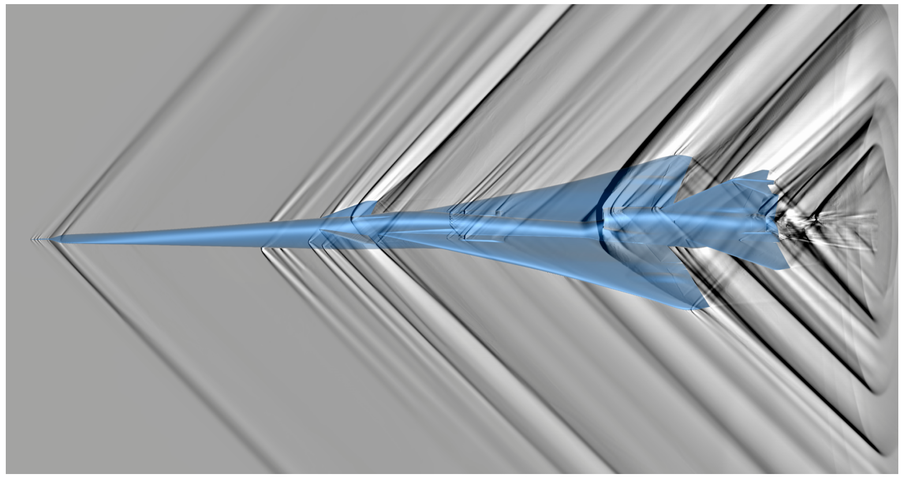
Sonic Boom Ground Noise Minimization Via the Adjoint Method



David L Rodriguez
Science & Technology Corp.
Michael Aftosmis, Marian Nemec, Sriram Rallabhandi
NASA Ames Research Center

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Motivation

- Recent increased interest in low-boom supersonic aircraft

§ 91.818 Special flight authorization to exceed Mach 1.

"For all civil aircraft, any operation that exceeds Mach 1 may be conducted only in accordance with a special flight authorization issued…"

  - X-59 QueSST designed for low-boom
  - goal is to produce data that can guide changes in the regulations to allow for quiet supersonic flight over land

