Jet Propulsion Laboratory
California Institute of Technology

Turbulent Boundary Layer Environment Derivation

Ryan Sorensen
Armen Derkevorkian
Ali Kolaini

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Outline

- Problem
- Motivation
  - Earth Atmosphere Re-entry
  - Mars Entry Descent and Landing
- Method for Deriving an Acoustic Loading Curve
  - Single Point Wall Spectrum Empirical Models
  - Attached Flow Pressure Spectra
  - Scaling for Separated Flow
- Acoustic Loading Results
- Vibroacoustic Analysis
- Future Work

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Problem

- Need to derive environmental loading on a structure exposed to fluid flow and turbulent boundary layer excitation
- Methods for defining acoustic loading due to turbulent flow are currently not well developed
  - NASA Handbook 7005 and various vibroacoustic software codes use methods developed several decades ago based on empirical models
  - Current Computation Fluid Dynamic (CFD) analysis is currently not capable of performing separated flow and shock analyses
- An improvement over current methods may be achievable by using a combination of more recent empirical methods and results from CFD analysis

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Motivation

- Currently working on two separate projects that both require a more sophisticated method of deriving acoustic loading due to turbulent boundary layer (TBL) excitation

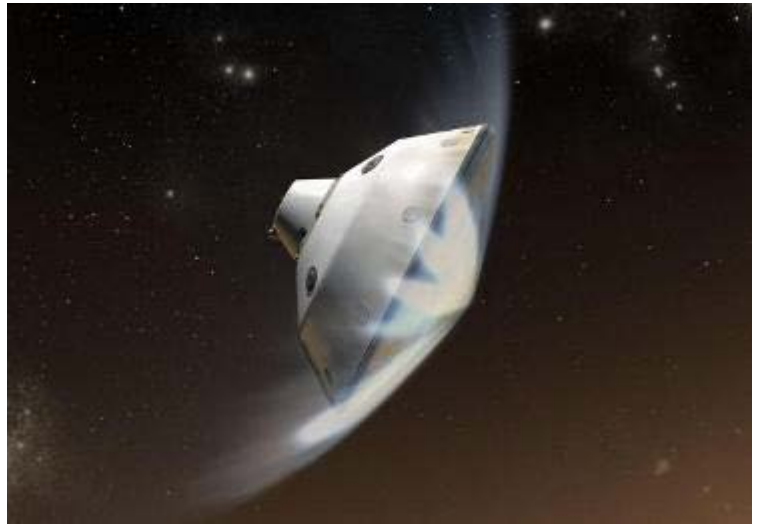
Earth Entry Vehicle (EEV) for Potential Mars Sample Return

- Analysis of blunt nose cone vehicle entering Earth atmosphere carrying samples from Mars

Artist's Concept

Mars 2020 Rover

- Analysis of M2020 Descent Stage during entry to Martian atmosphere



Artist's Concept

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Motivation

- Steps for deriving environment loading of a structure due to TBL excitation
  - Calculate acoustic pressure vs frequency loading to exterior surface of structure
  - Create Finite Element Model of structure and calculate modal frequencies and shapes
  - Import FEM and derived acoustic loading into a vibroacoustic software to perform analysis
- **The method for deriving the acoustic pressure curve will be the main focus of this presentation**

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Single Point Wall Spectrum Models

- Several empirical models have been developed that use experimentally measured flows and pressures at discrete locations to define a relationship between boundary layer parameters and the pressure spectrum (pressure vs frequency) at a point on a structure in a turbulent boundary layer
  - Goody
  - Smol'yakov
  - Effimstov
  - Robertson

Goody Model:

$$W(f) = \frac{6.0\pi(\delta/U_\infty)^3(2\pi f\tau_w)^2}{[(2\pi f\delta/U_\infty)^{0.75}+0.5]^{3.7}+[(1.1R_T^{-0.57})(2\pi f\delta/U_\infty)]^7}$$

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CFD Data

- In order to calculate the pressure spectra using a single point wall spectrum model several boundary layer parameters are needed at many different points along the surface of the structure
  - Boundary Layer Thickness
  - Edge Velocity
  - Friction Velocity
  - Shear Stress at the Wall
  - Kinematic Viscosity
  - Reynold's Number
- Fortunately we were able to leverage some previous analysis work done by NASA AMES and NASA Langley
  - EEV analysis from NASA Ames
  - M2020 analysis from NASA Langley

