Vibration & System ID

E80 Spring 2014

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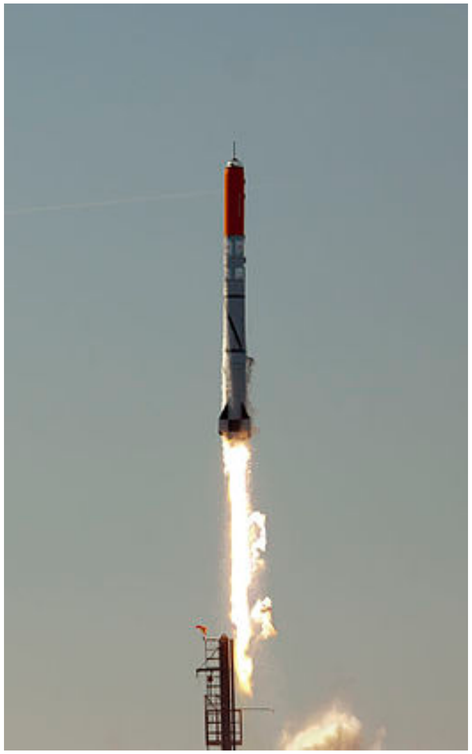
Lecture Outline

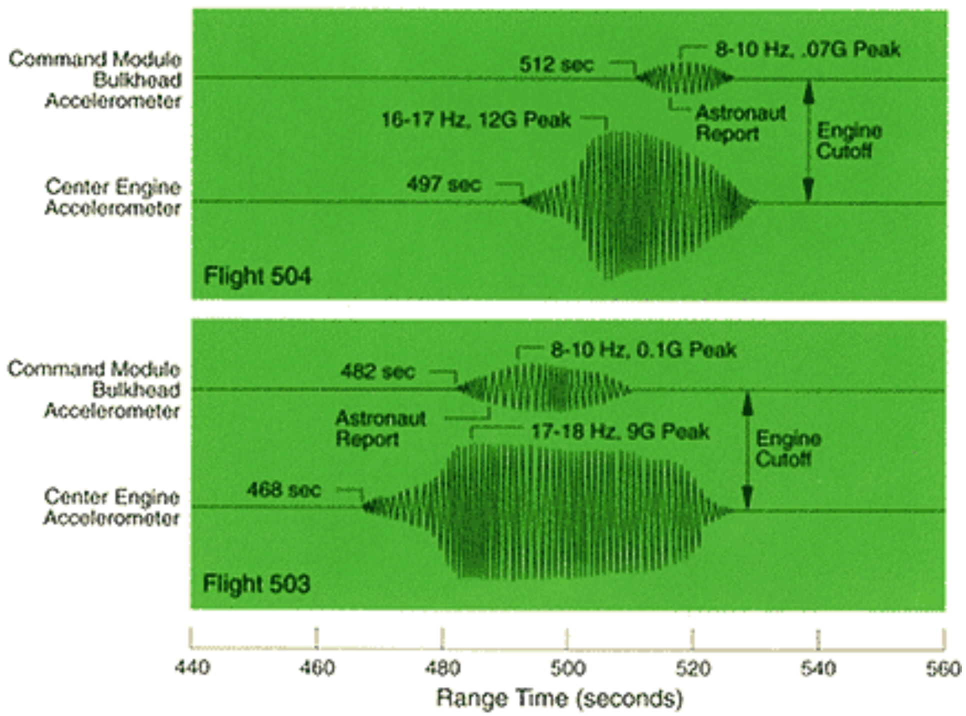
- Why
- How
  - Model
  - SMD Model
  - Vibration Sensors
  - Accelerometers
  - Tap Test
  - PSD

Rocket Vibration

- http://www.youtube.com/watch?v=-rASHRBo9Rg&feature=player_embedded
- **HEAT1X-Tycho Brahe inaugural flight / Pilot's POV – 9Hz oscillation**



Saturn Rocket Vibration



"Pain was directly associated with motion of the eyeballs and testicles, as well as from internal heating that resulted from sloshing of the brain and viscera. The vibration frequency was also in the range of normal brain waves, adding confusion to decision making, hand and arm movement, and even speech." –Jim Fenwick on Pogo oscillations

http://www.pwrengineering.com/articles/pogo.htm

Space Shuttle Main Engine Turbopumps

"The high-pressure pumps rotated at speeds reaching 36,000 rpm on the fuel side and 24,000 rpm on the oxidizer side. At these speeds, minor faults were exacerbated and could rapidly propagate to catastrophic engine failure."

"…the vibration spectral data contained potential failure indicators in the form of discrete rotordynamic spectral signatures. These signatures were prime indicators of turbomachinery health…"

"Wings in Orbit" edited by Wayne Hale and Helen Lane

March 2012

"While the lower stages of the North Korean rocket continued to function for several minutes, resonance at the top of the launch vehicle resulted in '**catastrophic disassembly** of the third stage at Max Q,' said Charles Vick, senior technical and space policy analyst at GlobalSecurity.org. 'The vibrations just tore it apart.'"

http://www.nytimes.com/2012/04/13/world/asia/north-korea-launches-rocket-defying-world-warnings.html?pagewanted=all&_r=0

http://www.eetimes.com/electronics-news/4370955/Severe-vibrations-likely-brought-down-N--Korean-rocket

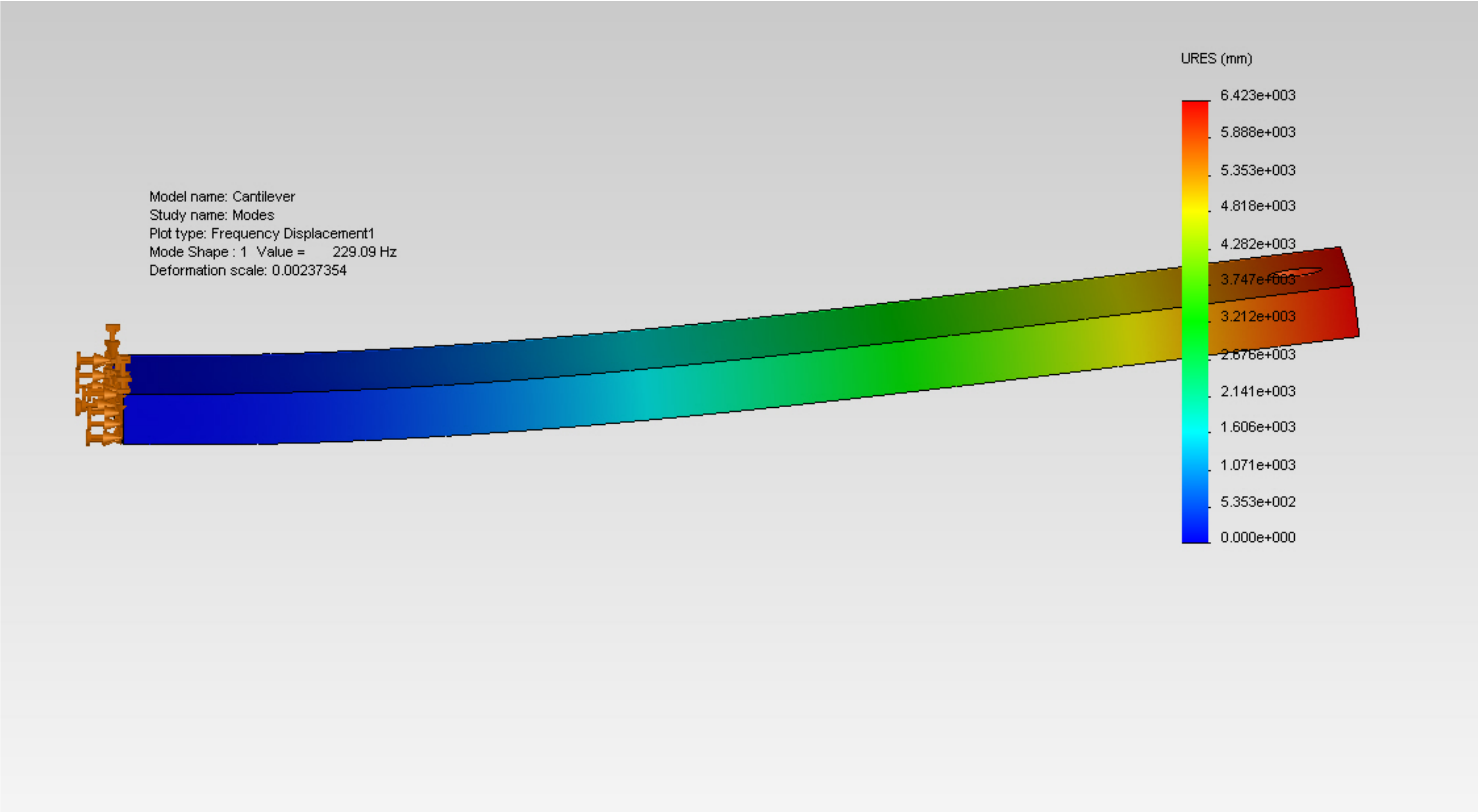
Model

- Continuum Model
  - Analytical <http://iitg.vlab.co.in/?sub=62&brch=175&sim=1080&cnt=1>
  - Finite Element (SolidWorks Simulation)
- SMD Model
  - Stiffness
  - Equivalent mass
  - Damping