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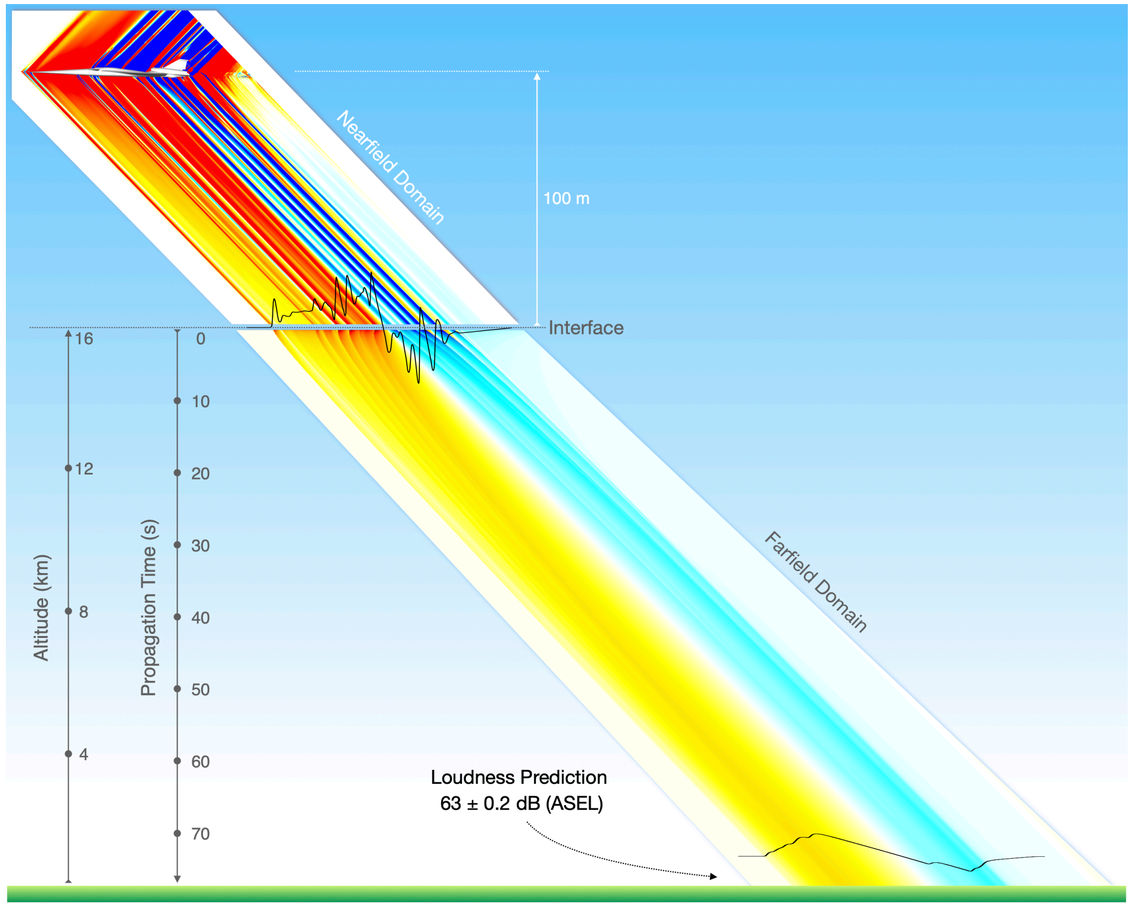
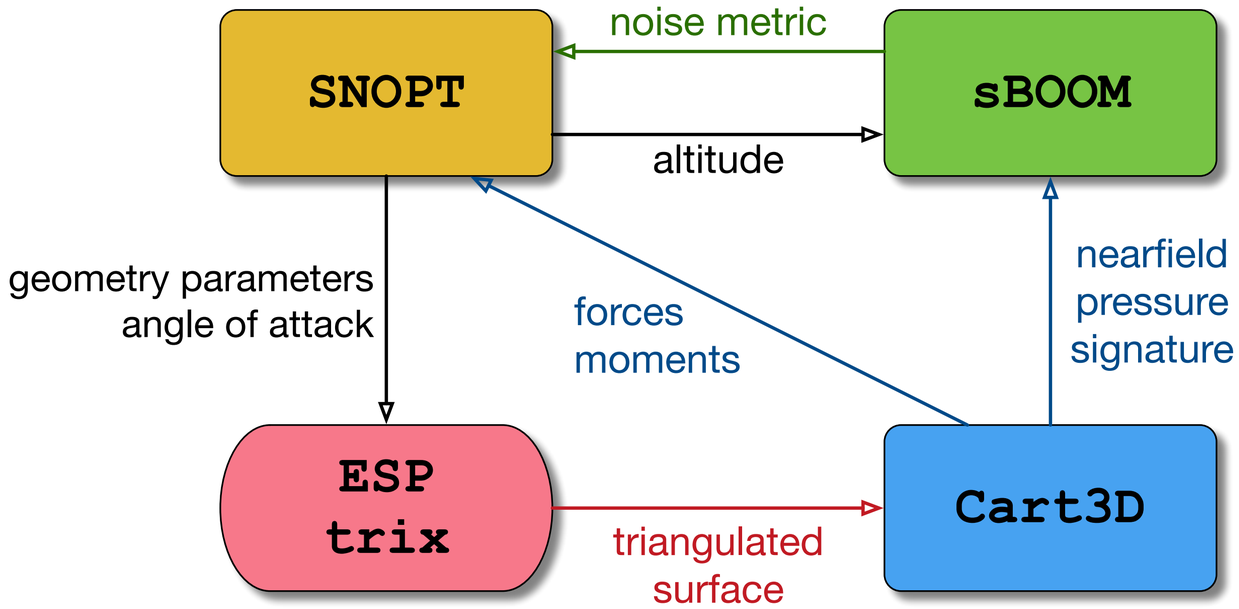
  - X-59 QueSST designed for low-boom
  - goal is to produce data that can guide changes in the regulations to allow for quiet supersonic flight over land
- Mature ground-level noise analysis methodology
  - CFD computes near-field
  - Atmospheric propagation tool computes ground signal
  - Signal processed to compute noise metric such as ASEL
- Can modern design optimization methods exploit this capability and optimize directly for noise?



