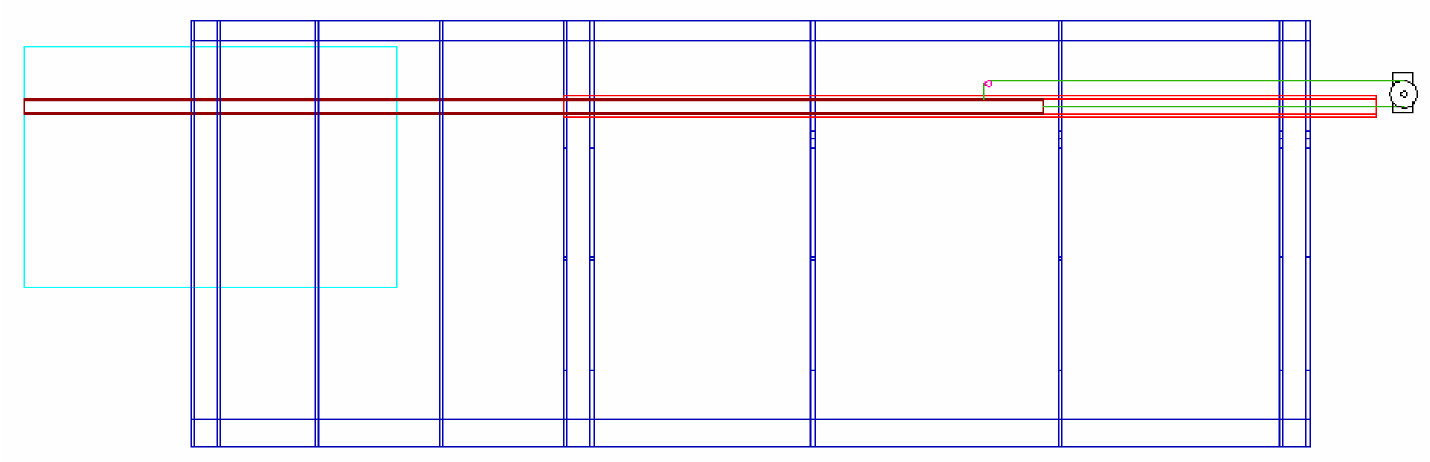
An electric motor drives a chain sprocket system

The sprockets are mounted on power screws

The screws expand or retract the two main wing spars



Span change is actuated by a sail winch servo



The main spar houses a smaller diameter extension spar

A winch servo is counter wrapped with 50 lb test fishing line

As the servo turns, one line unwraps while the other pulls the extension in or out

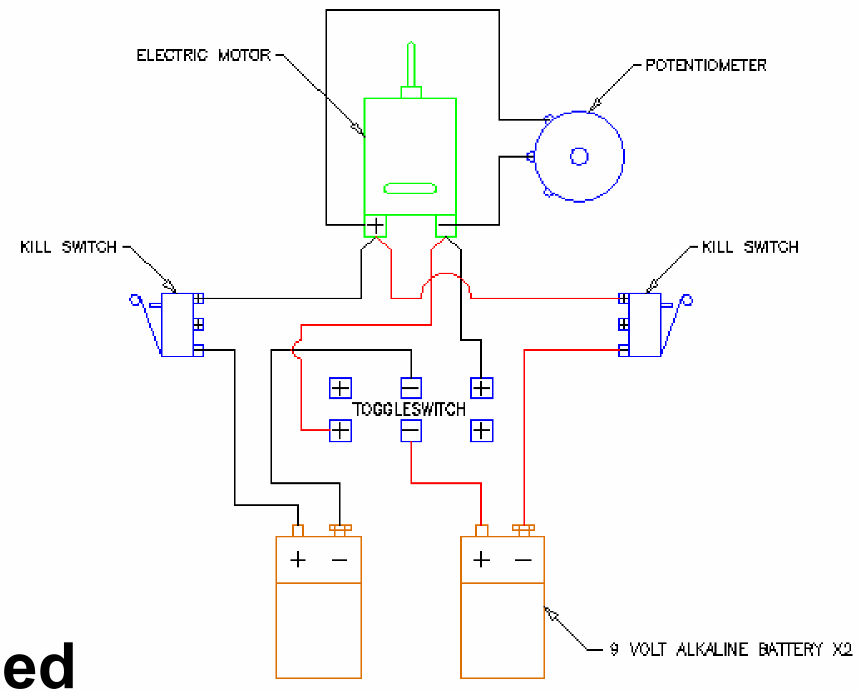
Sweep and chord changes are controlled by electric motors in a polarity changing circuit

The circuits are each powered by a 9 V battery

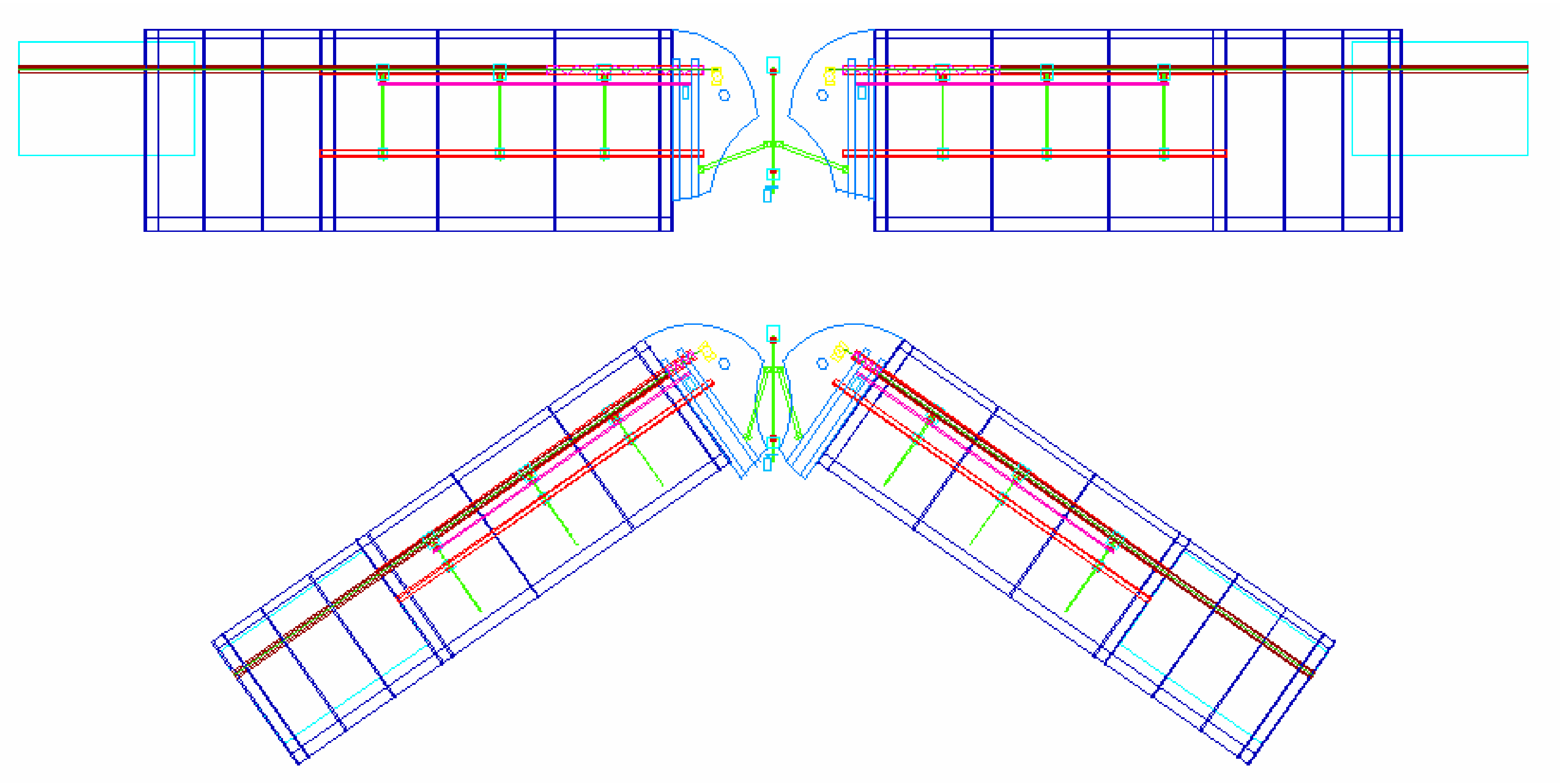
When the wing morph reaches a max a kill switch is tripped