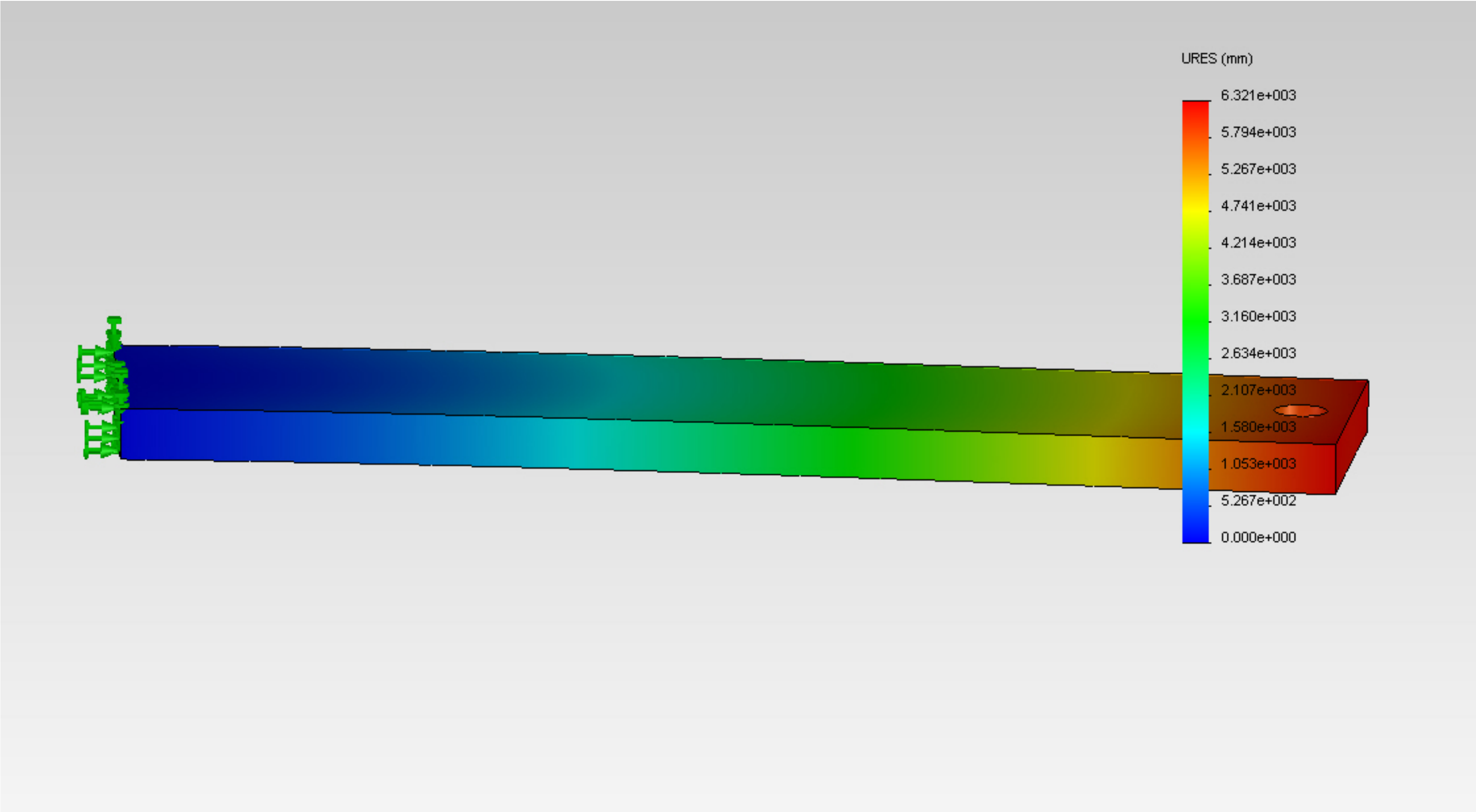
Finite Element Model

- SolidWorks Simulation

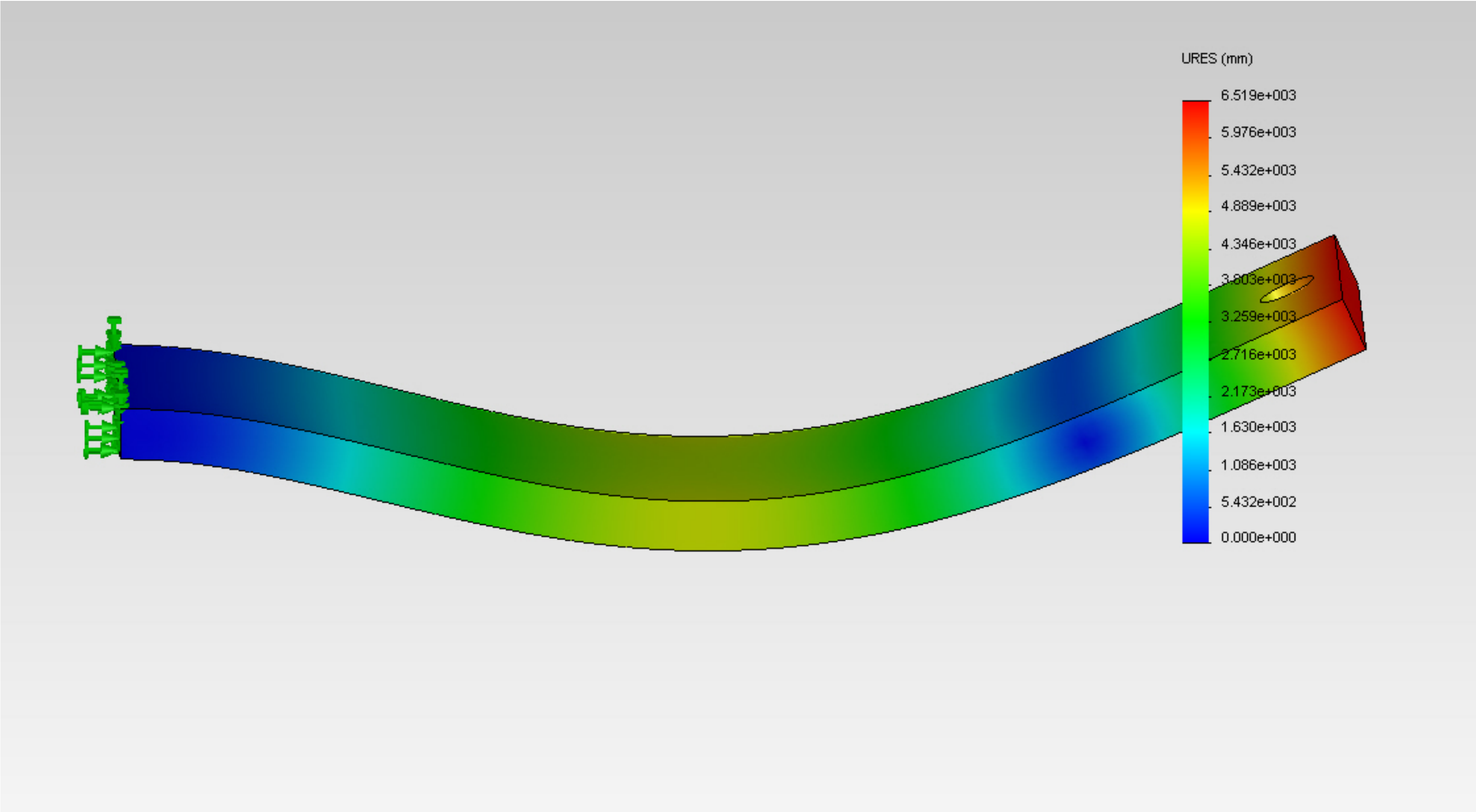
Mode 1 – 229.09 Hz



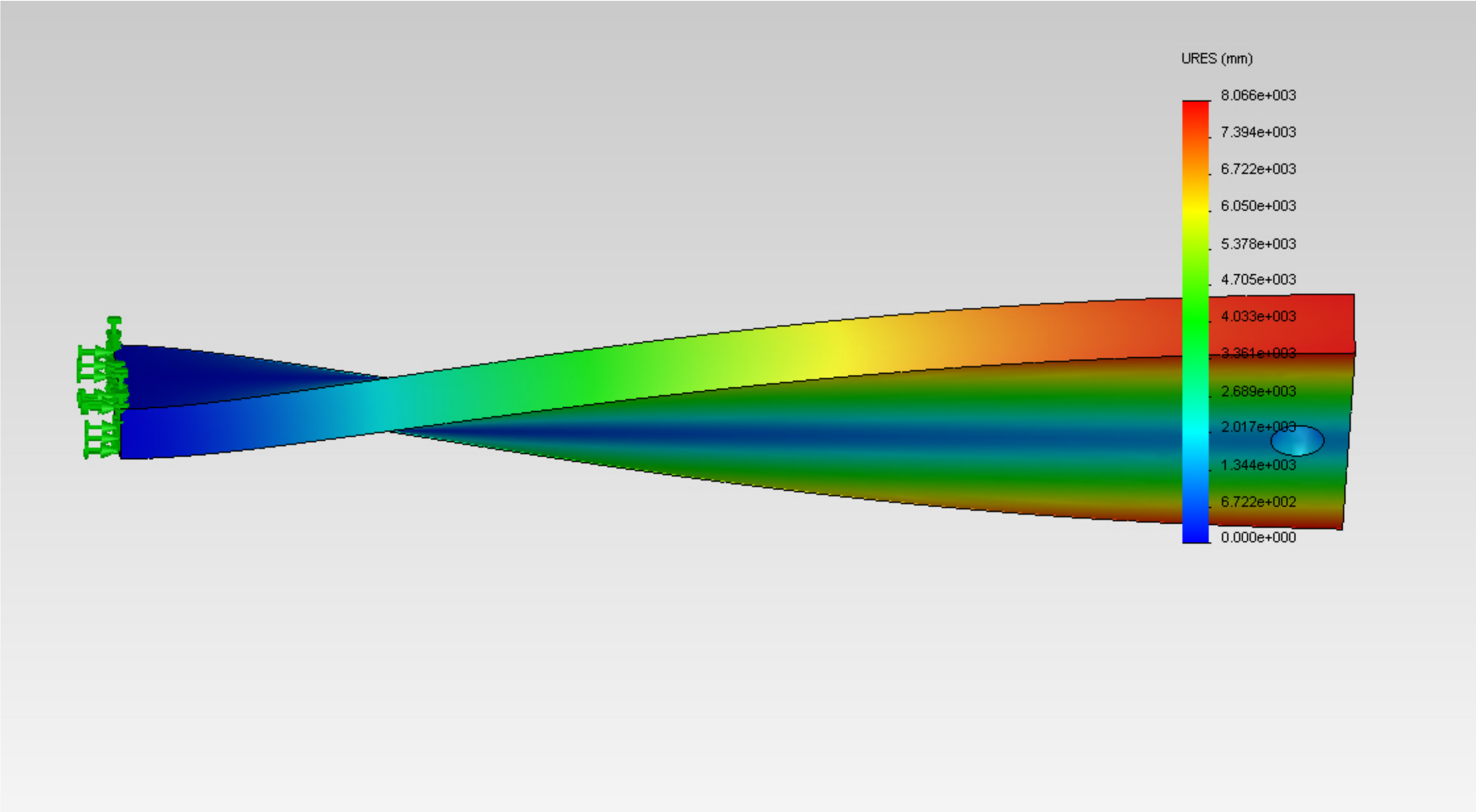
Mode 2 – 1297.9 Hz



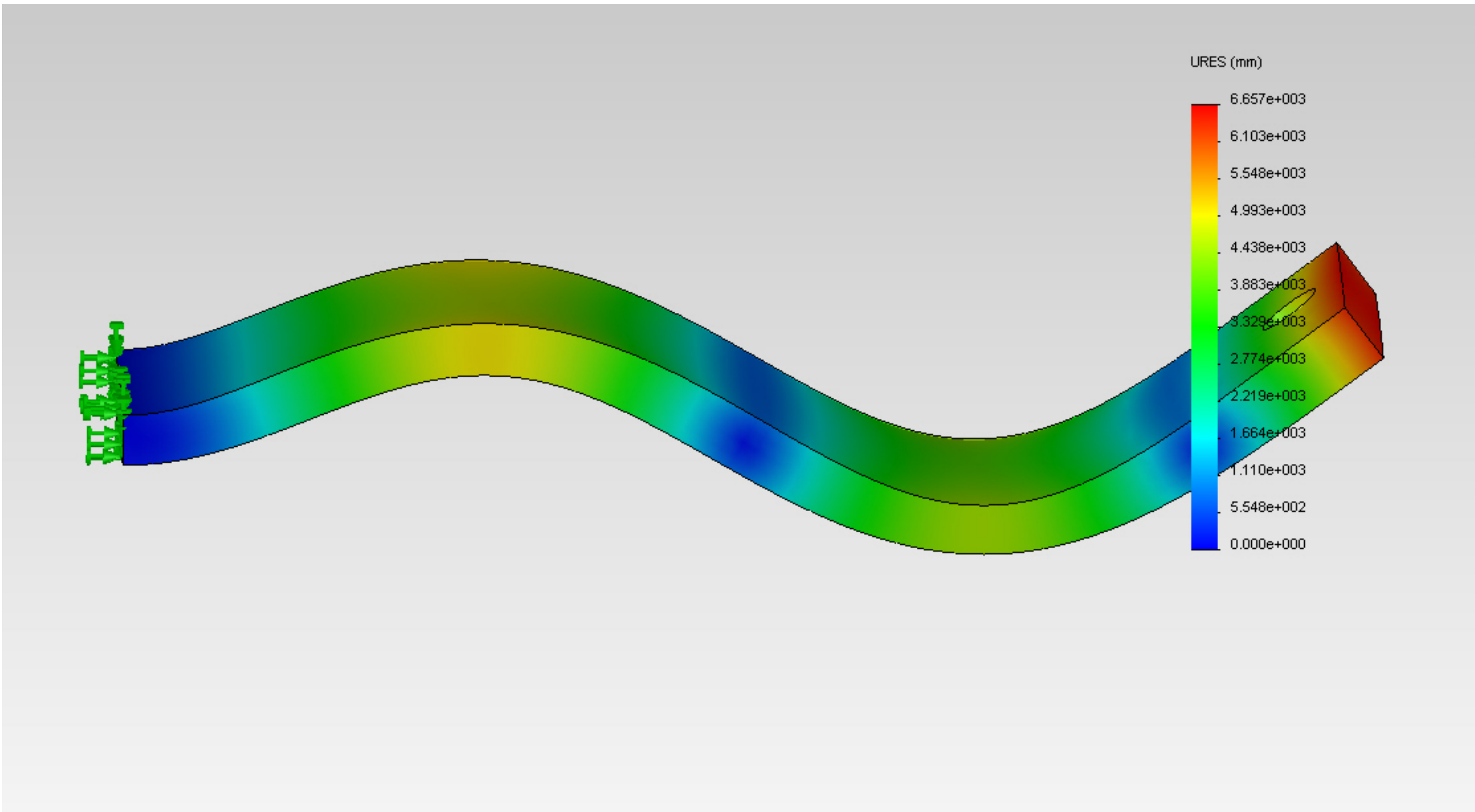
Mode 3 1417.6 Hz



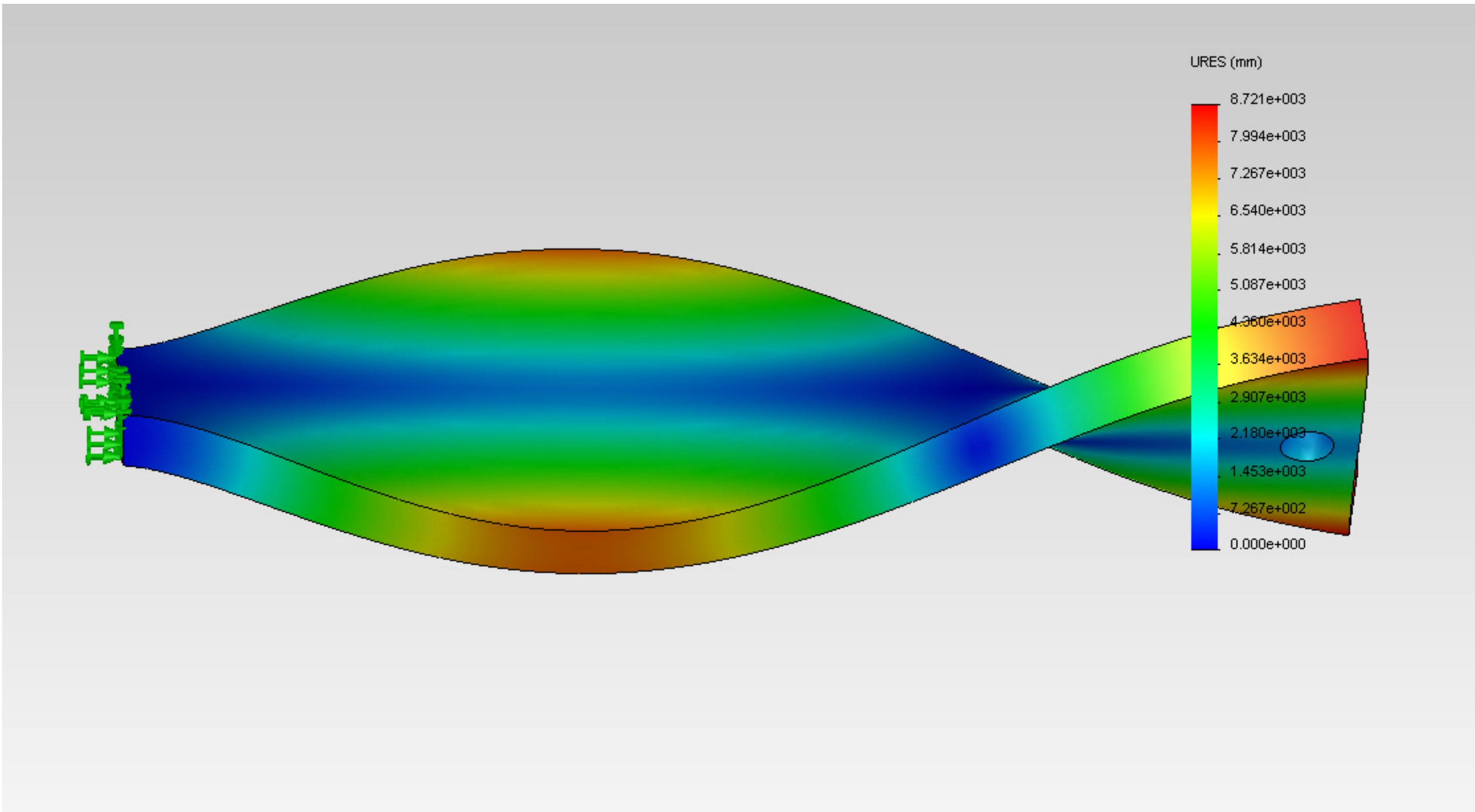
Mode 4 – 1679.3 Hz



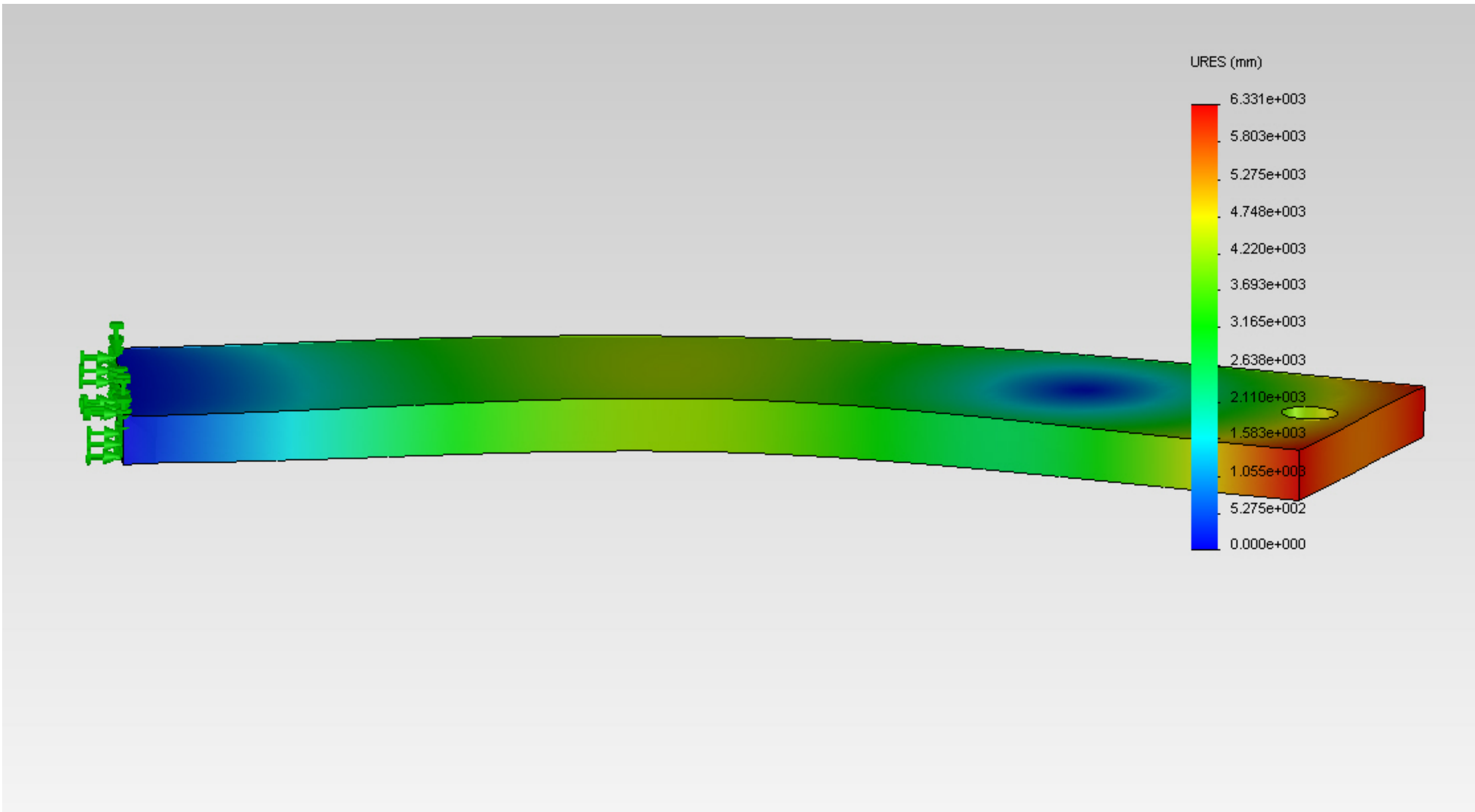
Mode 5 – 3917.6 Hz



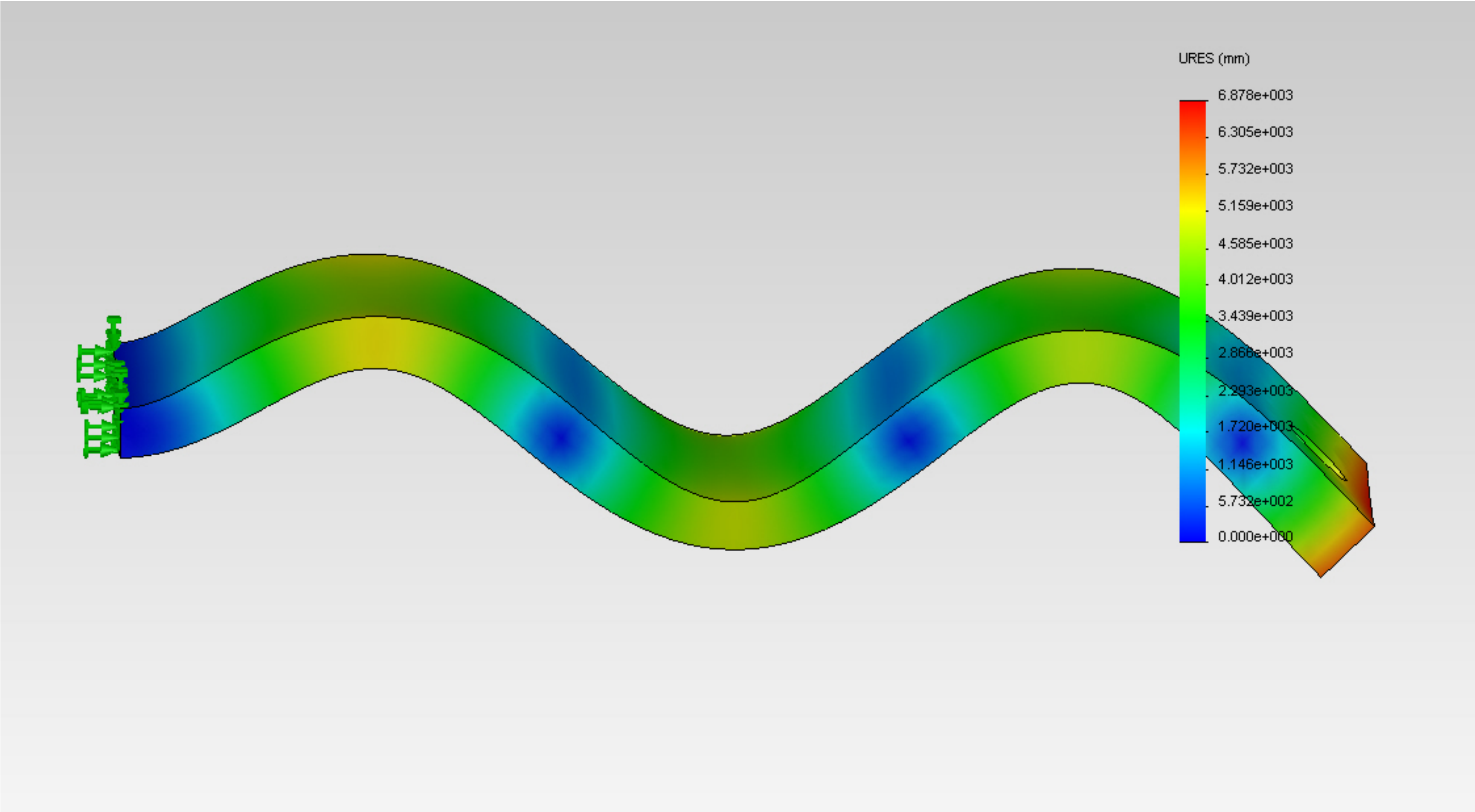
Mode 6 – 5149.6 Hz