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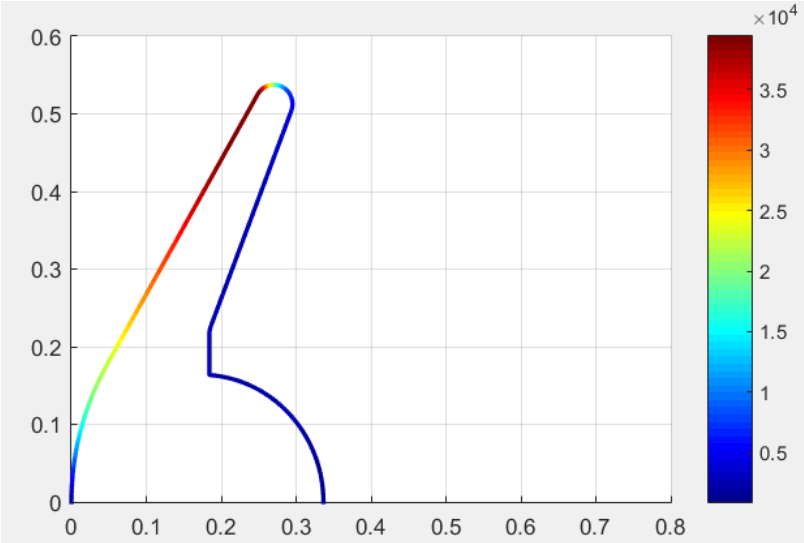
CFD Data

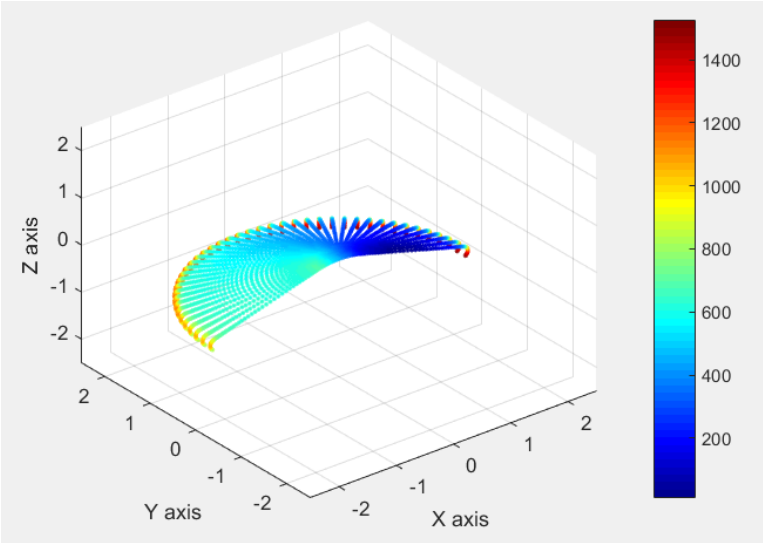
EEV

- Attached flow boundary layer data at 308 points on a 2-d surface at 9 different time instances during Earth atmosphere entry



M2020

- Attached flow boundary layer data at 3014 points on a 3-d surface at 13 different time instances during Mars atmosphere entry



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Solving Single Point Wall Spectrum Models

- Using the CFD data as the inputs to the various single point wall spectrum models results in an acoustic pressure vs frequency spectrum at each grid point for each time step
- The single point wall spectrum models are based off of the concept of scaling due to similarity, so when normalized the pressure vs frequency curves should collapse for similar flow cases
- The calculated acoustic pressure spectra were converted to dimensionless quantities and compared in order to see how well the curves were collapsing as a method to determine if the Single Point Wall Spectrum models were working well with the CFD data or not.