Design Optimization Tool for Low-Boom

- Consists of 4 tools
  - Geometry modeler
    - **`ESP`** - constructive CAD-based geometry system
    - **`trix`** - deflects control surfaces
  - **`Cart3D`** - Cartesian Euler solver that computes near-field pressure signature
  - **`sBOOM`** - atmospheric propagation and noise metric calculation
  - **`SNOPT`** - gradient-based nonlinear optimizer
- Typical design optimization
  - Objective is noise metric
  - Constraints on aircraft forces and moments
  - Bounded design variables include geometry shape, control surface deflections, angle of attack, and altitude



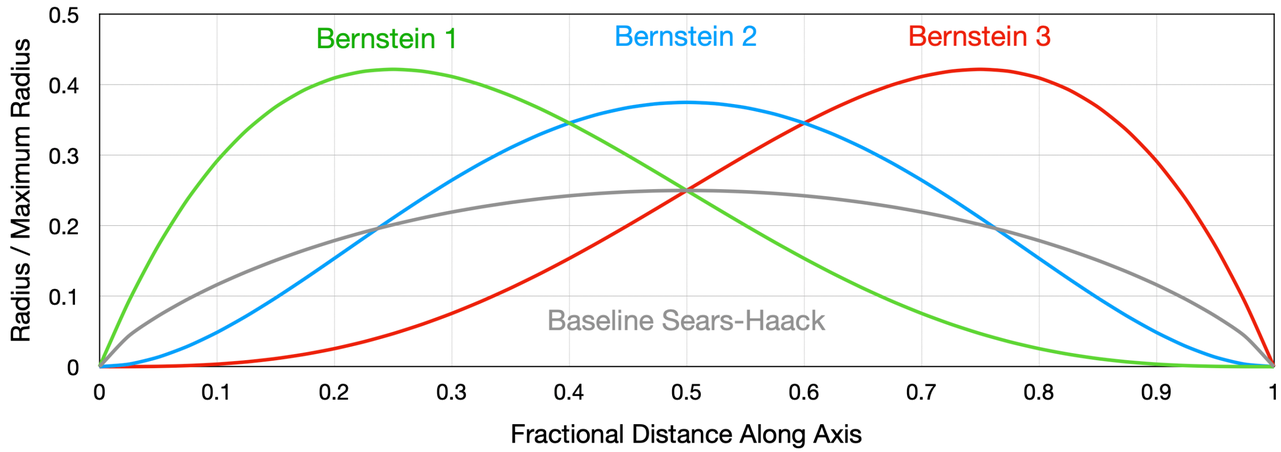
*values and **sensitivities** are passed between tools*

