Section 5

VERTICAL FORCE AND FLIGHT STABILITY REQUIREMENTS FOR FRANGIBLE STRUCTURES

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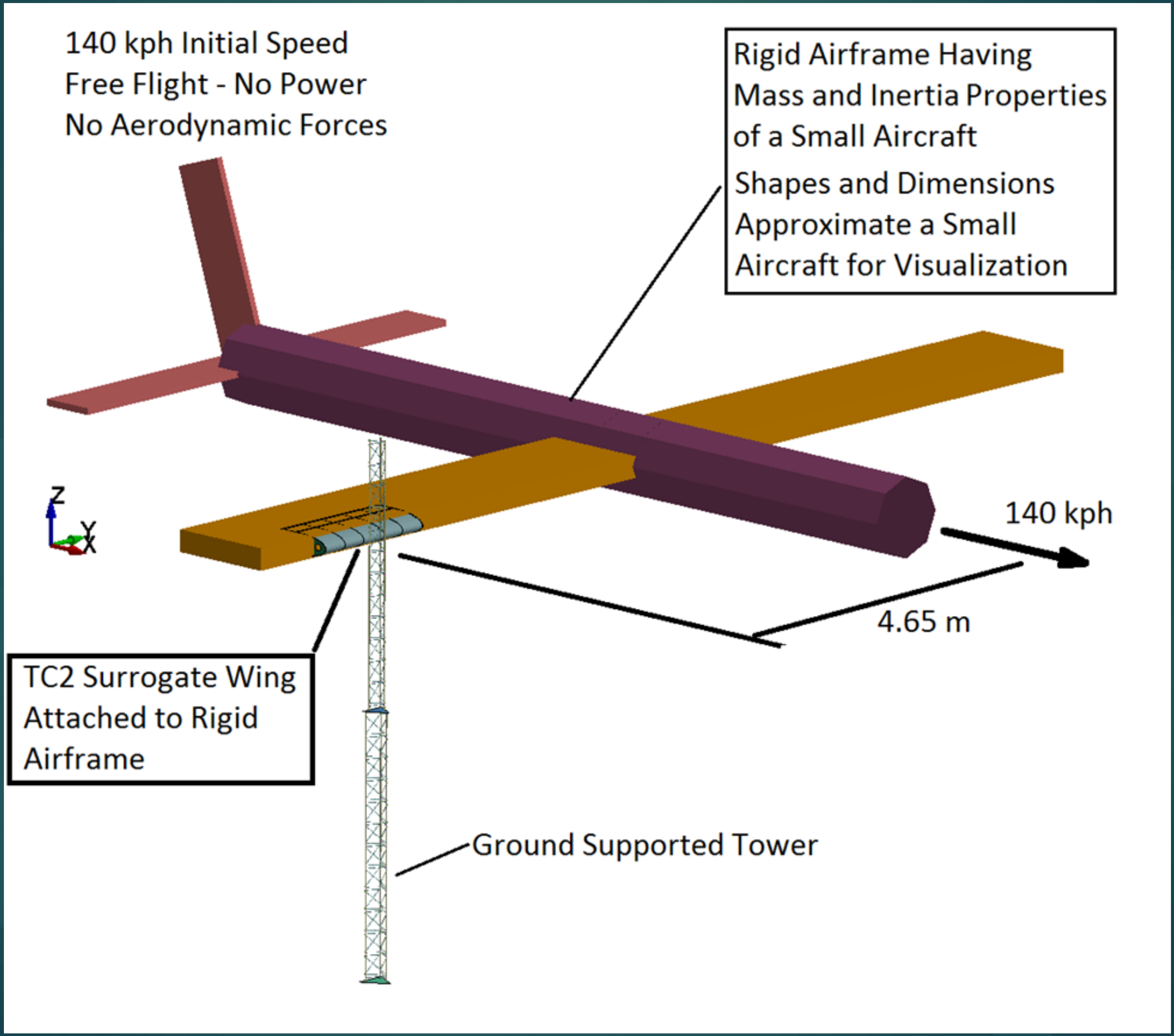
TRIDYNAMIC SOLUTIONS

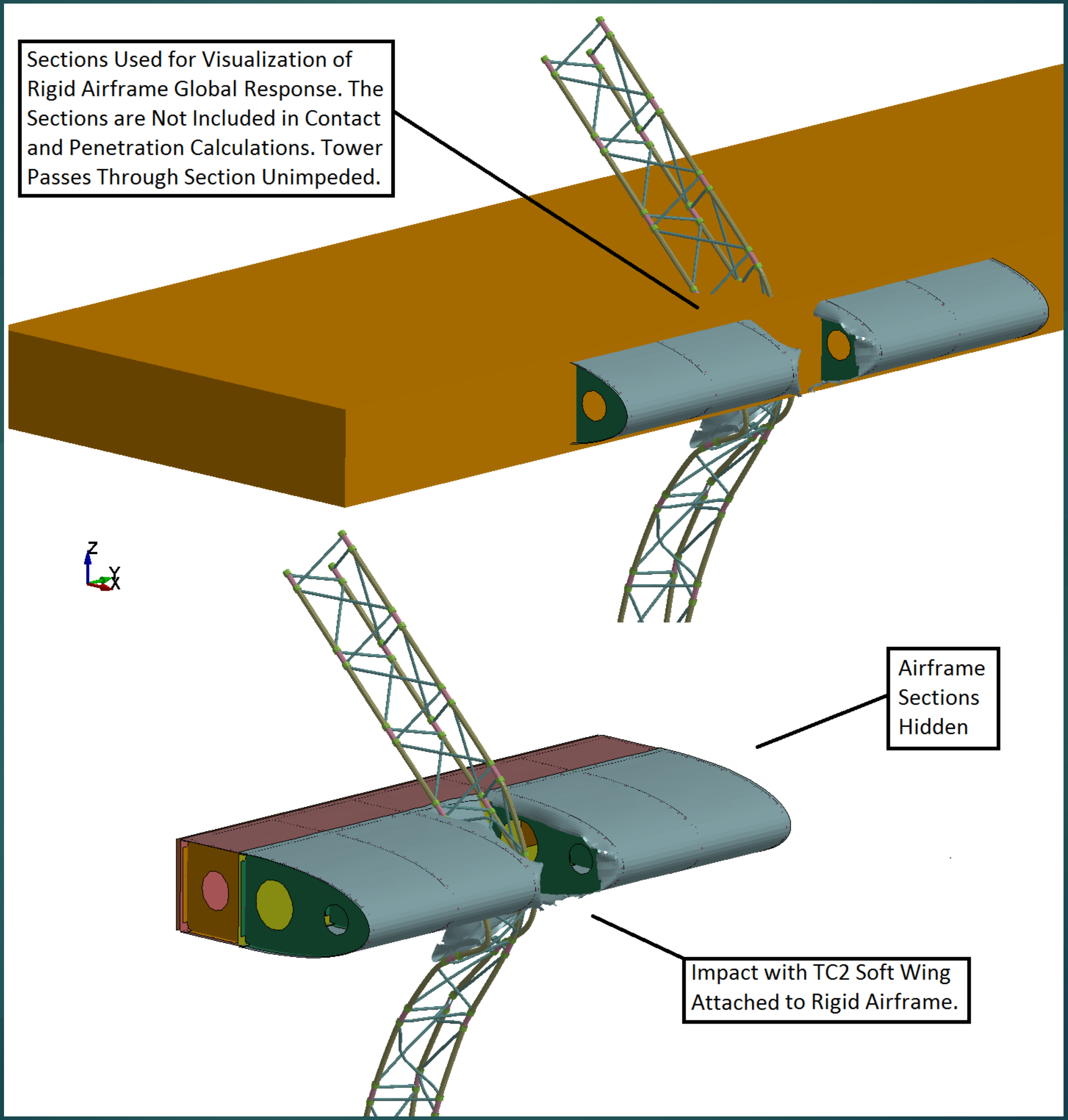
Recommendations

- Develop practical flight path disruption limits for impact by small aircraft.
  - Most importantly quantify reasonable limits for impact induced yaw or roll rotations.
  - Vertical force measurements shall be included in future testing.
- Prohibit the application of devices that do not exhibit local windowing mechanisms for frangibility.
- Navajo Wing Modeling Improvements
  - Validation testing of wing impacts
  - Uncertainty analysis on simulated wing response
- Further improvements to the soft HC impactor are needed to better represent the wing.

Vertical Forces and Flight Stability



Vertical Forces and Flight Stability



Vertical Forces and Flight Stability

Device Type	Model Number	Reference Model	Height (m)	Impact Distance from Top (m)	Top Mass (kg)
Aluminum Lattice	RAF M02	M02	6	1	0
Aluminum Pipe	RAF M26	M26	6	1	20
Composite Lattice	RAF M27	M27	6	1	20
Composite Pipe	RAF M28	M28	6	1	20