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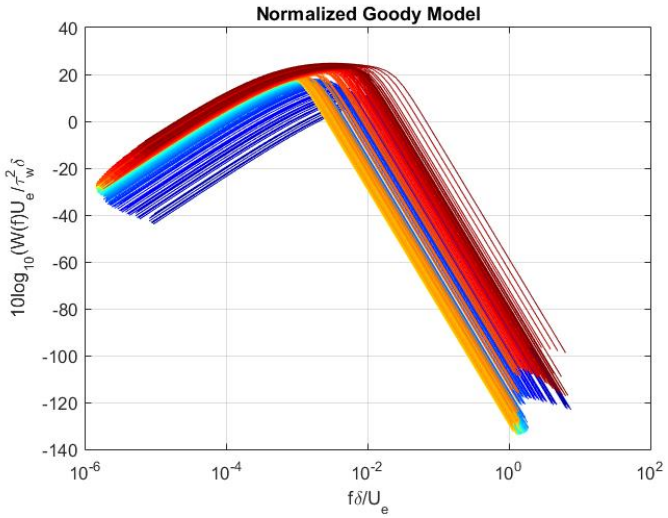
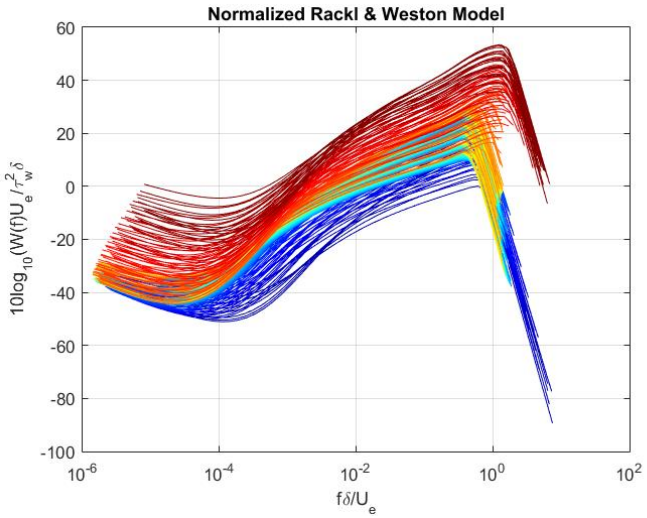
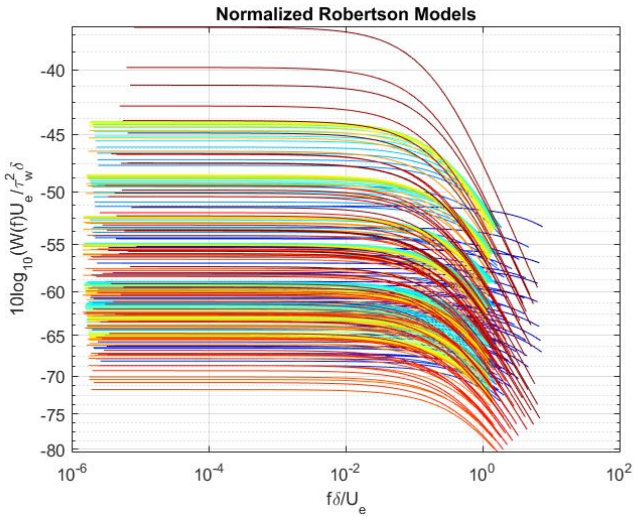
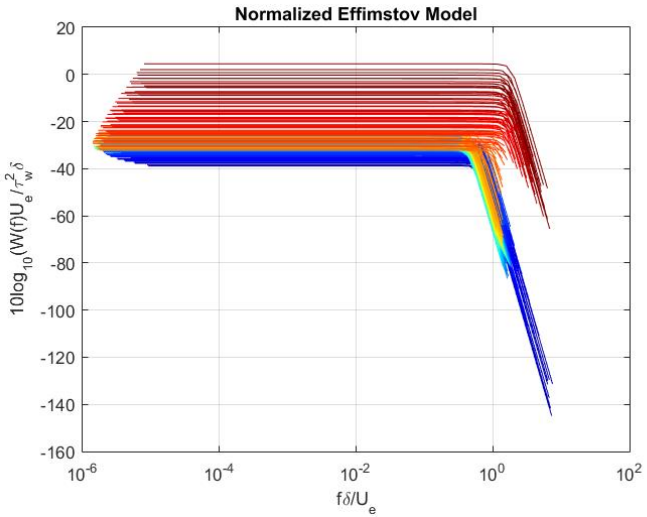
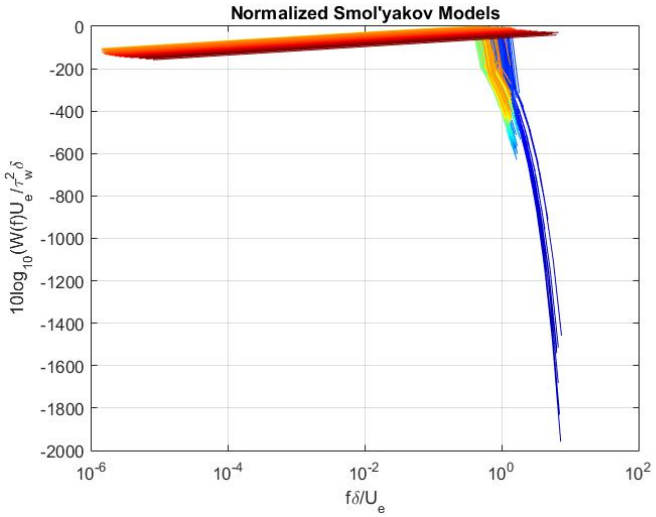
Solving Single Point Wall Spectrum Models