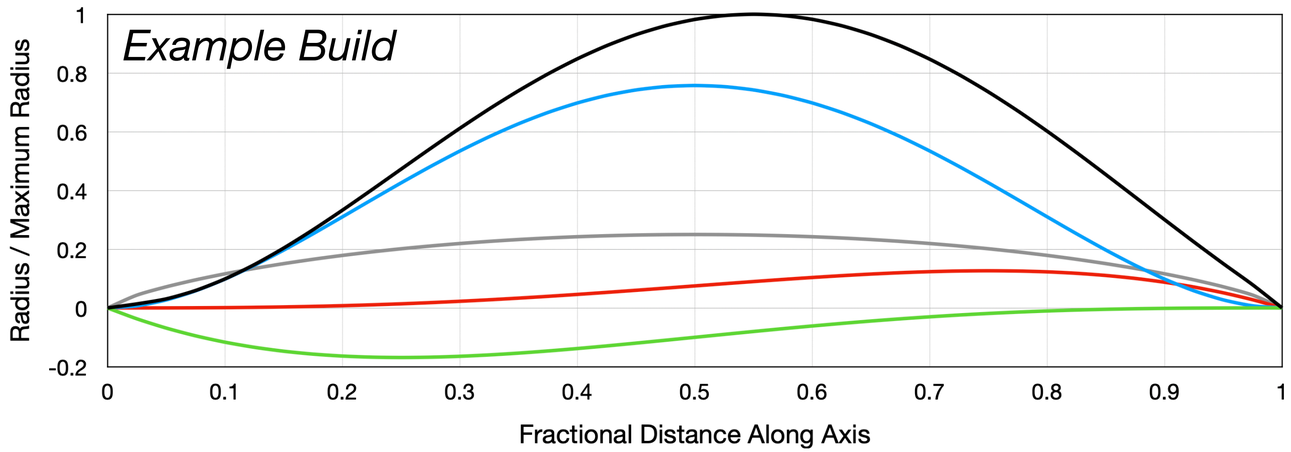
Simple Axisymmetric Body - Parameterization

- 200 feet long
- Constrained to have maximum radius of at least 5 feet

Simple Axisymmetric Body - Parameterization

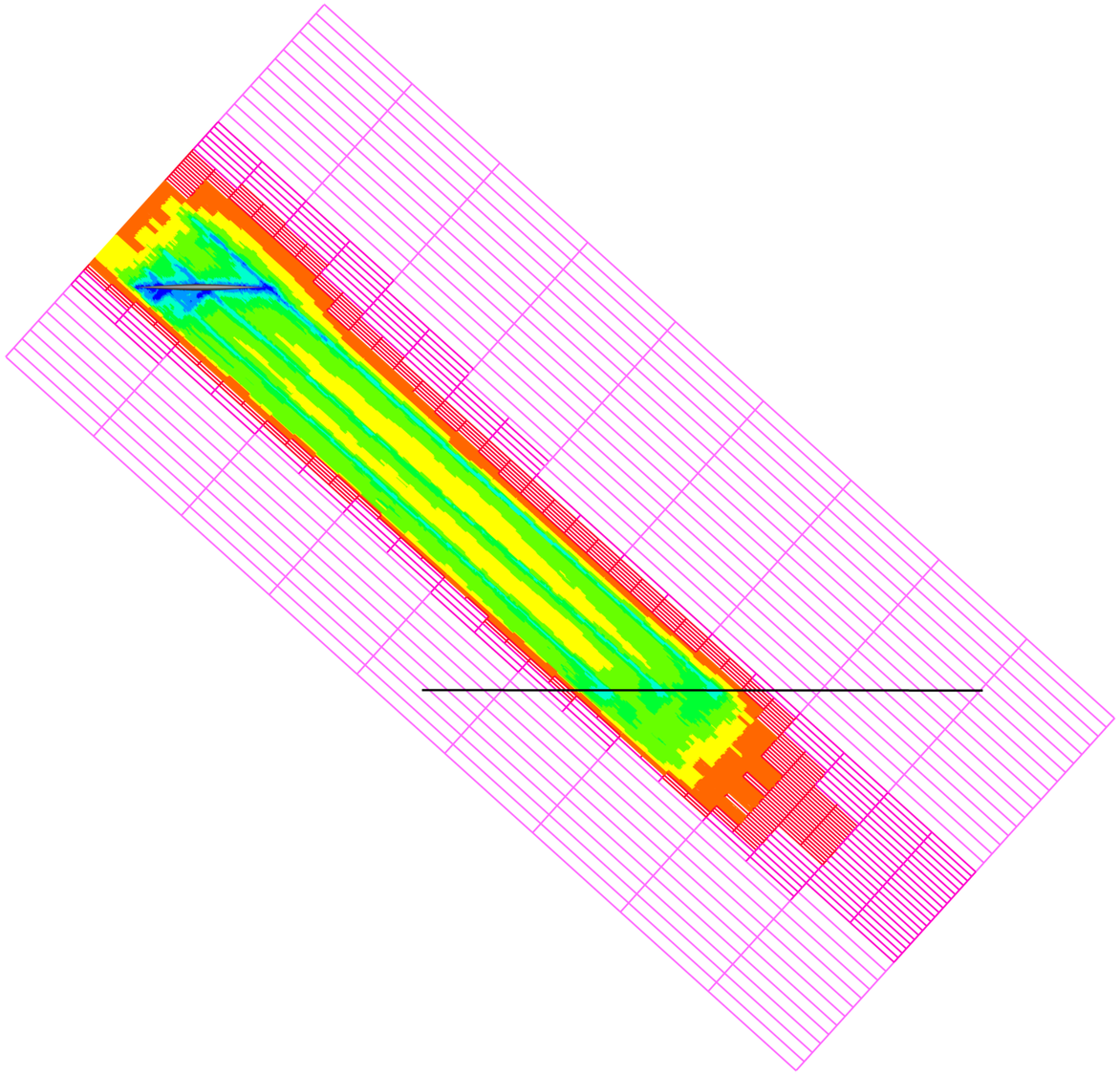
- 200 feet long
- Constrained to have maximum radius of at least 5 feet
- Constructed by superimposing
  - Sears-Haack body with radius of 1.25 feet (fixed)
  - 3 of the 4th-order Bernstein polynomials (each scaled)
- Parameterization is the scale factors of each polynomial