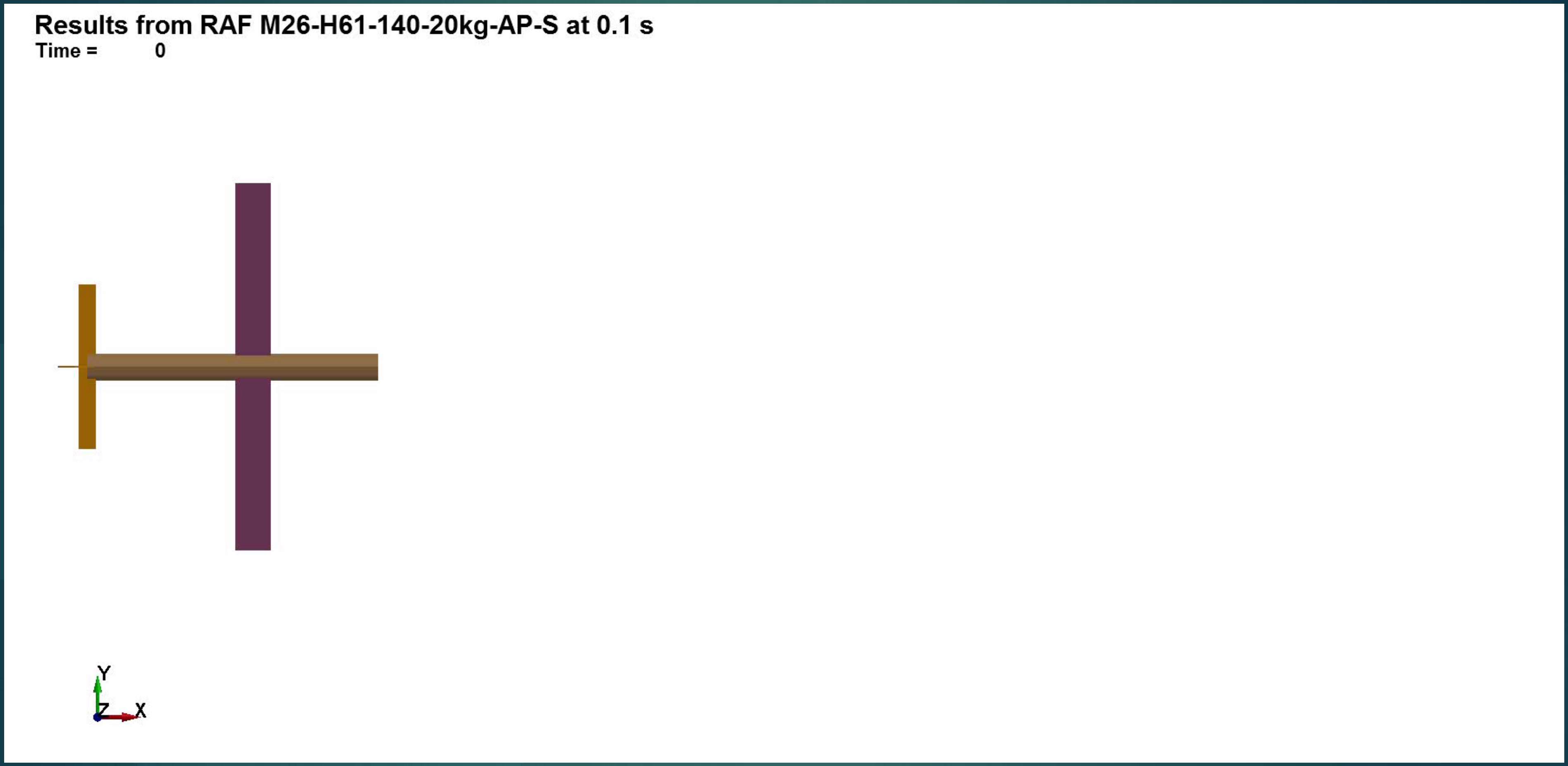
Post Impact Velocities

Device Type	Model Number	Vx (m/s)	Vy (m/s)	Vz (m/s)	RotX (rad/s)	RotY (rad/s)	RotZ (rad/s)
Aluminum Lattice	RAF M02	38.89	-0.003	-0.148	0.203	-0.008	-0.123
Aluminum Pipe	RAF M26 (100 msec)	38.62	-0.007	-0.384	0.535	-0.042	-0.442
Composite Lattice	RAF M27	38.81	-0.001	0.021	-0.026	0.002	-0.131
Composite Pipe	RAF M28	38.85	0.001	0.002	-0.003	0.000	-0.071

Apply as Initial Conditions for Post Impact Free Flight

Free Flight after Impact (1.0 sec)

Aluminum Pipe - Top

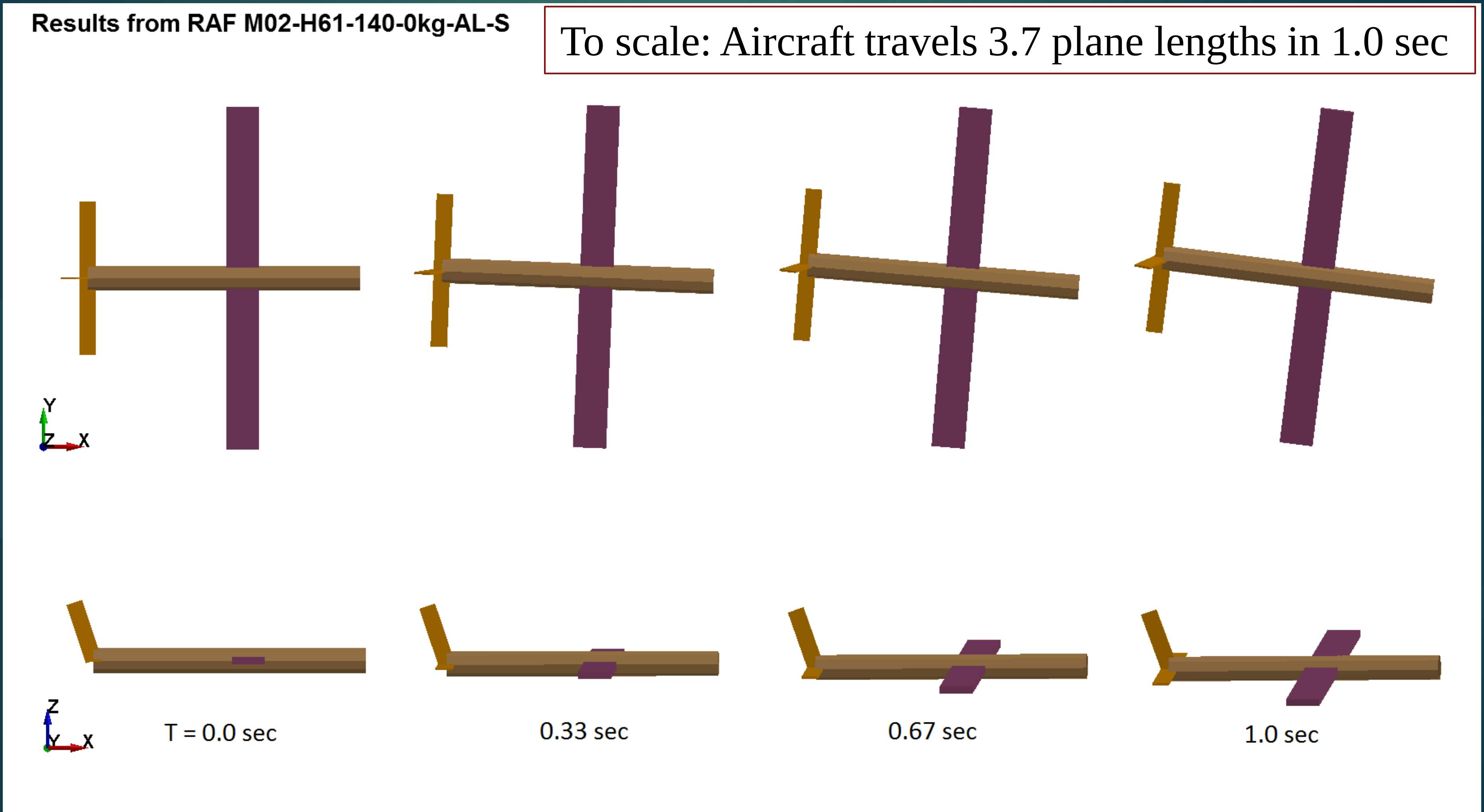


Free Flight after Impact (1.0 sec)

Aluminum Pipe - Side

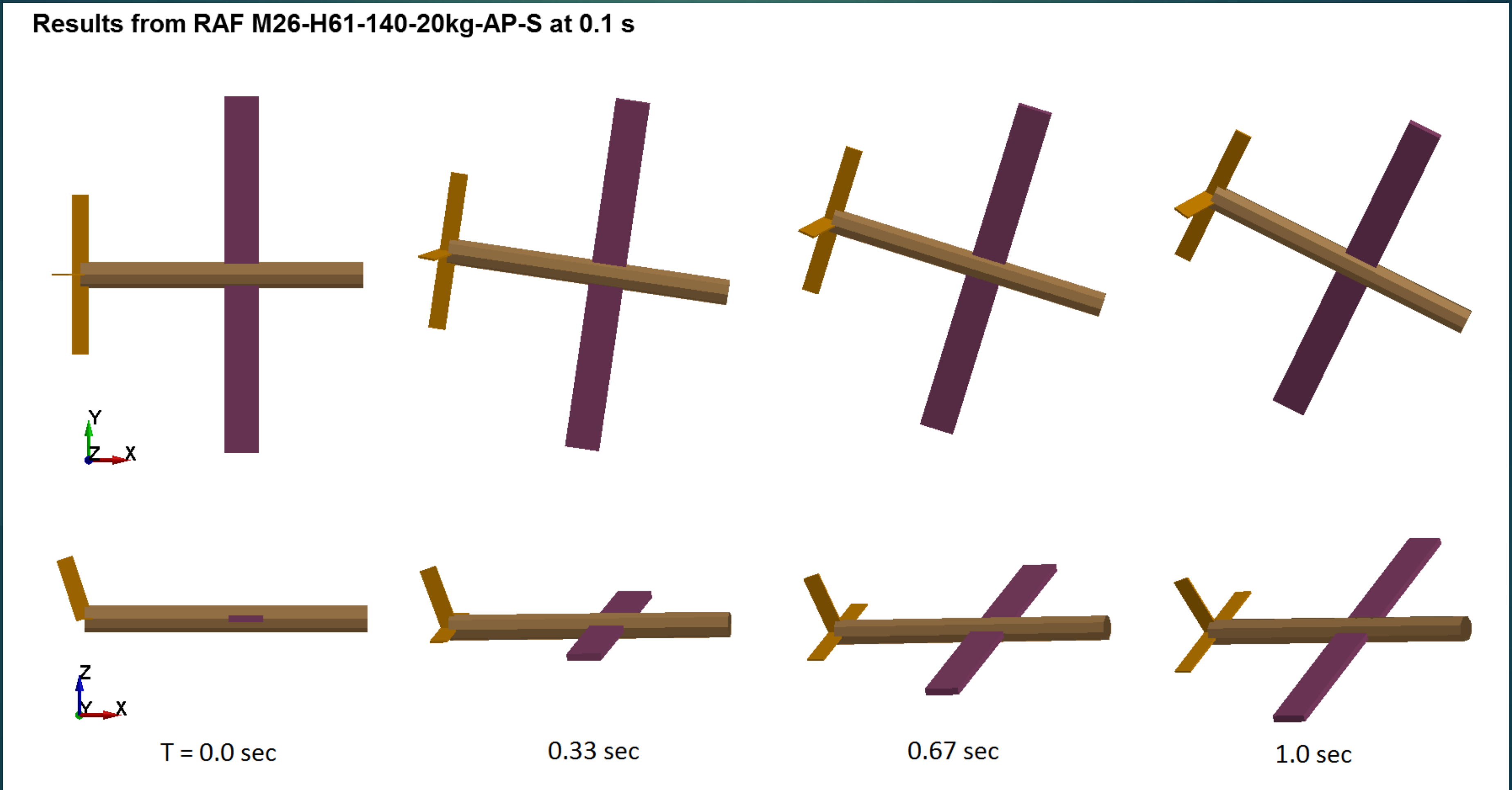
Free Flight after Impact (1.0 sec)