The toggle switch controls the polarity and engages the motor

The potentiometer acts as a speed controller by varying the motor voltage



Implementing all three actuators in the wing produces our final model



Since the wind tunnel cross-section is 6’x6’ we were unable to use the instrumentation strut

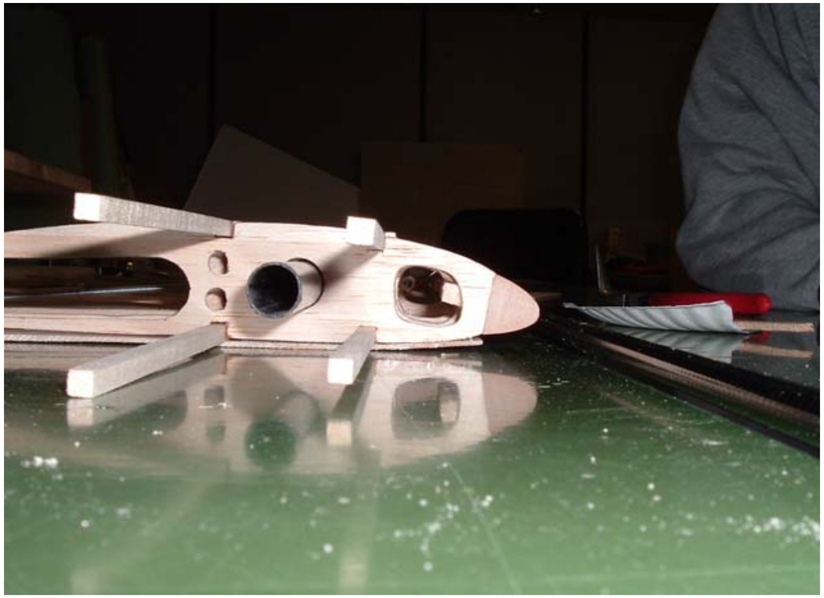
The testing strut is over 3’ tall

The full size wing is 4’-4”

To avoid wall effects we had to allow a 1’ clearance

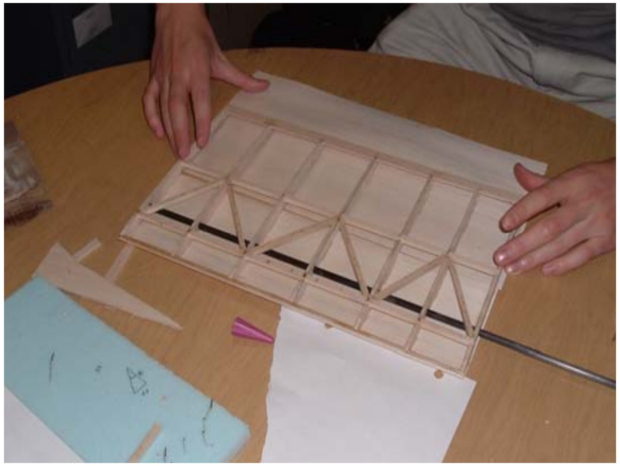
Building our own strut was too time consuming

The Clark Y was chosen because the flat bottom simplifies the construction and chord change