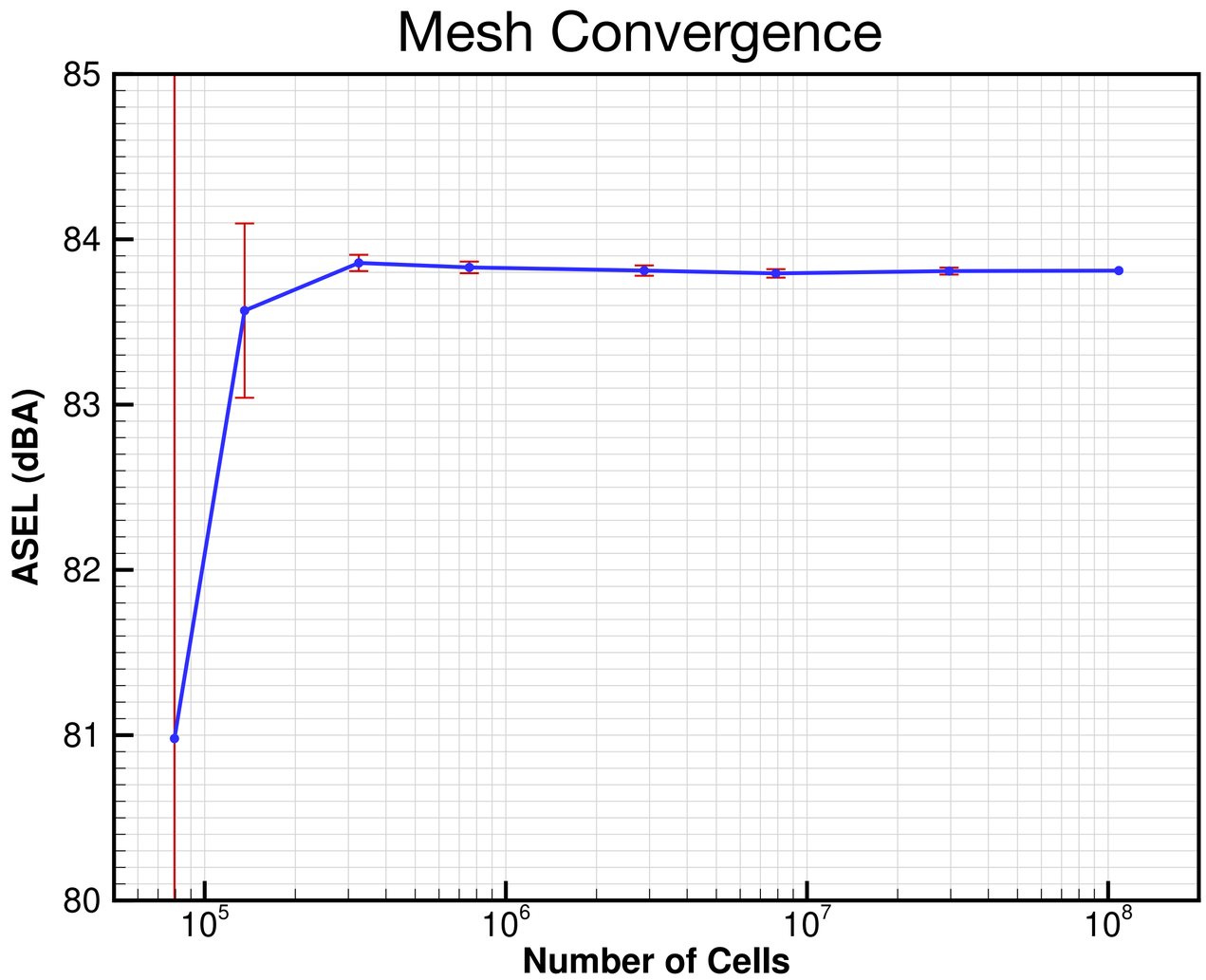
Simple Axisymmetric Body - Noise Analysis