Aluminum Lattice – No Top Mass



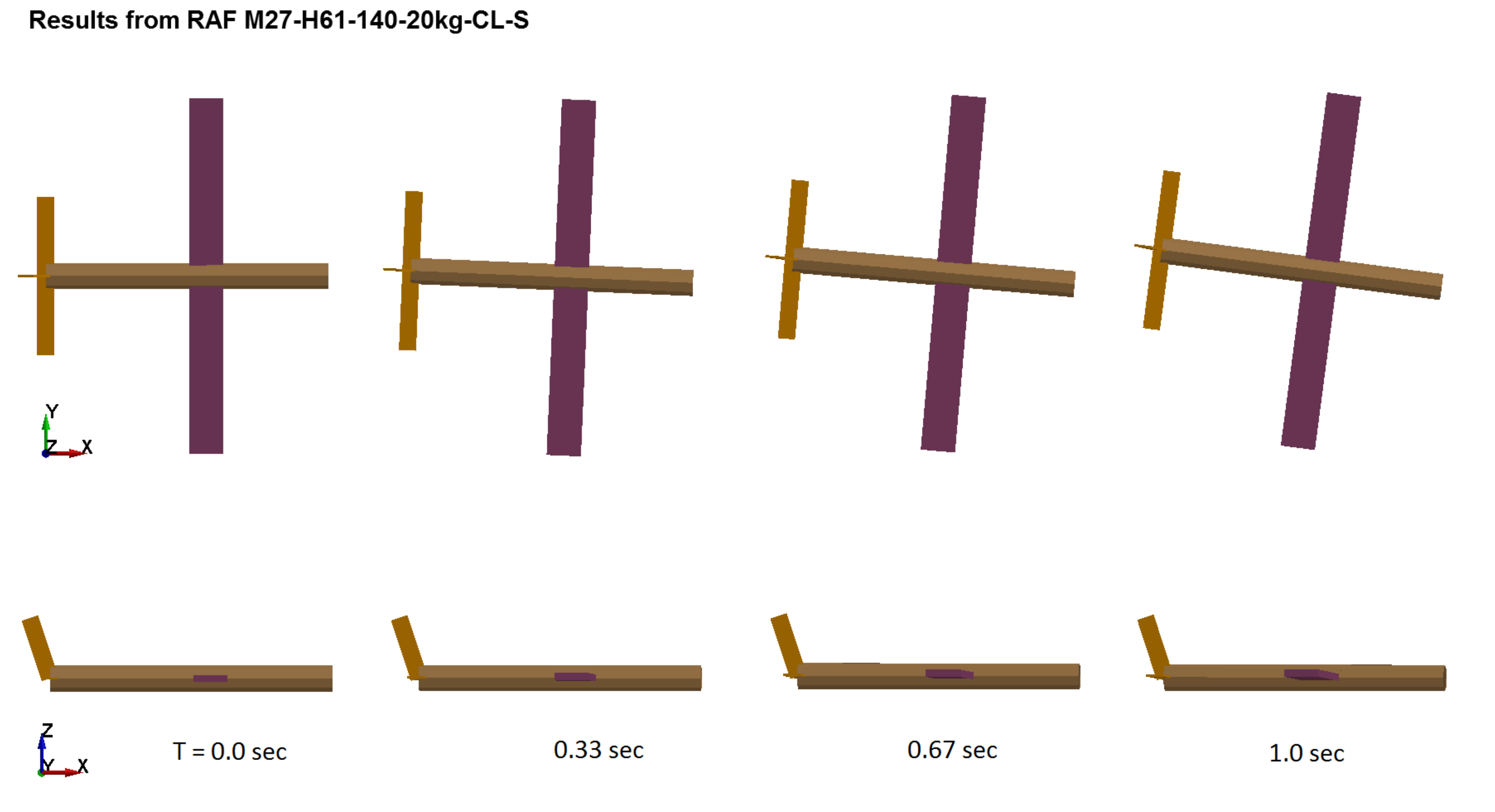
Free Flight after Impact (1.0 sec)

Aluminum Pipe



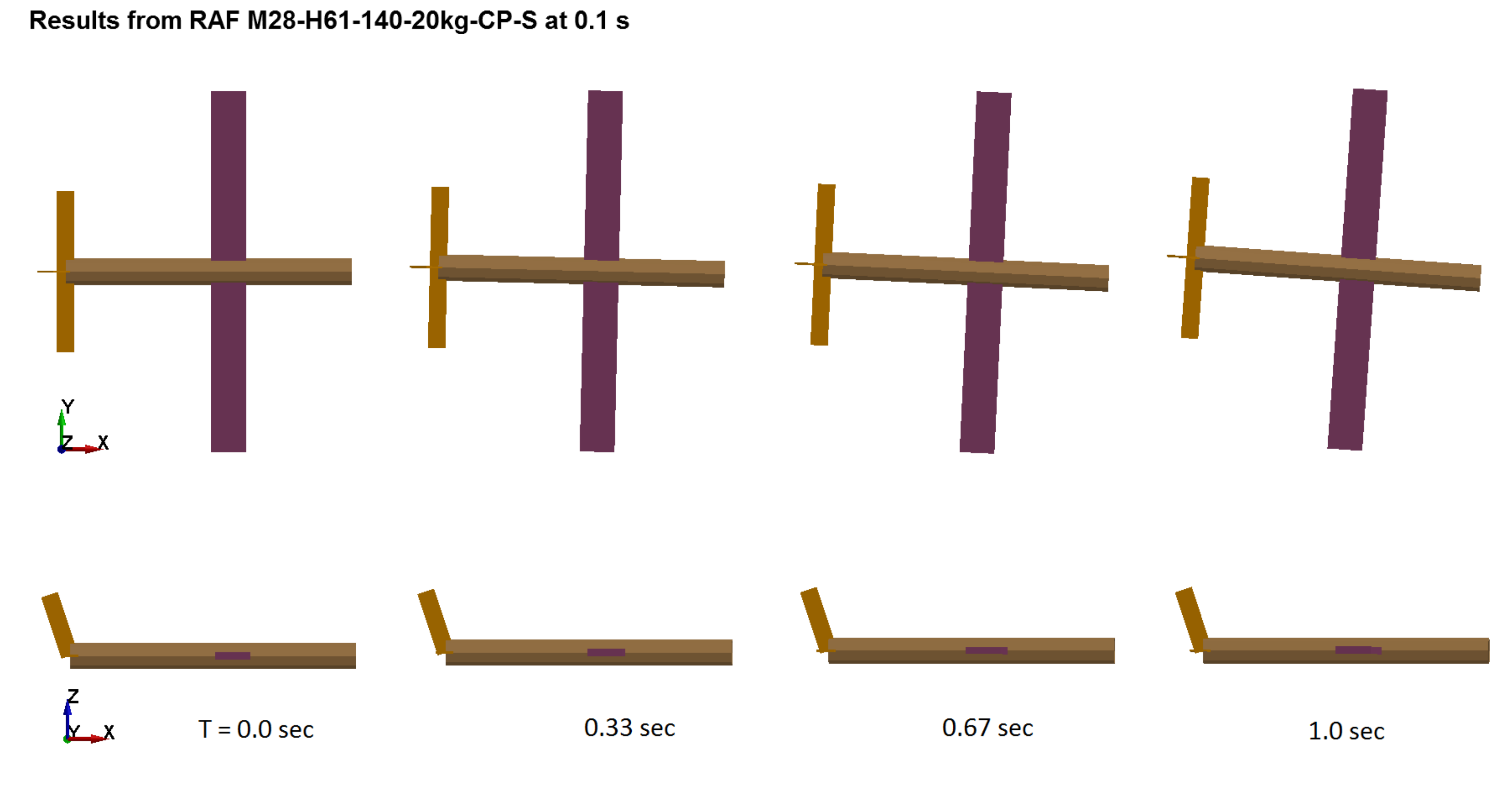
Free Flight after Impact (1.0 sec)

