October 8, 2015

mAEWing1-Hati Updates

CMSoft Inc.

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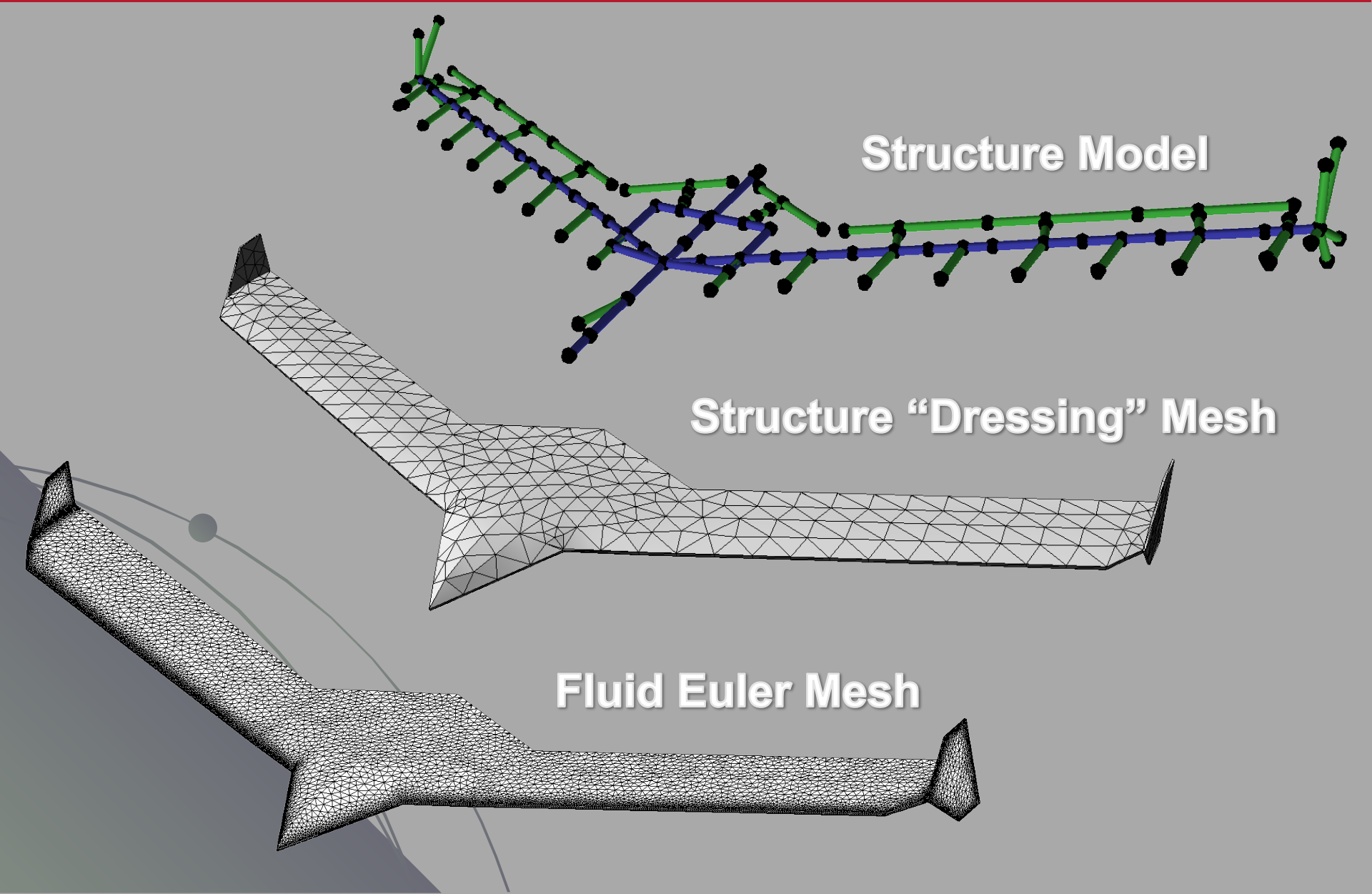
Summary

- Converted the Virginia Tech NASTRAN structural model of mAEwing1-Hati v3.3 to AERO-S.
- Edited the control surface connector properties in the AERO-S structural model.
- Performed an eigenvalue analysis to identify important dry structural modes.
- Connected the structure stick model to an aerodynamic “dressing” shell model.
- Ran unsteady aeroelastic simulations to compare models with different numbers of modes.
- Ran unsteady aeroelastic simulations to find the critical flutter conditions.

mAEWing1-Hati Meshes



mAEWing1-Hati Mass & Inertia Properties

Property	VirginiaTech NASTRAN Model	CMSoft AERO-S Model	Difference
Weight (lb.)	14.059	14.049	0.07%
Center of Mass Position X (in) Center of Mass Position Y (in) Center of Mass Position Z (in)	7.9475 0.0000 0.0000	8.0812 0.0000 0.0000	1.67%
Moment of Inertia Ixx (lb. in^2) Moment of Inertia Iyy (lb. in^2) Moment of Inertia Izz (lb. in^2)	9,577.9 1,633.1 9,602.9	9,580.6 1,600.0 9,604.6	0.03% 2.05% 0.02%
Product of Inertia Ixy (lb. in^2) Product of Inertia Ixz (lb. in^2) Product of Inertia Iyz (lb. in^2)	3.8 0.0 0.0	0.4 0.0 0.0	–

mAEWing1-Hati Dry Structural Modes

Mode	VirginiaTech Model	CMSoft Model	Difference
7	5.38 Hz	5.37 Hz	0.08%
8	9.47 Hz	9.55 Hz	0.80%
9	12.78 Hz	12.69 Hz	0.70%
10	14.41 Hz	14.47 Hz	0.43%
11	19.35 Hz	19.41 Hz	0.35%
12	27.26 Hz	27.42 Hz	0.57%
13	30.66 Hz	30.19 Hz	1.56%
14	31.65 Hz	31.78 Hz	0.40%
15	38.33 Hz	38.33 Hz	0.01%
16	46.15 Hz	45.89 Hz	0.58%
17	63.37 Hz	63.53 Hz	0.25%
18	66.14 Hz	66.42 Hz	0.41%
19	67.17 Hz	67.43 Hz	0.39%
20	71.45 Hz	70.82 Hz	0.88%

mAEWing1-Hati Dry Structural Modes

Mode	CMSoft Original Model	CMSoft Model with Edited Control Surfaces	Difference
7	5.37 Hz	5.37 Hz	0.00%
8	9.55 Hz	9.55 Hz	0.00%
9	12.69 Hz	12.69 Hz	0.05%
10	14.47 Hz	14.47 Hz	0.04%
11	19.41 Hz	19.41 Hz	0.04%
12	27.42 Hz	27.41 Hz	0.01%
13	30.19 Hz	30.16 Hz	0.10%
14	31.78 Hz	31.77 Hz	0.05%
15	38.33 Hz	38.30 Hz	0.07%
16	45.89 Hz	45.86 Hz	0.06%
17	63.53 Hz	63.38 Hz	0.23%
18	66.42 Hz	66.39 Hz	0.05%
19	67.43 Hz	67.40 Hz	0.05%
20	70.82 Hz	70.63 Hz	0.26%

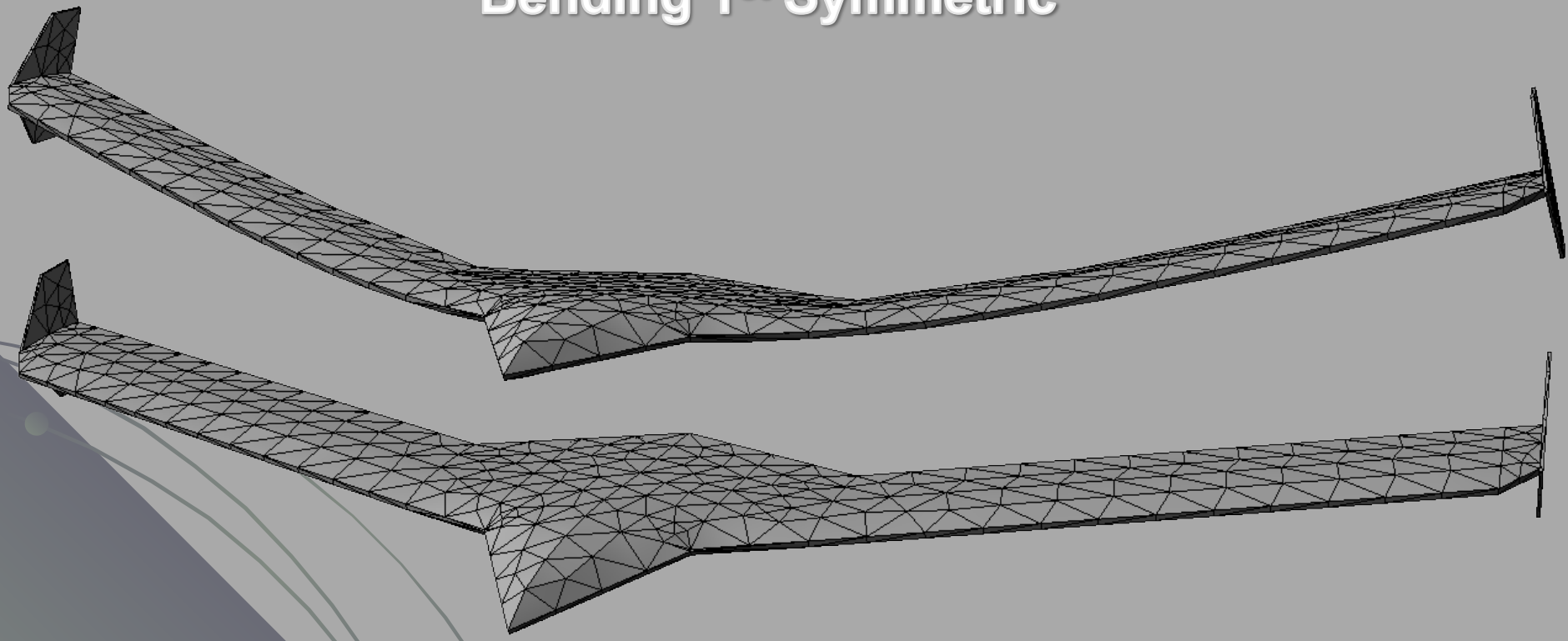
mAEWing1-Hati Dry Structural Modes

Mode	Freq. (Hz)	Description
1−6	0.00	6 Rigid-Body Modes
7	5.37	Bending 1st Symmetric
8	9.55	Bending 1st Anti-Sym.
9	12.69	Torsion 1st Anti-Sym.
10	14.47	Torsion 1st Symmetric
11	19.41	Bending 2nd Symmetric
12	27.42	Bending 2nd Anti-Sym.
13	30.19	Torsion 2nd Anti-Sym.
14	31.78	Torsion 2nd Symmetric
15	38.33	Bending 3rd Symmetric
16	45.89	Bending 3rd Anti-Sym.
18	66.42	Torsion 3rd Anti-Sym.
19	67.43	Torsion 3rd Symmetric

Mode	Freq. (Hz)	Description
27	109.21	+ 1*L3 – 4*L4
32	126.12	+ 1*R3 – 2*R4
36	136.03	+ 4*L3 + 1*L4
37	142.15	+ 1*R3 + 1*R4
43	174.95	+ 1*L2 – 8*R2
44	175.01	+ 8*L2 + 1*R2
48	193.24	+ 1*L1 – 1*R1
49	195.44	+ 1*L1 + 1*R1