- Plots show normalized model results at 40 grid points along EEV at different time steps

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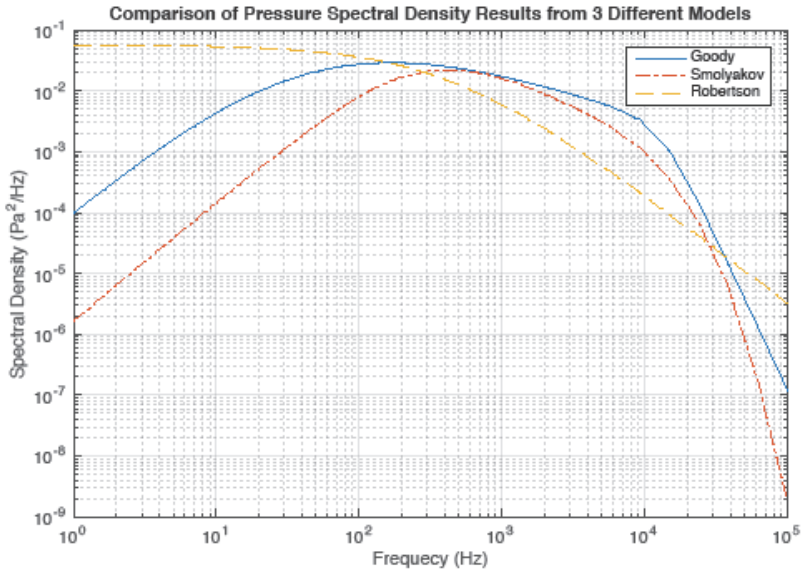
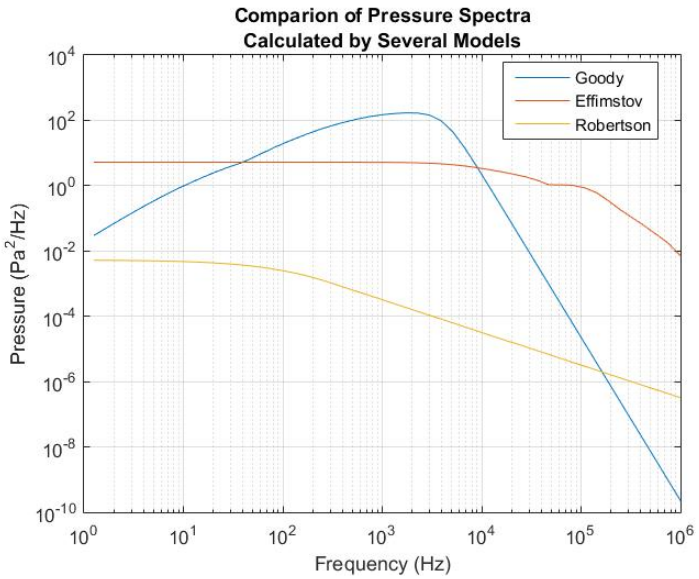
Solving Single Point Wall Spectrum Models