Composite Lattice

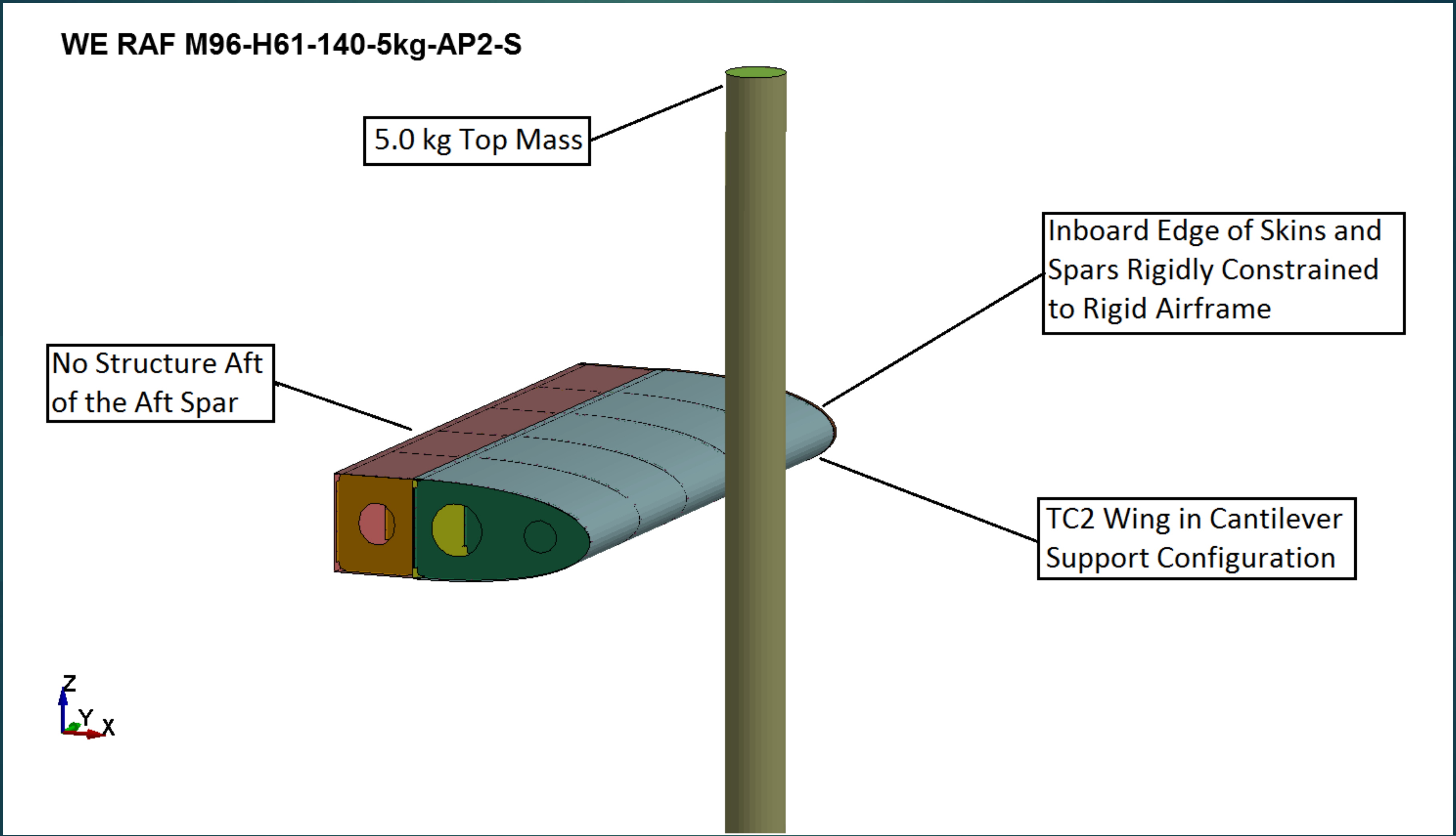


Free Flight after Impact (1.0 sec)

Composite Pipe



TC2 Cantilevered From RAF



Impact Test Simulation:

Aluminum Pipe 2 mm wall – 5.0 kg Top Mass

Tower Response – WT (Wrap and Tear through)

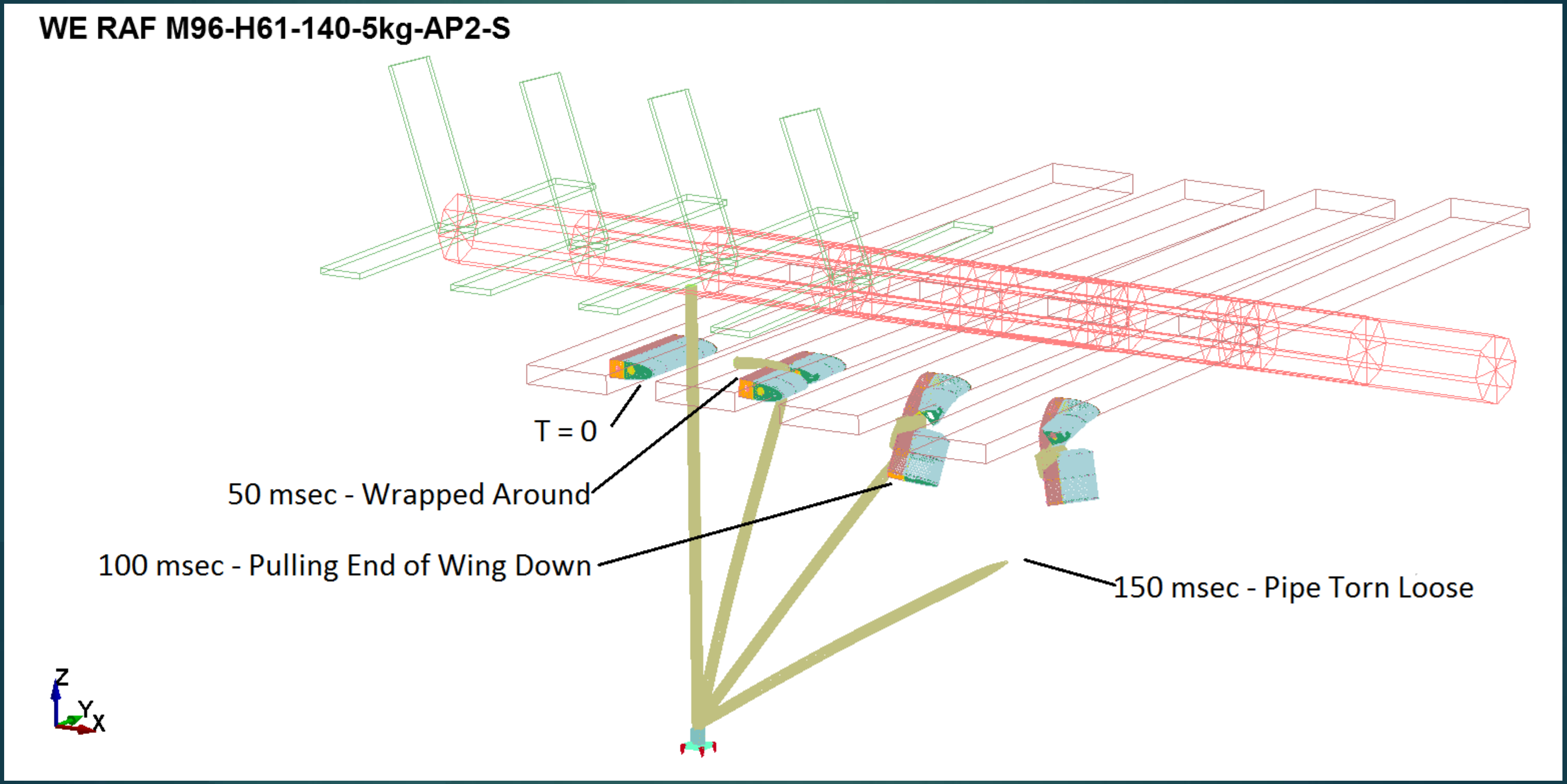
Peak Force = 31.9 kN < 45 kN

Maximum Energy = 42.2 kN-m < 55 kN-m

Wing Damage Category = 2

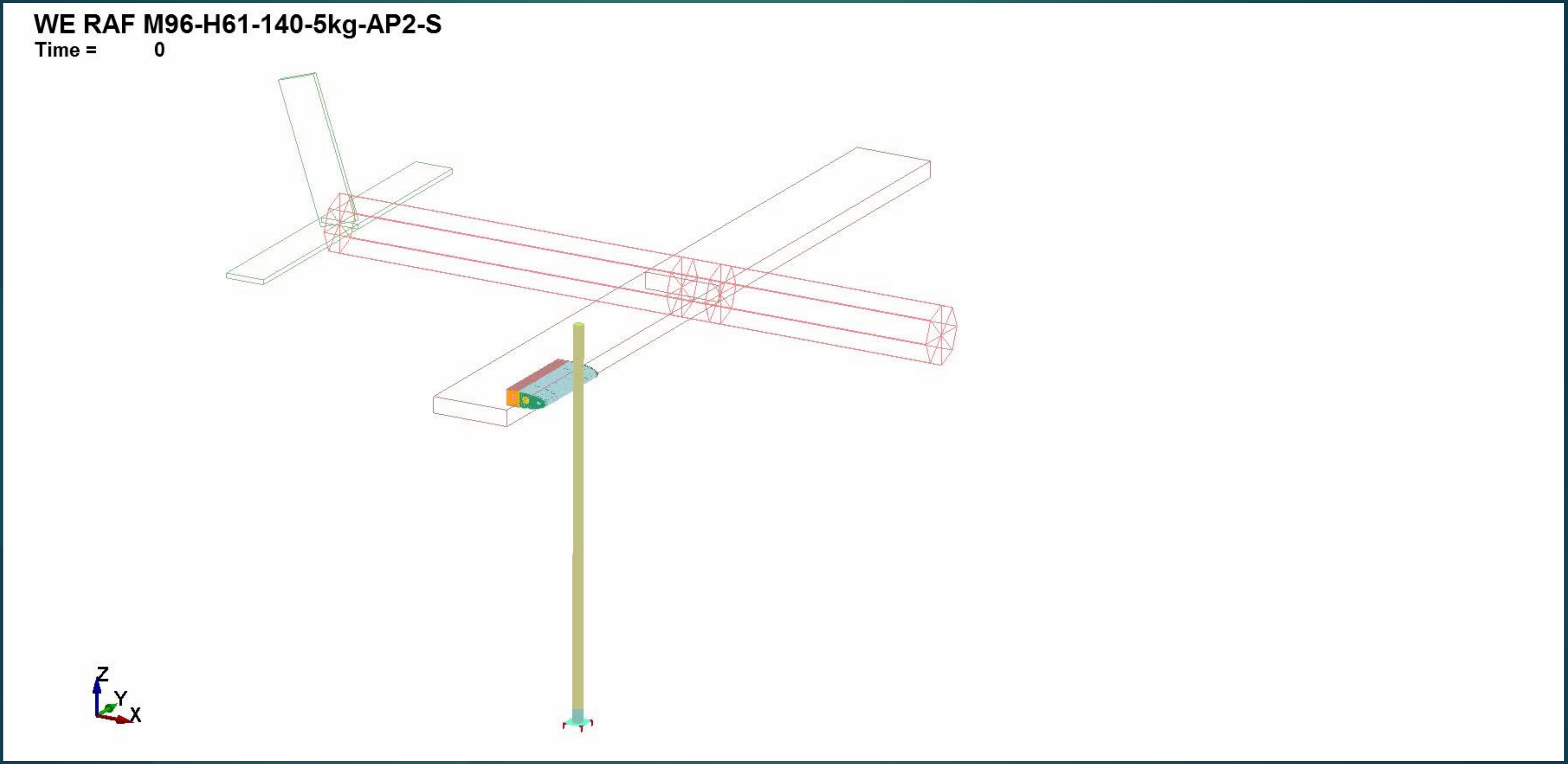
Progression Through Impact

Aluminum Pipe 2 mm wall – 5 kg Top Mass



TC2 Wing (No Structure Aft of Aft Spar)

Aluminum Pipe 2 mm wall – 5.0 kg Top Mass



Robert T. Bocchieri, Ph.D.

