Images contained herein are used to provide a visual reference and are not intended to convey complete designs or product selections

mAEWing2 Concept Description

Rev: 0.6

This is an initial draft version for team review

The scope crept during writing this draft. The intent was for this to a description of the vehicle configuration, I ended up adding a lot of programmatic and test information as well. This will get separated into project documents in the future.

Objective and Requirements Document (ORD)

Concept of Operations (ConOp)

Test Plan

Configuration Terminology

- “Baseline”
  - This is the aircraft configuration that we're developing. Baseline work is always priority! Costing, scheduling, and resource estimates are all done against the baseline. Options are worked only when resources allow.
- “Protect for”
  - Potential configuration that is considered likely enough to occur that the Baseline needs to allow for its incorporation. As the Baseline configuration progresses we make sure we don't design-out these alternates. These are almost always risk reducing options. There is a continual resource cost for protecting a configuration option. There are critical points during the development at which the configuration may not be able to be protected. Protected options will not be costed, scheduled, or resource loaded independent of the Baseline (it needs to be accounted for at the task level)
- “Option”
  - This is a potential configuration that is under consideration. Option typically need to show sufficient benefit versus the resources required to implement to be traded onto the Baseline. There are critical points during the development at which the configuration may not be able to be traded-on or the cost to do so increases dramatically. Options will not be costed, scheduled, or resource loaded independent of the Baseline.

- At some point Protected Configurations and Options are retired and no longer considered. The goal is to retire protected configurations and options as early as possible to minimize resource use.

mAEWing2 Programmatic Overview

- NASA Objectives
  - 1) Applicability to a broad category of integrated wing concepts
  - 2) Integrated novel effectors and control strategies to:
    - 2a) reduce fuel burn
    - 2b) tailor wing shape and control local loads
    - 2c) provide roll and high lift control
    - 2d) reduce drag
  - 3) Integrated sensor technology to:
    - 3a) enable shape control
    - 3b) provide GLA/flutter suppression
  - 4) Increased overall aircraft efficiency
  - 5) Provide an open transfer of knowledge
- PAAW Objectives

  The overall objective of this proposal is to research, design, and validate a high aspect ratio wing that: 1) Significantly reduces weight through structural design optimization and use of active flutter suppression and gust load alleviation. 2) Actively adapts its shape over the entire flight envelope to minimize drag over a range of cruise and off-nominal conditions and provides high-lift performance for takeoff and landing. The proposed program will mature integrated multidisciplinary tools, techniques, models, technology and processes to create a performance adaptive aeroelastic (AE) wing.
- Associates mAEWing2 Milestones
  - Year 2: The goal is to **validate mathematical models, MDAO tools and conformal mold line for wing, sensor and effector placement algorithms in flight, with conformal mold line effectors**. The design of X-56A performance adaptive aeroelastic wing will result.
    - Design and develop mini-MUTT wing (mAEWing2) with optimal sensors and effectors, from MDAO, and with a conformal mold line. [Addresses 2, 3, 4, and 5]
    - Build, ground test, and perform a preliminary first flight test of mAEWing2 for the mini-MUTT platform, [Toward validation of 2, 3, and 4]
  - Year 3: The goal is to build and flight test the X-56A wing, **validate sensor and effector placement, flutter suppression, optimal allocation, and open-loop shape control**.
    - Conduct a comprehensive flight test and model validation program for mAEWing2 on the mini-MUTT platform. [Validation of 2, 3, and 4]

mAEWing2
Programmatic Overview

- mAEWing2 needs to:
  - Provide a stepping stone to xAEWing3
  - Validate MDAO based design processes
    - optimal sensor definition
    - optimal effector definition
  - Use a conformal mold line control surface
  - Validate optimal control allocation
  - Validate flight mechanics models
  - Validate open-loop shape control
    - Beyond open loop flutter

- Notional Timeline
  - Long-lead tooling Release - 10/1/2015
  - Preliminary Design Release - 12/1/2015
  - Critical Design - 2/1/2016
  - First Flight - 6/1/2016

mAEWing2
Programmatic Overview

- Flight units
  - Centerbody
    - 1x Fully populated (Baseline)
    - 1x Primary Structure (w/ trapped components) (Baseline)
  - Wing Shipsets
    - 1x Stiff Fully populated (Baseline)
    - 1x Flexible Fully populated (Baseline)
    - 2x Flexible Primary Structure (w/ trapped components) (Baseline)
  - Winglets
    - 3x Shipsets (Baseline)
- Ground units
  - 1x Ground Control System
  - 1x Test and Support