- Cart3D mesh is Mach-wave aligned and stretched
- Near-field sensor is 3 body lengths below
- Adapted for ASEL resulting in final mesh just over 100 million cells



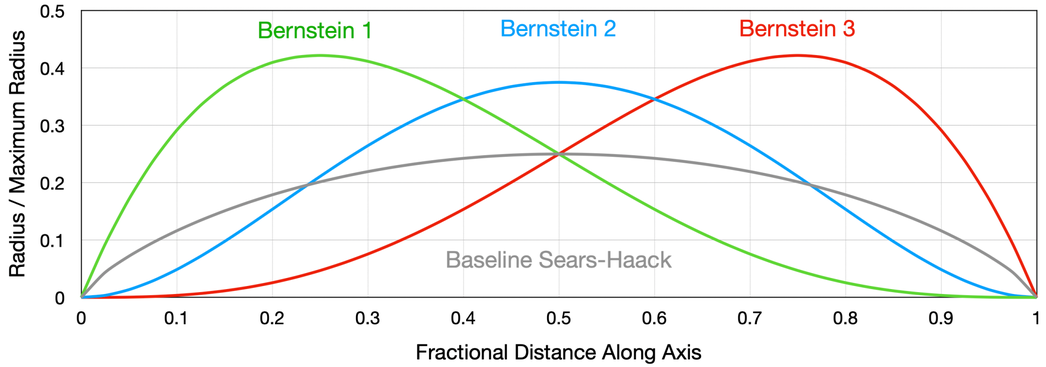
Simple Axisymmetric Body - Noise Analysis

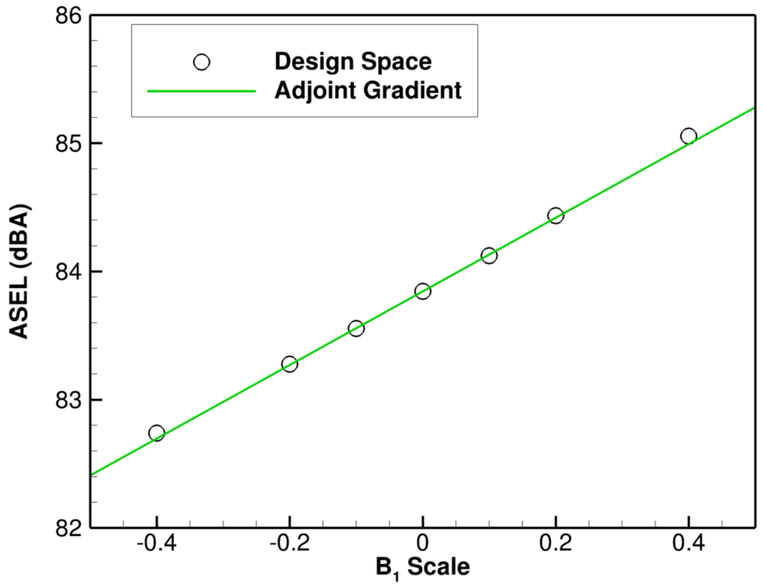
- Cart3D mesh is Mach-wave aligned and stretched
- Near-field sensor is 3 body lengths below
- Adapted for ASEL resulting in final mesh just over 100 million cells
- Excellent convergence of functional
- Error estimates suggest value is correct to within 0.1 dBA