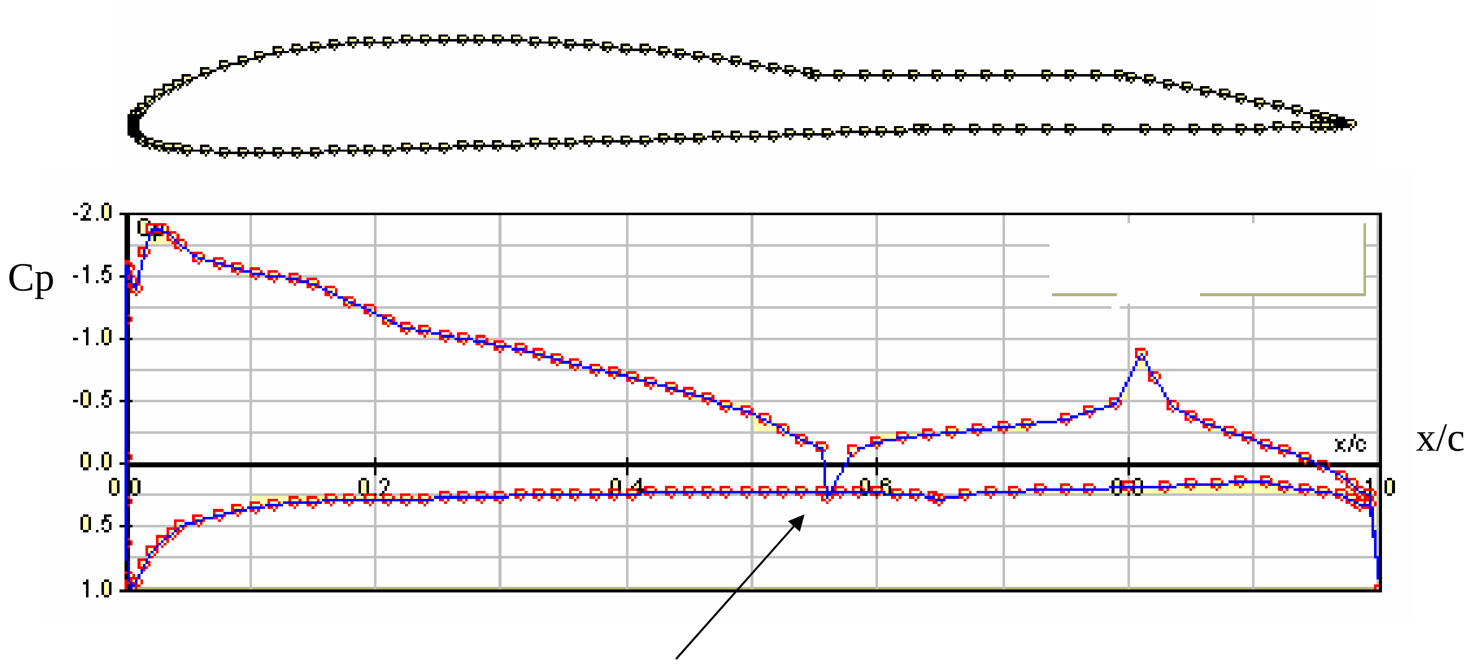


Because time constraints the airfoil selection for the wing was based only on the requirements of the actuation and not the aerodynamic performance need for optimal performance in the four configurations.

To simplify the construction the full scale wing was built in three different components.

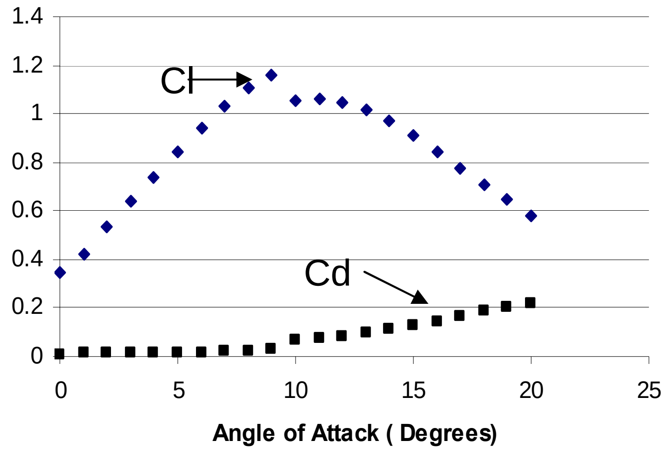


The potential for flow separation with the chord extended was a reason for wind tunnel testing

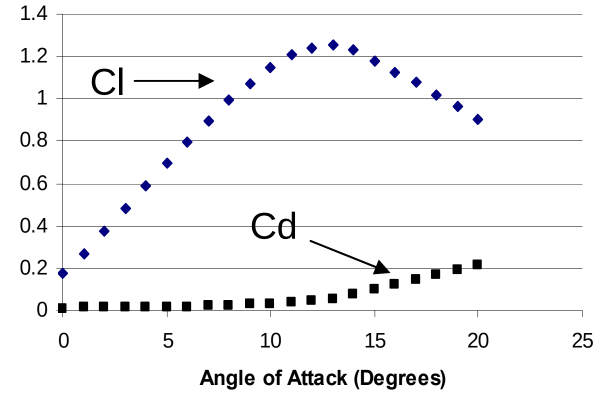


The pressure coefficient crossing the axis shows the potential for separation at the location of the chord extension

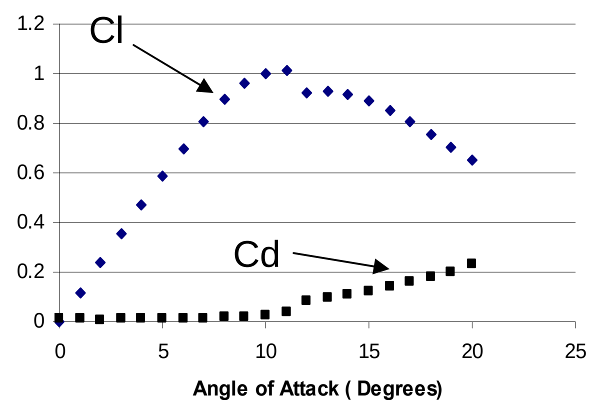
The Selig 8036 and the Eppler 168 were chosen to challenge the Clark Y



The extended Clark Y estimated aerodynamic performance was used as the baseline for comparison

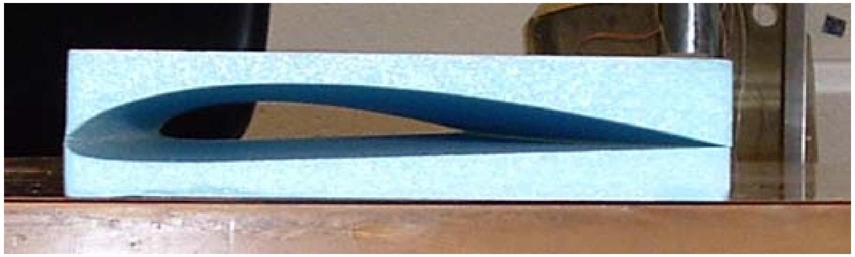


The Selig 8036 was chosen due to its high estimated maximum Cl and controlled stall

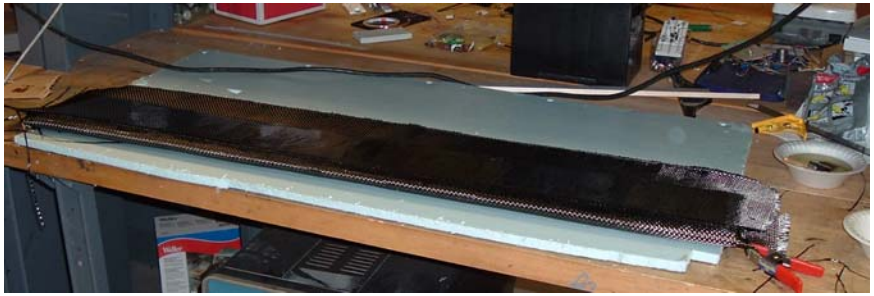


The Eppler 168 was chosen because it showed potential for lower drag and a later stall than the Clark Y

The wind tunnel models were constructed from spider foam and carbon fiber



The foam cores were ordered from FlyingFoam.com



Bi-directional Carbon Fiber was epoxyed to the foam cores.

The models were finally sanded for smoothness.

Tests in the wind tunnel were needed to validate the wing design

Some questions concerning the chord extension could not be answered using theory :

Separation?

Aerodynamic benefit from extension?