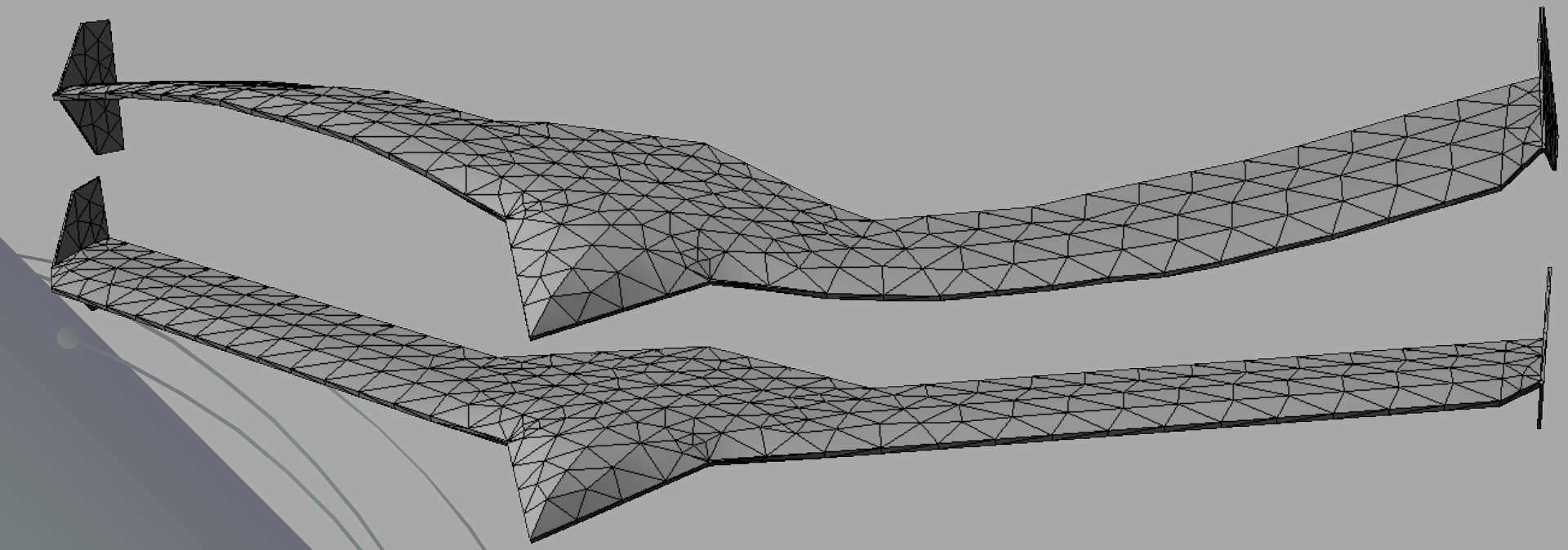
mAEWing1-Hati Dry Structural Modes

Mode 7
5.37 Hz
Bending 1st Symmetric



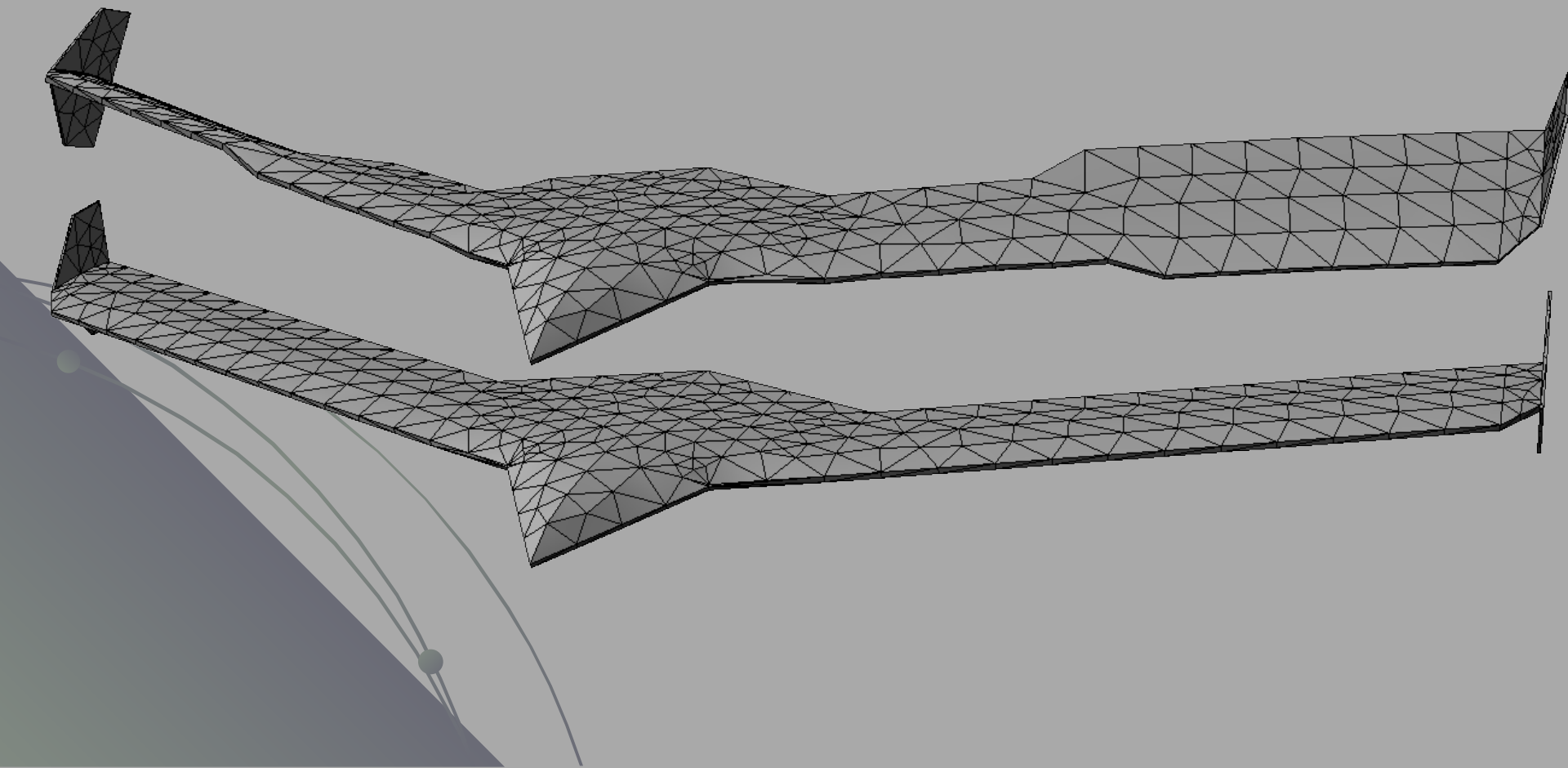
mAEWing1-Hati Dry Structural Modes

Mode 8
9.55 Hz
Bending 1st Anti-Sym.



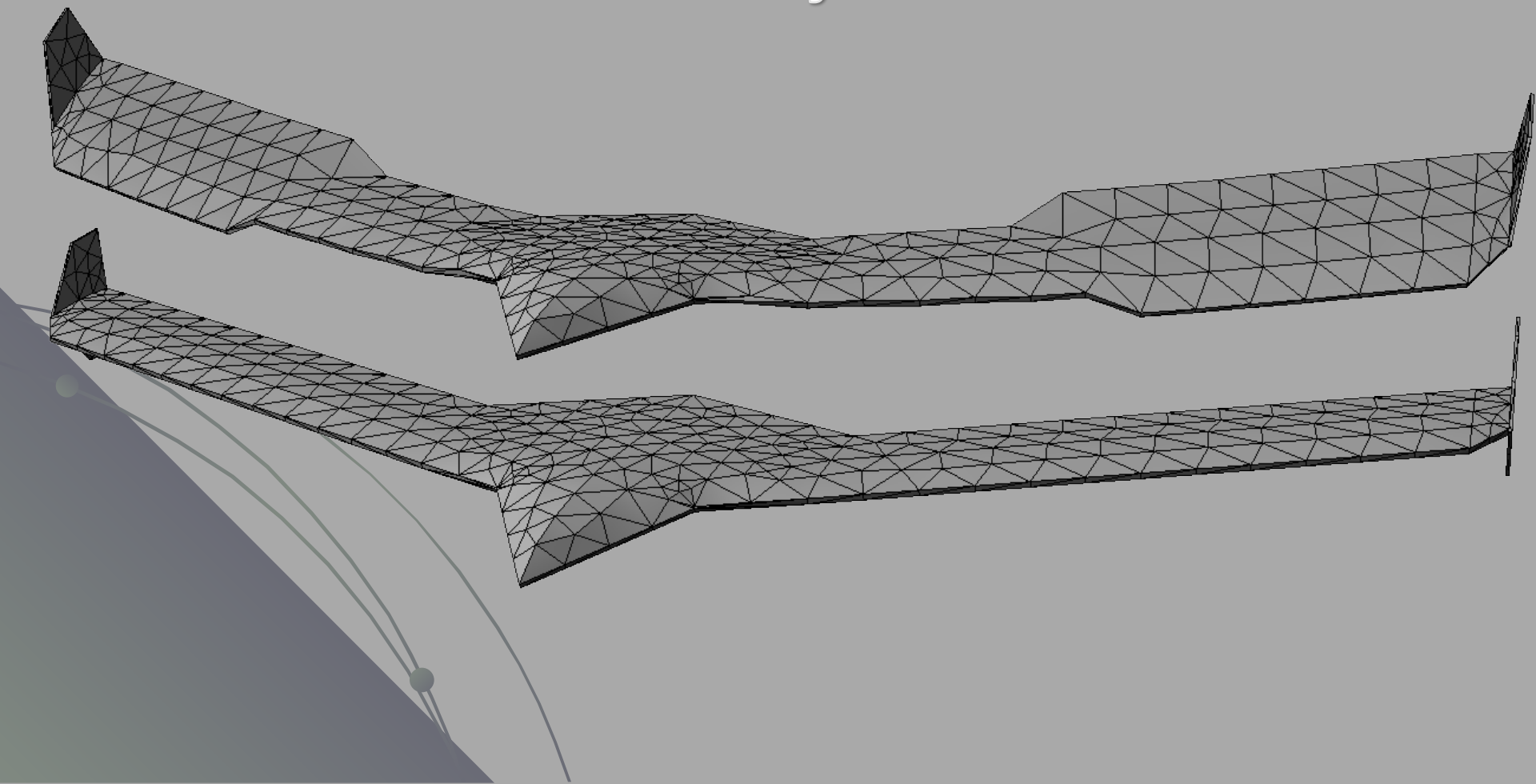
mAEWing1-Hati Dry Structural Modes

Mode 9
12.69 Hz
Torsion 1st Anti-Sym.