APPLIED RESEARCH ASSOCIATES

Outline

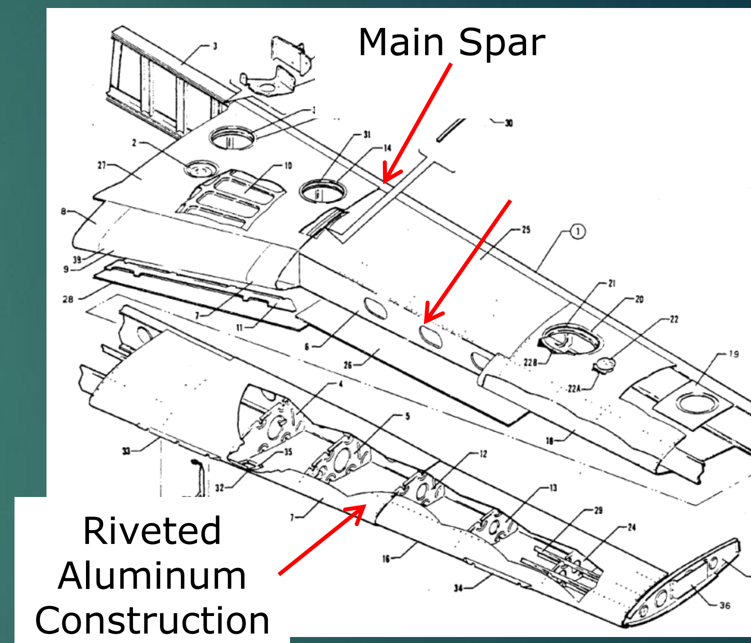
- Review of LS-DYNA model for the Piper Navajo
- Navajo impact simulations on FAA ALS structure
  - Structural response of FAA ALS and Navajo wing
  - Effect on flight dynamics (including Product C)
- Comparison of impactor type on FAA ALS response (Rigid, HC, Navajo Wing)
  - Reaction forces on the FAA ALS pole
  - Comparison of FAA ALS structure response.
- Conclusions on impactor type

Representative Aircraft

Piper Navajo

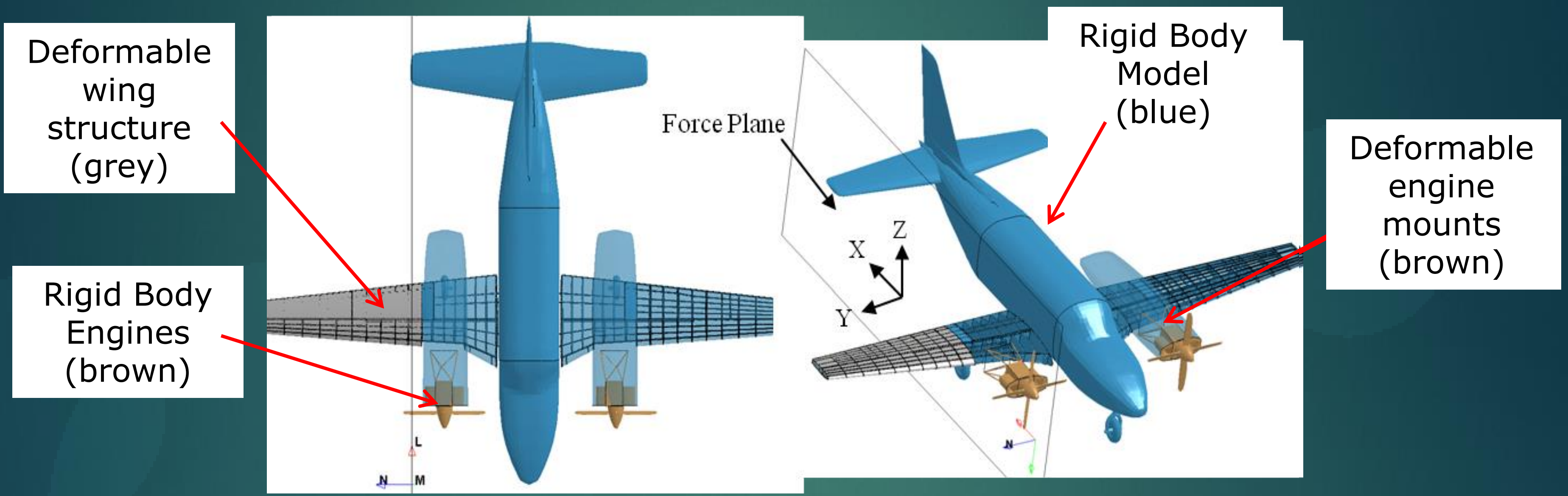
Max Takeoff Weight
2948 kg. (6500 lb)

Leading Edge Assembly



- Detailed structural and mass information from Piper Aircraft Service Manual, Parts Catalog and Engineering Drawings.
- Nonlinear material behavior and fastener strength information from MIL-HDBK-5J and other open literature sources.

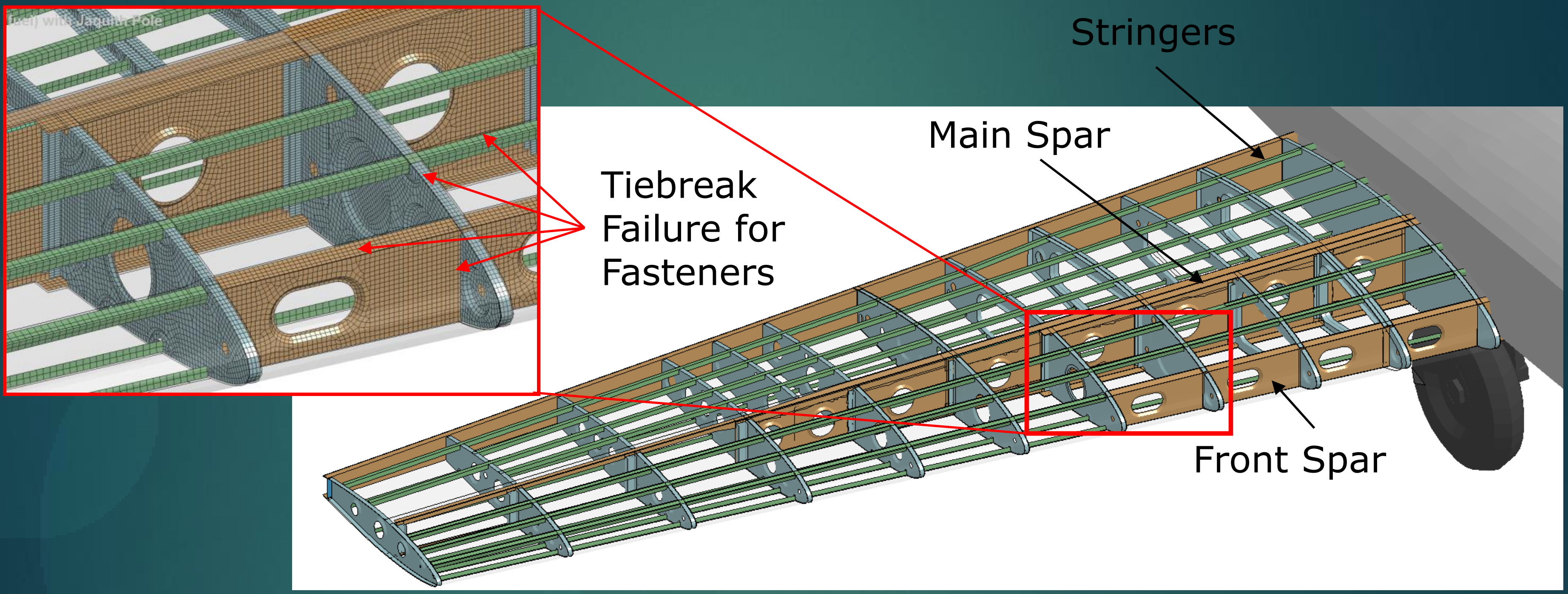
Navajo LS-DYNA Model



- Model constructed to predict damage to wing from impacts at various locations from varied frangible structures.
- Remainder of aircraft modeled with rigid bodies to get correct C.G. and Moments of Inertia for predicting vehicle dynamics.