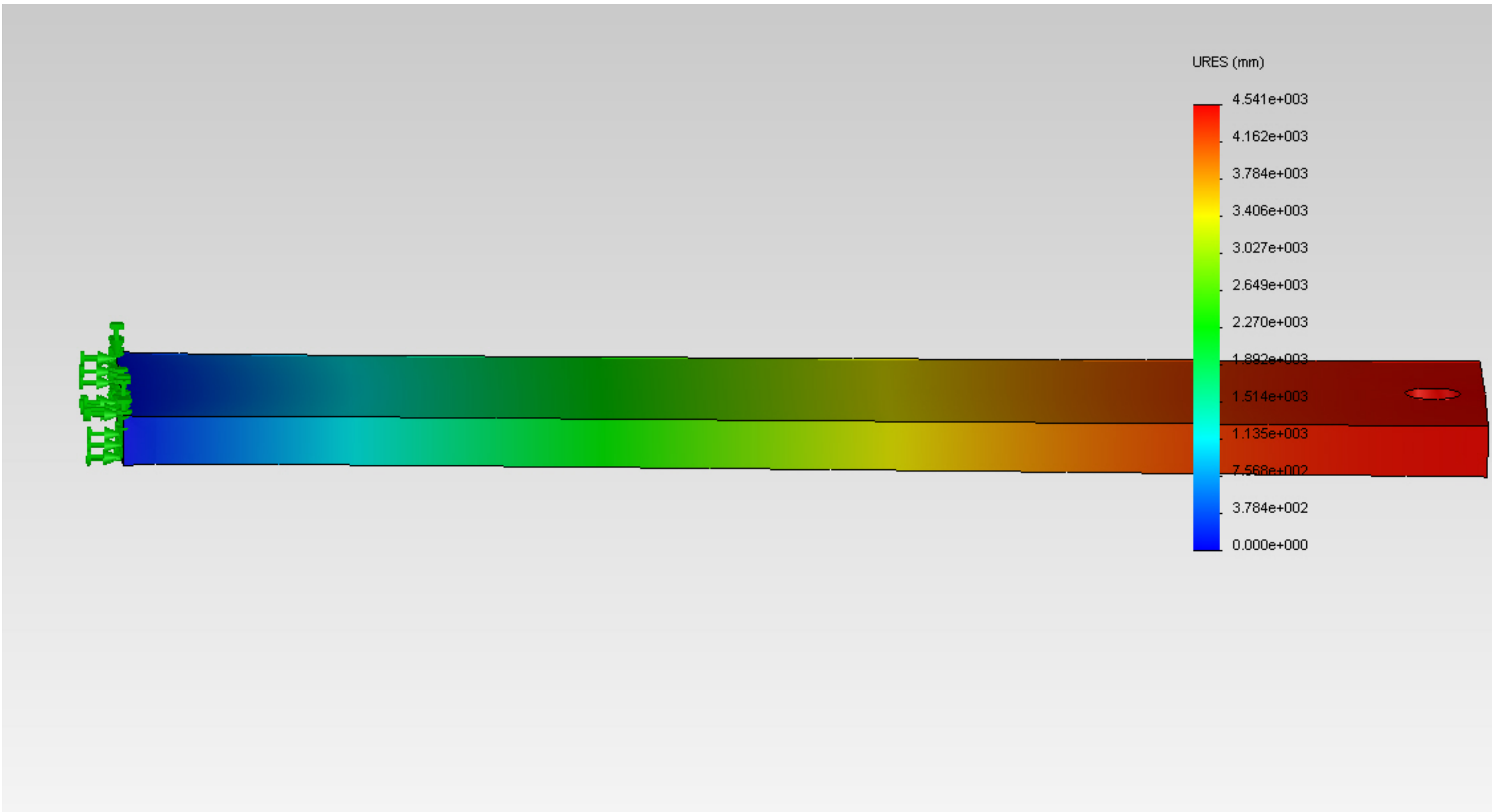
Mode 7 – 6538.1 Hz



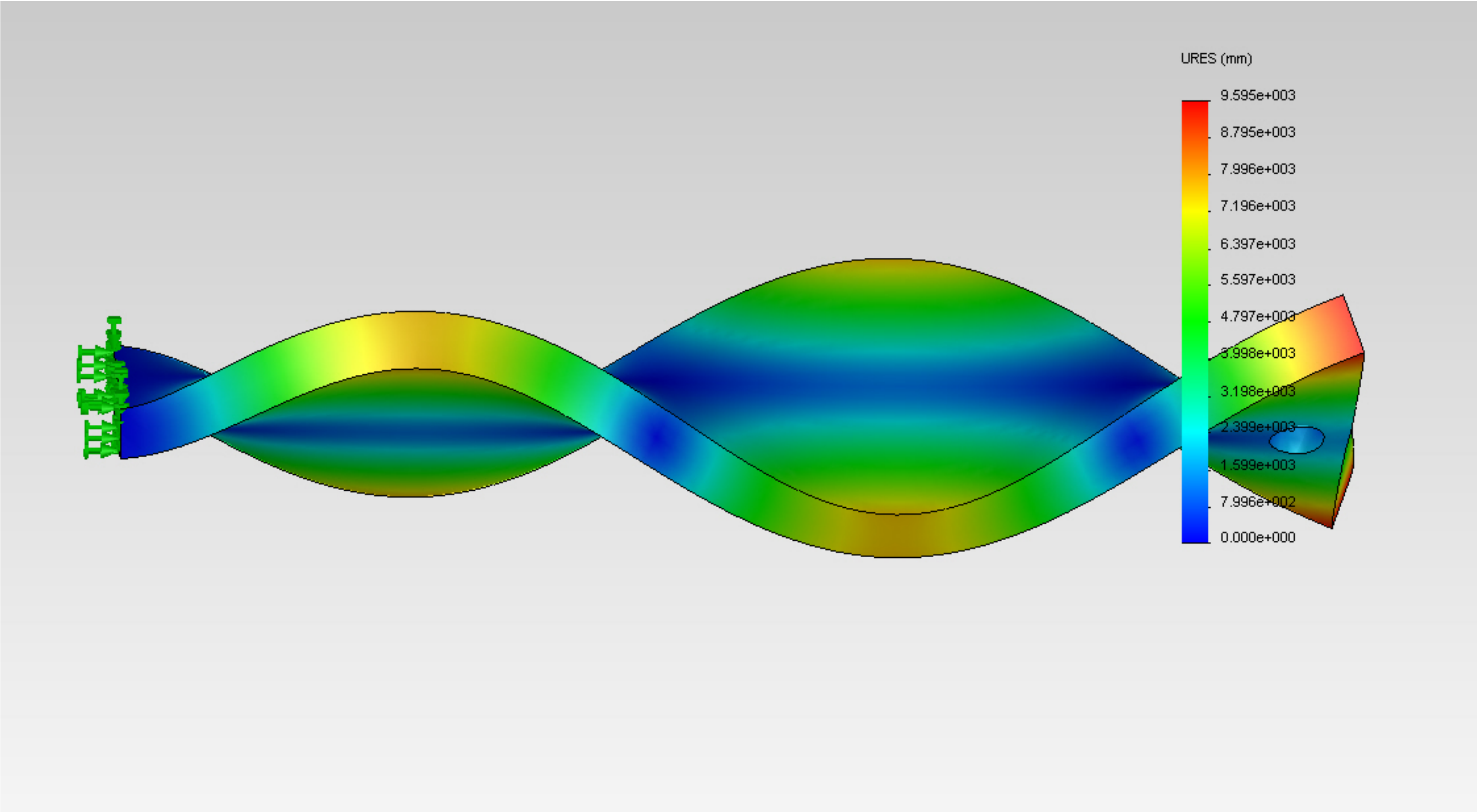
Mode 8 – 7545.1 Hz



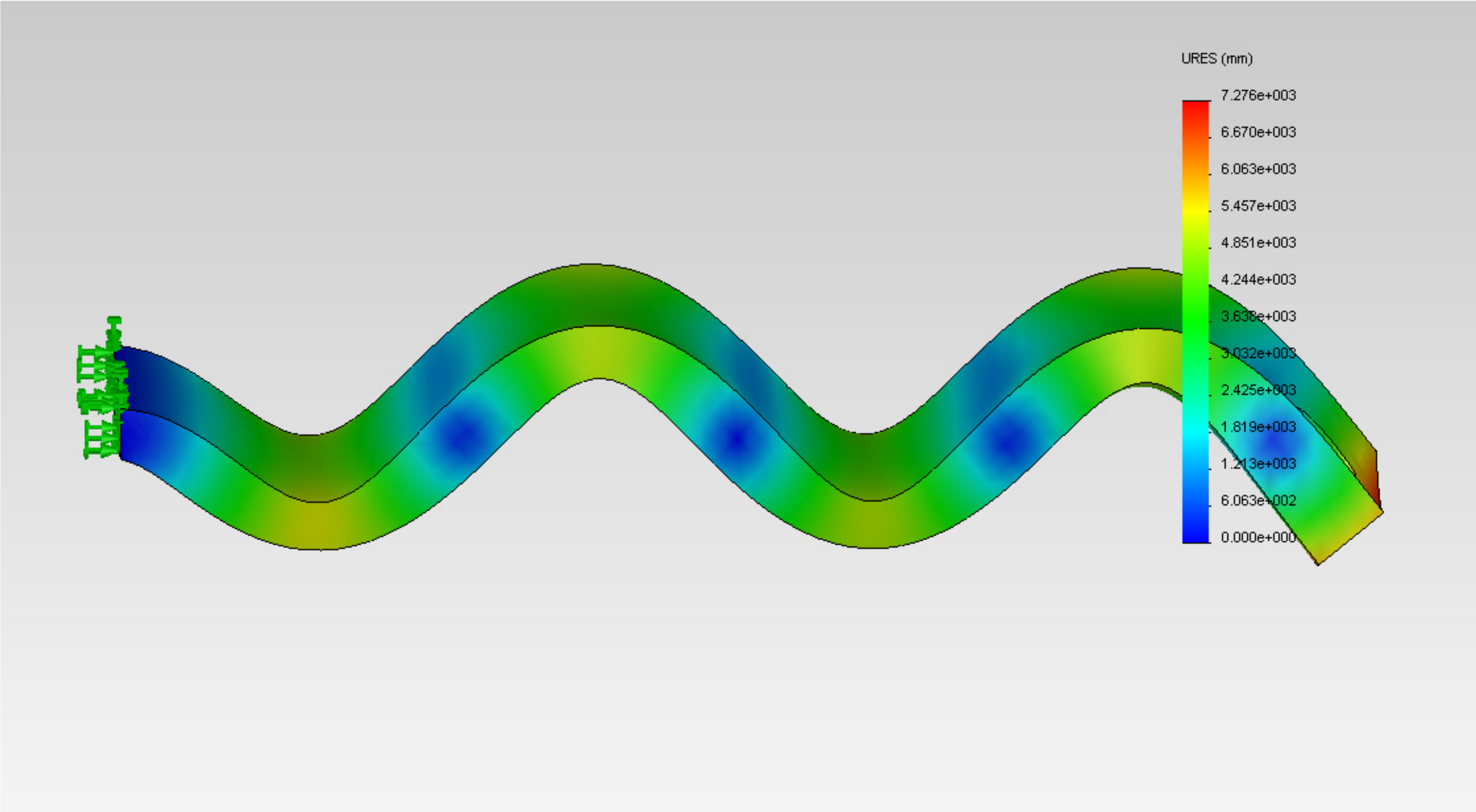
Mode 9 – 8377.9 Hz



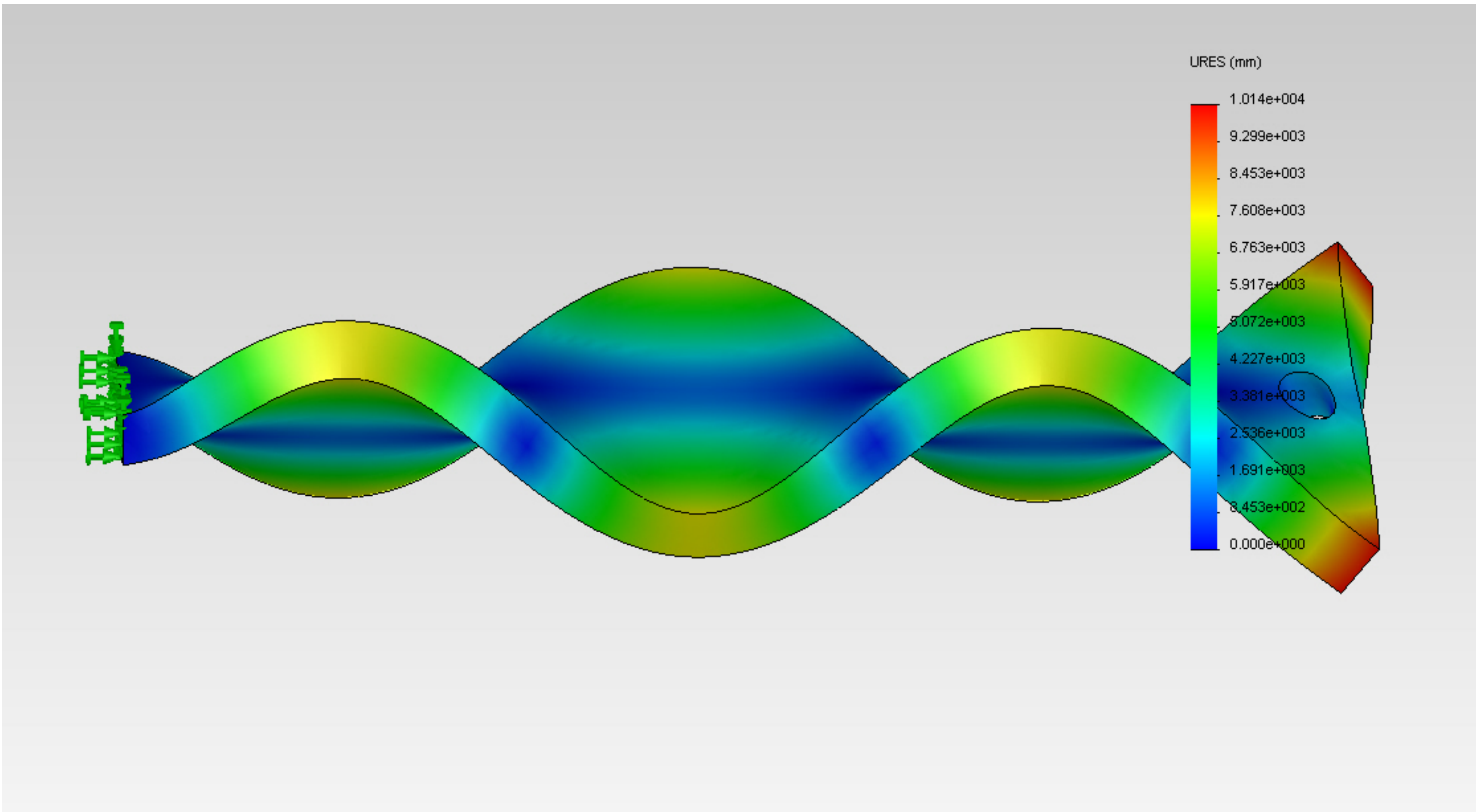
Mode 10 – 8933.4 Hz



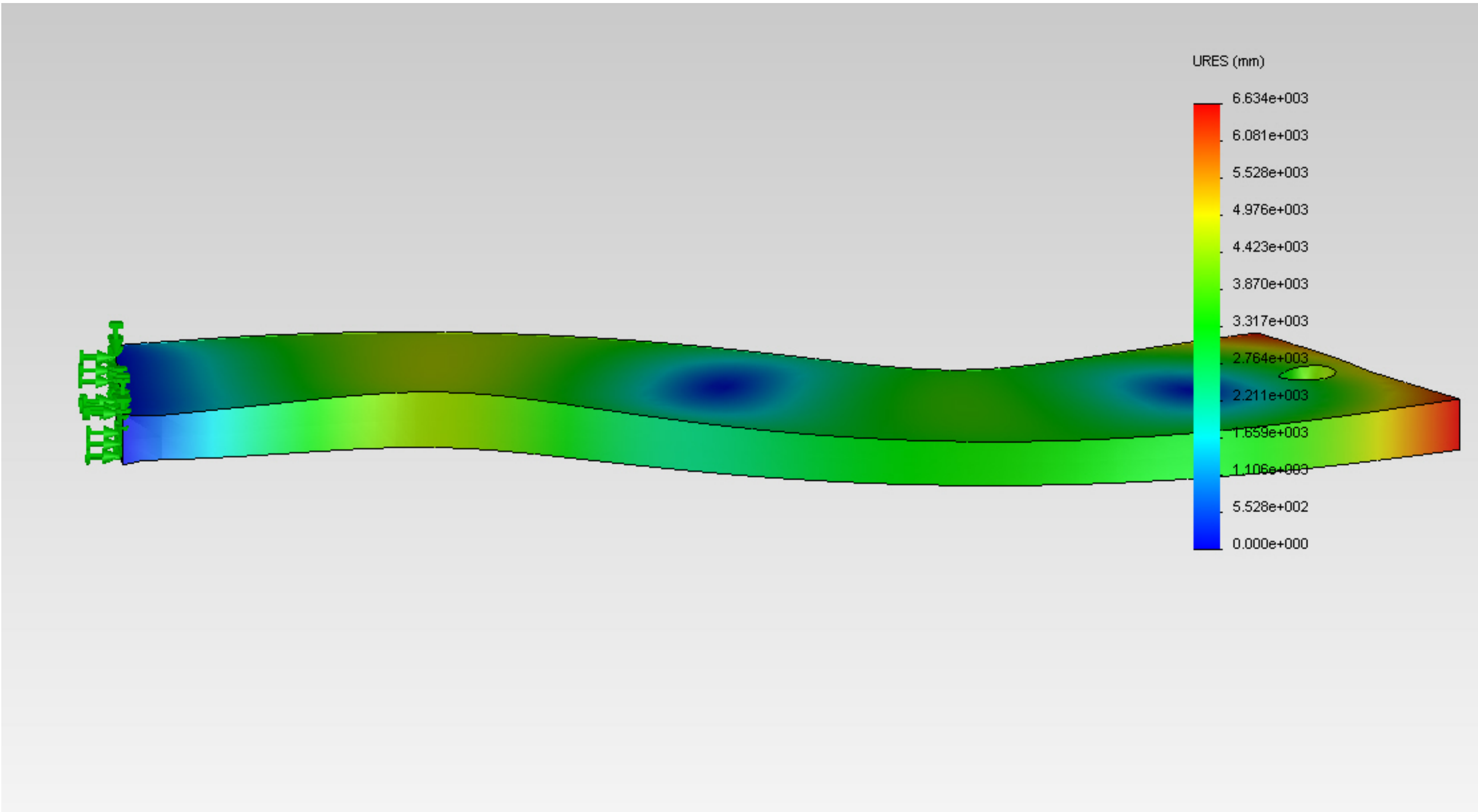
Mode 11 – 12199 Hz



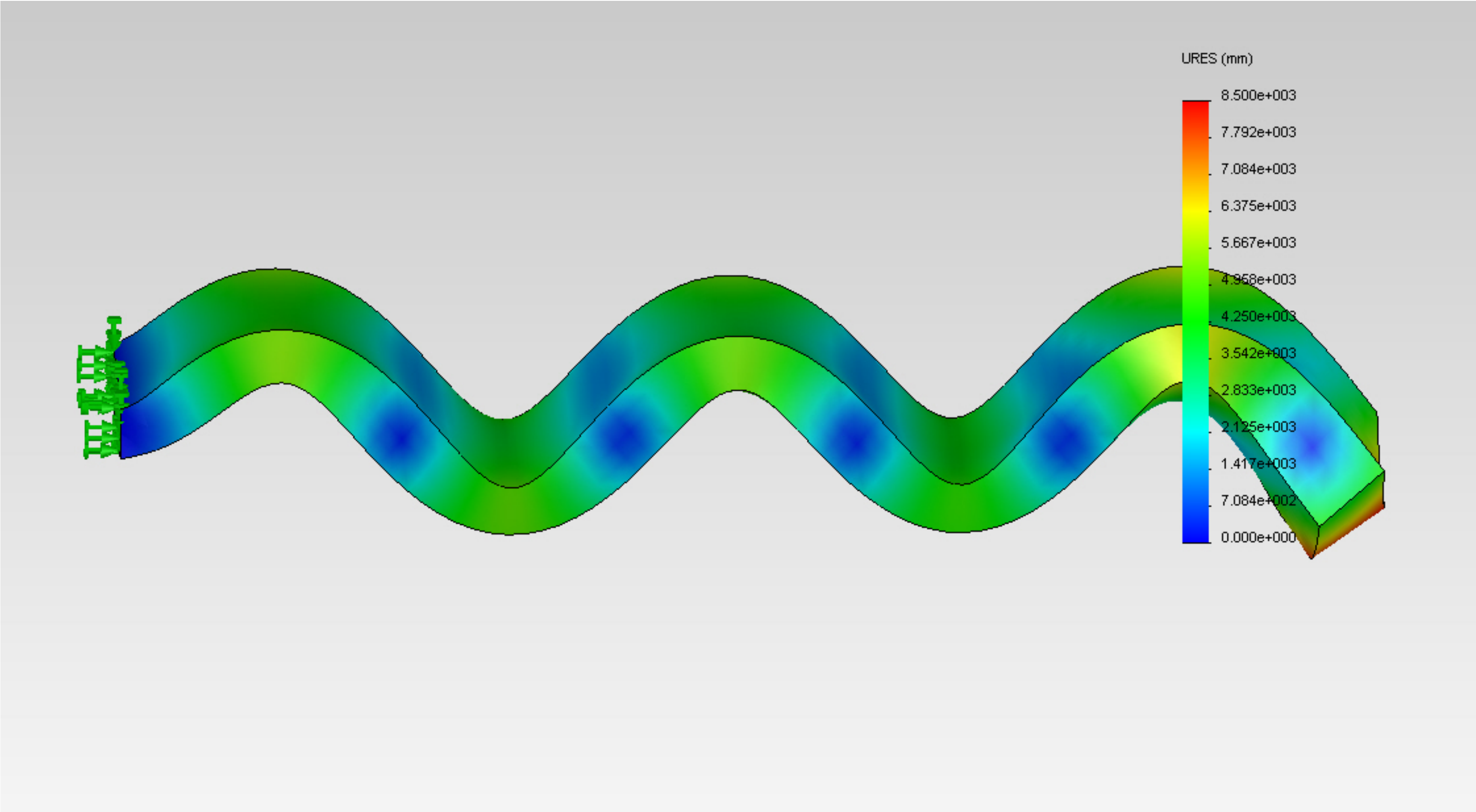
Mode 12 – 13198 Hz



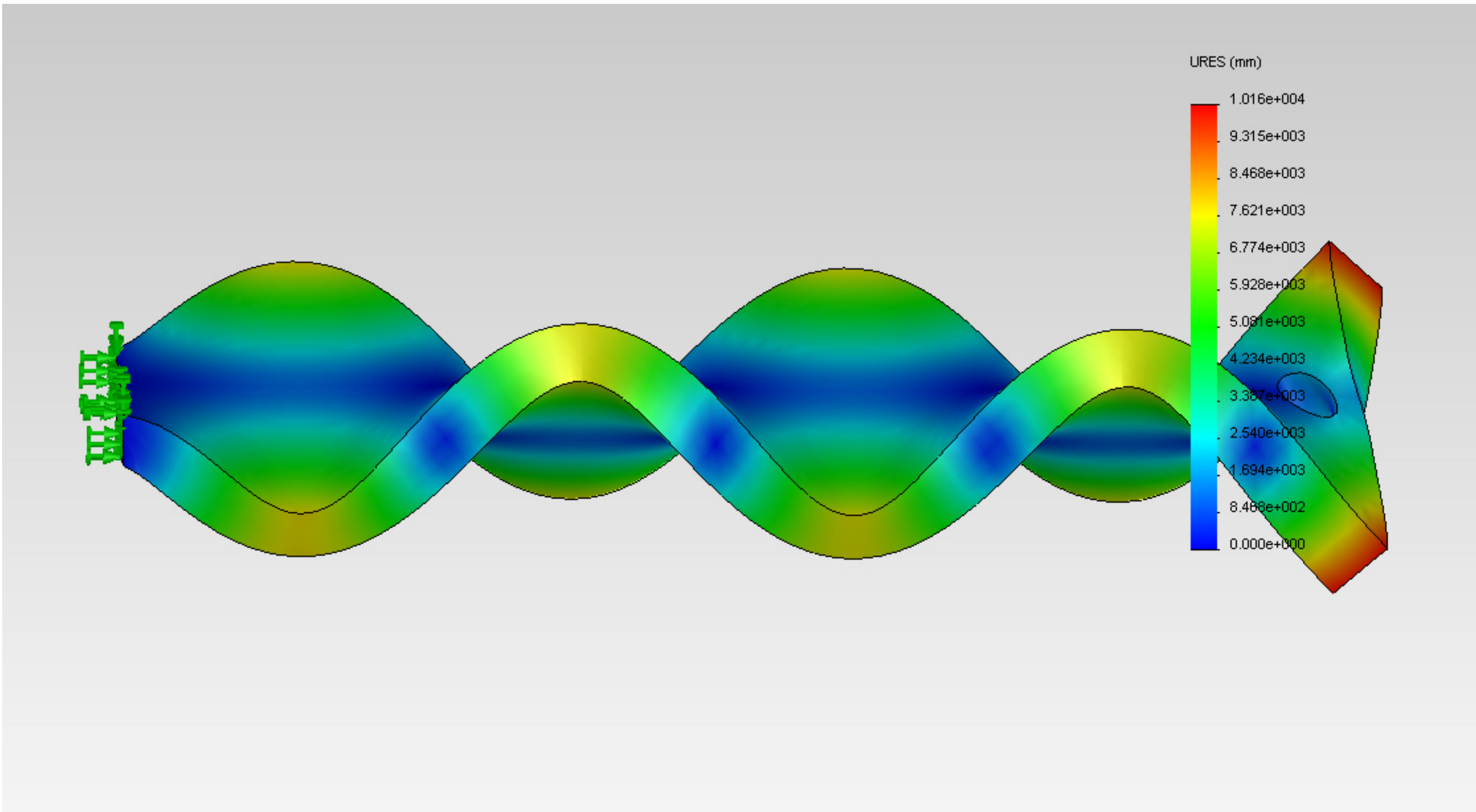
Mode 13 – 14941 Hz



Mode 14 – 17714 Hz



Mode 15 – 18072 Hz



SMD Model

- Around a resonance you can model as

$$m_e \ddot{y} = f - ky - c\dot{y}$$

$$m \;\; \ddot{y} + c\dot{y} + ky = f$$

$$\ddot{y} + \frac{c}{m_e}\dot{y} + \frac{k}{m_e}y = \frac{f}{m_e}$$

$$\ddot{y} + 2\zeta\omega_n\dot{y} + \omega_n^2 y = f / m_e$$

$$\omega_n = \sqrt{\frac{k}{m_e}} \qquad \zeta = \frac{c}{2\sqrt{m_e k}}$$

FRF

- Position

$$\frac{Y}{F}=\frac{\frac{1}{m_e}\left(\frac{1}{\omega_n}\right)^2}{1-\left(\frac{\omega}{\omega_n}\right)^2+2\zeta\frac{\omega}{\omega_n}j}$$