Apparatus and instrumentation used for testing of the foam wing models

Virginia Tech Stability Wind Tunnel

- Test section: 24 feet long, 6x6 feet in cross-section
- Max speed: 275 ft/s

6 Wind Tunnel Models

- 4 feet in span and 0.64 feet in chord: this choice was made to match the Aspect Ratio of the morphing wing
- Airfoils: original and extended-chord version of the Clark-Y, Selig 8036, and Eppler168

Stability Tunnel Strut Mount

- Located in the middle of the test section
- Equipped with a six-component strain gauge balance and an automated angle of attack-sweep system

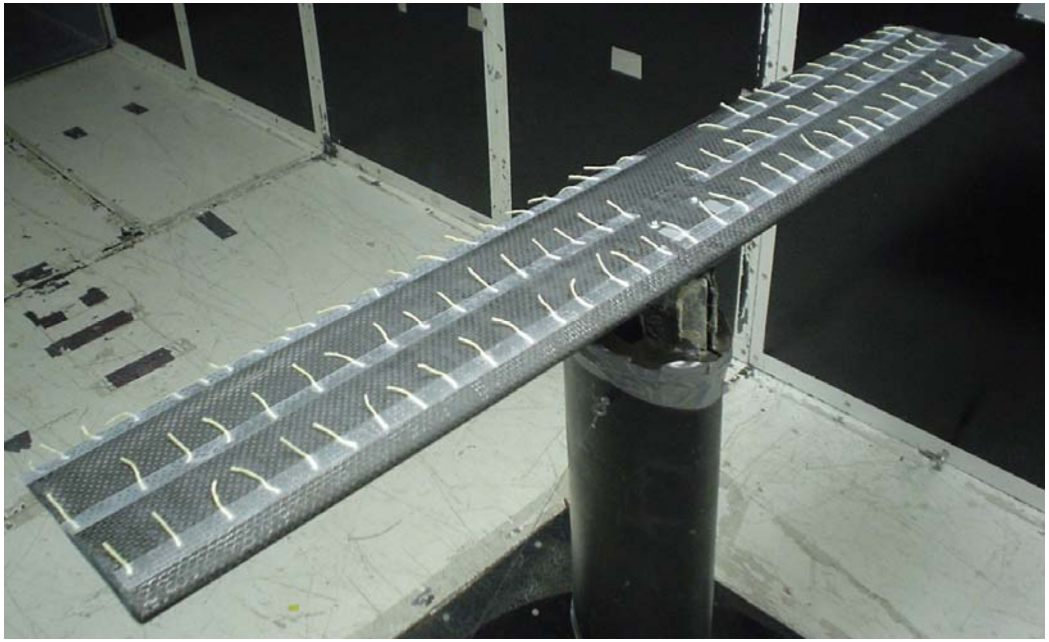
The following is important test information

A total of 24 runs were performed:

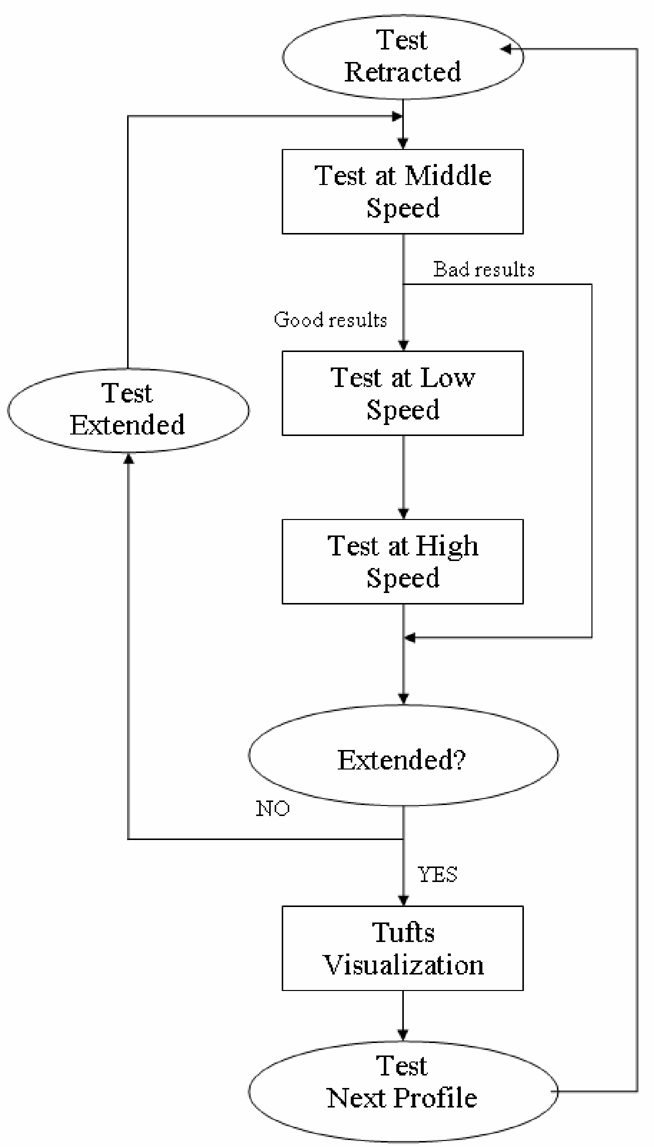
- **Longitudinal tests (-6 to 20deg alpha-sweep)**
- **Flow visualization**

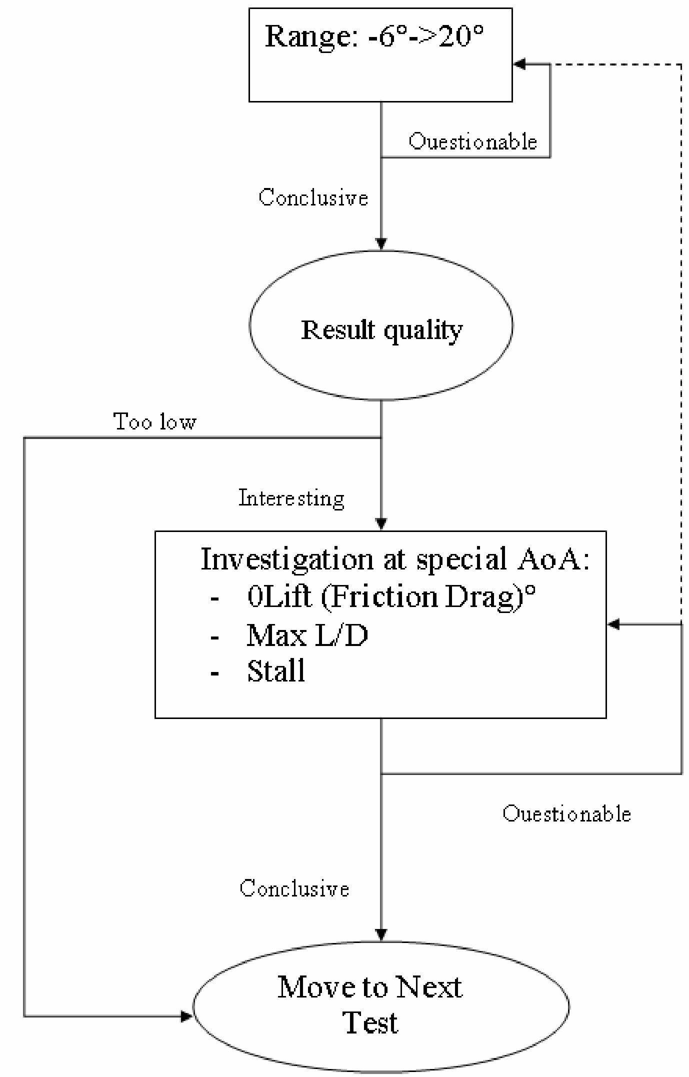
The choice of the tunnel speeds was made to match the Reynolds number of the morphing aircraft in actual flight conditions