Navajo LS-DYNA Model

Deformable Wing Model (Skin Semi-Transparent)

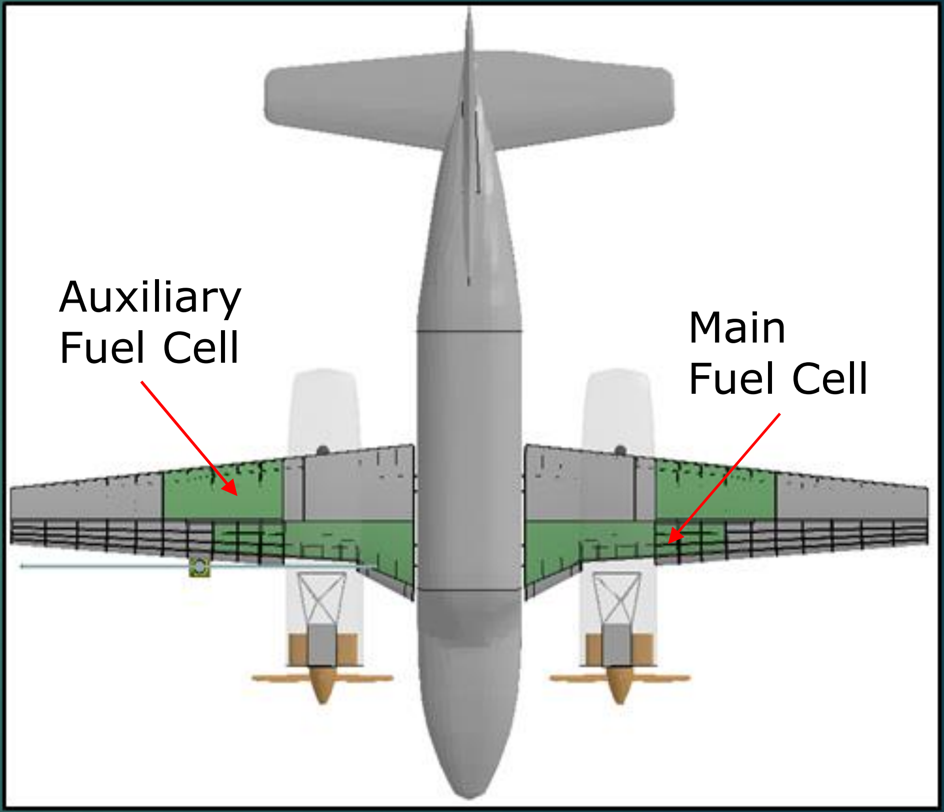


- High-fidelity model of the main airframe was developed.
- Includes nonlinear aluminum material behavior and embrittlement in regions with holes from fasteners.
- Connection failure included based on fastener design values.

Navajo LS-DYNA Model

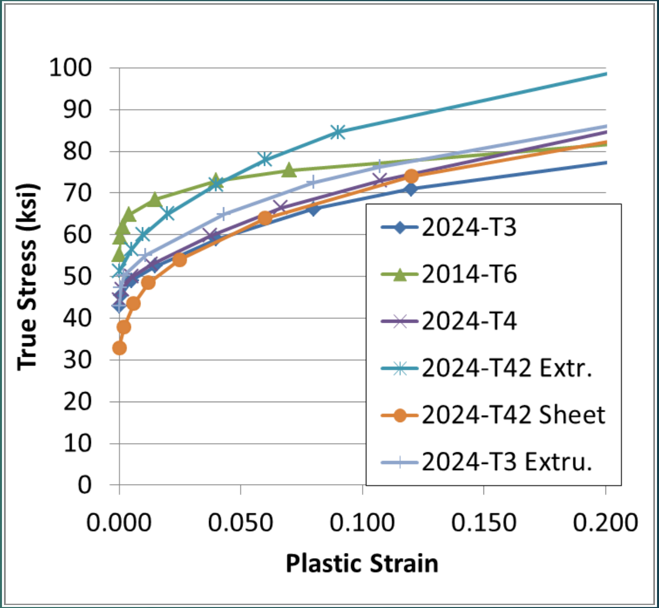
Aircraft Mass Distribution

- Mass distribution estimated based on similar aircraft component weights.
- The modeled structure was mass scaled to include non-structural mass not explicitly in the model.
  - E.g., insulation, hydraulics, control lines, fuel, etc.
- Fuel weight was distributed in the position of the fuel tanks.
- Weight distribution based on maximum fuel capacity and max takeoff weight.



Navajo Material Modeling

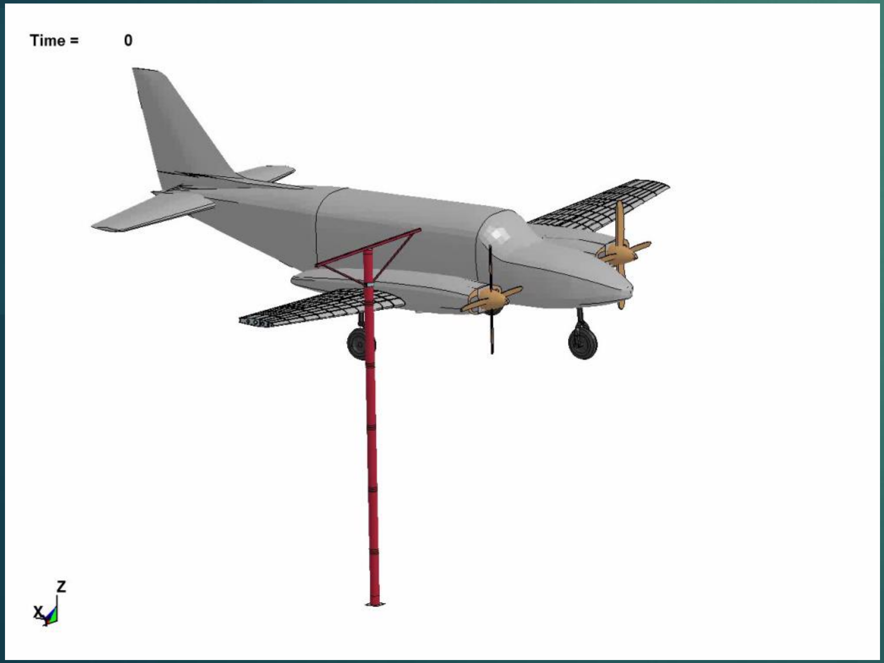
- Navajo Al Alloys
  - Piecewise linear plasticity constitutive model.
  - Fracture at engineering design failure strain.
  - Regions with holes from fasteners embrittled using Net Ligament Loss methodology.

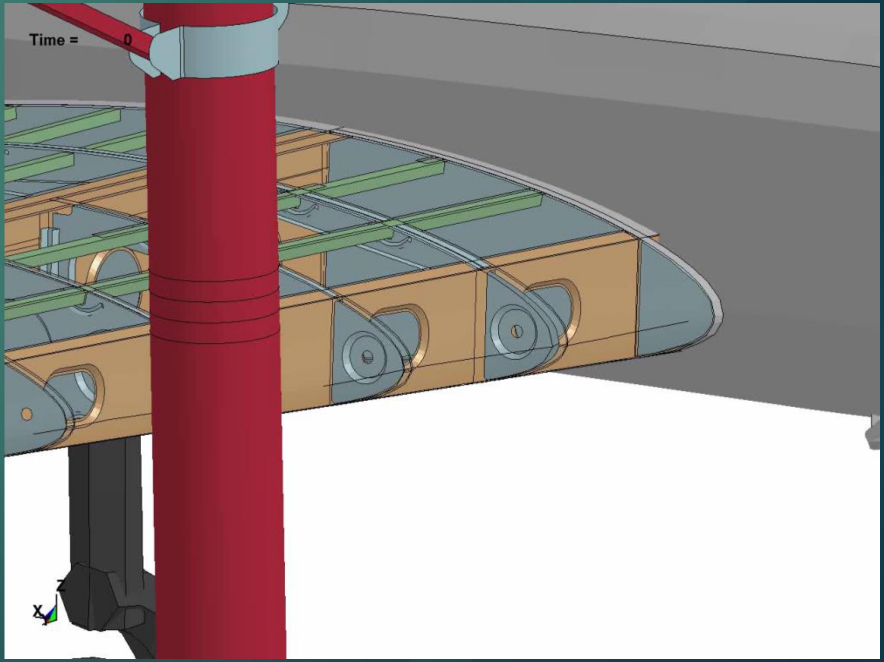


- Uncertainty in degree of embrittlement and actual fracture strains affect the crushing and damage to the wing model
  - Recommend (1)validation testing of wing impacts and (2) uncertainty analysis on simulated wing response

FAA ALS Structure Impact Simulation – Navajo Wing Bay 4

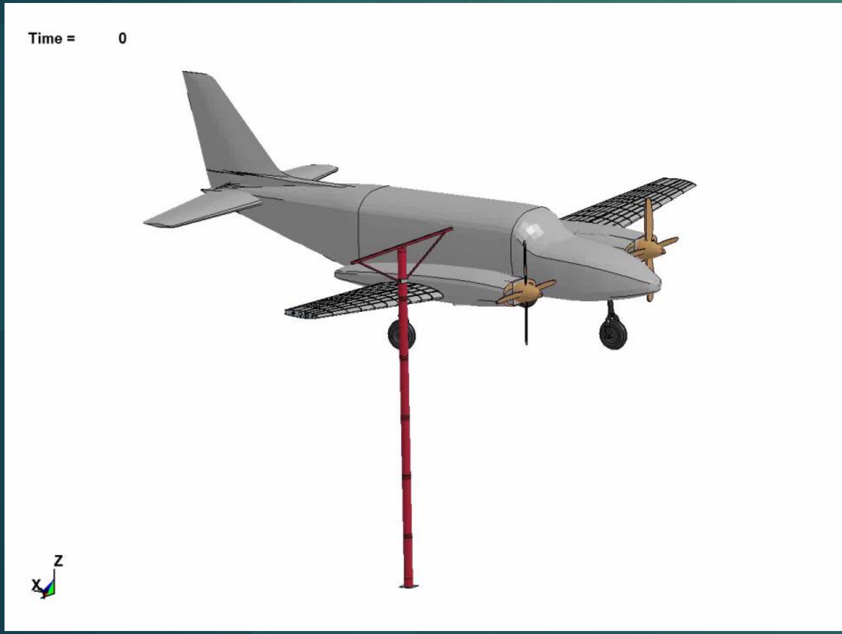
- Impact positioned between leading edge ribs at bay 4.
- Joint fails during impact with leading edge, but pole does impact main spar with some damage to spar.