- After reviewing the results it was determined that the estimates from the Goody Model were the most appropriate for this particular application
- The main reason for this decision is that the Goody Model curves tended to provide spectra with highest levels in the mid frequency range and rolled off at higher frequencies as typically energy rolls off at higher frequencies





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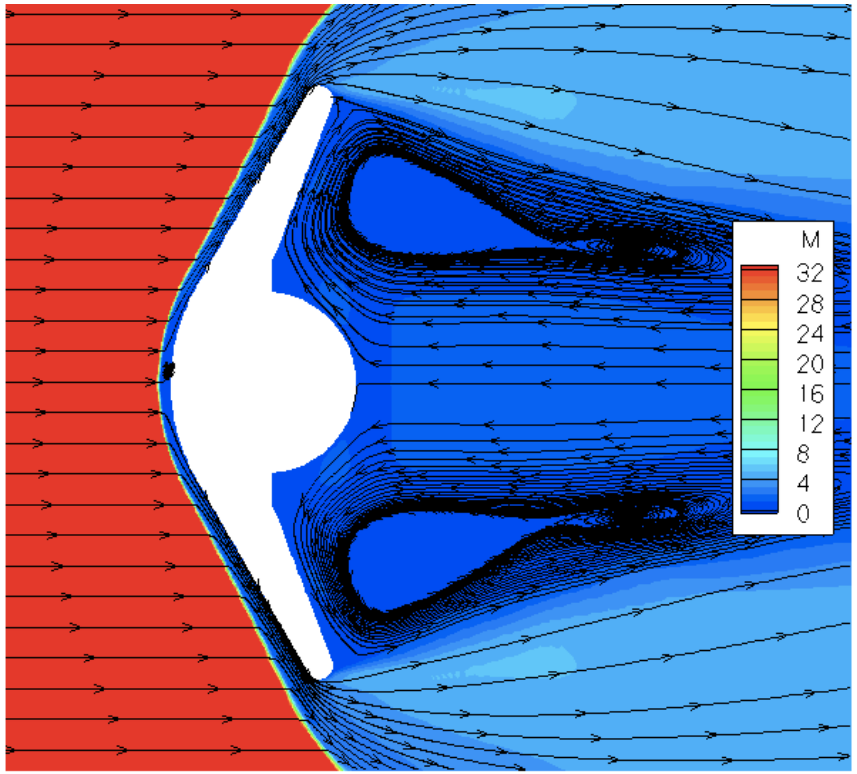
Scaling for Separated Flow

- When the velocity of the flow very close to the wall reverses the flow detaches and forms a wake with large eddies
- Occurs when flow passes over curved surfaces, compression corners, etc
- Acoustic loading due to separated flow is greater than attached flow and must be accounted for since it is likely to occur at the shoulders of any re-entry vehicle



MMEEV Aero Analysis (NASA Ames)

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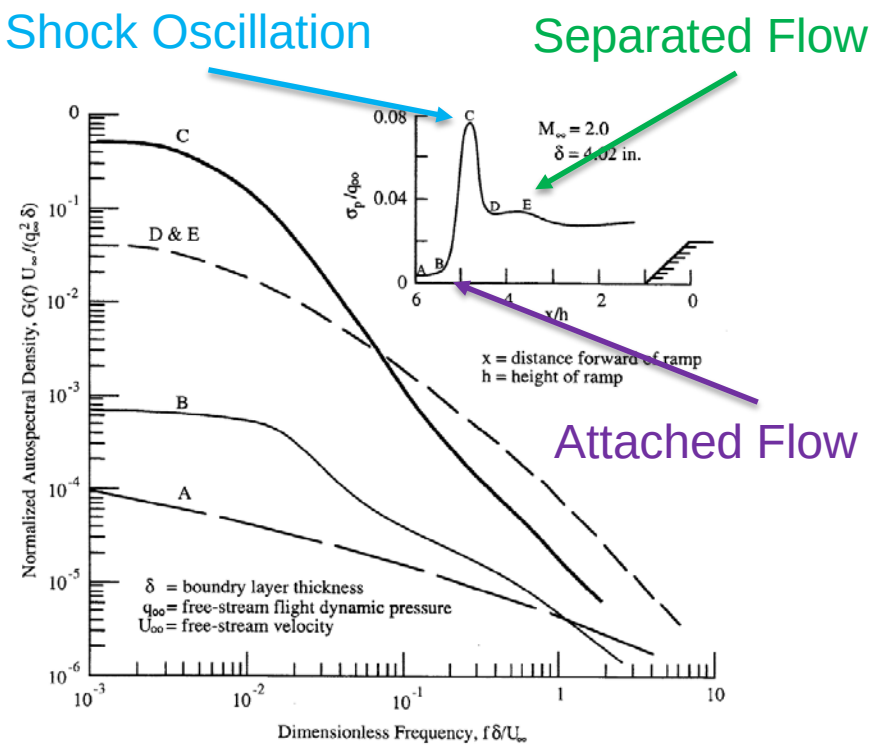
Scaling for Separated Flow