Flow visualization was achieved using 1.5” long yarn tufts arranged in three rows on the upper surface of the model



The following strategy was applied to test the foam models

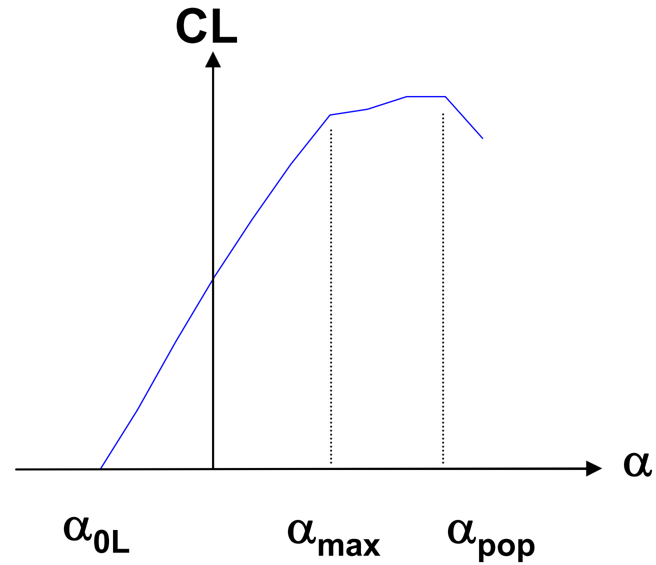


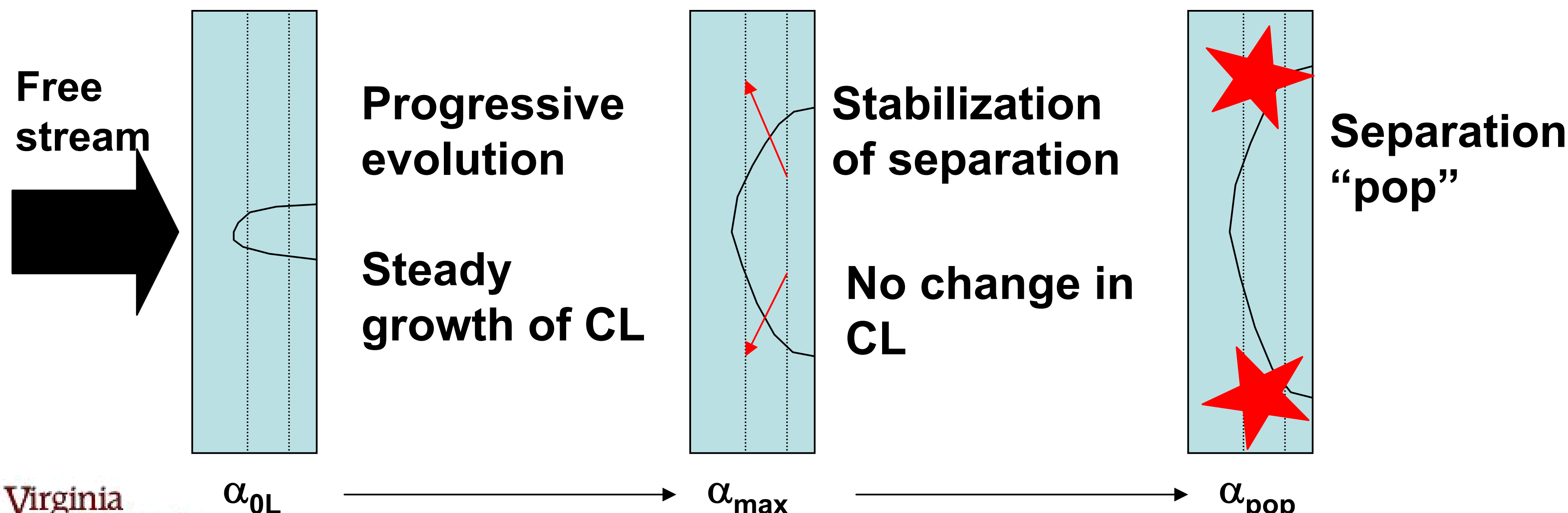


The flow separation on the extended models was acceptable

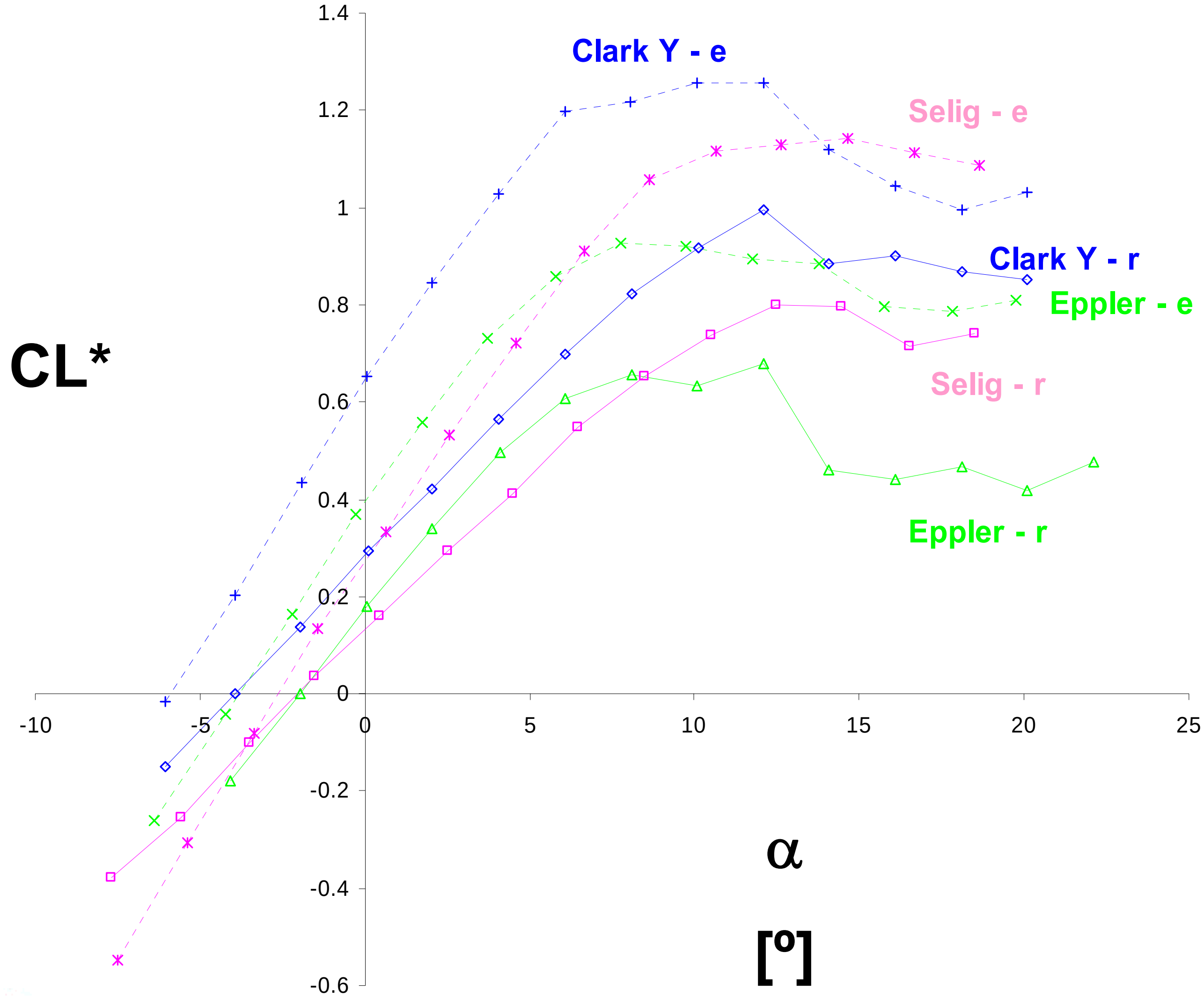
No early separation was observed on critical parts of the extended wing