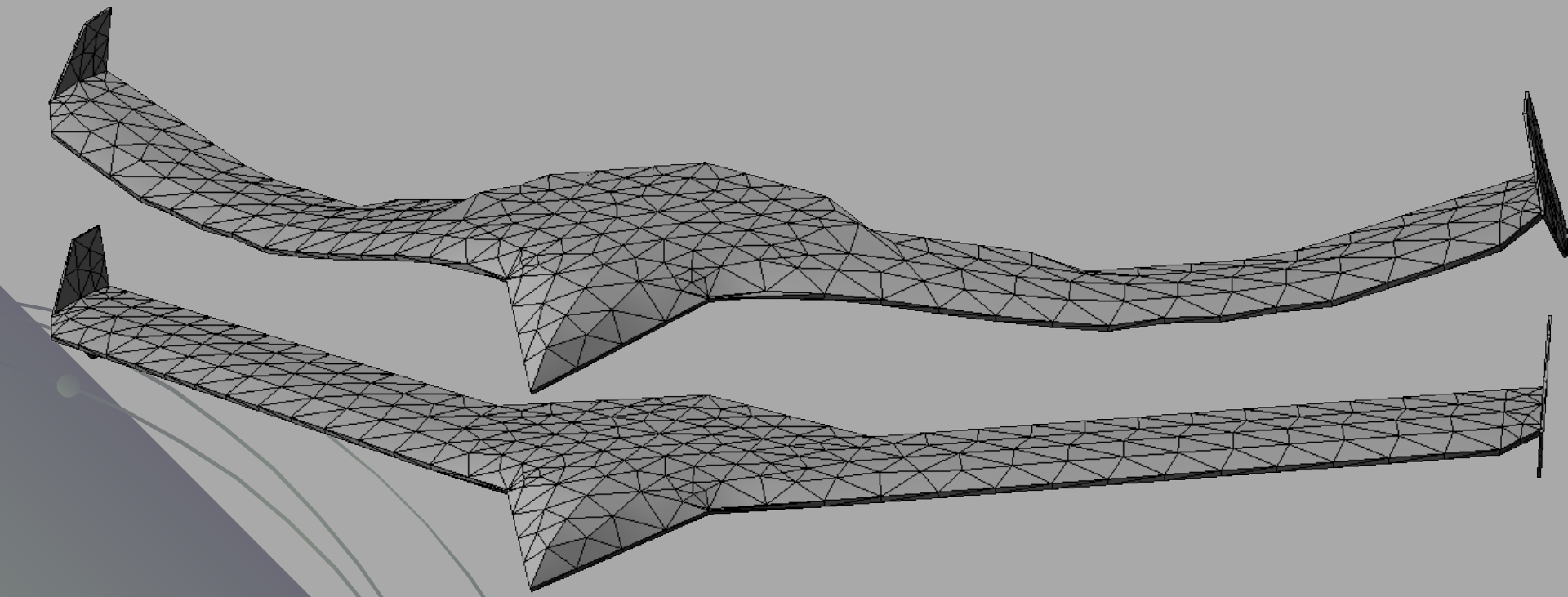
mAEWing1-Hati Dry Structural Modes

Mode 10
14.47 Hz
Torsion 1st Symmetric



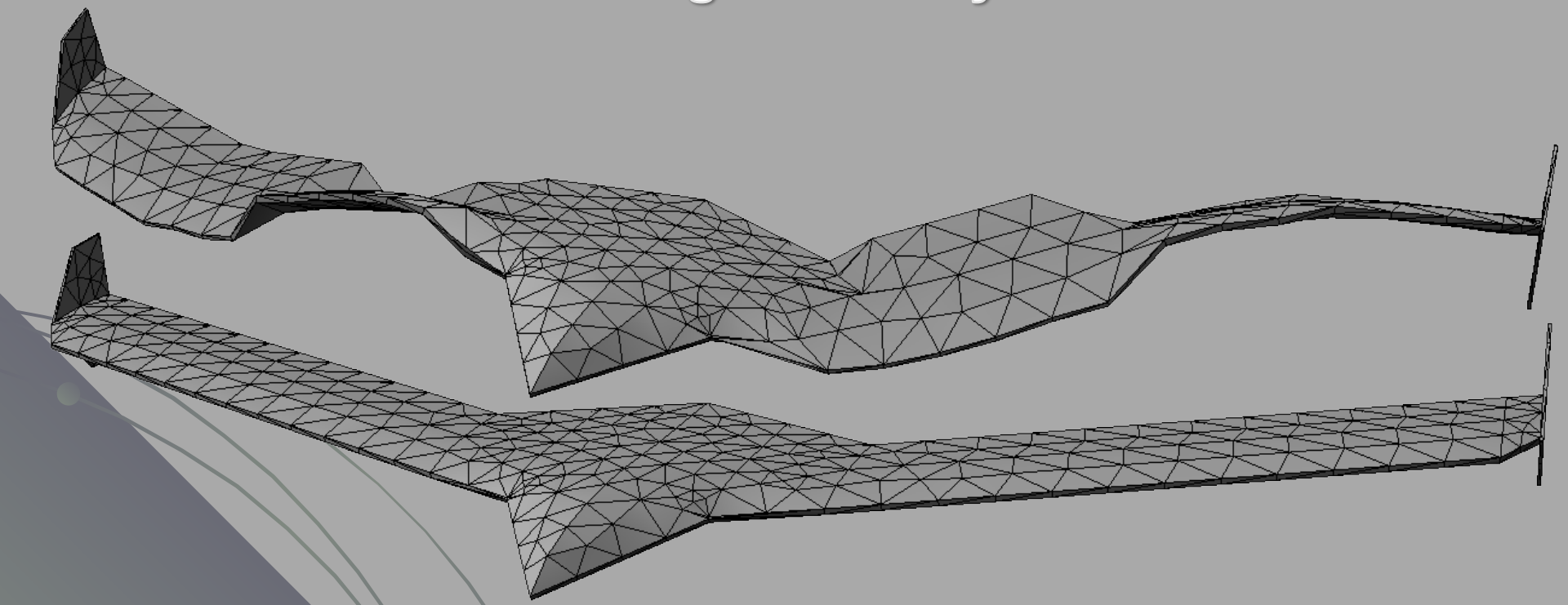
mAEWing1-Hati Dry Structural Modes

Mode 11
19.41 Hz
Bending 2nd Symmetric



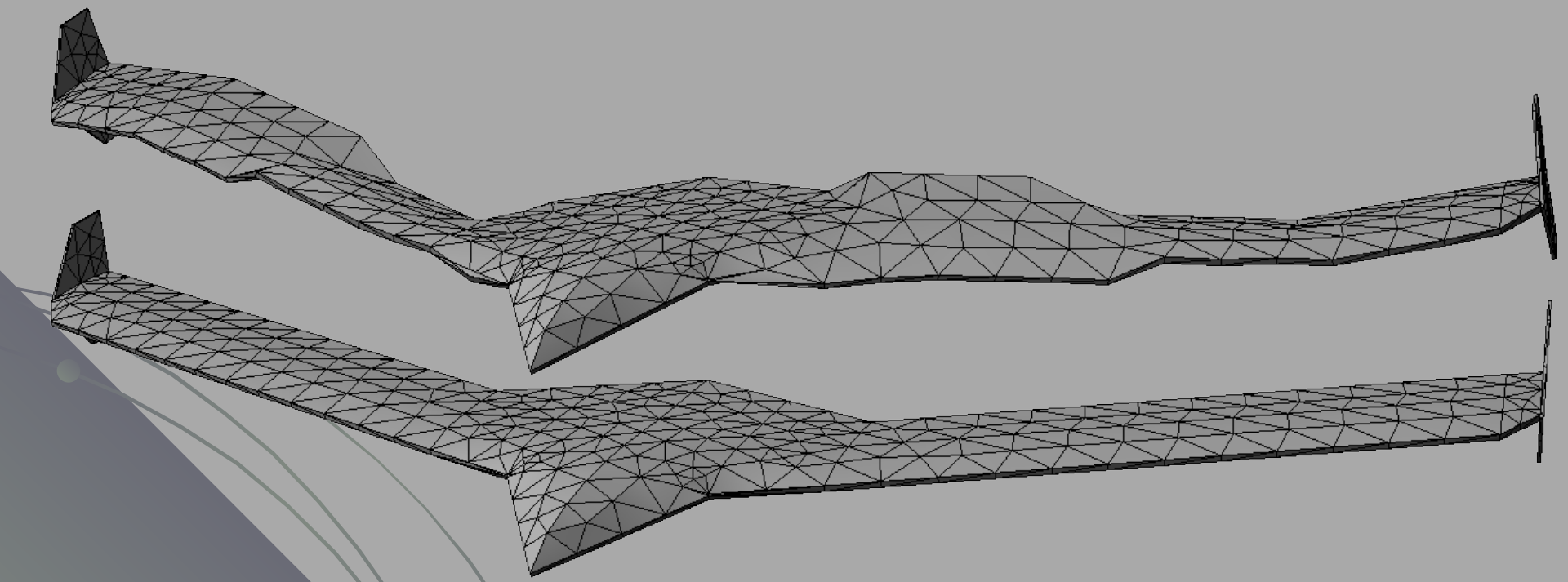
mAEWing1-Hati Dry Structural Modes

Mode 12
27.41 Hz
Bending 2nd Anti-Sym.



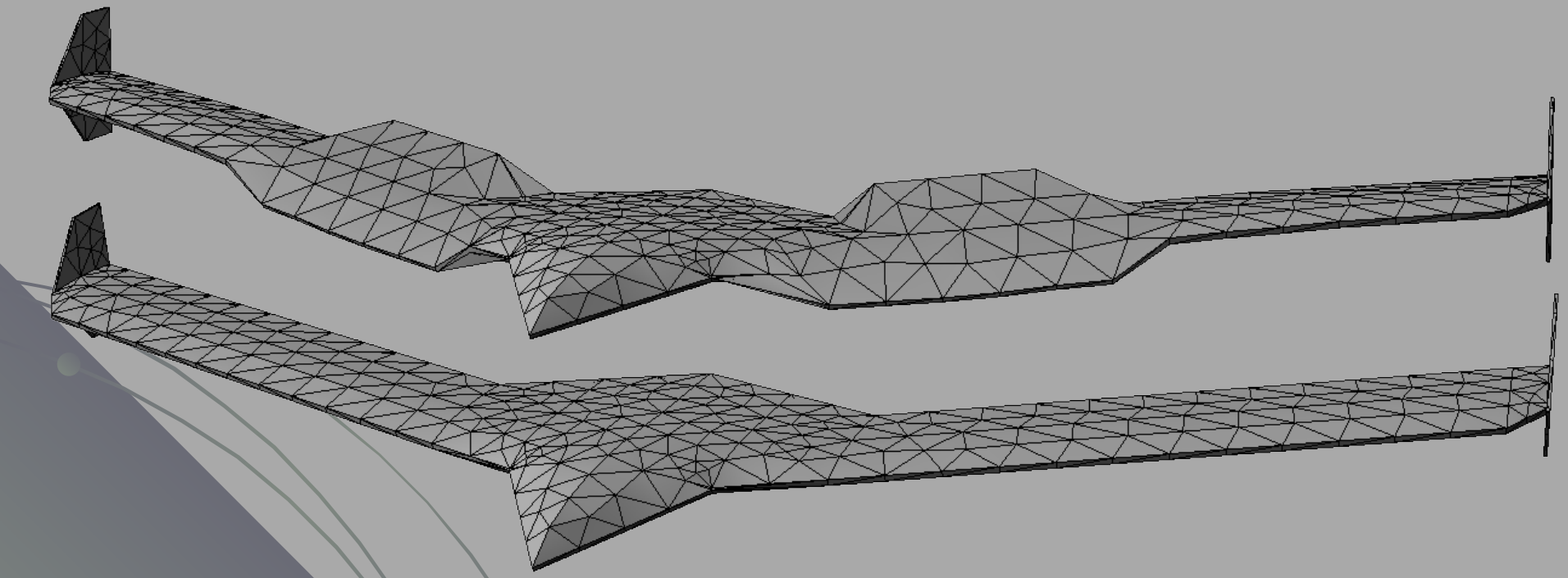
mAEWing1-Hati Dry Structural Modes

Mode 13
30.16 Hz
Torsion 2nd Anti-Sym.