Desire is to have spare flight units that can be completed and ready to fly in 3 weeks.

mAEWing2
Performance Overview

- Flight Envelope
  - Speeds
    - Stall = ~~12~~ 14.5 m/s (28 kts)
    - Flutter = 30-35 m/s (58-68 kts) @ 3-5 Hz (Dynamic Scale X-56A)
    - Normal Operation/Manuever Range = 1.2 Vstall to 0.85 Vflutter
    - Test Range = Vstall to 1.15 Vflutter
    - Thrust limited steady level speed = 1.15 Vflutter
  - Climb
    - Minimum ROC in Maneuver Range = 500 ft/min
  - Altitude
    - AGL: 0 to 400 ft
    - MSL: 0 to 3000 ft
  - Temperature
    - Ambient: 35°F to 90°F (Baseline)
    - Aircraft Surface: 35°F to 120°F (Baseline)
    - Pitot heat to lower operation temp to 10°F (Option)
- Flight Duration
  - Mission Profile: Launch -> Climb to 300 ft -> Racetrack at Test Airspeed -> Descend -> Recover
    - Nominal Mission Duration: 10 minutes (Maneuver Envelope Testing)
    - Max Performance Mission Duration: 7 minutes (High Speed Testing)
- Weight
  - ~~~30~~ 40 lbs
- Static Stability
  - 6% Static Margin

mAEWing2
Loads and Limits Overview

- Flight
  - Maneuvering and Gust loads (Baseline)
    - "Manuevering Range" (V < 0.85* Vflutter)
      - Manuevering Loads: +3.8g/-1.5g
      - Gust Encounters: U_{ref}: 28 ft/s
    - "Flutter Test Range" (V > 0.85 * Vflutter)
      - Manuevering Loads: +3.0g/-1.0g
      - Gust Encounters: U_{ref}: 22 ft/s
  - Launch (Baseline)
    - Winch/Bungee Launch off short rails
    - Point load to yield 2g longitudinal acceleration on Centerline
  - Landing
    - Touchdown: 7 ft/s (2 m/s) decent rate @ 1.2 Vstall (Baseline)
      - Landing on rough turf
      - Assume winglets will impact ground
    - Parachute ~10 ft/s decent rate (Option)
- Special Handling
  - Transportation ??

U_{ref} is half the value defined in FAR 25.341. mAEWing2 is not an all weather aircraft, we only fly during low wind conditions which limits the gust encounter magnitude/probability.