Progressive stall behavior allowing pilot correction before stall





By comparing the lifting performance of the different models, the Clark Y is the best choice

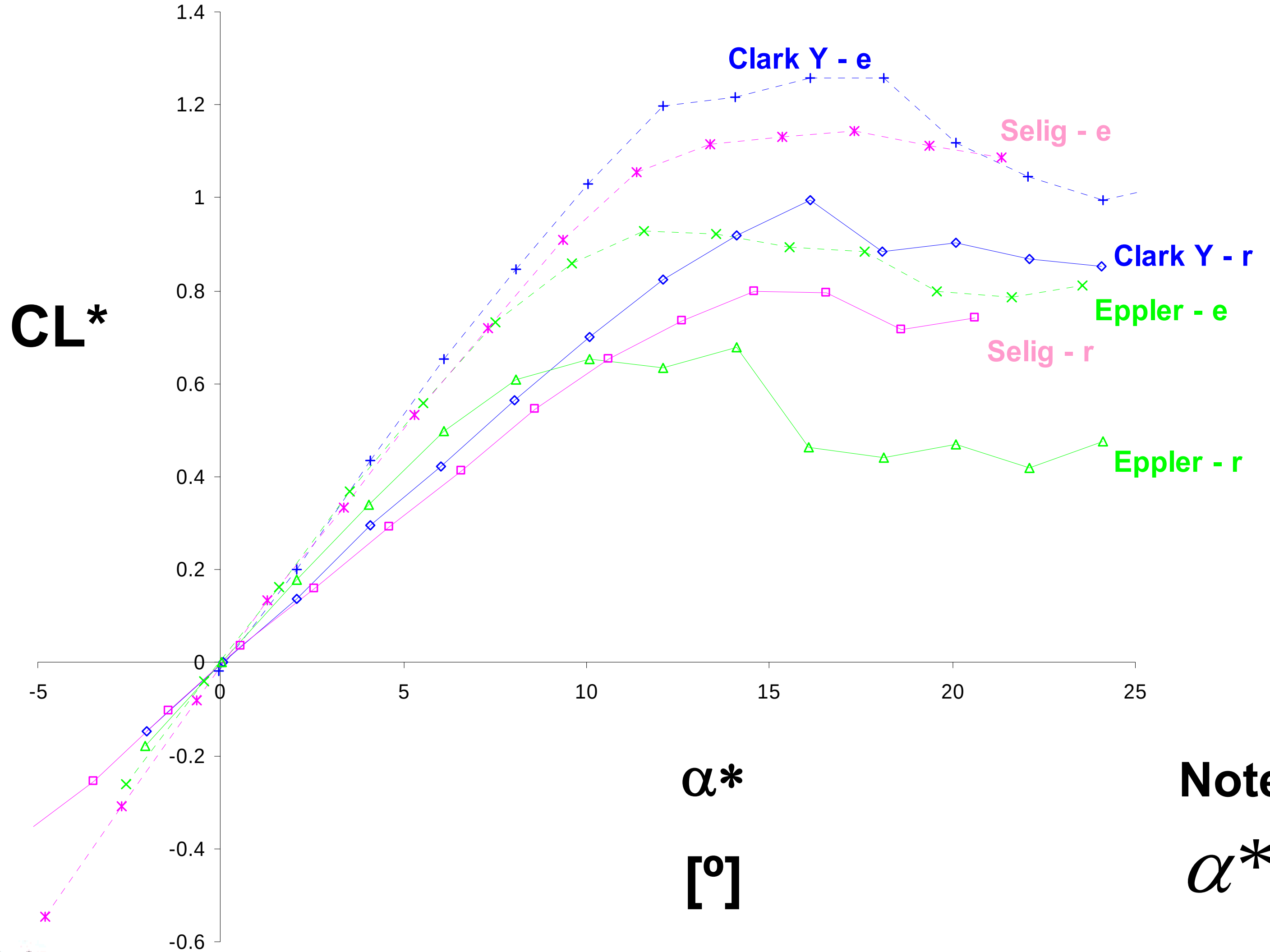


$$CL^* \equiv \frac{L}{q \times b \times c_{\min}}$$

r ≡ retracted

e ≡ extended

By comparing the lifting performance of the different models, the Clark Y is the best choice.