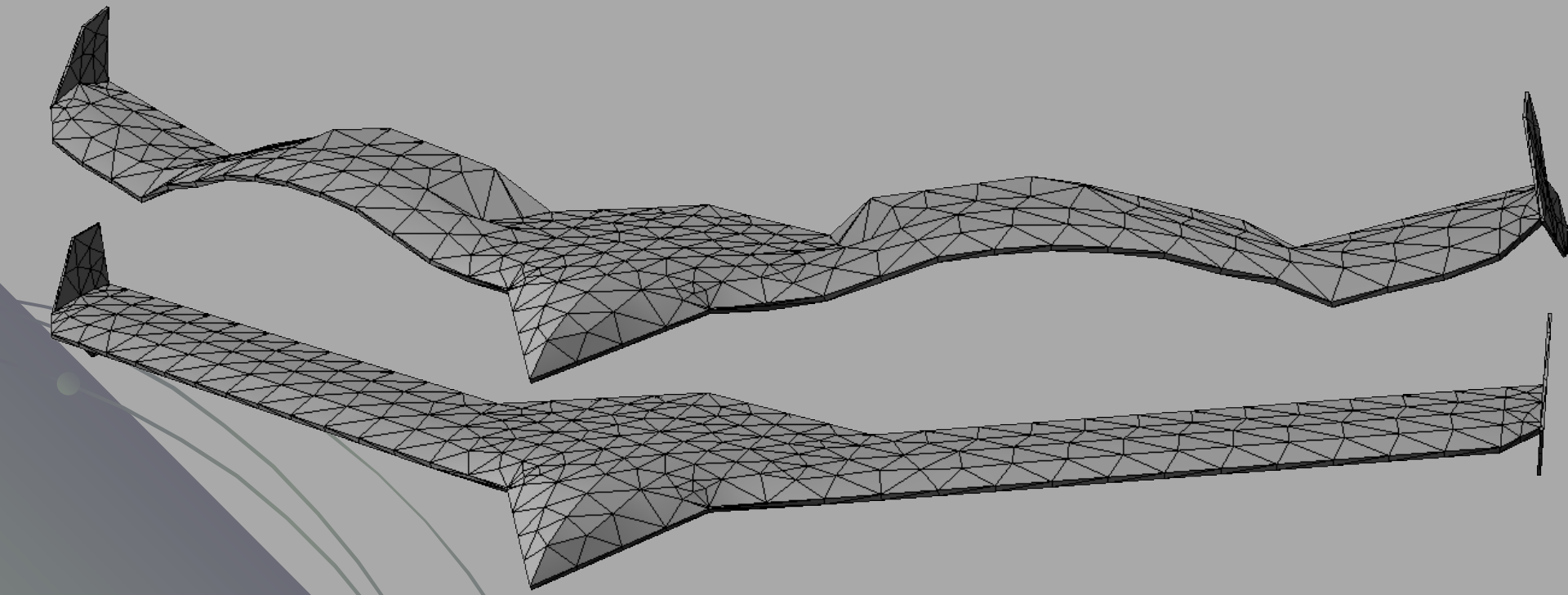
mAEWing1-Hati Dry Structural Modes

Mode 14
31.77 Hz
Torsion 2nd Symmetric



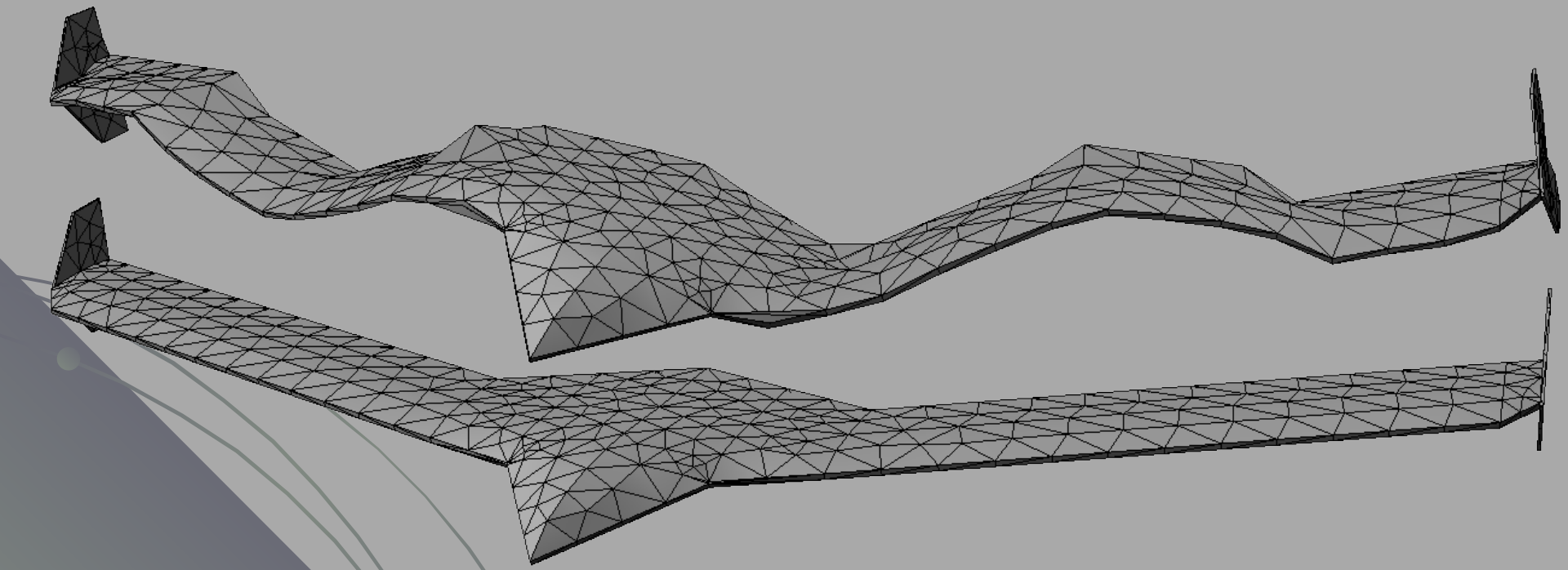
mAEWing1-Hati Dry Structural Modes

Mode 15
38.30 Hz
Bending 3rd Symmetric



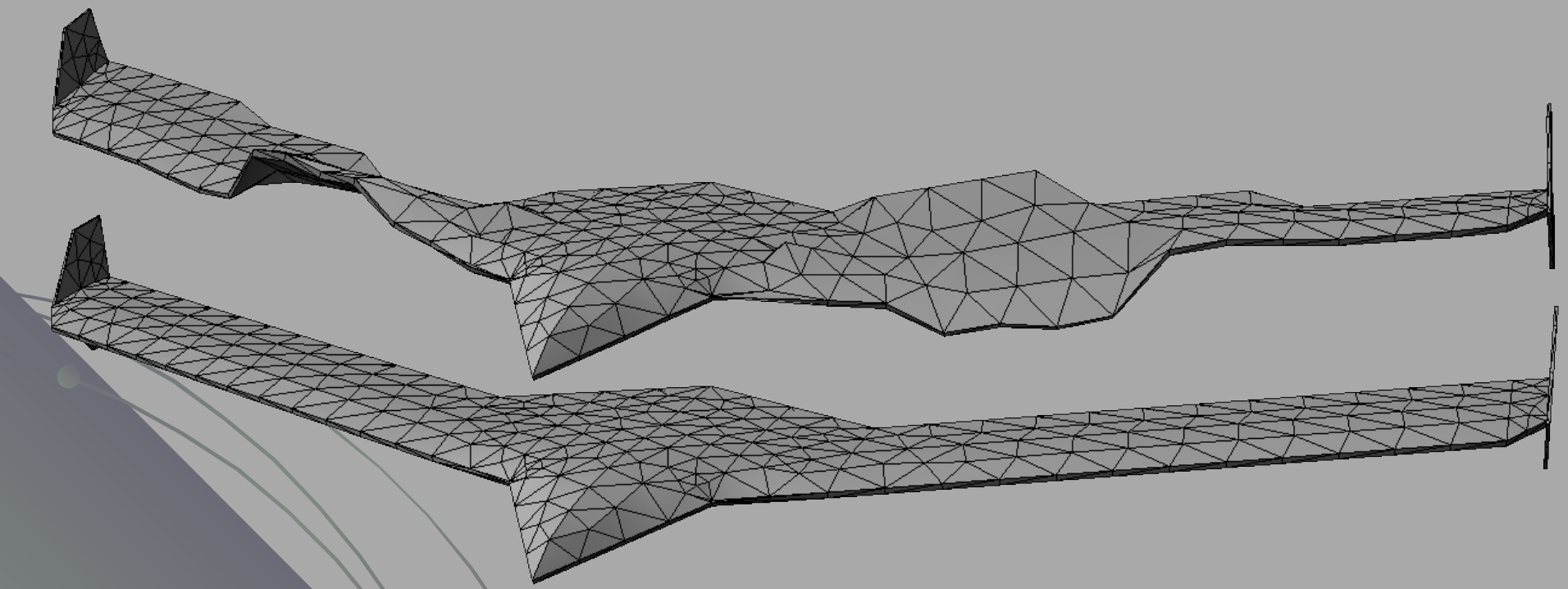
mAEWing1-Hati Dry Structural Modes

Mode 16
45.86 Hz
Bending 3rd Anti-Sym.



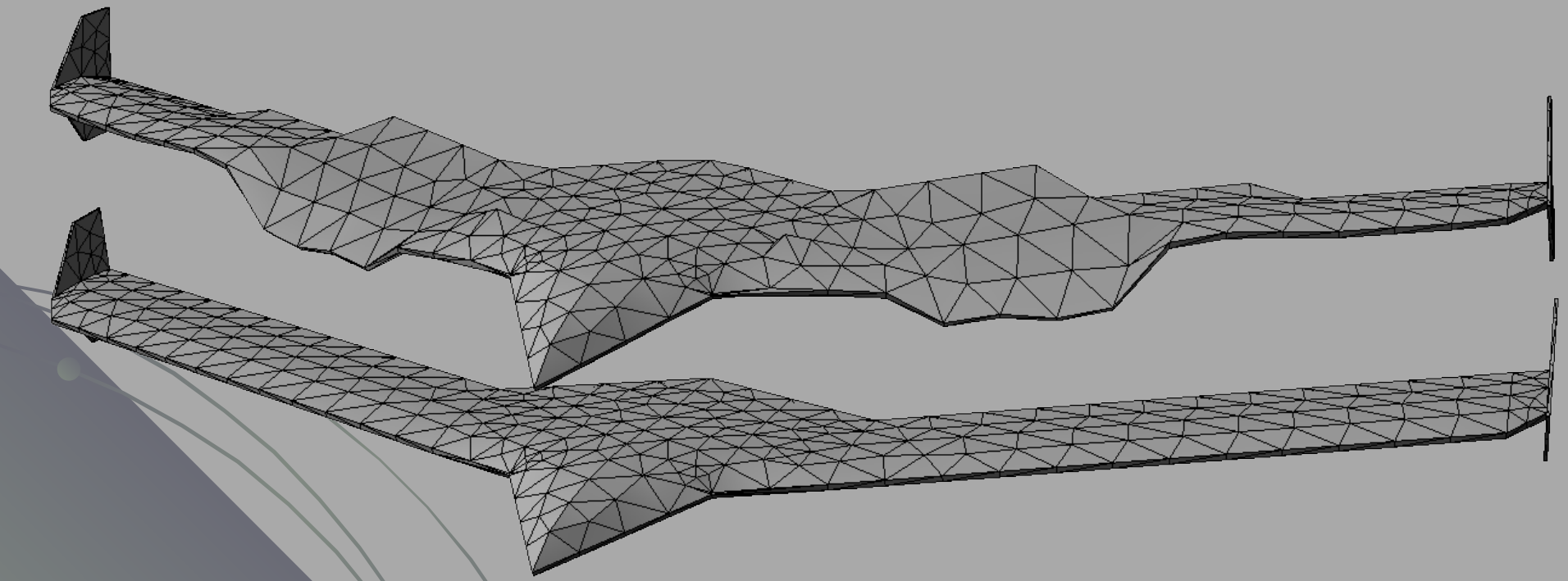
mAEWing1-Hati Dry Structural Modes

Mode 18
66.39 Hz
Torsion 3rd Anti-Sym.