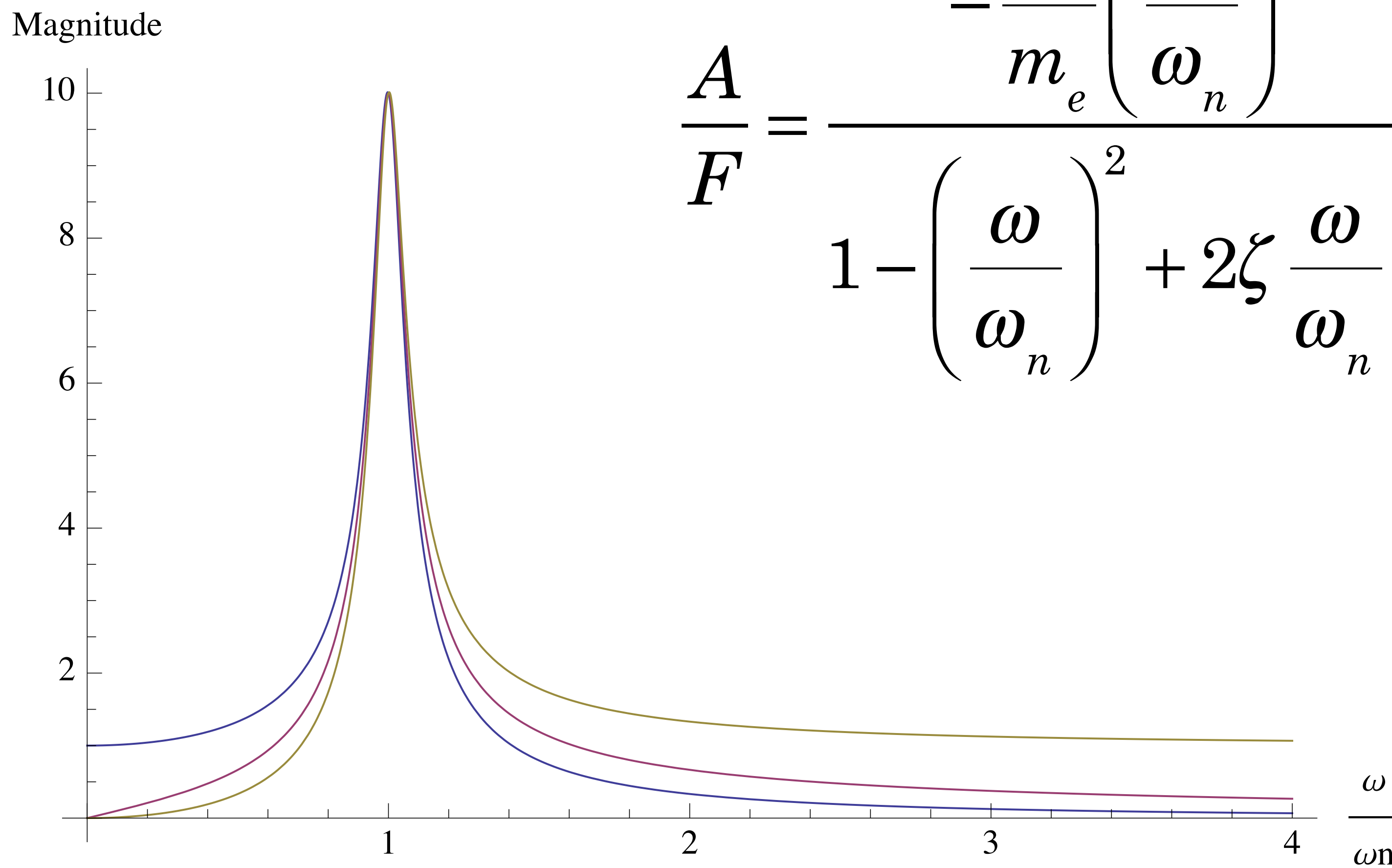
- Velocity

$$\frac{V}{F}=\frac{j\omega\frac{1}{m_e}\left(\frac{1}{\omega_n}\right)^2}{1-\left(\frac{\omega}{\omega_n}\right)^2+2\zeta\frac{\omega}{\omega_n}j}$$

FRF

- Acceleration

$$\frac{A}{F} = \frac{-\frac{1}{m_e}\left(\frac{\omega}{\omega_n}\right)^2}{1-\left(\frac{\omega}{\omega_n}\right)^2 + 2\zeta\frac{\omega}{\omega_n}j}$$



From your data

- From the peak $\omega_r = \omega_n \sqrt{1-\zeta^2}$
- From the ½ power bandwidth $\Delta\omega = \omega_{+hp} - \omega_{-hp}$

$$Q = \frac{\omega_r}{\Delta\omega}$$

$$\zeta = \frac{1}{2Q}$$

- You can also use log decrement.

How Do We Measure?

- Expensive Accelerometers

DYTRAN INSTRUMENTS, INC.

MODEL 3133A1, TRIAXIAL ACCELEROMETER

Model# 3133A1

DOWNLOAD PDF | 3D MODEL | RFQ

FEATURES:

- 10 mV/g sensitivity
- 500g range
- Axis 1 & 2: 0.25 to 7,000 Hz frequency range (±10%)
- Axis 3: 0.25 to 10,000 Hz frequency range (±10%)
- 3-foot integral cable
- Adhesive mount
- 0.8 grams
- Titanium
- Ultra miniature teardrop design
- Triaxial
- IEPE

APPLICATIONS:

- Environmental Stress Screening (ESS)
- HALT/HASS
- Modal and structural analysis
- Product response testing
- General purpose triaxial vibration measurements

PCB PIEZOTRONICS INC.

Click to zoom

Model: 356A01

Platinum Stock Products;Triaxial, lightweight (1.0 gm) miniature, ceramic shear ICP® accelerometer, 5 mV/g, 0.25" cube

Price: Call for pricing
Quantity in stock: Call for stock

Product Manual (PDF)
Specifications (PDF)
Drawing (PDF)

Measure (cont.)

- Expensive Impulse Hammers

DYTRAN INSTRUMENTS, INC.

MODEL 5800B2, DYNAPULSE™ IMPULSE HAMMER

Model# 5800B2

DOWNLOAD PDF | 3D MODEL | RFQ

FEATURES:

- 100 mV/lbf sensitivity
- 50 lbf range
- 1,000 lbf maximum force
- BNC connector
- 100 gram head weight
- IEPE

APPLICATIONS:

- Machinery parts
- MIMO test
- Modal and structural analysis
- Root cause failure analysis
- General purpose use on car frames, bearing housings, brake rotors, I-beams, plates and other small-to-medium sized structures and machinery

Measure (cont.)

- Moderately Priced Strain Gauges

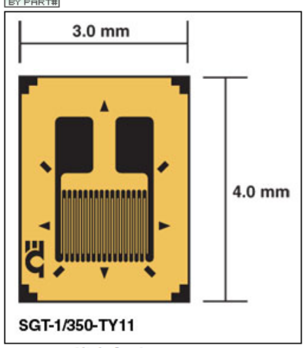
OMEGA®

Your One-Stop Source for Process Measurement & Control!

Linear Strain Gages, Transducer Quality, Uniaxial

SGT-2C/350-TY11

RoHS BY PARTS



Click for larger image.

$27.60 SGT-1/350-TY11

- FAST IMMEDIATE DELIVERY ON LARGE ORDERS! Stock to 1-Week!
- Conveniently Priced per Pack of 5
- Rugged, High Reliability
- Flexible, Small Bending Radius
- Broad Temperature Range
- Clear Alignment Marks
- Affix with Cold or Hot Cure Adhesives
- Conviently priced per pack of 5

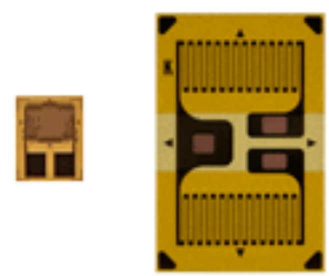
View related products - Strain Gages, Accessories and Instrumentation

VISHAY PRECISION GROUP

Linear Patterns

Single Grid

Dual Grid



Measure (cont.)

- Low Priced Dynamic Strain Gauges

Piezo Sensor - FDT Series

Overview | Literature | Quality & Compliance | Related Products | Additional Information | How To Buy

Applications: Contact microphone, Dynamic strain gages, Speakers, Switches

Industries:

Replaces:

Datasheet: FDT_Series

measurement SPECIALTIES™

Piezo Sensor - DT Series

Overview | Literature | Quality & Compliance | Related Products | Additional Information | How To Buy

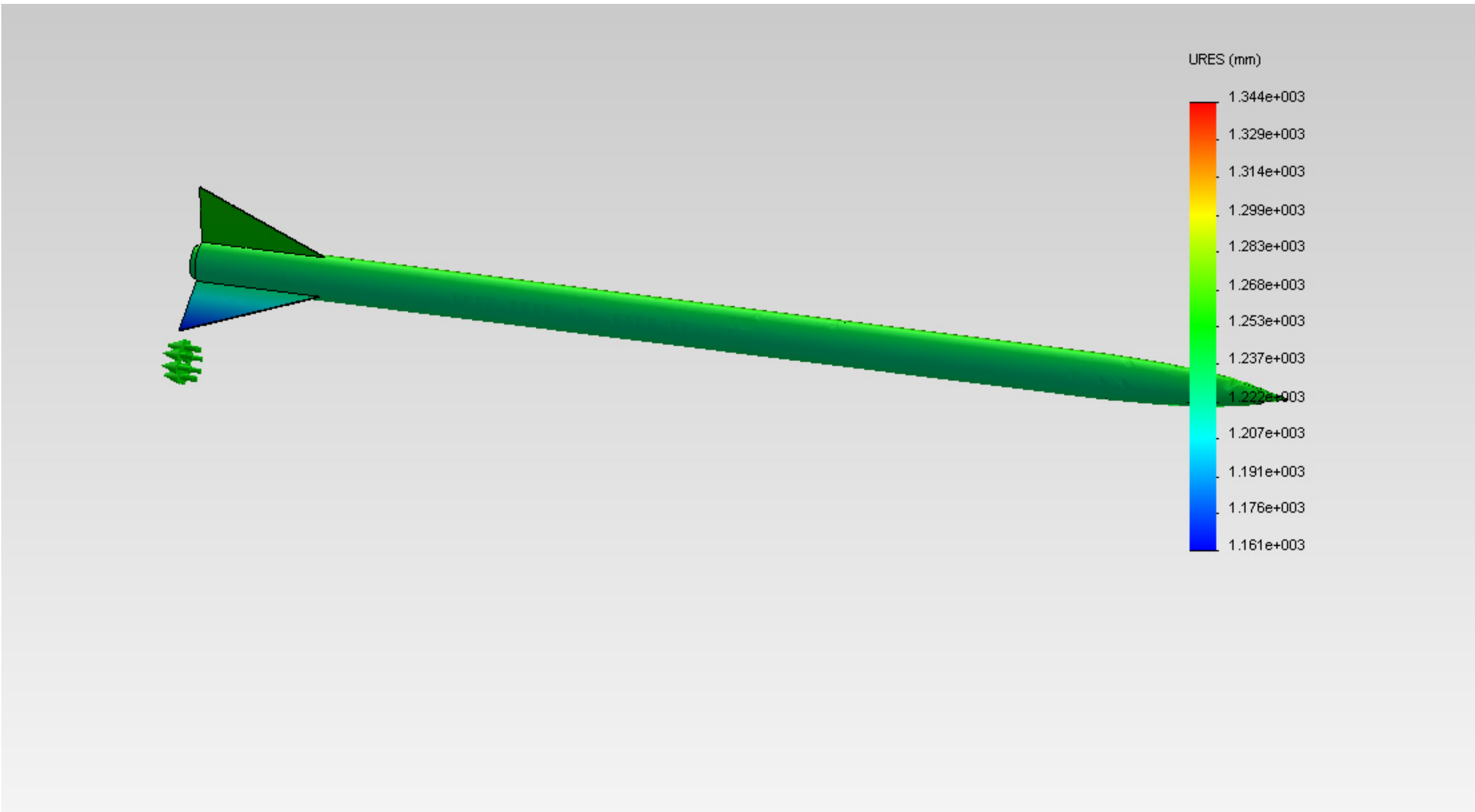
Applications: Contact microphone, Dynamic strain gages, Speakers, Switches

Industries:

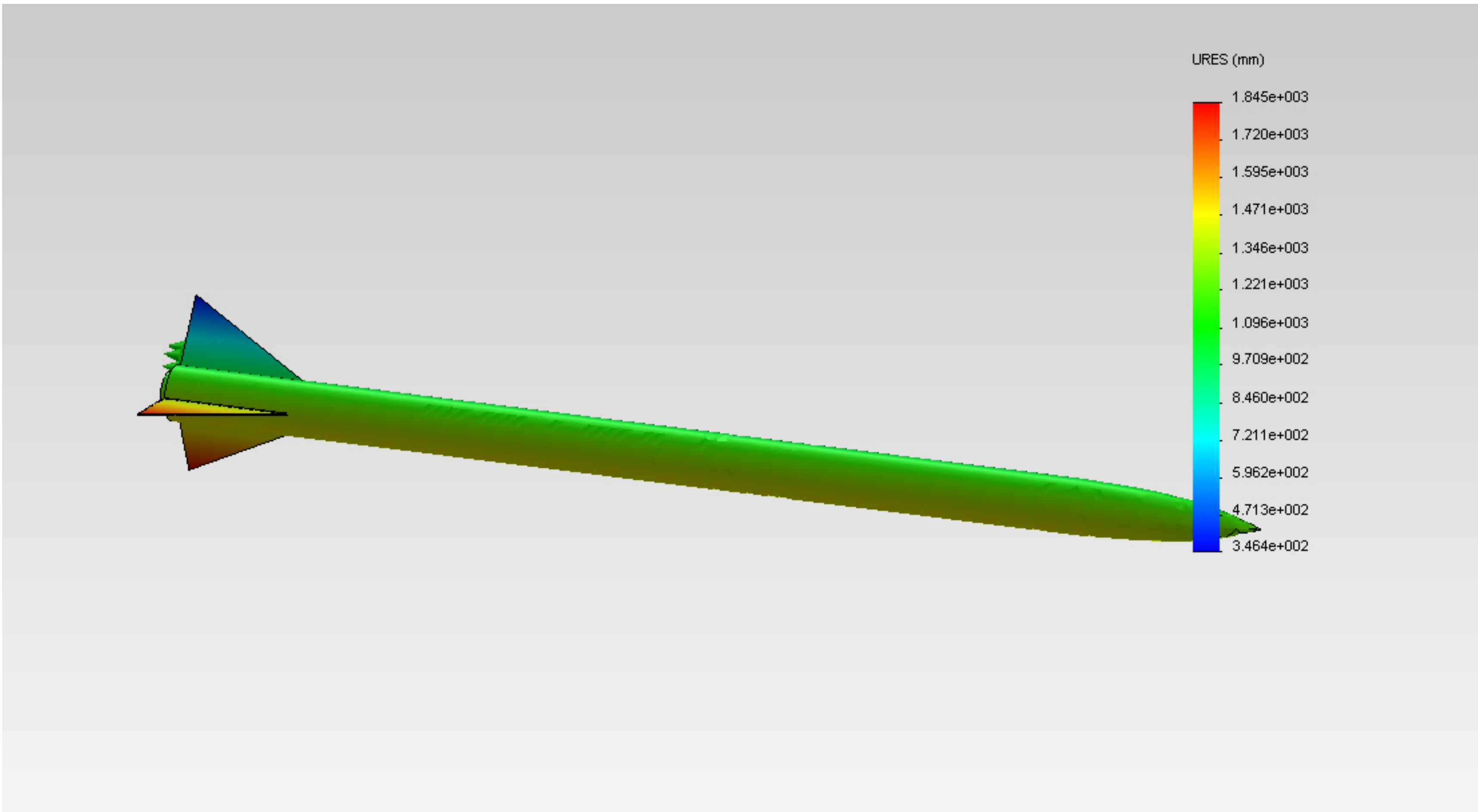
Replaces:

Datasheet: DT_Series

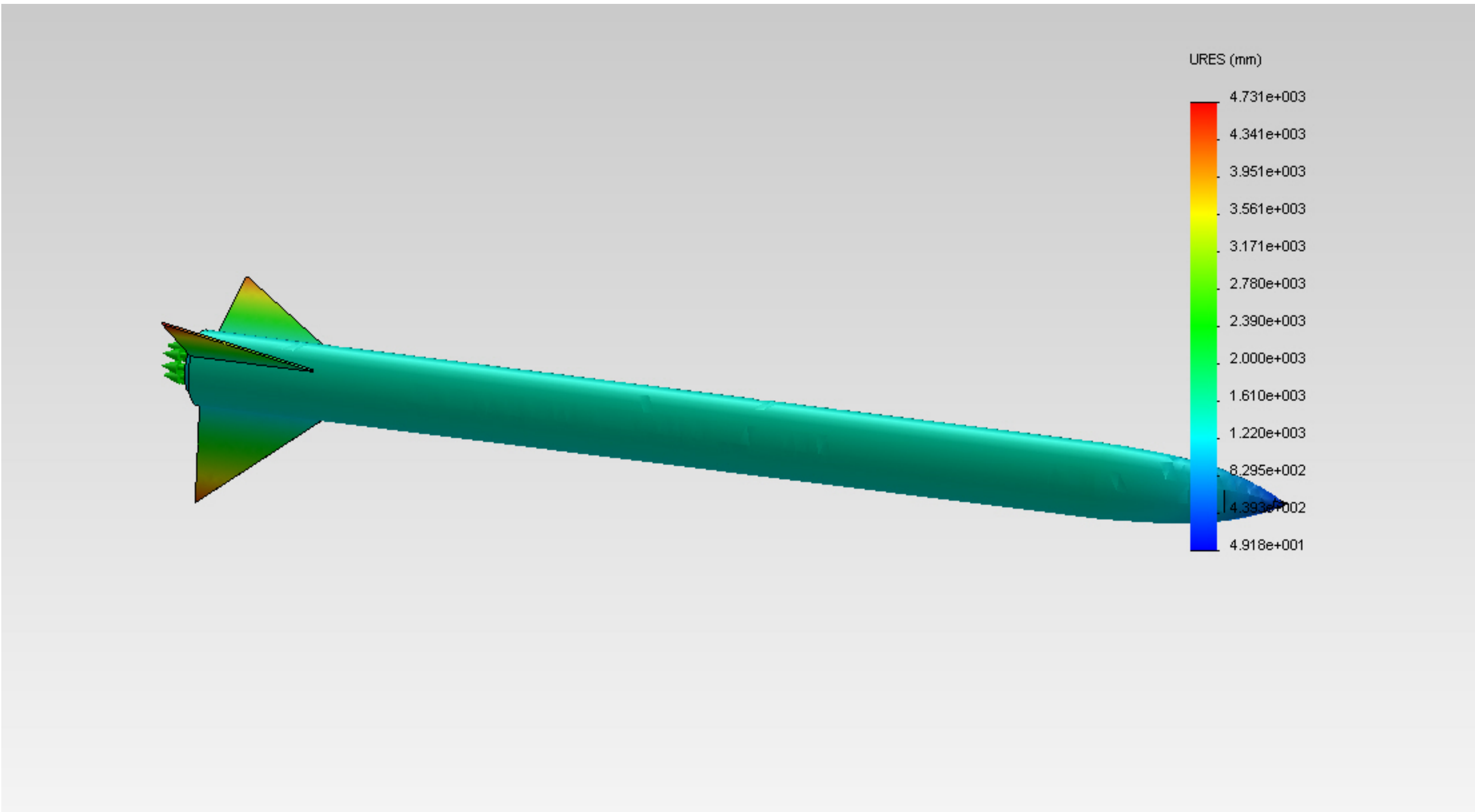
Mode 1 – 0 Hz


URES (mm)
1.344e+003
1.329e+003
1.314e+003
1.299e+003
1.283e+003
1.268e+003
1.253e+003
1.237e+003
1.222e+003
1.207e+003
1.191e+003
1.176e+003
1.161e+003