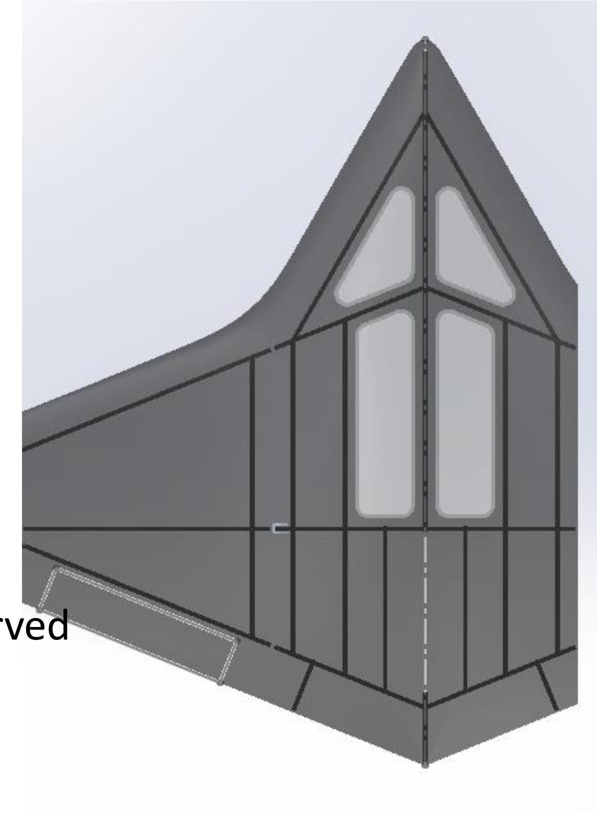
$$U_{ds} = U_{ref} * \left(\frac{H}{350}\right)^{1/6}$$

$$U_{gust} = \frac{U_{ds}}{2}\left(1 - \cos\left(\frac{2\pi s}{H}\right)\right)$$

Tuned gust lengths for 1SWB and short period must be evaluated. These will likely be shorter gusts than defined in FAR 25.341.

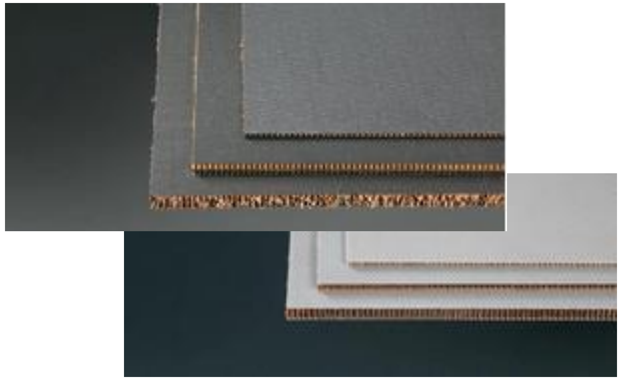
mAEWing2 Configuration Outer Mold Line

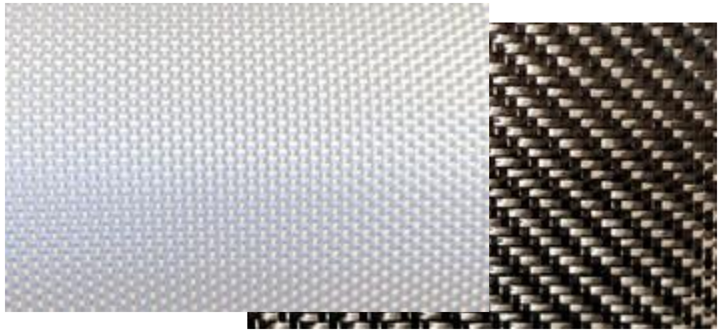
- Aerodynamic
  - OML scaled from X-56A OML
  - X-56A OML scaled 50% (Baseline)
    - Anticipate modification of blisters, access panels, landing gear, linkages, etc.
    - Control Surfaces definition and sizing may differ from X-56A definition
- Modularity
  - Wings removable similar X-56A (Baseline)
    - Separation plane is the same, joint definitions and mechanisms may be different
  - Winglet removable (Baseline)
    - Joint definition and mechanism may be different
  - Control Surfaces removable (Baseline)
    - Hinge definition and mechanism may be different
- Wing OML Modification is an Option
  - Strong desire to preserve continuity from mAEWing2 to xAEWing3
  - Centerbody interface definition and loads limits on X-56A/xAEWing3 must be preserved



mAEWing2 Configuration Primary Structure

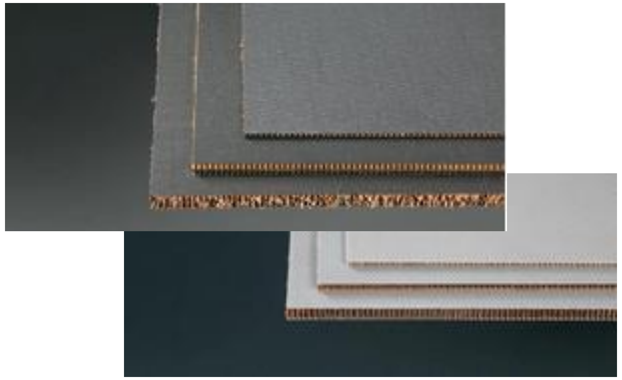
- Centerbody
  - Bulkhead and Ribs
    - Layout same as X-56A (Baseline)
      - Anticipate sizing and penetrations to deviate from X-56A definition
    - Flat composite sandwich panel (Baseline)
      - Face sheet and core material is undefined
      - Strong desire to use common off the shelf definitions throughout
  - Skin
    - Solid Fiberglass Fabric w/ Epoxy Laminate (Baseline)
      - Room temp cure Epoxy
      - Must employ a simple ply definitions
    - Core in the laminate stack (Option)
    - Kevlar and/or Carbon fiber (Option)
  - Primary Structure assembled with secondary bonding (Baseline)
    - Mechanical fastening or externally taped joints as required