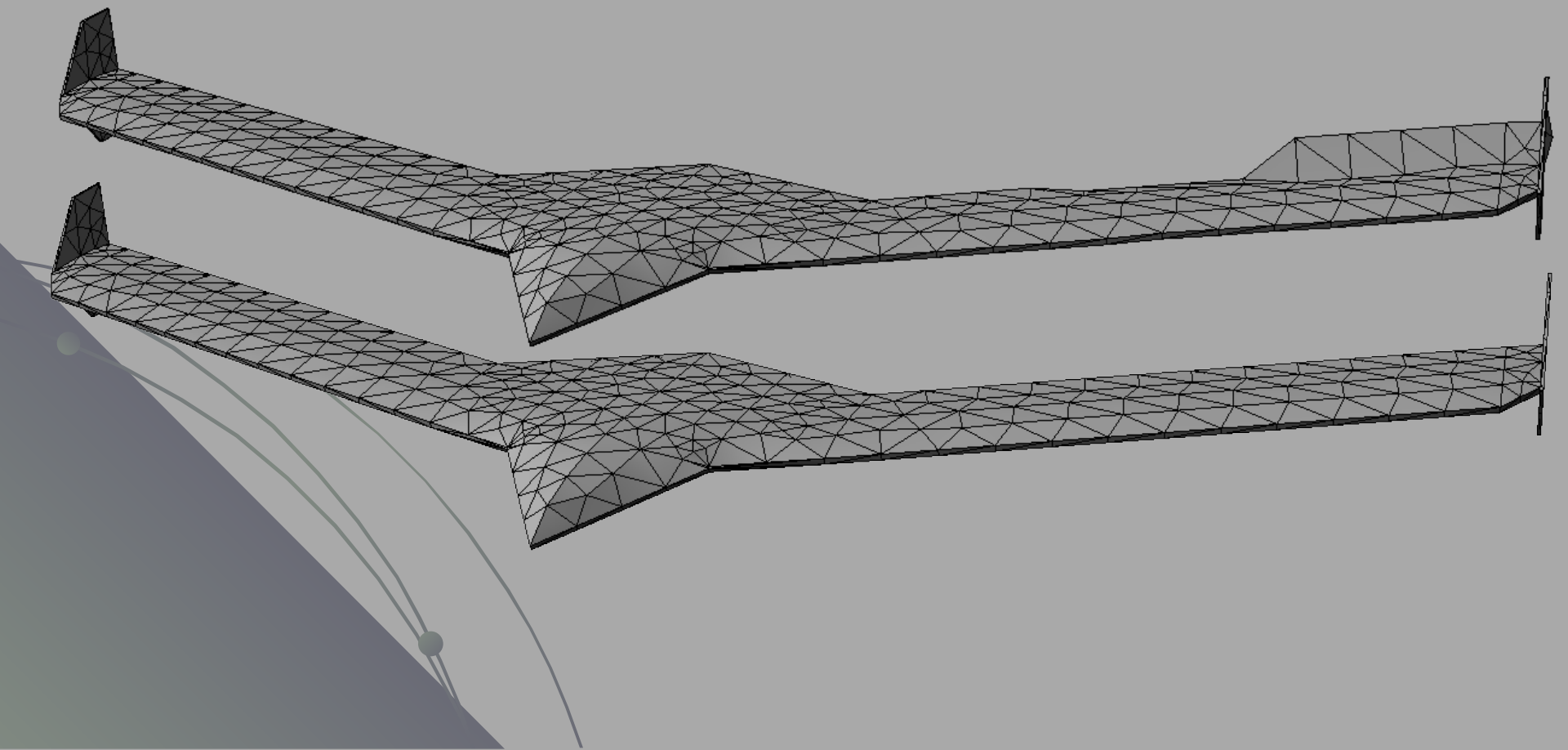
mAEWing1-Hati Dry Structural Modes

Mode 19
67.40 Hz
Torsion 3rd Symmetric



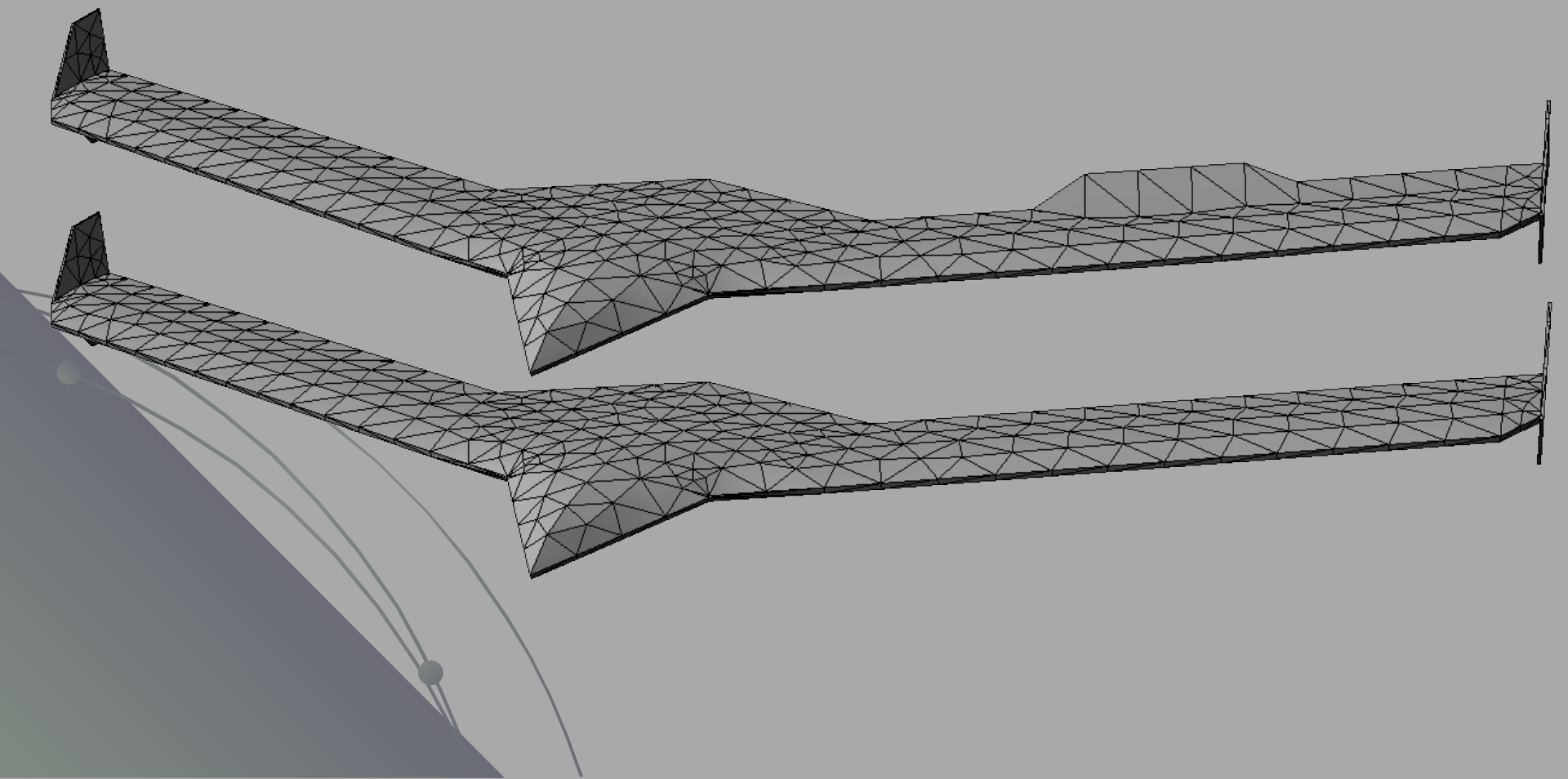
mAEWing1-Hati Dry Structural Modes

Mode 27
109.21 Hz
+ 1*L3 – 4*L4 Control Surfaces



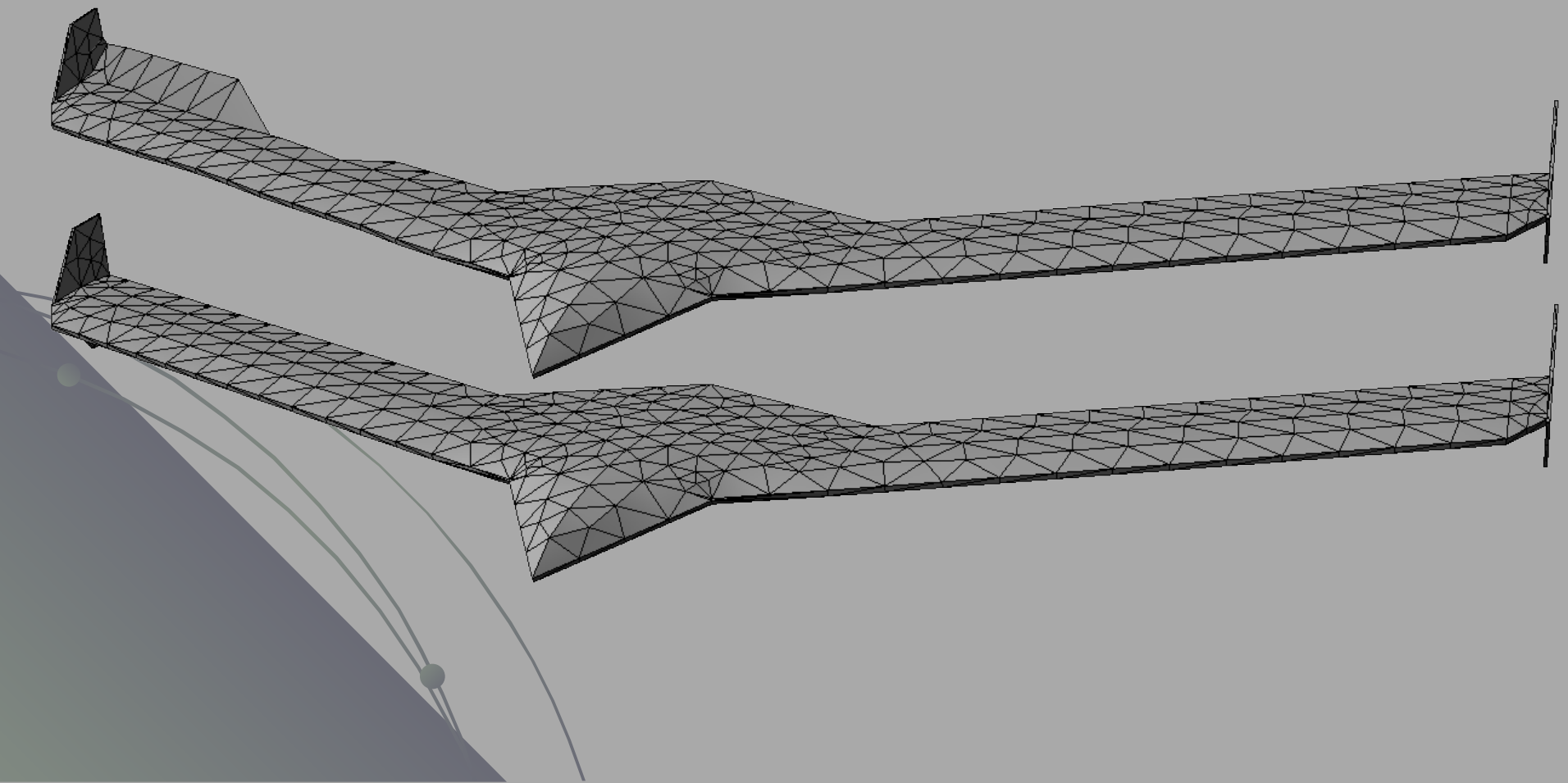
mAEWing1-Hati Dry Structural Modes

Mode 36
136.03 Hz
+ 4*L3 + 1*L4 Control Surfaces



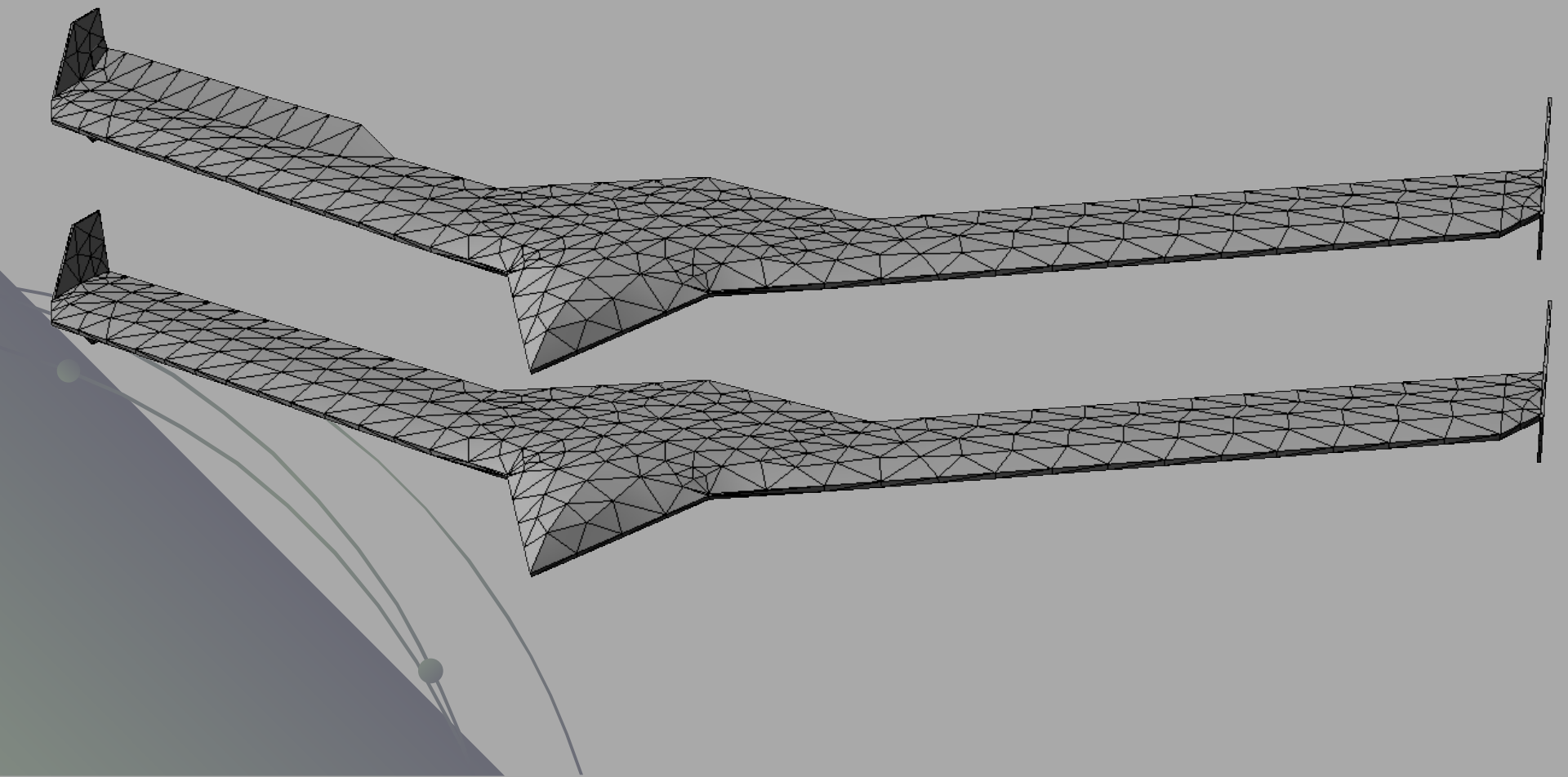
mAEWing1-Hati Dry Structural Modes

Mode 32
126.12 Hz
+ 1*R3 – 2*R4 Control Surfaces



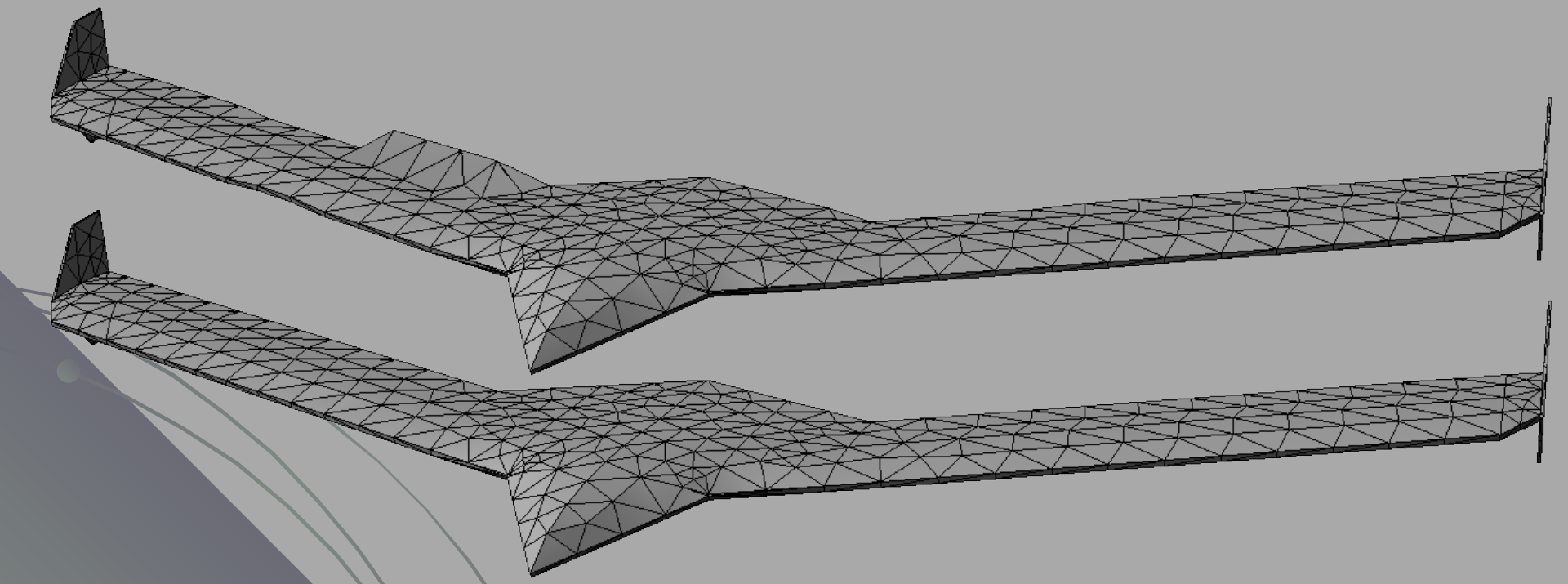
mAEWing1-Hati Dry Structural Modes

Mode 37
142.15 Hz
+ 1*R3 + 1*R4 Control Surfaces