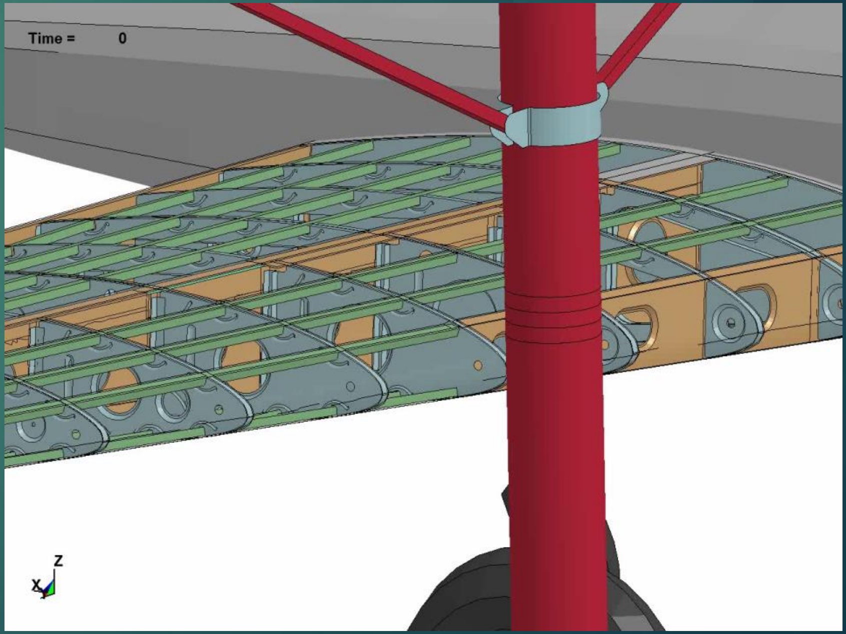




FAA ALS Structure Impact Simulation – Navajo Wing WS 147

- Impact positioned at rib outboard of Bay 4.
- Joint fails during impact with leading edge, but NO damage to main spar.

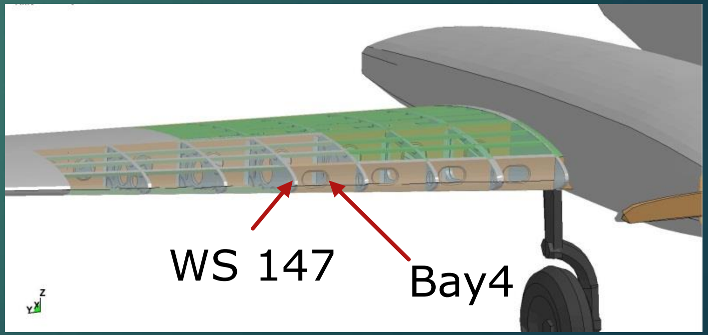




LIR Structure Impact Simulation with Navajo: Flight Dynamics

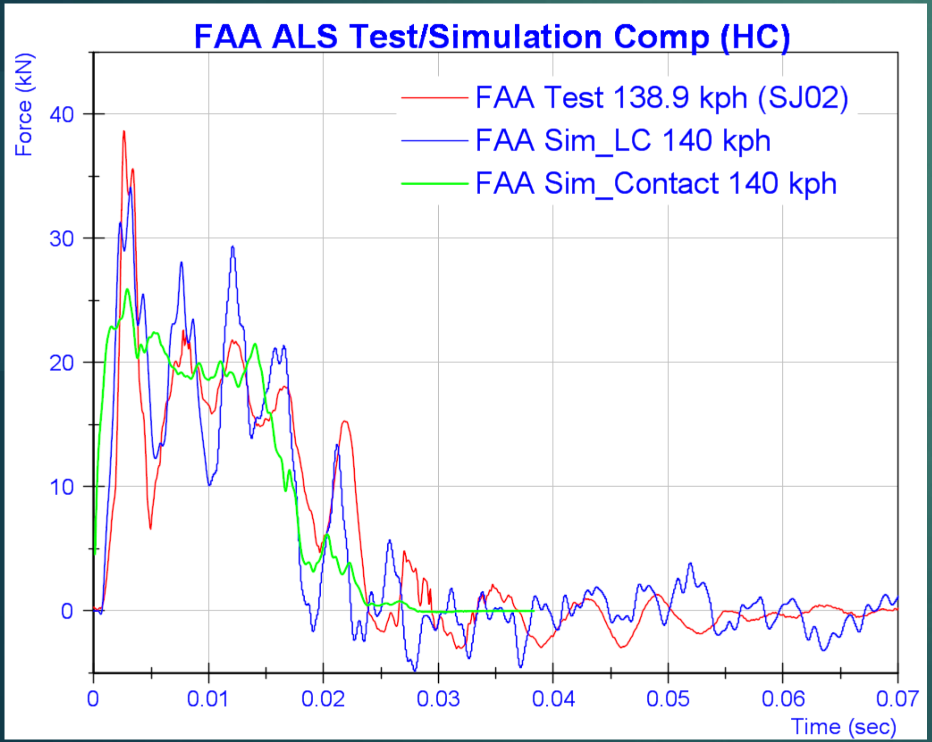
- Peak yaw rate from impact can be significant.
- Rate not affected much by impact location (on rib vs between).
- Other considerations: Control surfaces on trailing edge (not modeled) could be damaged if product wraps around wing.

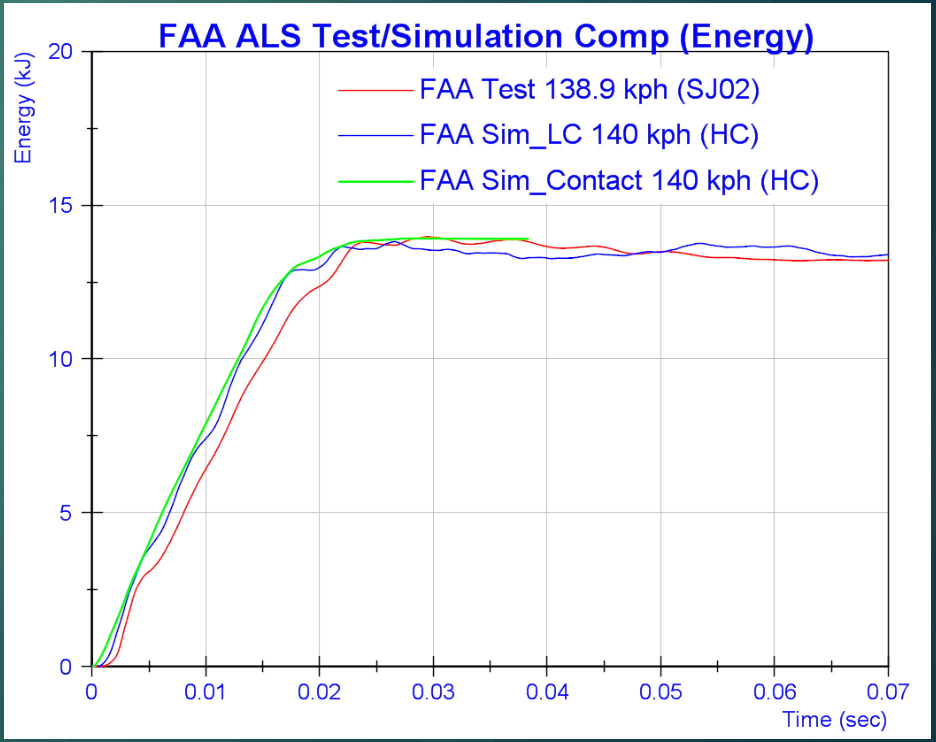
FAA Approved Products	Impact Point	Yaw Rate (deg/s)	Roll Rate (deg/s)
1	Bay 4	3.06	0.6
	WS 147 (rib)	3.01	0.23
2	Bay 4	10.27	1.98



HC Impactor Force on Lighting Structure: FAA ALS

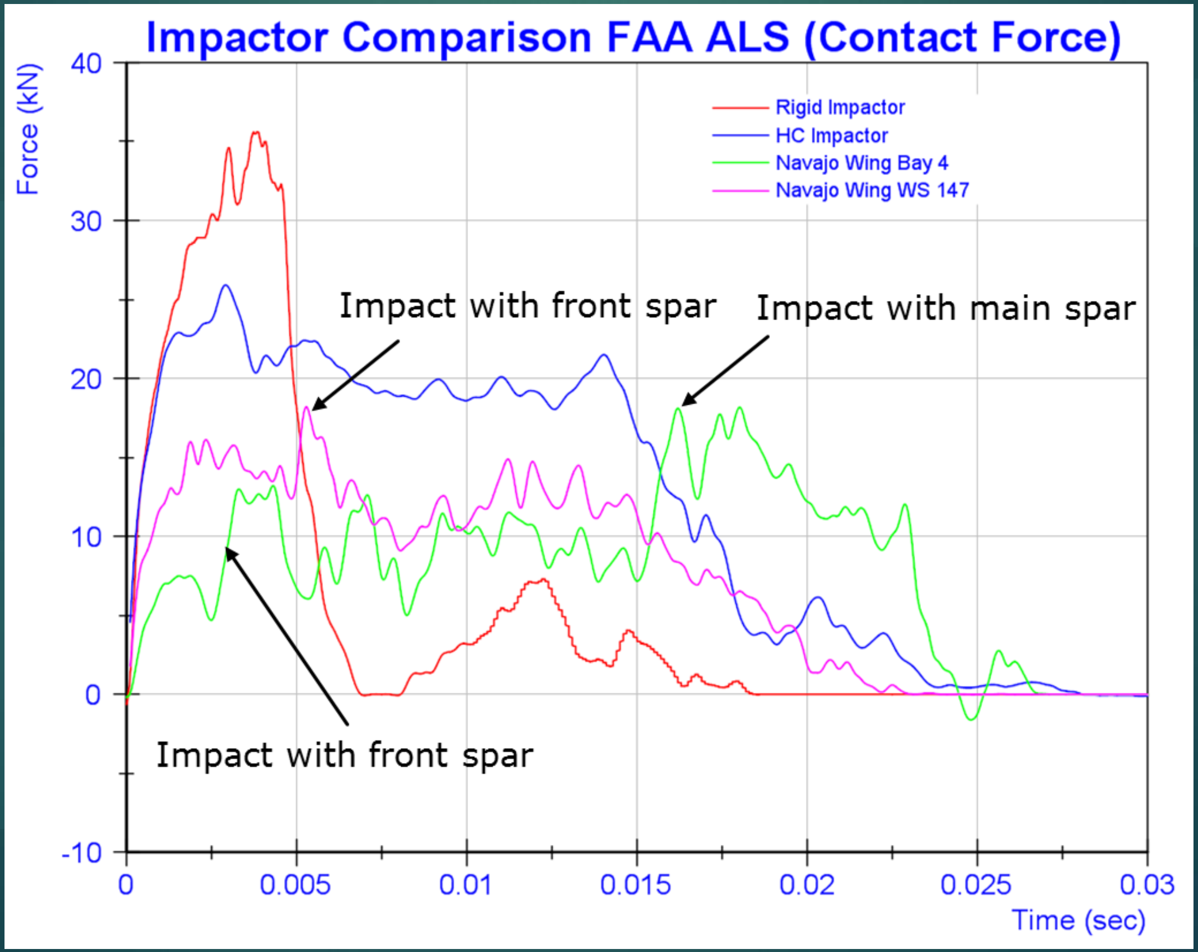
- Net contact forces between an impactor and a structure can be extracted from simulations.
- These forces show similar histories to the load cell data, but without the higher frequency response coming from the test frame.