- It is a challenging task to simulate separated flow using currently available CFD codes, therefore it is necessary to use empirical methods again
- NASA Handbook 7005 has dimensionless pressure spectra at various points along a separating flow
- Simple method for scaling to account for separated flow is used
  - Create approximate curves for the different points along flow
  - Calculate the ratio between the curves and apply it to the attached flow results



NASA Handbook 7005

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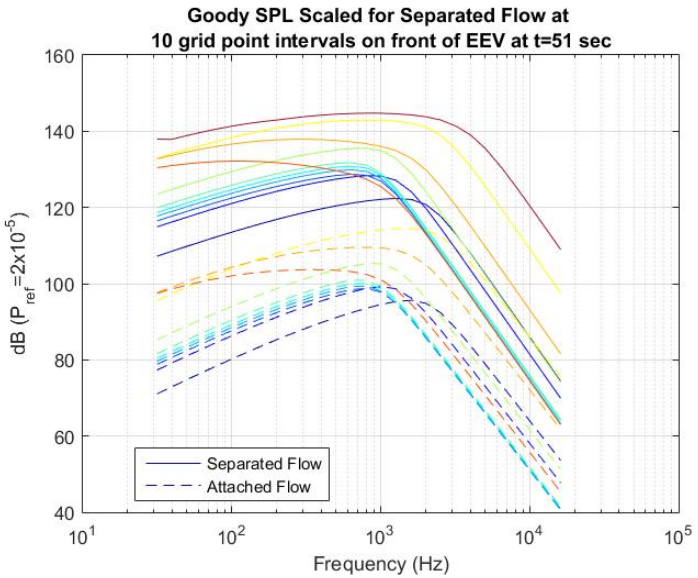
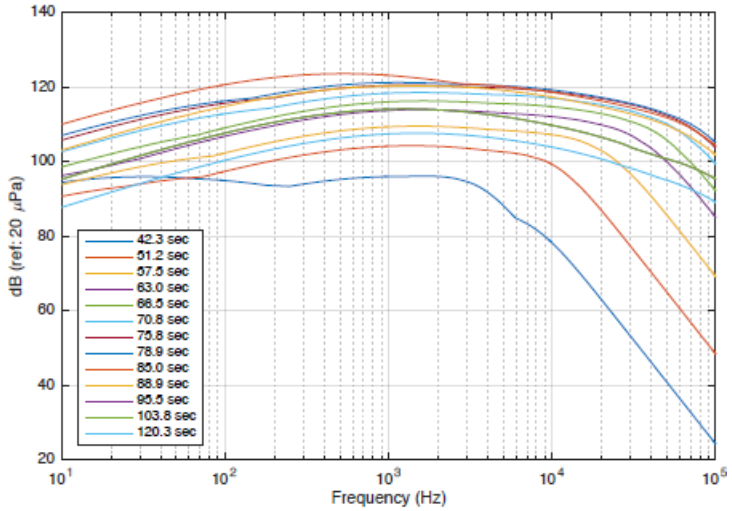
Scaling for Separated Flow

- Ratio from curve A to Curve D&E was applied to all Goody model curves
- Max responses at each frequency were used to envelope results and set as Flight Acceptance level acoustic loading