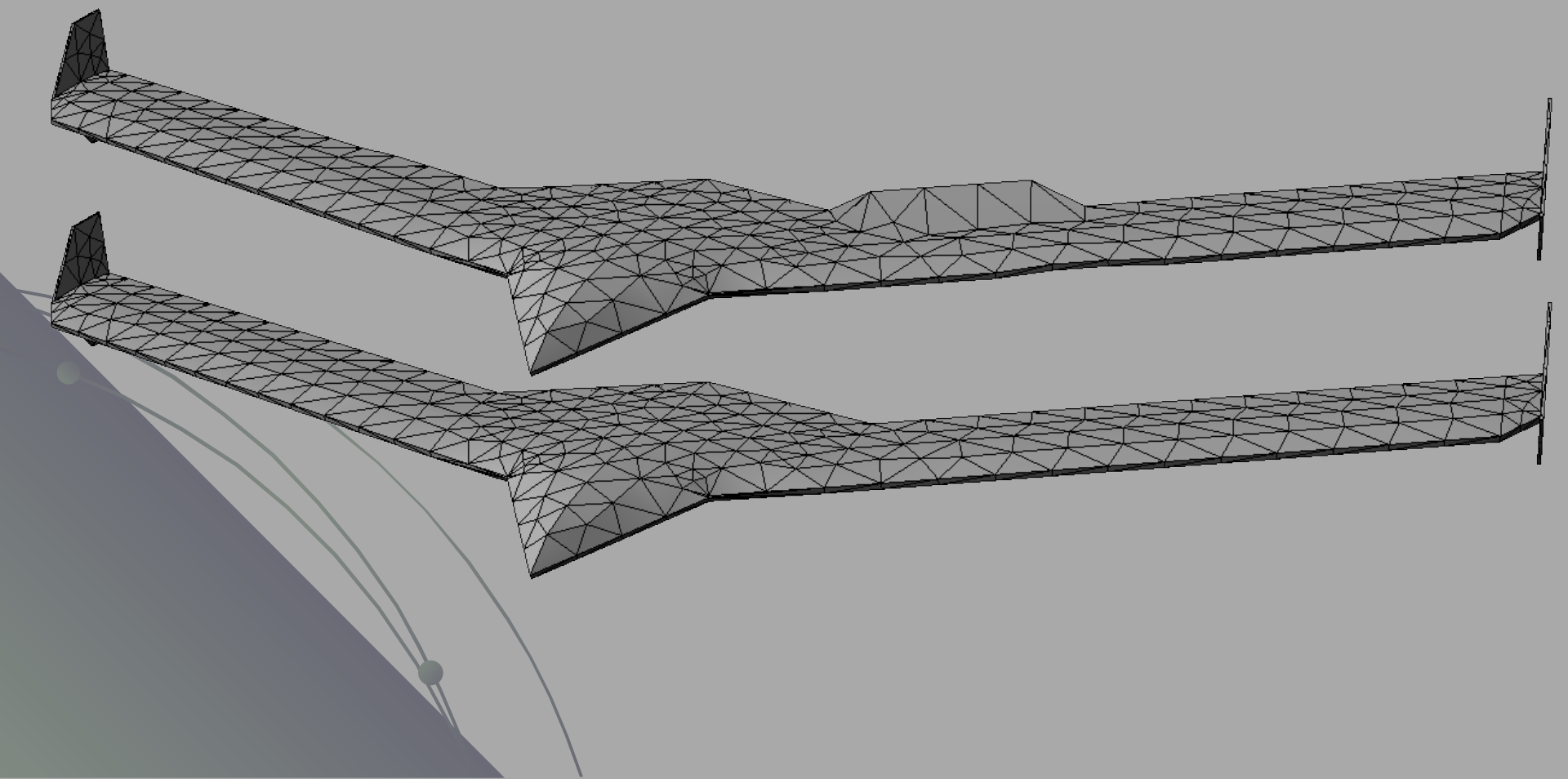
mAEWing1-Hati Dry Structural Modes

Mode 43
174.95 Hz
R2 Control Surface



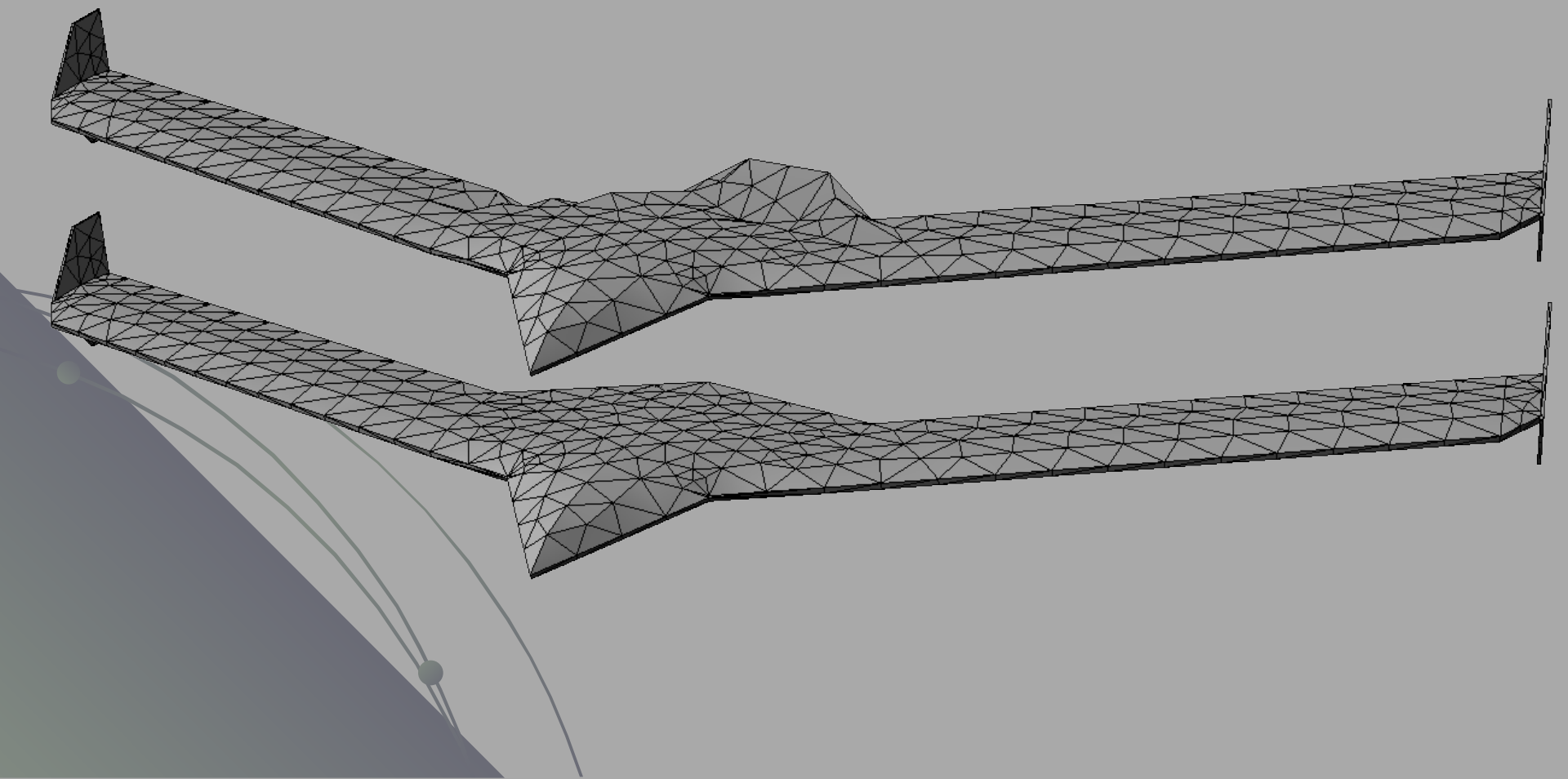
mAEWing1-Hati Dry Structural Modes

Mode 44
175.01 Hz
L2 Control Surface



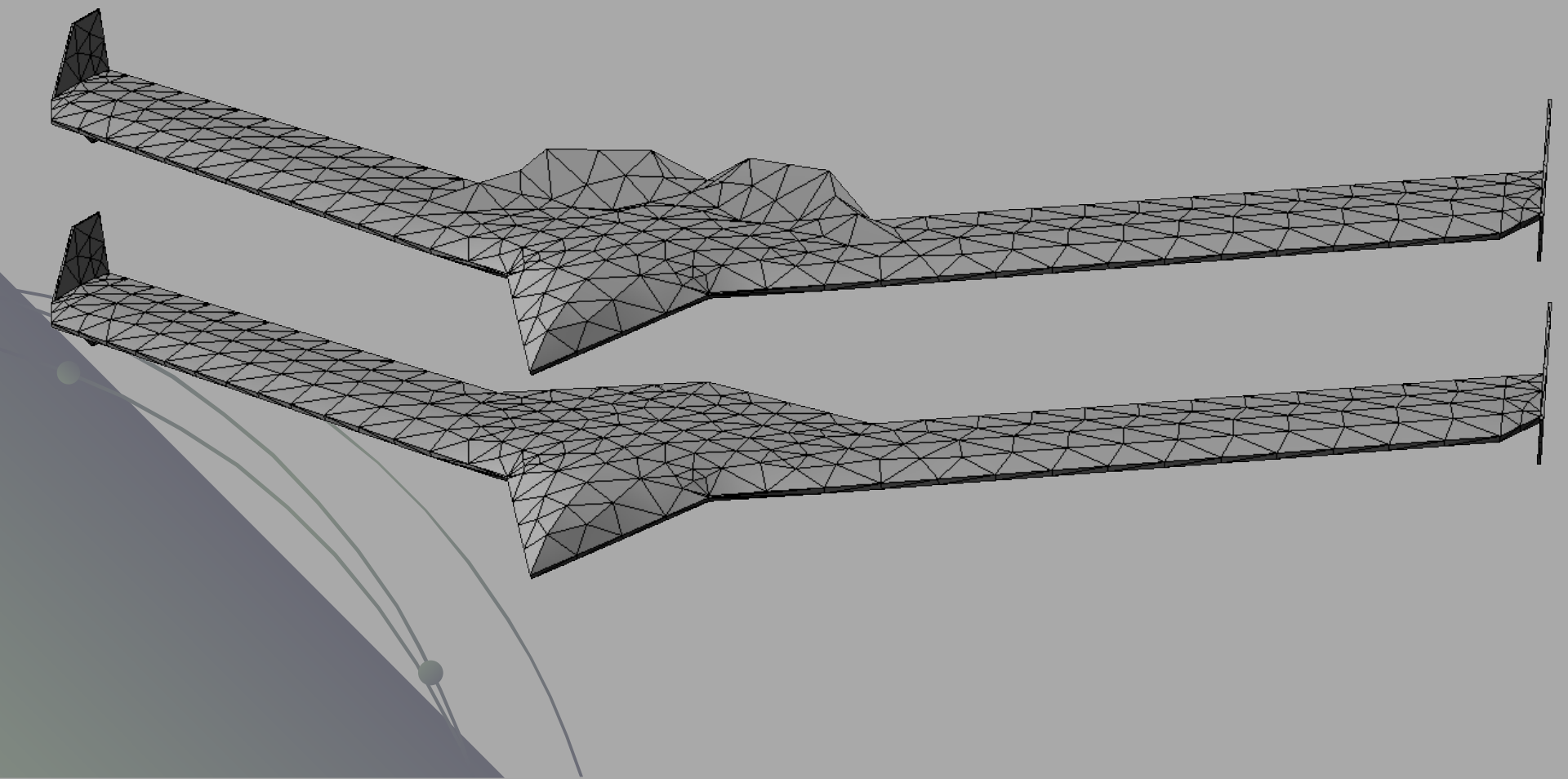
mAEWing1-Hati Dry Structural Modes

Mode 48
193.24 Hz
+ 1*L1 – 1*R1 Control Surfaces



mAEWing1-Hati Dry Structural Modes

Mode 49
195.44 Hz
+ 1*L1 + 1*R1 Control Surfaces



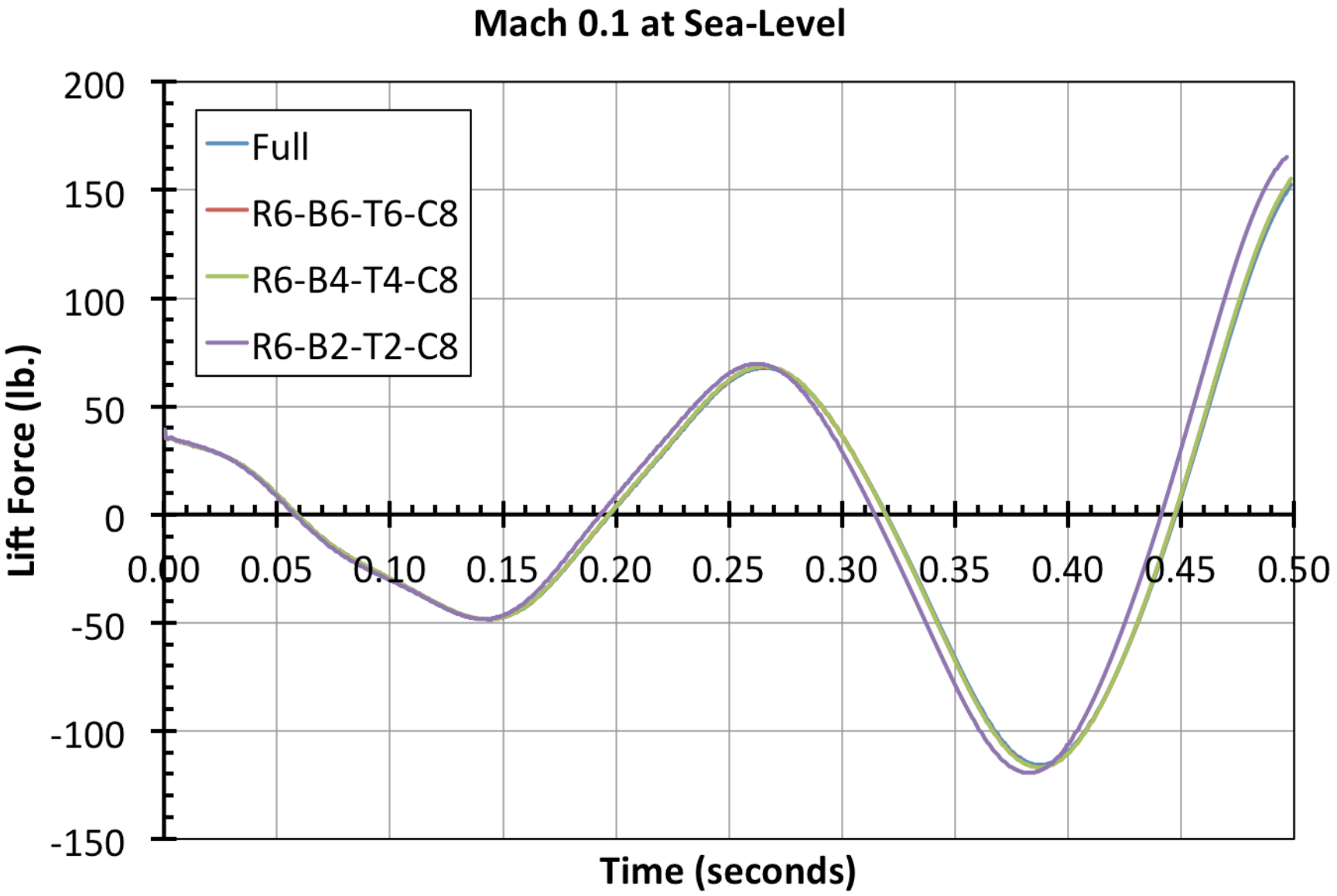
mAEWing1-Hati Modalized Models

Parameter	Value
Equations	Inviscid (Euler) fluid equations; linear structure
Fluid Problem Size	360,000 nodes in total, including 38,000 nodes on aircraft surface
Structure Problem Size	Full Model: 126 nodes Modalized Models: 6 rigid-body modes + 4, 8, and 12 flexible modes + 8 control surface deflection modes
Order	2^{nd} order in space, 2^{nd} order in time
Time Step	Time Step: 0.0005 seconds Total Time: 0.5 seconds Number of Time Steps: 1,000
Flight Conditions	Mach 0.1 at sea-level, which gives: Speed: 34.03 m/s, 111.64 ft./s, 66.14 kt. Pressure: 14.696 psi Density: 1.376×10^{-6} slug/in^3
Initial Conditions	Structure deformed about its first flexible mode.
Solvers	Implicit for both structure (modal) and fluid