    - Henkel Loctite Hysol EA9394
      - Bond thickness: 0.005” to 0.125”

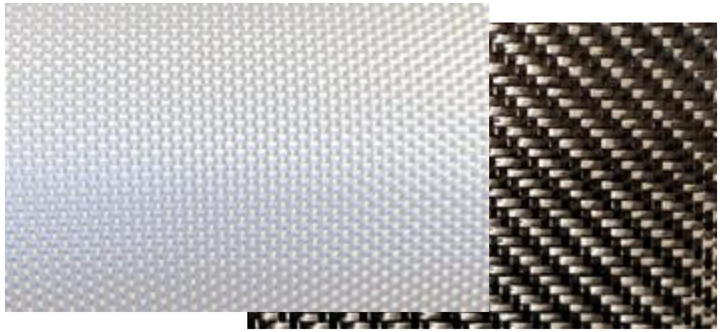




mAEWing2 Configuration Primary Structure (continued)

- Flexible Wings
  - Spars and Ribs
    - Custom Layout (Baseline)
    - Flat composite sandwich panel (Baseline)
      - Face sheet and core material is undefined
      - Strong desire to use common off the shelf definitions throughout
  - Skin
    - Solid Fiberglass Fabric w/ Epoxy Laminate (Baseline)
      - Room temp cure Epoxy
      - Must employ a simple ply definitions
    - Core in the laminate stack (Option)
    - Kevlar and/or Carbon fiber (Option)
  - Primary Structure assembled with secondary bonding (Baseline)
    - Mechanical fastening or externally taped joints as required
    - Henkel Loctite Hysol EA9394
      - Bond thickness: 0.005” to 0.125”
- Stiff Wing (Baseline)
  - Preferably accomplished through a material change on the wing skin





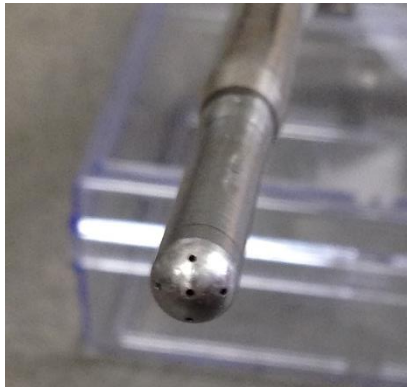
mAEWing 2 Configuration Flight Systems

- Flight Computer
  - Goldy 2 (Baseline)
    - VectorNav IMU, Novatel OEMStar, Beagle Bone Black Processor, Microhard C2 radio
    - 100+Hz framerate
    - Closed loop Time delay < 25.0ms (45° phase @ 5 Hz)

- RC Systems
  - Receiver w/ S-bus (Baseline)
- Power
  - Independent Avionics/Instrumentation, Actuation, and Propulsion power buses (Baseline)
  - External Ground Power (Baseline)
  - Power Health and Status Monitoring (Baseline)

mAEWing2 Configuration Flight Systems (continued)

- Instrumentation
  - Bus/Distribution
    - CAN Bus with CAN Nodes located near sensors (Baseline)
  - Onboard Video
    - Winglet Cameras (Baseline)
      - Centerline mounted, pointing at L & R winglets
    - Nose Camera (Protect for)
      - Impact to: Minimal integration impact, slight weight change
    - Video Transmission [Qty 1] (Option)
    - Onboard Video Processing (Option)
  - Inertial Measurement