EEV Scaled Goody Spectra at different grid locations



M2020 Scaled Goody Spectra at different time instances

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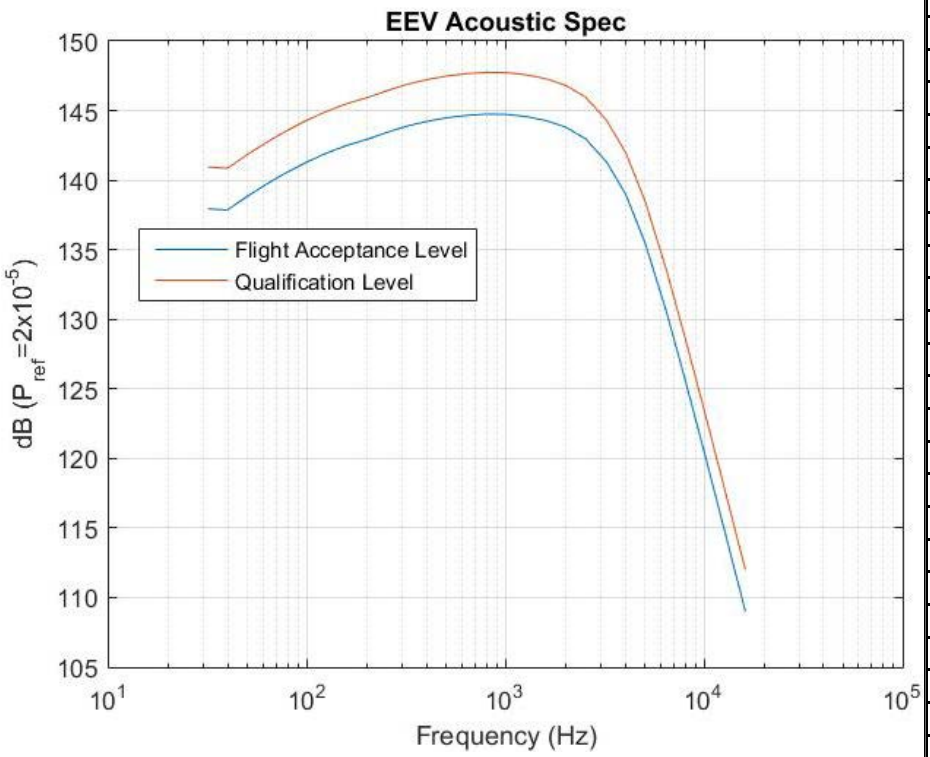
EEV Acoustic Loading Results

- The acoustic spec calculated is intended to provide an envelope of expected acoustic loading with additional margin
- The methods used to calculate the spec still involves a good deal of approximation but is an improvement to previous methods



One-third Octave Band Center Frequency, Hz	Flight Acceptance Level, dB	Qualification / Protoflight Level, dB
31.5	138	141
40	138	141
50	139	142
63	140	143
80	141	144
100	141	144
125	142	145
160	142	145
200	143	146
250	143	146
315	144	147
400	144	147
500	144	147
630	145	148
800	145	148
1000	145	148
1250	145	148
1600	144	147
2000	144	147
2500	143	146
3150	141	144
4000	139	142
5000	135	138
6300	131	134
8000	126	129
10000	120	123
Overall SPL (dB)	156	159

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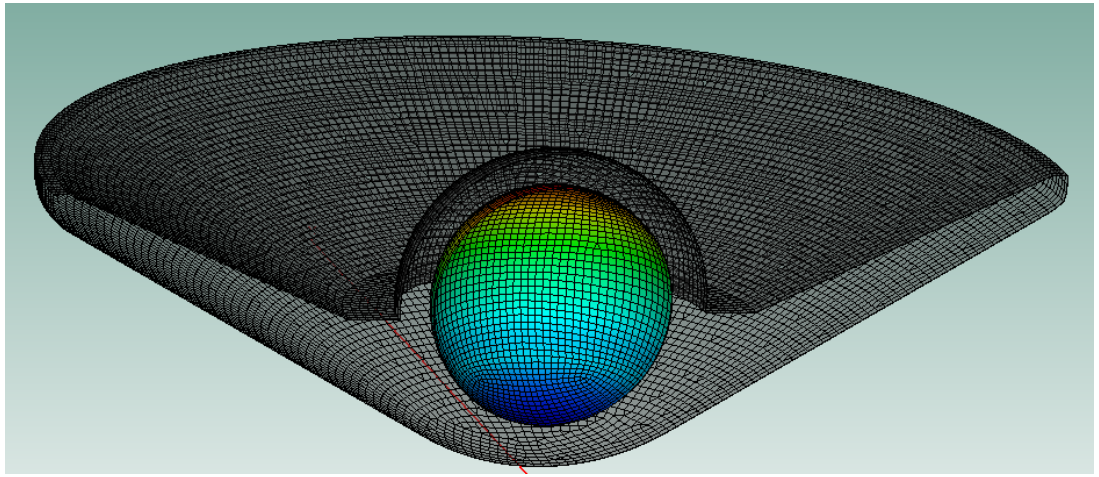
Vibroacoustic Analysis