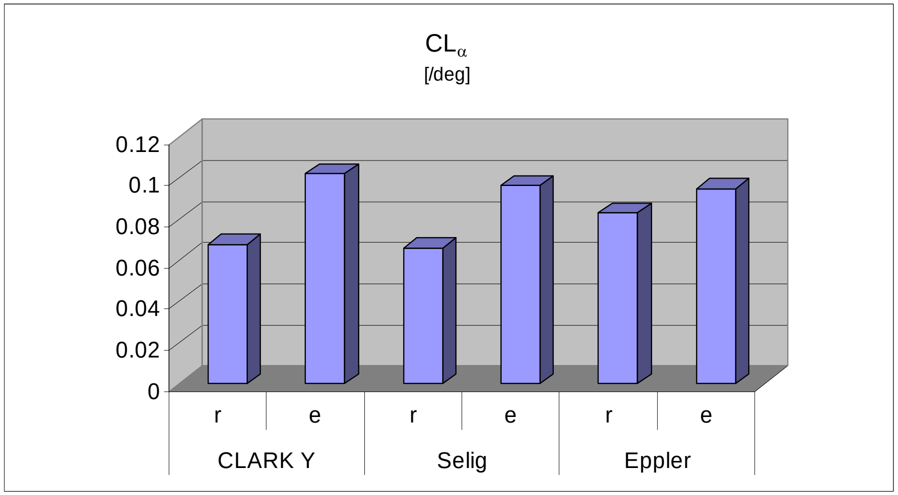


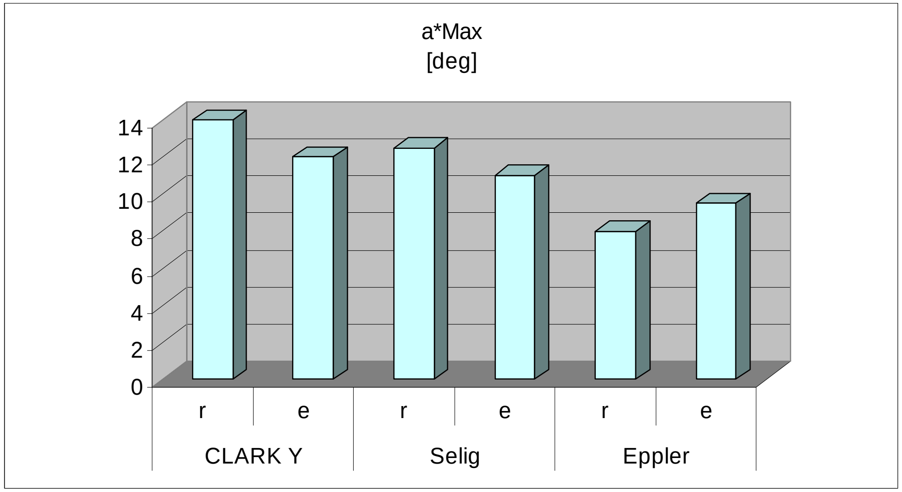
Note:

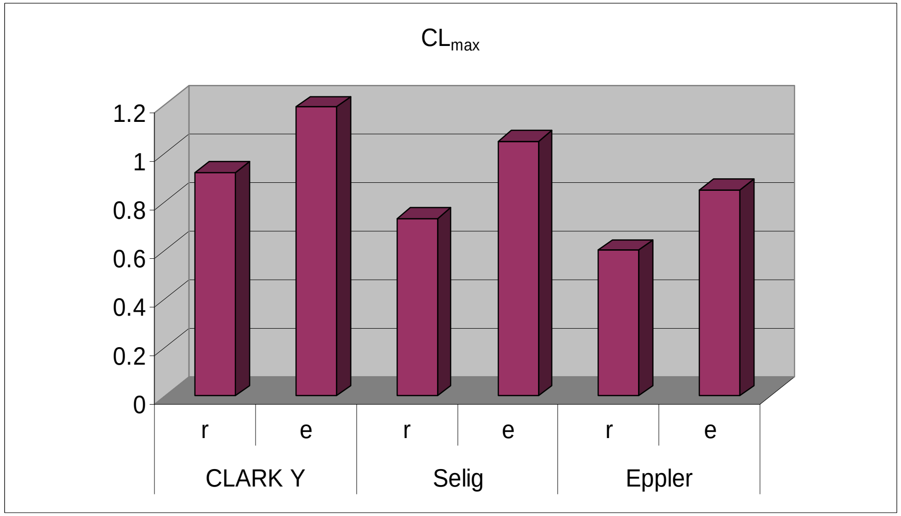
$$\alpha^* \equiv \alpha - \alpha_{0L}$$

Virginia Tech

Reviewing different aerodynamic characteristics confirms the choice of the Clark Y

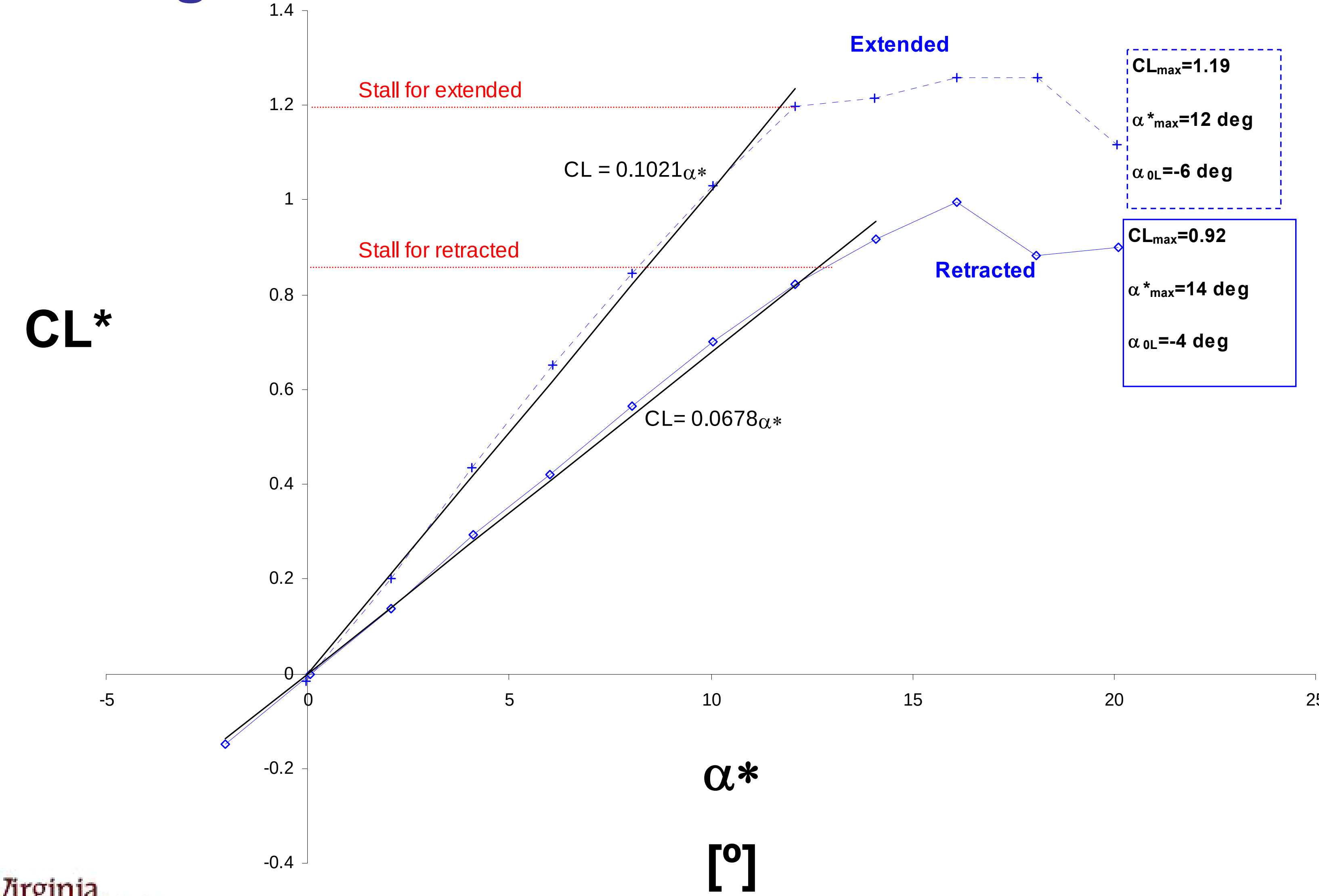






With a high CL_{α} and a long α–range, the Clark Y can reach the highest value in lift.