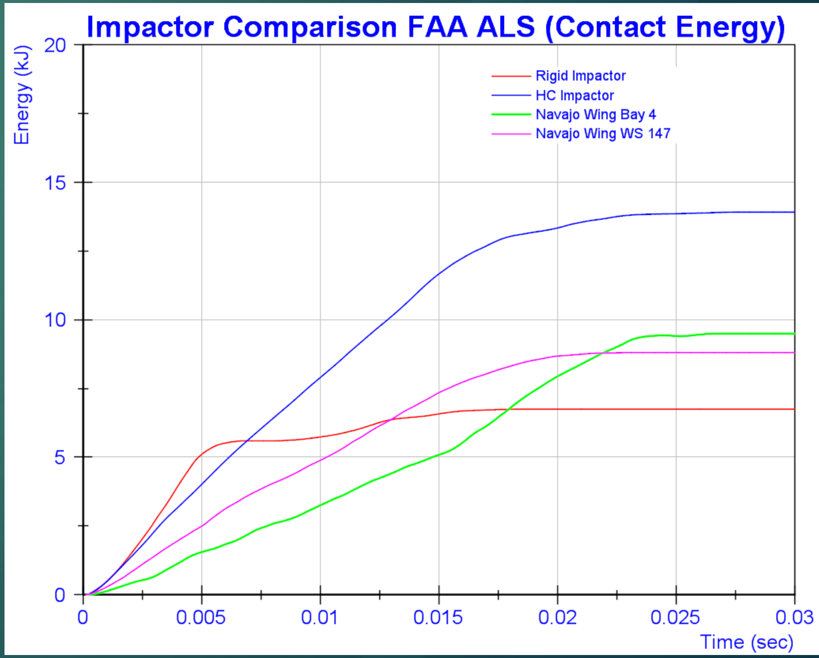
Impactor Force on FAA ALS Lighting Structure: Various Impactors

- Simulation contact forces allow us to compare the reaction load of the LIR structure on the wing compared with the two impactor types.



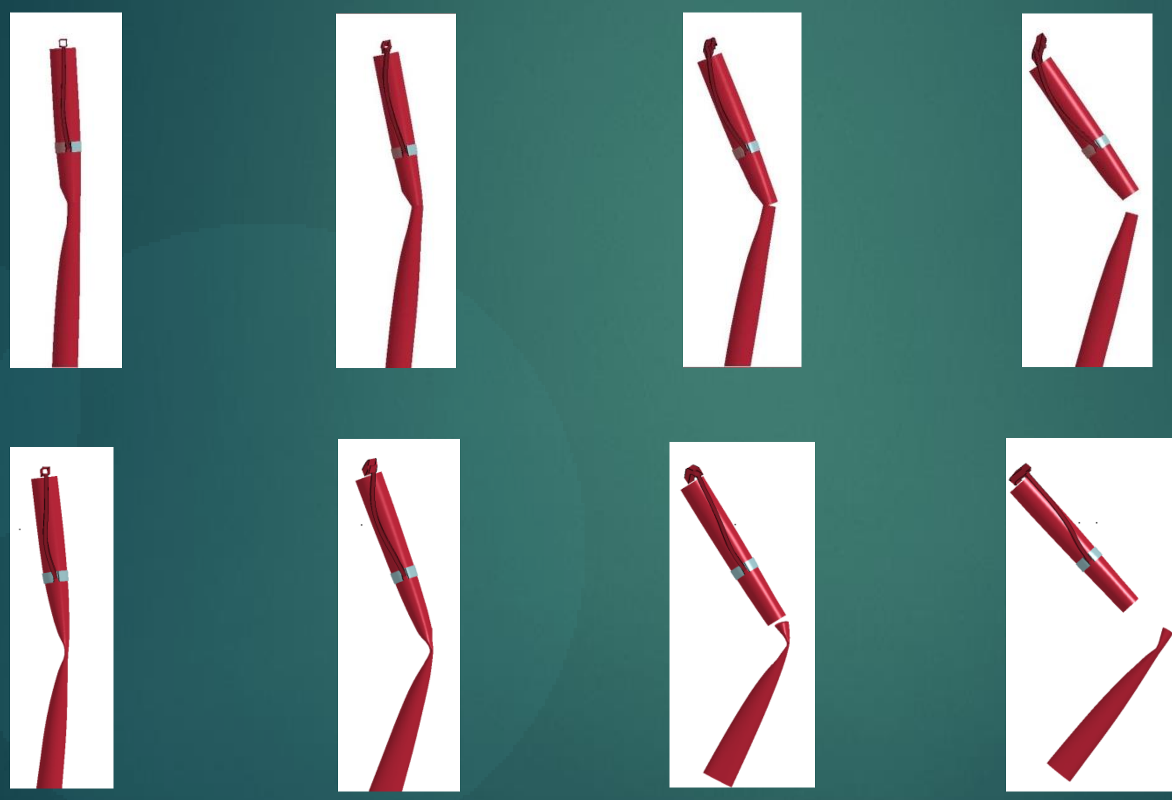
Impactor Force on FAA ALS Lighting Structure: Various Impactors

- The reaction load on the rigid impactor has a very different force history on the structure than from the soft HC and wing.
  - Structure response leads to least energy absorbed.
- The HC impactor has similar force duration, but greater magnitude
- Total energy not significantly different for two wing impact locations.
- HC impact still too high and rigid too low compared to wing at these locations.



FAA ALS Lighting Structure Response: Wing vs Rigid Impactor

5 ms 10 ms 15 ms 20 ms



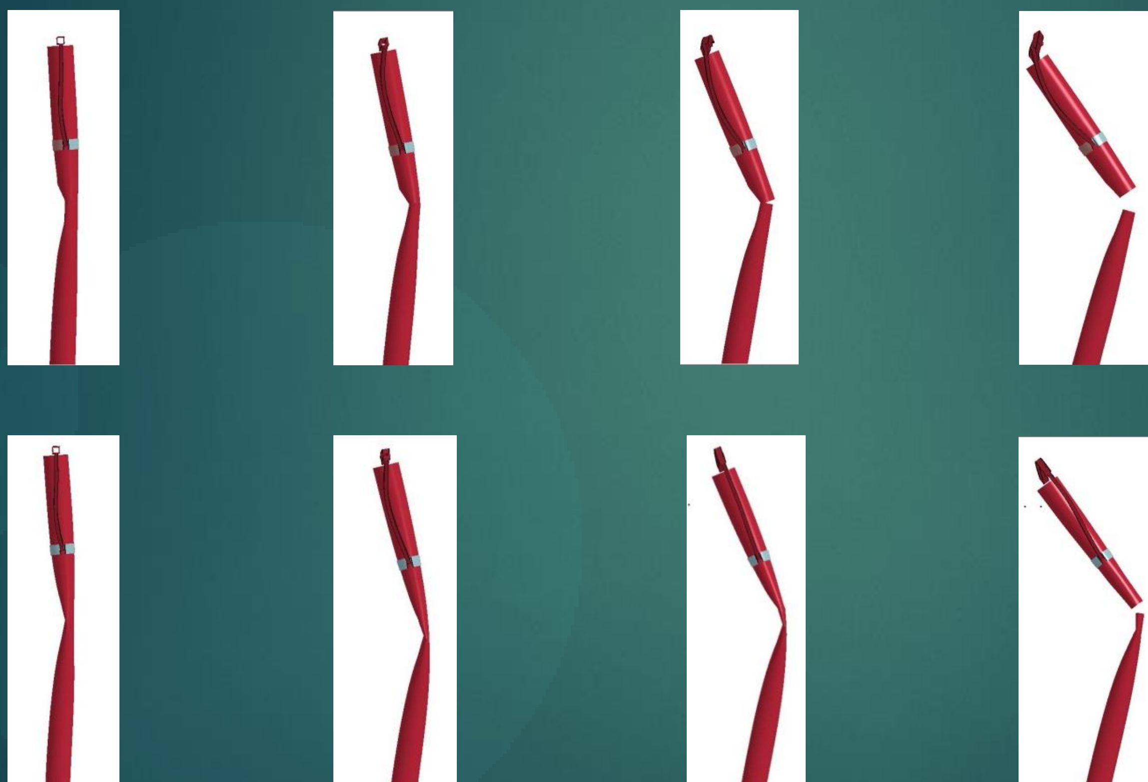
Navajo Wing At Rib (WS147)

Rigid Impactor

Note: impactor removed from view

FAA ALS Lighting Structure Response: Wing vs HC Impactor

5 ms 10 ms 15 ms 20 ms



Navajo Wing At Rib (WS147)

HC Impactor

Note: impactor removed from view

Effect of Impactor on FAA ALS Structure Response

- Structural response of the FAA ALS is significantly different for a rigid and soft impactor.
  - More localized damage to pole with rigid impactor
  - Joints fail more quickly with rigid and at different locations.
- Response with the honeycomb impactor more closely resembles the Navajo wing response.
  - Significant improvement over a rigid impactor.
  - Damage to the FAA ALS pole is still larger and more localized with the HC impactor.
  - Further improvements to the soft HC impactor are needed to better represent the wing.

Summary

- Vertical forces are significant factors in both aircraft flight stability and wing damage
- Local windowing failure reduces vertical forces

Recommendations

- Develop practical flight path disruption limits for impact by small aircraft.
  - Most importantly quantify reasonable limits for impact induced yaw or roll rotations.
  - Vertical force measurements shall be included in future testing.
- Prohibit the application of devices that do not exhibit local windowing mechanisms for frangibility.
- Navajo Wing Modeling Improvements
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