- After acoustic spec is derived it can be used along with a FEM of the structure to calculate the acceleration and stress loading on the structure



Orbiting Sample interface random vibration loading due to acoustic excitation

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Future Work

- Apply this method on M2020 vibroacoustic analysis
- Currently developing a GUI that will allow a user to easily import boundary layer data from CFD analysis in a variety of formats and derive the acoustic loading using one of the single point pressure spectrum models

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Acknowledgements

- NASA Ames Research Center
- NASA Langley Research Center

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Backup

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M2020 Normalized Results

- Plots show normalized model results at all points on M2020 heat shield at one time step
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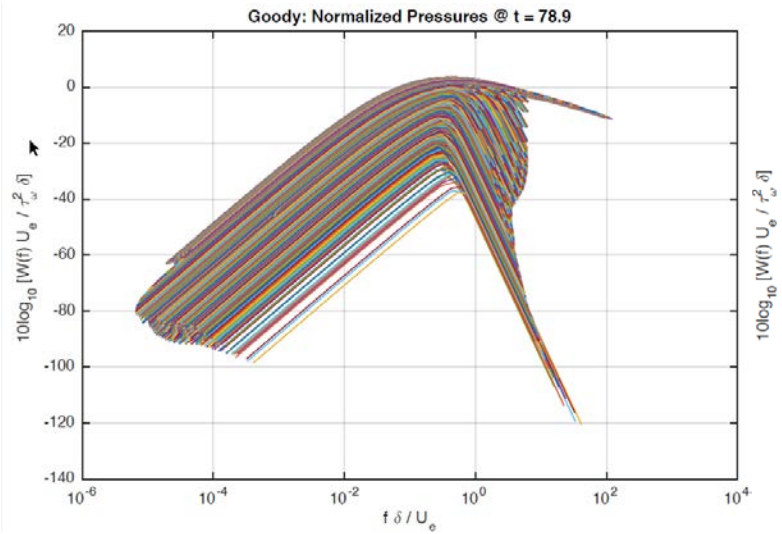

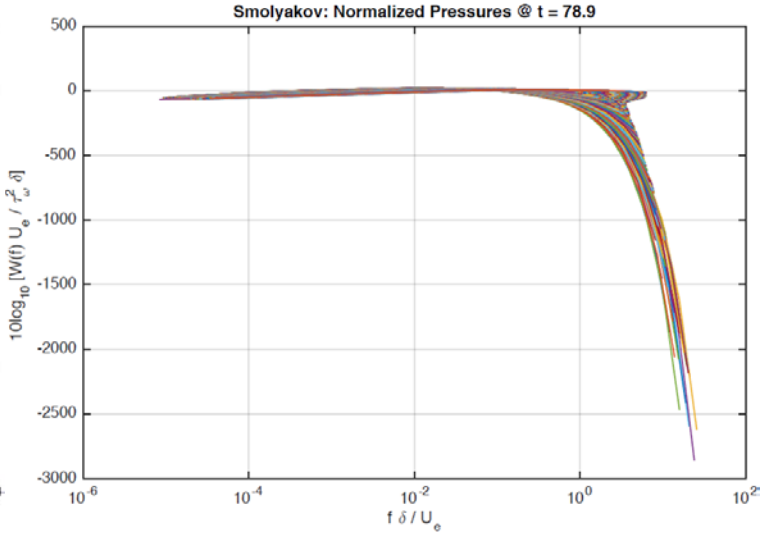

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