    - Centerbody fwd & aft vertical Accelerometers (Baseline)
    - Wingtip fwd & aft vertical Accelerometers (Baseline)
    - Wingtip longitudinal Accelerometers (Protect for)
      - Impact to: Mounting structure provisioning
    - Wing Midspan fwd & aft vertical Accelerometers (Protect for)
      - Impact to: Mounting structure provisioning
    - Replace Accelerometers with IMU (Option)
    - Bandwidth > 5x fastest controlled mode
  - Airdata
    - 5-Hole Pitot-Static Probe (Baseline)
  - Control Surfaces and Actuation
    - Actuator Voltage and Current (Baseline all locations)
    - Control Surface Rotary Position (Baseline all locations)

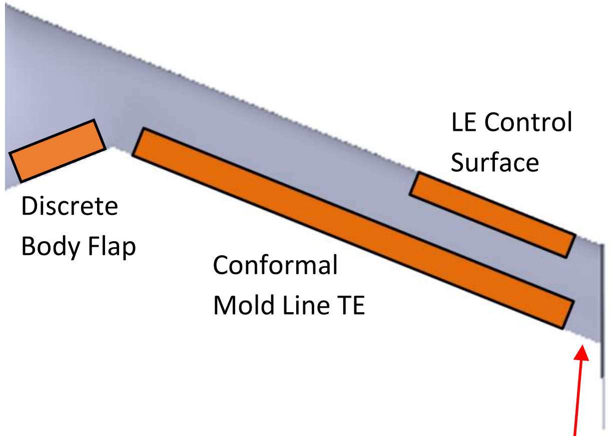


mAEWing2 Configuration Propulsion

- Propulsion
  - Dual (L & R) Electric Ducted Fans (EDF) (Baseline)
    - Independent Speed Controller on each motor
    - Common Power Bus for both motors
    - Provisions to re-locate fwd-aft on centerbody
  - Single Centerline EDF (Option)
    - Provisision to re-locate fwd-aft on centerbody
  - Sensing
    - Motor Voltage and Current Monitoring (Baseline)
    - Motor RPM Monitoring (Baseline)
    - Motor Thrust measurement in pylon (Option)
    - Fan Differential Pressure (Option)

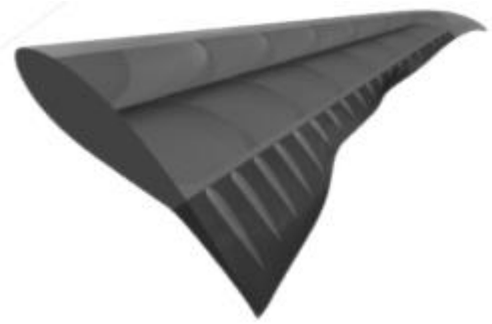
mAEWing2 Configuration Control Surfaces

- Body Flaps
  - Same layout as X-56A (Baseline)
- Wing Trailing Edge
  - Same sizing as X-56A (%Chord and span)
  - Continuous/Flexible Outboard Surface (Baseline)
    - Hinge mechanism, Rotary sensor placement, and Actuator placement and sizing is undetermined
    - Material specification and fabrication is undetermined
    - Extend the outboard end to terminate at Winglets (Option)
  - Discrete Surfaces (Qty 4) for risk reduction (Protect for)
    - Impact to: potential backing structure placement and sizing
- Wing Leading Edge
  - Discrete, movable surface for partial span (Baseline)
    - Similar Concept to Lockheed Martin Sensorcraft wind tunnel model