Clark Y performance results from wind tunnel testing



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The following are conclusions based on the wind tunnel testing of the foam models

Flow visualization showed that the extended-ClarkY does not stall as predicted.

The chord extension mechanism improves the lifting Characteristics.

The aerodynamic performances between the Clark-Y, Selig8036 and Epler168 airfoils reaffirms our original design choice of using the Clark-Y.

The following are conclusions based on the wind tunnel testing of the foam models

Critical aerodynamic data were obtained for the retracted and extended configuration of the Clark-Y:

- **CL_{max} = 1.19**
- **CL_{α} = 0.1021/º extended & 0.0678 /º retracted**

Based on these results we can deduce a take off velocity of 30 Mph assuming a lift off CL* of 1.1 (which correspond to CL=0.8 and a = 6º).

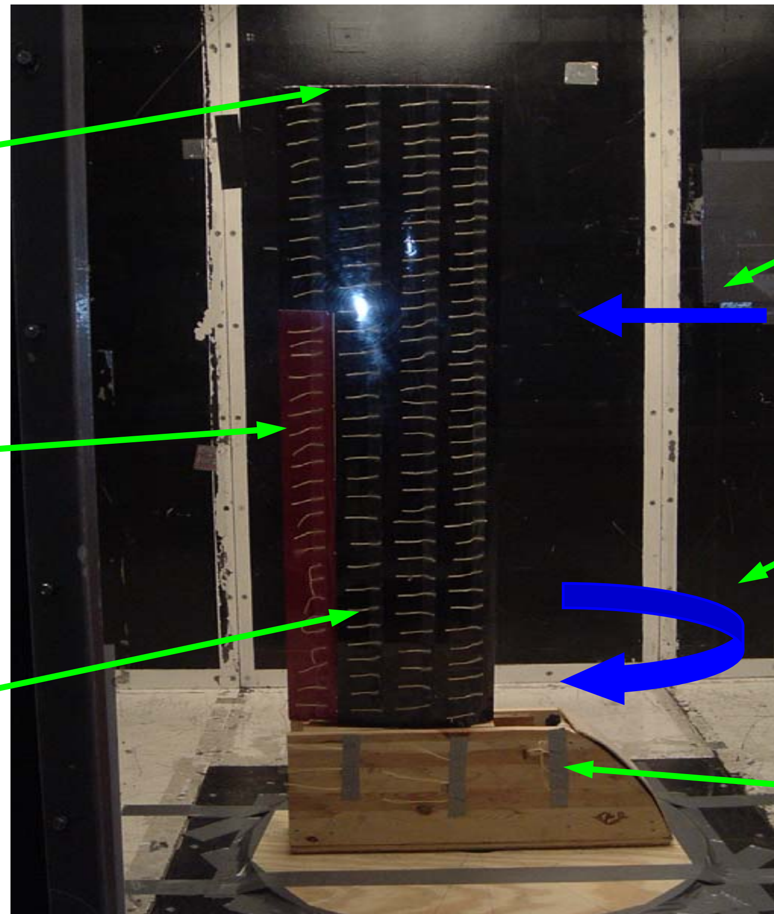
Note: the surface roughness of the model might have been a factor concerning the separation pattern

The image below shows the wind tunnel setup used for the full scale wing

Span Change

Chord Change

Four rows of tuft ~2 in long



Flow directions

Positive Angle of attack

Tuft on attachment system

Proposed setup for the full scale wing wind tunnel tests

Test velocity = 30 -35 mph (Takeoff speeds)

Angle of attack range = 0 – 25 degrees

Test case 1:

- Flow visualization for NO span and NO chord change, normal wing.
- Determine approximate stall angel of attack

Test Case 2:

- Span change under aerodynamic loads and flow visualizations
- Determine approximate stall angle of attack

Test case 3:

- Flow visualization for Chord change
- Determine Approximate stall angle of attack

Test Case 4:

- Flow visualization for span and chord change
- Determine approximate stall angle of attack

Special Case:

- Look at flow interaction between Mounting system and wing

The per-test matrix was not used during wing tunnel tests because of safety concerns.

Test Conditions

Date: Thursday 11/18/04 4:45 AM

Tunnel Temperature: 64.6 ° F

Outside Temperature: 52 ° F

Pressure: 28.01 ins of Hg

Actual Test Matrix

Case one: NO span and NO chord

Increased angle of attack at a velocity ~ 20 mph. Considerable motion of the wing TEST ABORTED.

Increase angle of attack to 10 degrees with tunnel at ideal and increased velocity. Considerable motion of the wing at ~25 mph TEST ABORTED

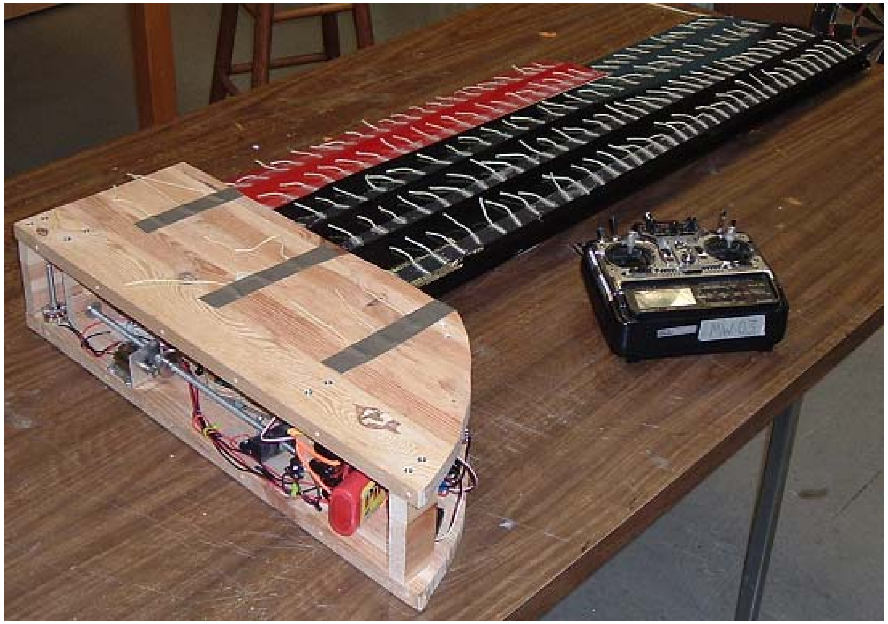
In conclusion, next semester we hope to build and fly a fully functional radio controlled model

Design control surfaces and their actuation

Moving mass to counter center of gravity from wing sweep

Focus on two major dimension changes instead of three minor changes

Design, build and fly a morphing radio controlled aircraft



Questions?