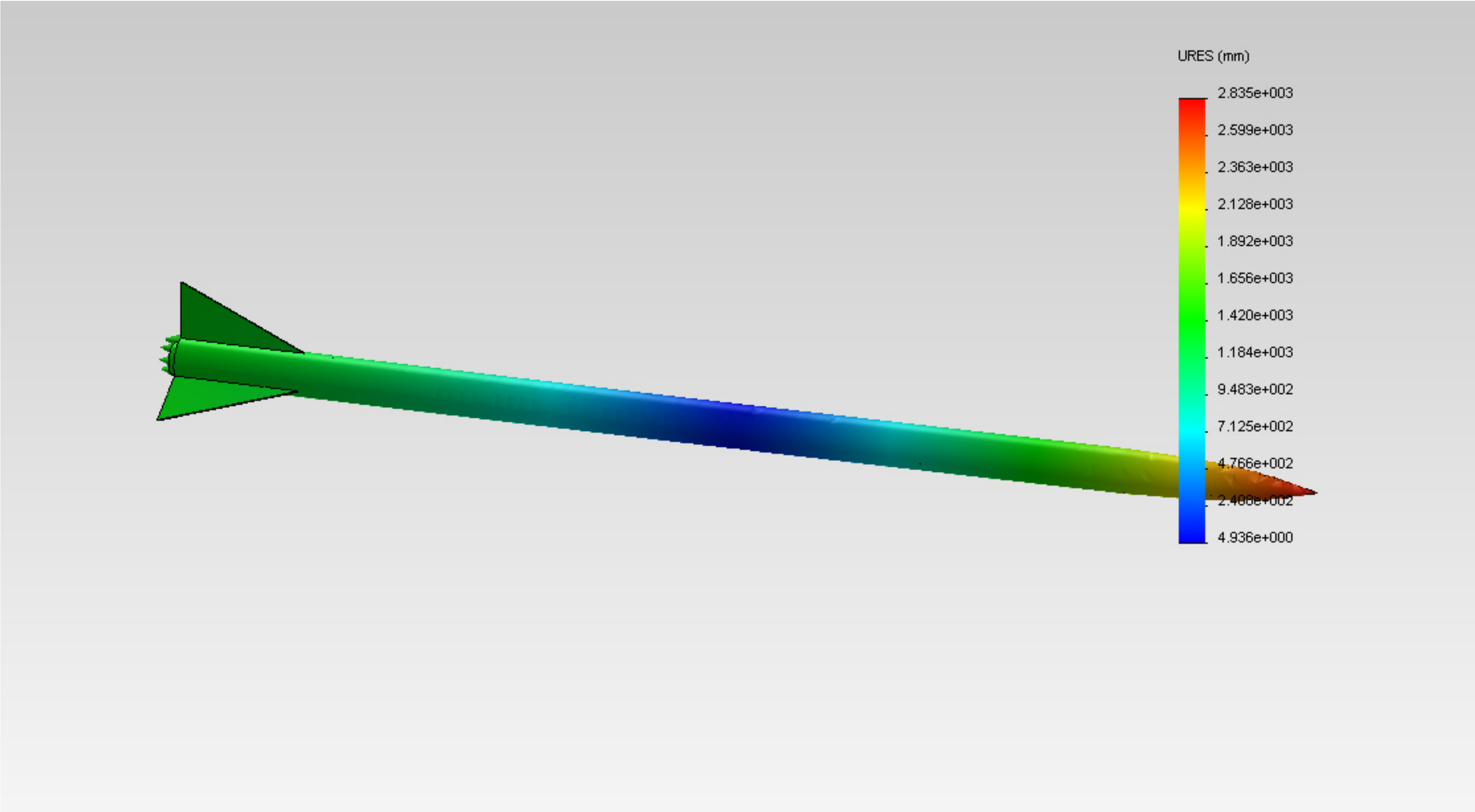
Mode 2 – 7.0439E–4 Hz



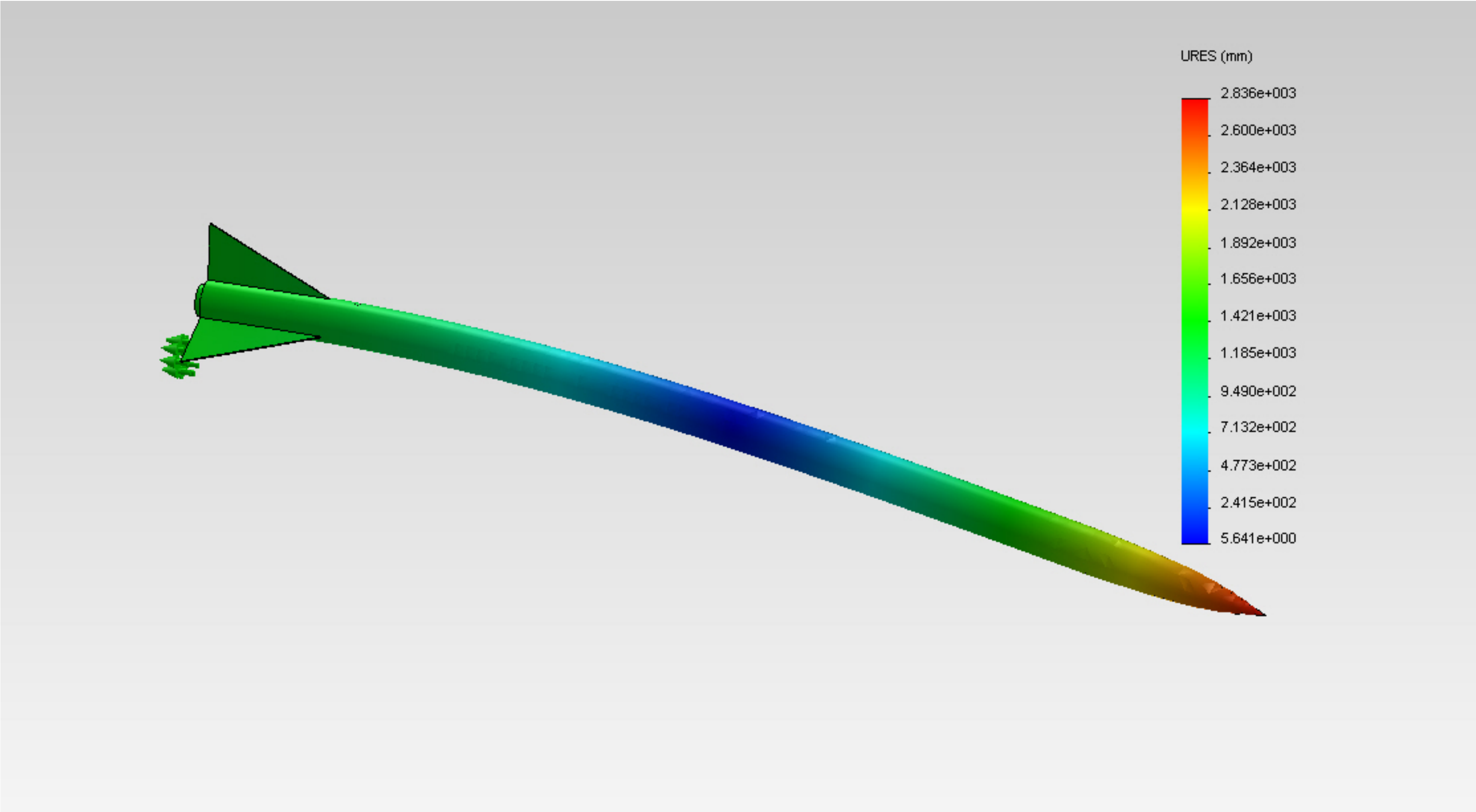
Mode 3 – 1.7816E–3 Hz



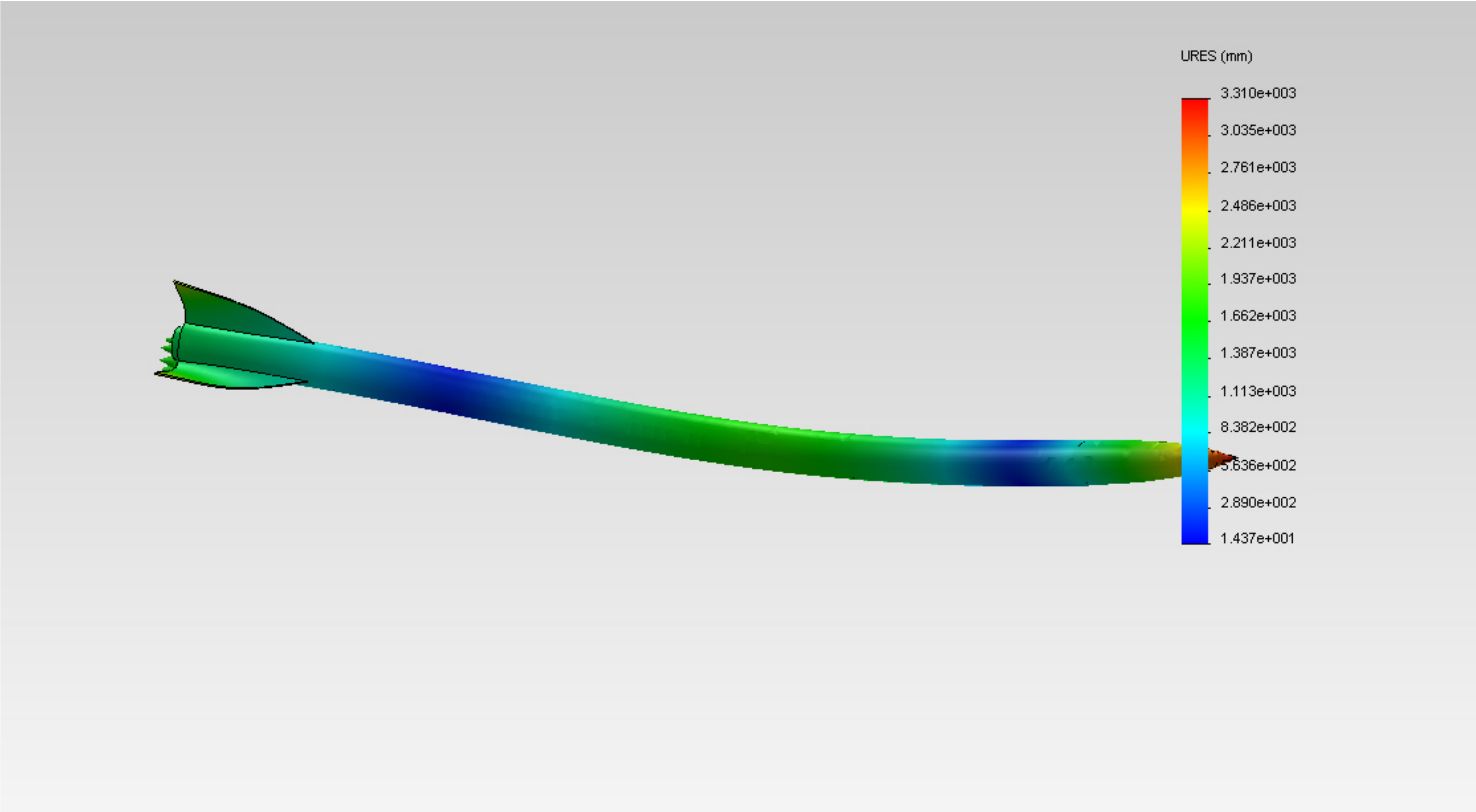
Mode 4 – 11.752 Hz



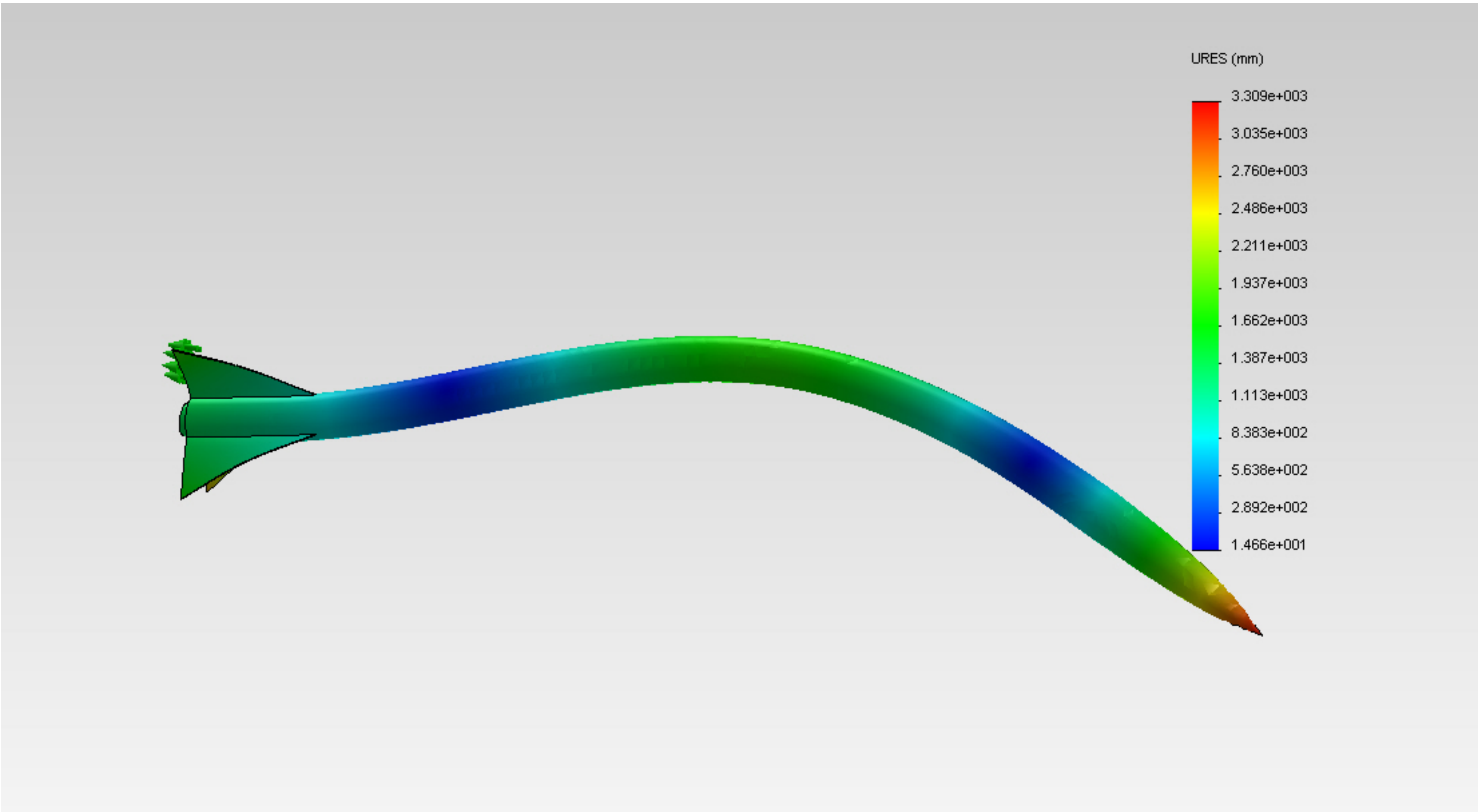
Mode 5 – 11.802 Hz



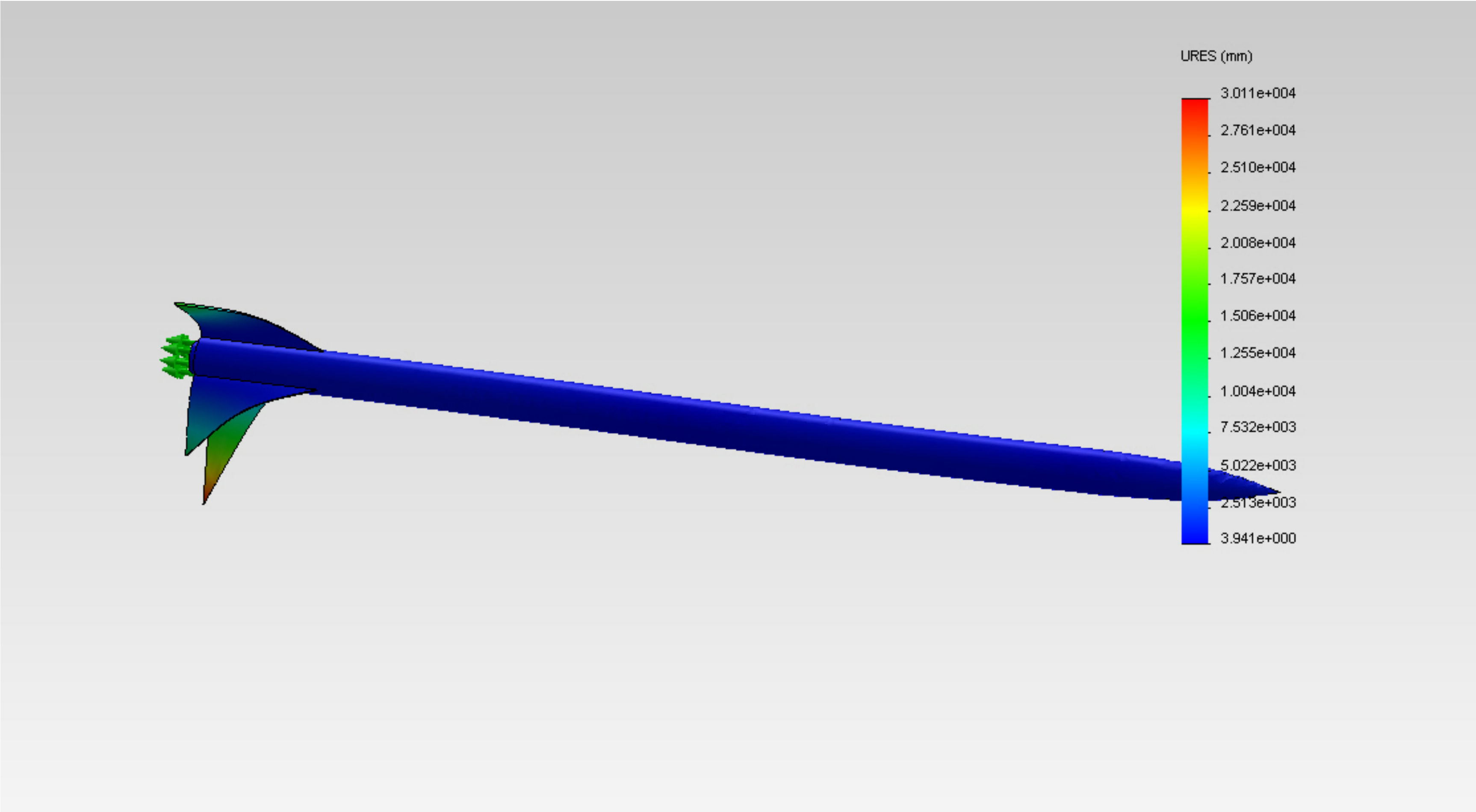
Mode 6 – 62.133 Hz



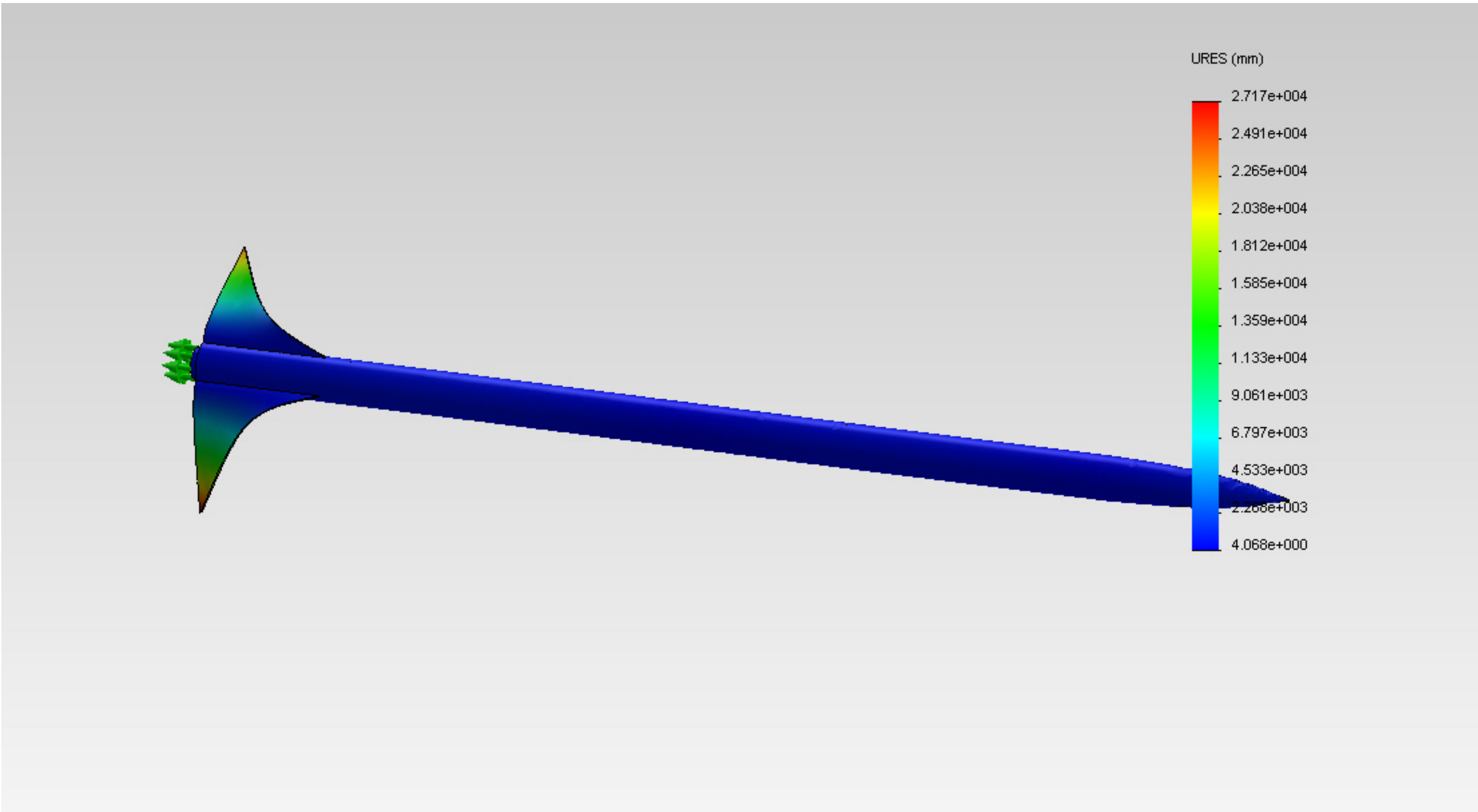
Mode 7 – 62.287 Hz