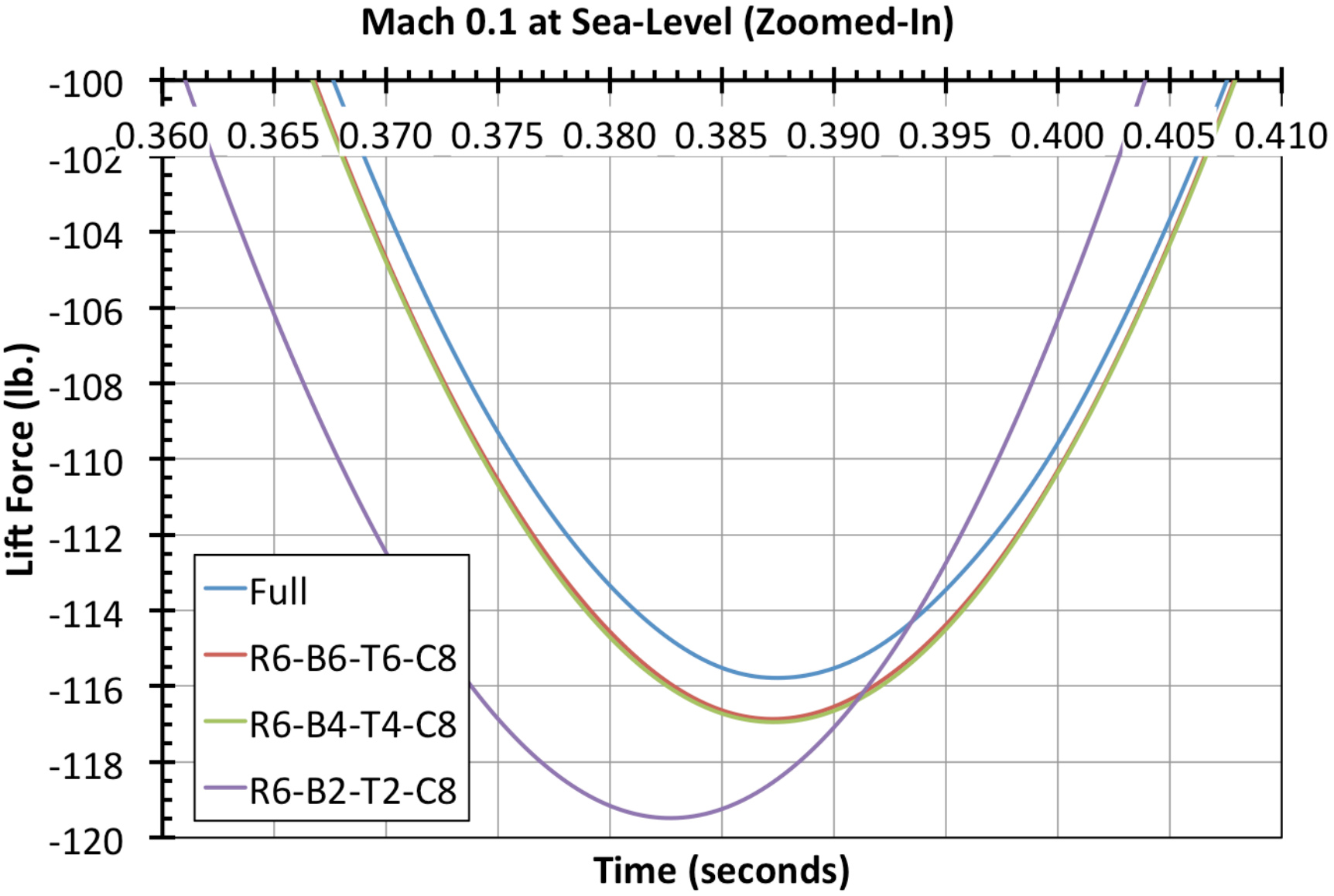
mAEWing1-Hati Modalized Models

- The full structural model is compared to 3 modalized structural models:
- Modalized Model 1:
  - 6 rigid-body modes, 2 bending modes, 2 torsion modes, and 8 control surface modes, for a total of 18 modes.
- Modalized Model 2:
  - 6 rigid-body modes, 4 bending modes, 4 torsion modes, and 8 control surface modes, for a total of 22 modes.
- Modalized Model 3:
  - 6 rigid-body modes, 6 bending modes, 6 torsion modes, and 8 control surface modes, for a total of 26 modes.
- These models are abbreviated as R6-B2-T2-C8, R6-B4-T4-C8 and R6-B6-T6-C8.

mAEWing1-Hati Modalized Models



mAEWing1-Hati Modalized Models



mAEWing1-Hati Aeroelastic Frequency

Model	1st Aeroelastic Mode Frequency (Hz)	1st Aeroelastic Mode Damping Ratio	Frequency Difference with Full Model	Damping Ratio Difference with Full Model
Full	4.3012	−0.2921	–	–
R6-B6-T6-C8	4.3091	−0.3003	0.18%	0.40%
R6-B4-T4-C8	4.2915	−0.3020	0.22%	0.97%
R6-B2-T2-C8	4.1901	−0.3162	2.58%	5.72%

- **The R6-B4-T4-C8 modalized structural model is a good compromise and is used to perform future unsteady aeroelastic simulations to determine the flutter conditions.**

mAEWing1-Hati Flutter Conditions

Parameter	Value
Equations	Inviscid (Euler) fluid equations; linear structure
Fluid Problem Size	360,000 nodes in total, including 38,000 nodes on aircraft surface
Structure Problem Size	Modalized Model: R6-B4-T4-C8 6 rigid-body modes + 8 flexible modes + 8 control surface deflection modes
Order	2^{nd} order in space, 2^{nd} order in time
Time Step	Time Step: 0.001 seconds Total Time: 3 seconds Number of Time Steps: 3,000
Flight Conditions	Mach Numbers: { 0.08 , 0.09 , 0.10 , 0.11 } Altitudes: { 0 , 1,000 , 3,000 , 6,000 } ft.
Initial Conditions	Structure deformed about its first flexible mode
Solvers	Implicit for both structure (modal) and fluid

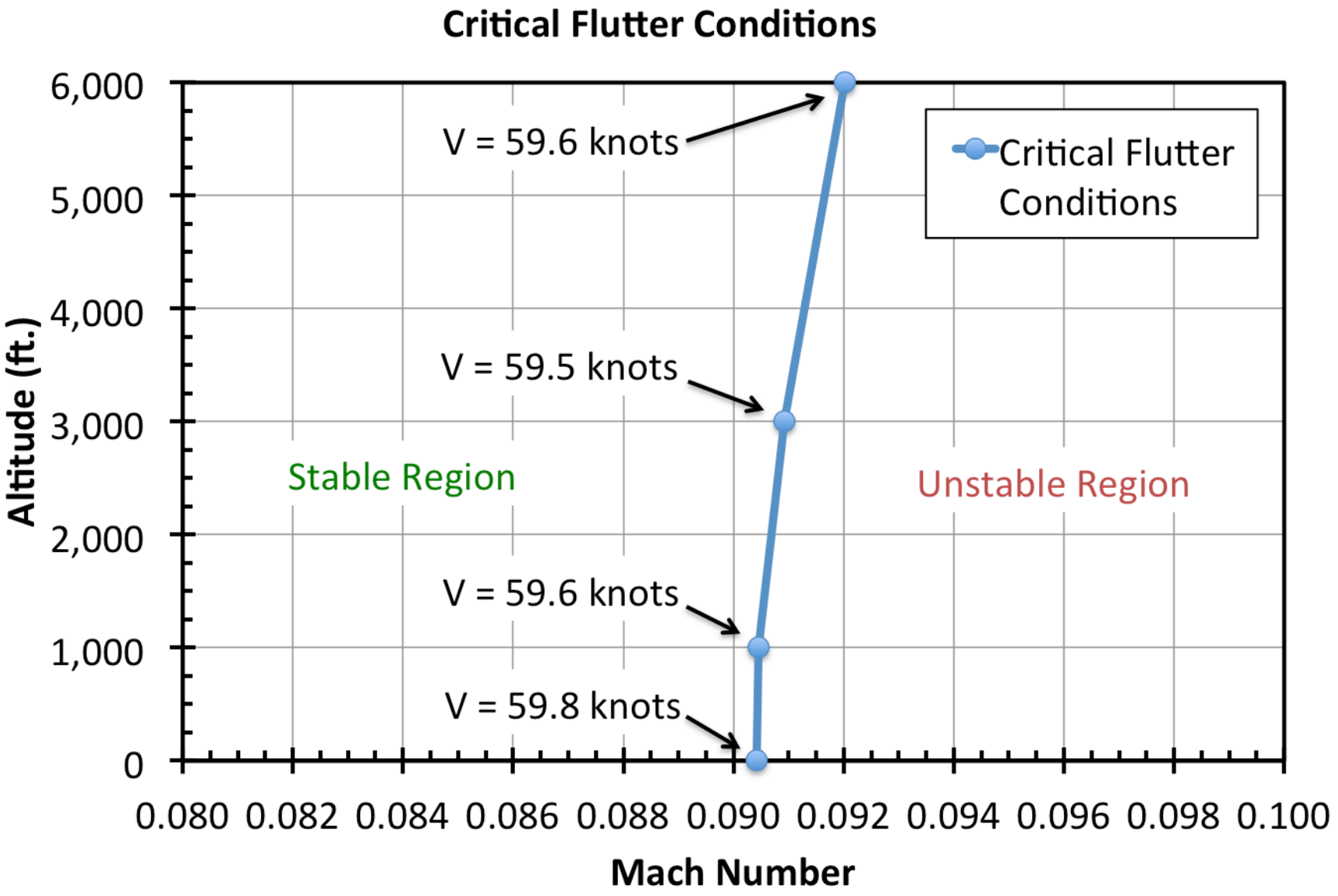
mAEWing1-Hati Aeroelastic Frequency

- After running the lift-time history data through an eigensystem realization algorithm, the following aeroelastic damping ratios are obtained:

Aeroelastic Damping Ratios	Ma = 0.08	Ma = 0.09	Ma = 0.10	Ma = 0.11
Altitude = 6,000 ft.	0.142	0.030	−0.119	−0.148
Altitude = 3,000 ft.	0.089	0.017	−0.166	−0.287
Altitude = 1,000 ft.	0.056	0.015	−0.302	−0.350
Altitude = 0 ft.	0.045	0.014	−0.314	−0.452

- Linear interpolation is used between the Mach 0.09 and Mach 0.10 results to find the critical flutter points (where the damping ratio is 0).

mAEWing1-Hati Modalized Models



Conclusions & Questions

- **Based on the results of the unsteady aeroelastic simulations with the inviscid full-order fluid model and the 22-mode modalized structural model, we can conclude:**
  - **mAEWing1-Hati becomes unstable at an airspeed of 59−60 knots.**
  - **This critical speed is essentially independent of altitude and corresponds to a Mach number of 0.0905 at altitudes of 0−1,000 ft.**

- **Contact Information:**

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