    - Location, Sizing, and Mechanism undetermined
    - Sizing constrained by LE spar placement
    - Actuator and linkage sized to brake unstable moment
    - Slow deflection to not interact with unsteady aero
  - Fixed Leading Edge (Protect for)
    - Impact to: front spar placement and sizing, backing structure placement and sizing
- Winglet
  - Fixed Winglet (Baseline)
  - Discrete surface on the trailing edge (Option)
    - Similar to X-48B winglet surfaces

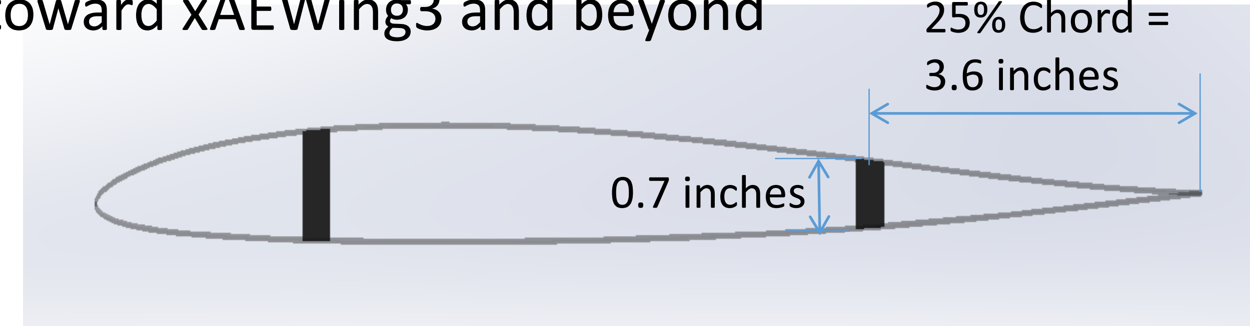


Extend conformal TE surface to winglet (Option)

mAEWing2
Conformal Control Surface

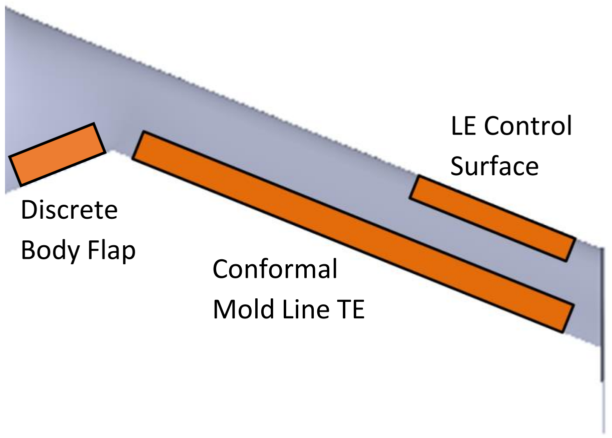


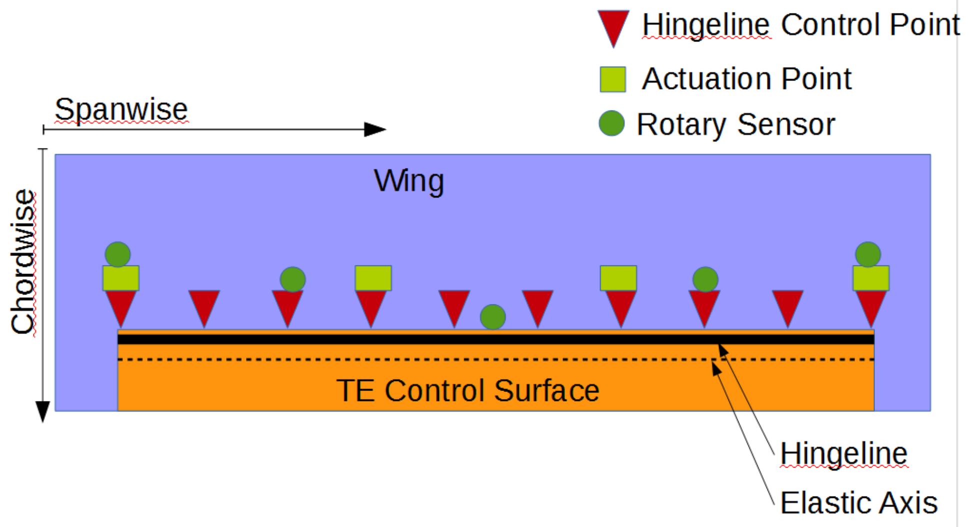
- Conformal Control Surface
  - The objective of a conformal control surface is typically drag reduction (implications for stealth, high lift configuration, etc.). Ideally it is gapless with continuous deformation both chordwise and spanwise.
- mAEWing2 Implementation Needs
  - Needs to be modular
  - Needs to be realizable and cost effective at this scale
  - Needs to be feasible on our timeline
  - Needs to provide a stepping stone toward xAEWing3 and beyond



mAEWing2
Conformal Control Surface (Continued)

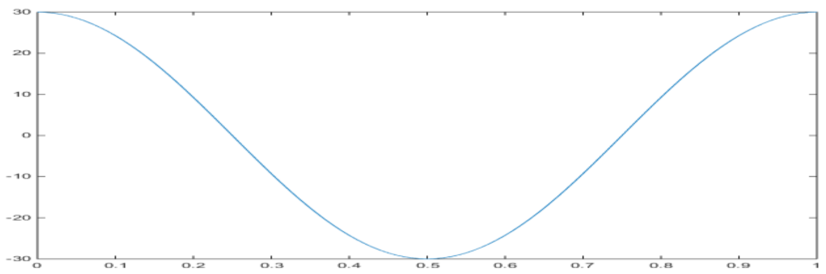
- mAEWing2 Notional Concept is to demonstrate **spanwise continuous deformation** using the wing TE control surface
  - Allows relatively simple and conventional actuation concepts
    - Stiff in Chordwise direction, simply hinged
  - Allocation of control effectiveness for both flutter suppression and shape control are significant challenges that must be addressed for any conformal surface





mAEWing2
Conformal Control Surface (Continued)

- Design Variables
  - Location of Hinges, Actuators, and Sensors
  - Spanwise location and % chord (aft spar is constraint)
  - Materials
    - Ribs can be carbon panel or solid laminate
    - Core and Skin are undefined
  - Required deflection shapes