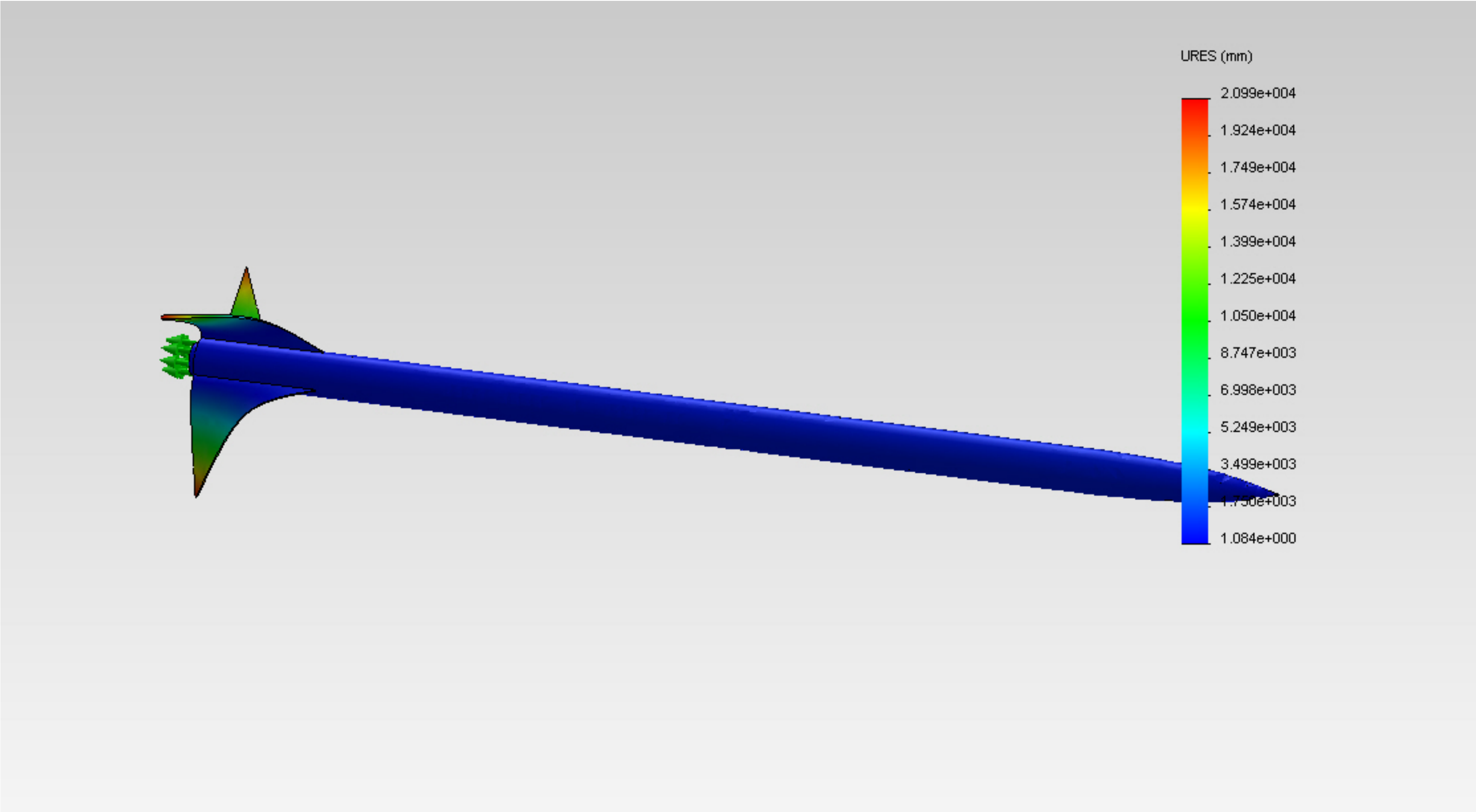
Mode 8 – 111.02 Hz



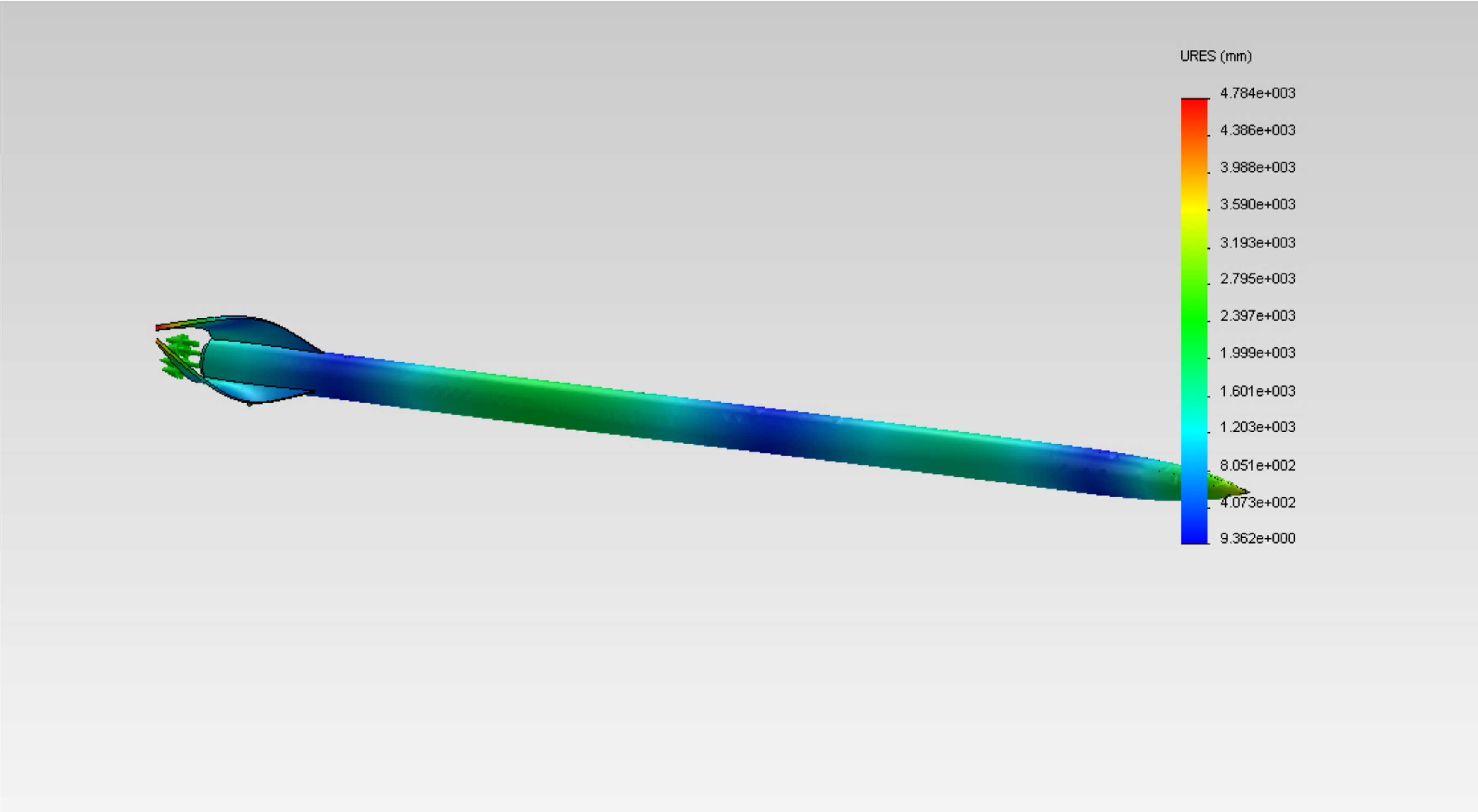
Mode 9 – 111.06 Hz



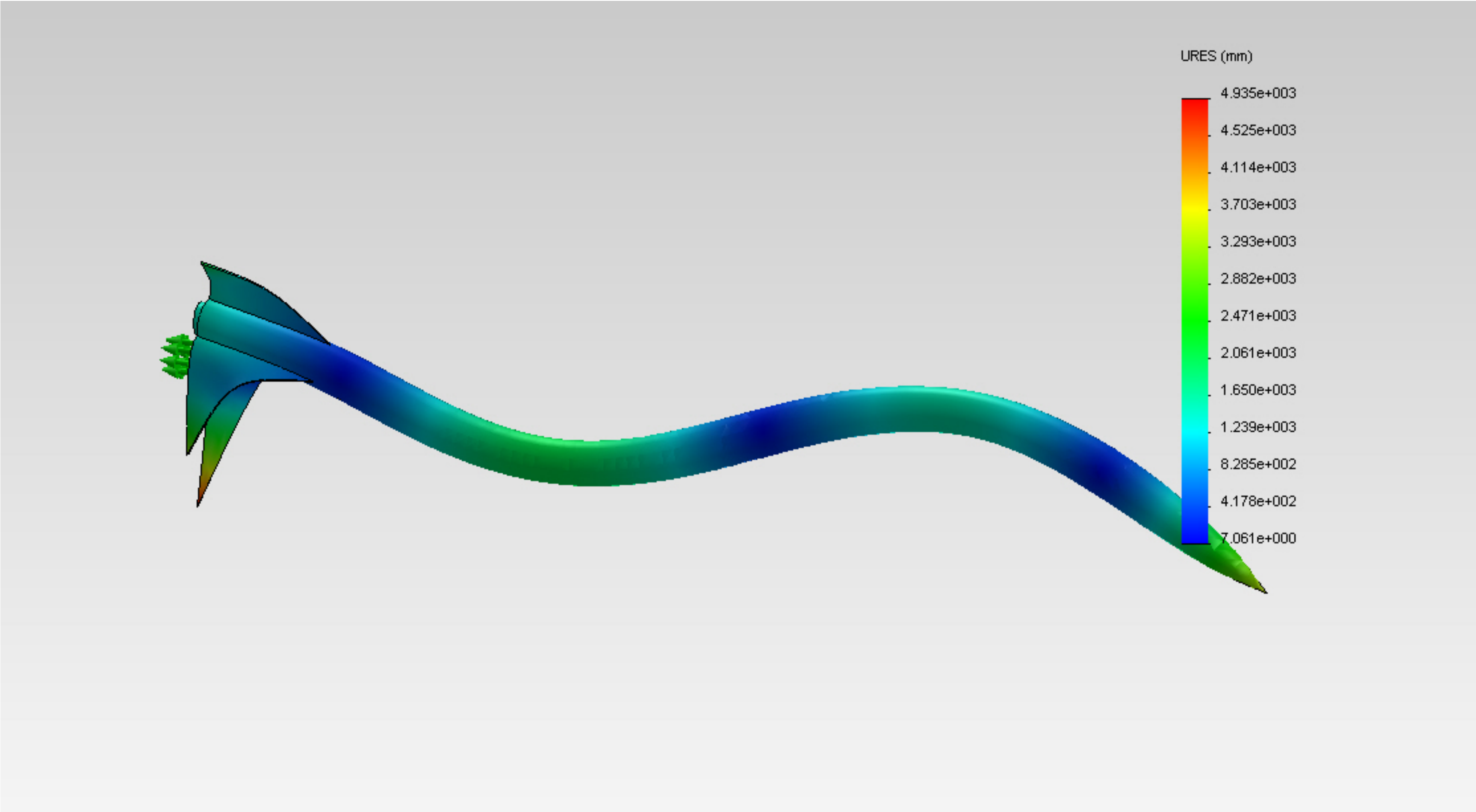
Mode 10 – 114.37 Hz



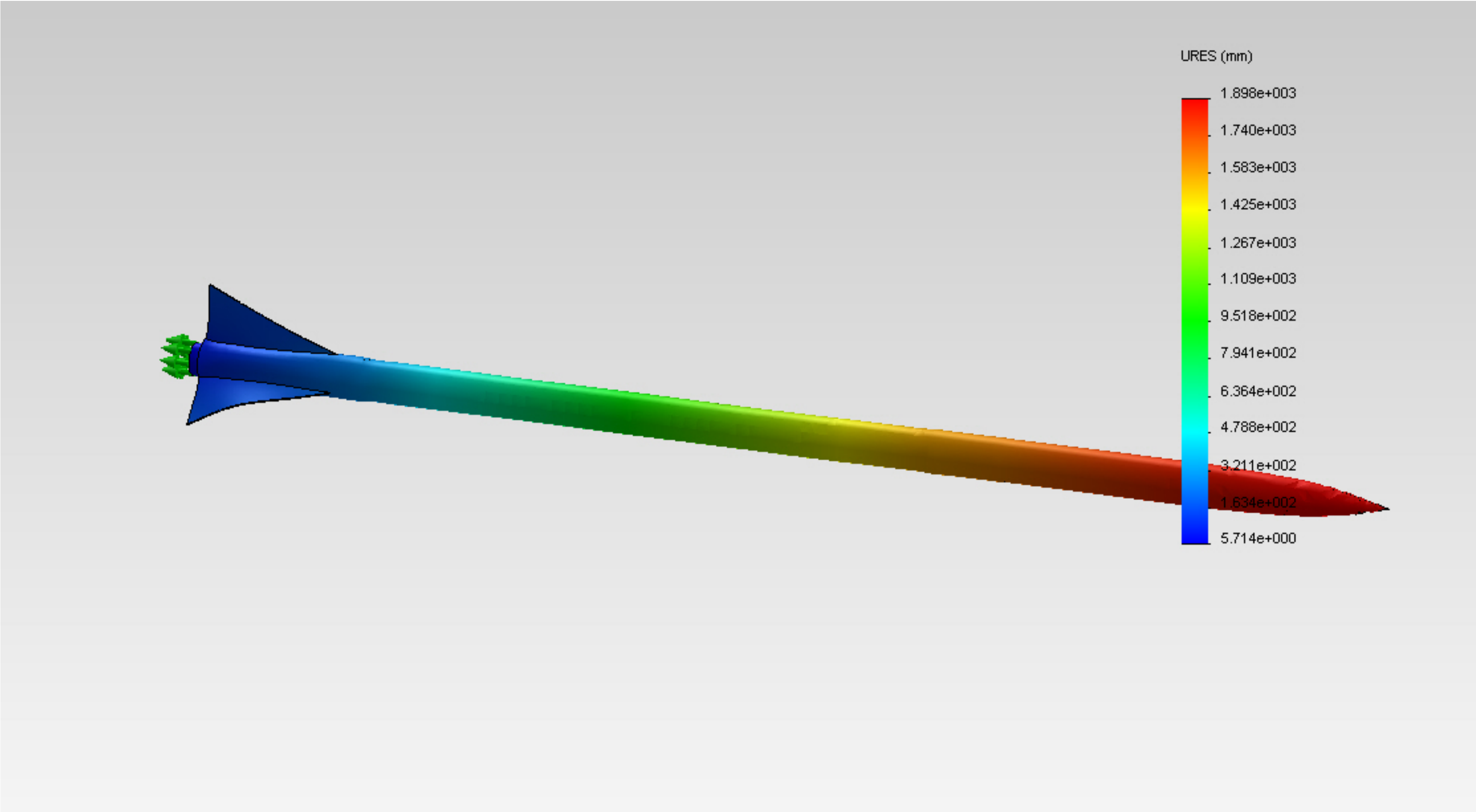
Mode 11 – 154.73 Hz



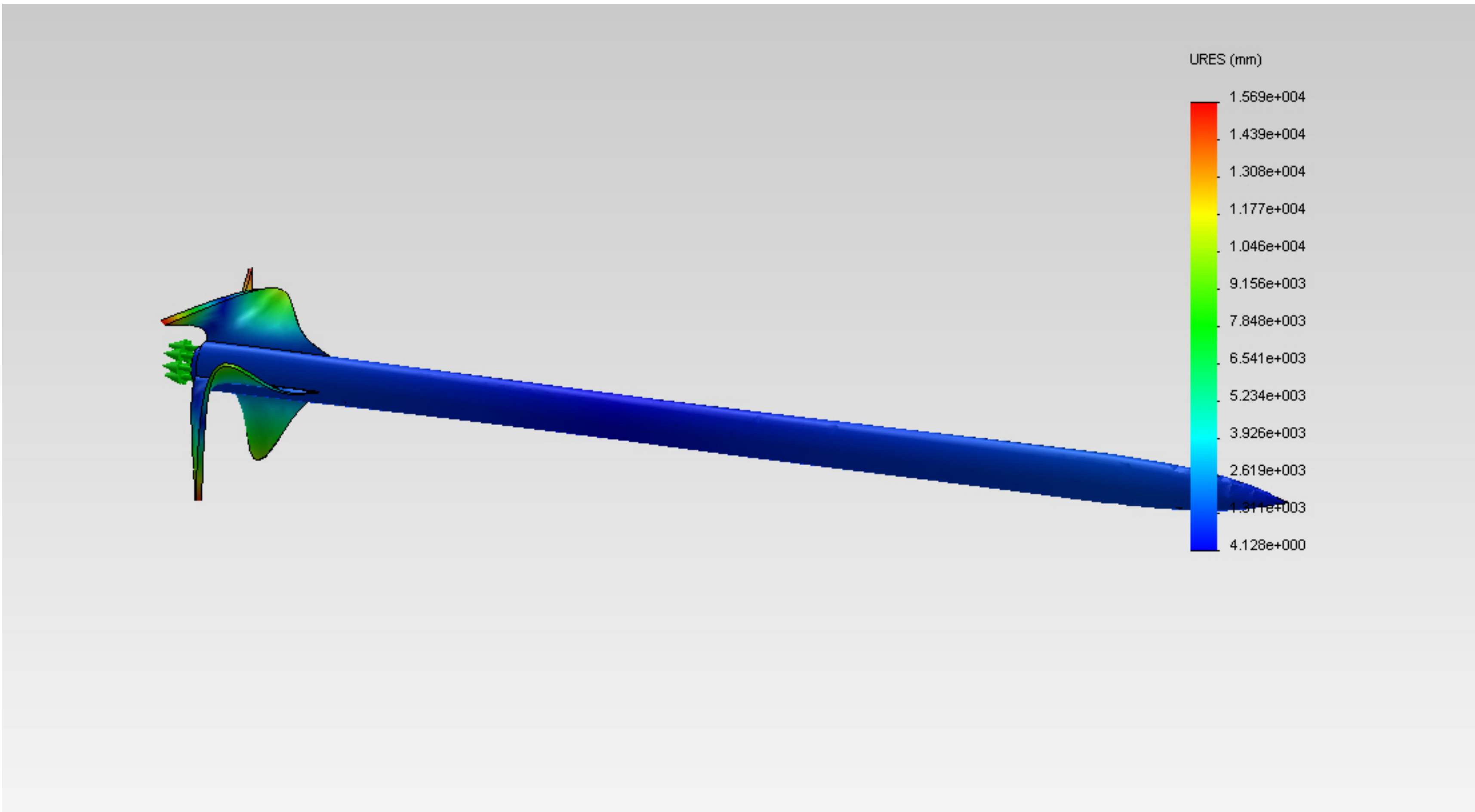
Mode 12 – 155.32 Hz



Mode 13 – 257.09 Hz



Mode 14 – 266.75 Hz



Mode 15 – 273.79 Hz