    - 0° at inboard end (This can be relaxed initially)
    - +/- 30° max deflection
    - 1 wavelength/span spanwise deformation
      - This should ensure more than enough surface shape control
      - May be too extreme



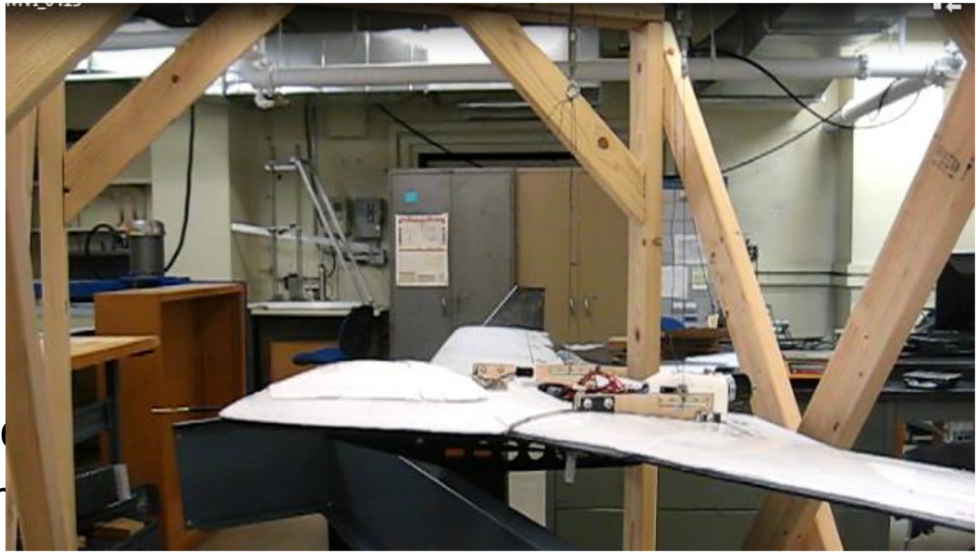
- Constraints
  - Actuator Stall Torque << Structural Failure
  - Hingeline Deflection < 0.030"
  - Hinge Moment < 50 in-oz (Futaba S9254)
  - Actuator Bandwidth > 18 Hz (Futaba S9254)
  - Sized to Suppress Flutter and Minimize Drag!!

mAEWing2
Launch and Recovery

- Launch
  - Winch, Bungee, or Catapult (Baseline)
  - Automobile rooftop launch (Option)

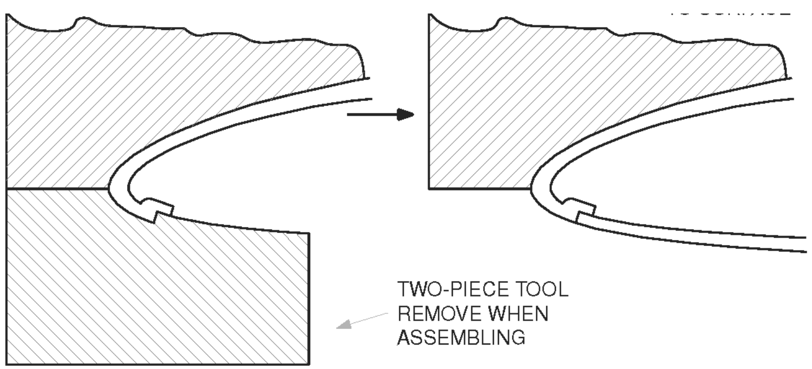
- Recovery
  - Landing Gear (Baseline)
    - Bicycle Deployable (Partial) on Centerline (Baseline)
    - Winglet modification for fixed skids w/ absorption (Baseline)
    - Skids (Option)
  - Parachute (Option)
    - Some form of shock absorption would likely be required on Centerbody and Winglets

mAEWing2
Tools and Fixtures



- Operational Tools and Fixtures
  - Aircraft alignment and suspension test fixture (Bas
    - Part applied fixture, general dimensional measuremen testing
  - Aircraft test frame (Baseline)
    - Inertia Swings and GVT test frame and mechanisms
  - Launch System Assembly (Baseline)
  - Aircraft support workstand (Baseline)
    - Portable fixture
    - Attach and Detach the wings
    - Hold the airframe in the “jig” shape
    - Allow actuation and landing gear testing
  - Control Surface alignment aide (Option)
    - Part applied fixture
  - Transportation fixture (Option)
  - Airdata probe alignment aide (Option)

mAEWing2
Tools and Fixtures (continued)



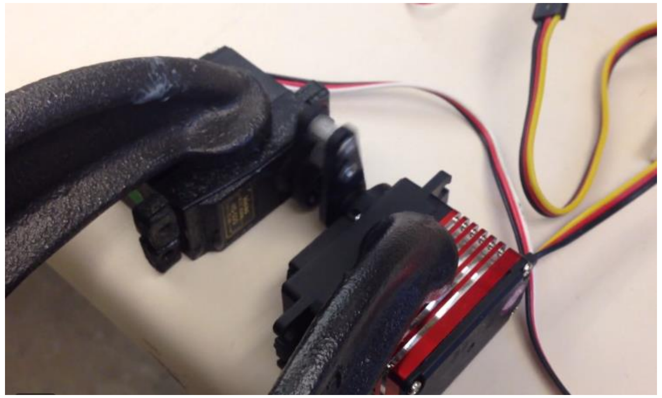
- Production Tools and Fixtures
  - Layup and Cure Molds
    - Wing Panels Left and Right, Upper and Lower [Total Qty 4] (Baseline)
    - Centerbody Panels Upper and Lower [Total Qty 2] (Baseline)
    - Wing Trailing Edge Control Surface Upper and Lower [Total Qty 2] (Baseline)
    - Wing Leading Edge (Option)
  - Bond Assembly Assist
    - Centerbody Structure BAJ (Hold Bulkheads and Alignment points)
    - Centerbody Wing Attach Bracket BAJ (Hold Wing Attach features)
    - Wing (Left & Right) Structure BAJ (Hold Spars and Alignment points)
    - Wing (Left & Right) Wing Attach Bracket BAJ (Hold Wing Attach features)
    - Wing TE Surface Hingeline BAJ (Baseline)
    - Wing LE Surface Hingeline BAJ (Option)

mAEWing2
Test Fixtures and Articles

- Wind tunnel model
  - Airframe scaled for UMN Close Return Tunnel (Baseline)
    - Rigid structure (Baseline)
    - No movable surfaces (Baseline)
    - Tuned beam structure for static aeroelastic matching (Option)
    - Movable or configurable control surfaces (Option)
  - Partial Span airfoil with actuated surfaces to test interaction and conformal/flexible surface under load (Option)

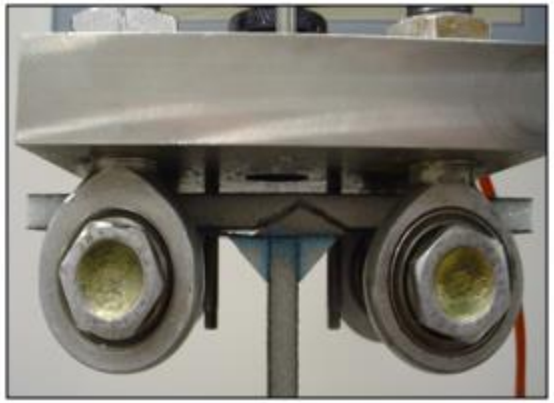
- Thrust Stand
  - Measure: Voltage, Current, Thrust, Torque, and Rotation rate (Baseline)
  - Static and WT testing (Baseline)

- Actuator Characterization
  - Each Servo type used on the aircraft
  - Measure: Voltage, Current, Torque, and Rotation Angle (Baseline)
  - Unloaded wrt voltage and amplitude (Baseline)
  - Inertially loaded wrt voltage and amplitude (Option)
  - Statically loaded wrt voltage (Option)



mAEWing2
Test Fixtures and Articles (Continued)

- Structural Trials and Qualification
  - Strength and Stiffness of Principle Structure material coupons (Baseline)
    - Skins and sandwich panel
  - Principle Structure bond component testing (Baseline)
  - Component Testing of critical mechanical joints (Baseline)
    - Wing Attach
    - “Hard Point” feature
    - Hinge subassembly



- Fabrication and Assembly Trials
  - Continuous/Flexible control surface fabrication and assembly trial (Baseline)
    - Will require some material screening trials prior to fabrication trial