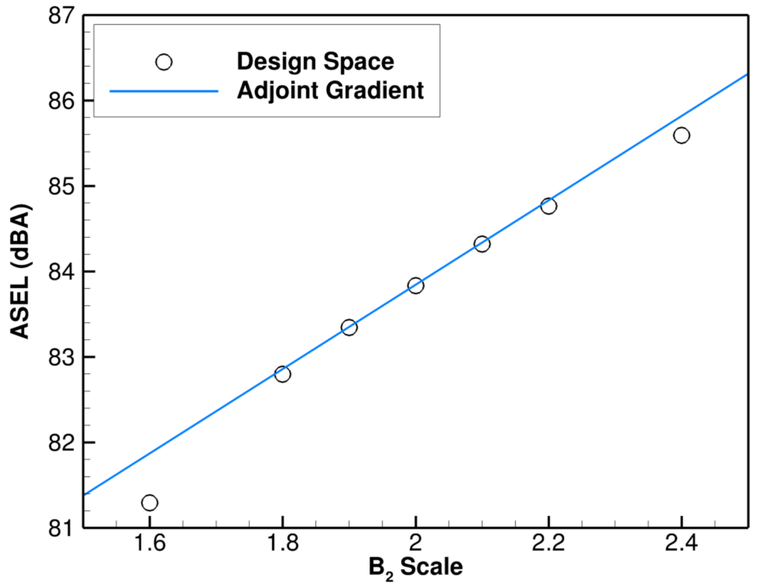


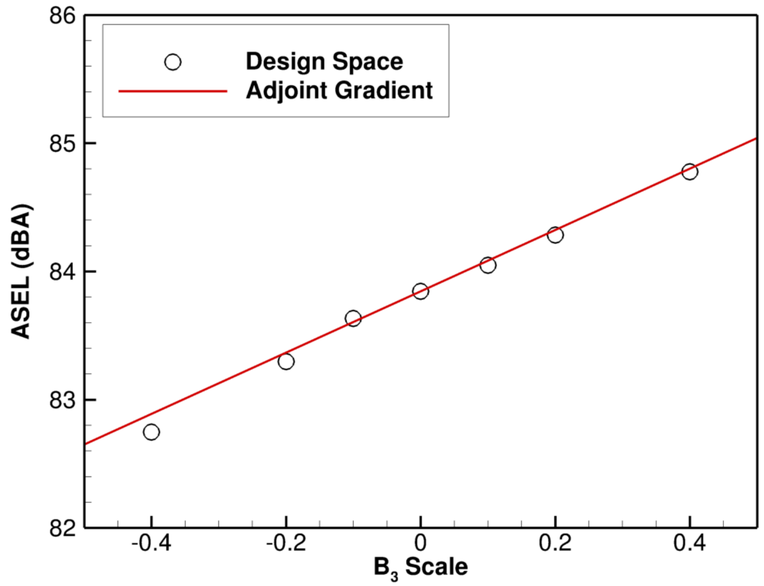
Simple Axisymmetric Body - Gradient Check

- Compute gradients
- Compare to sampled design space
- All gradients found to be very accurate



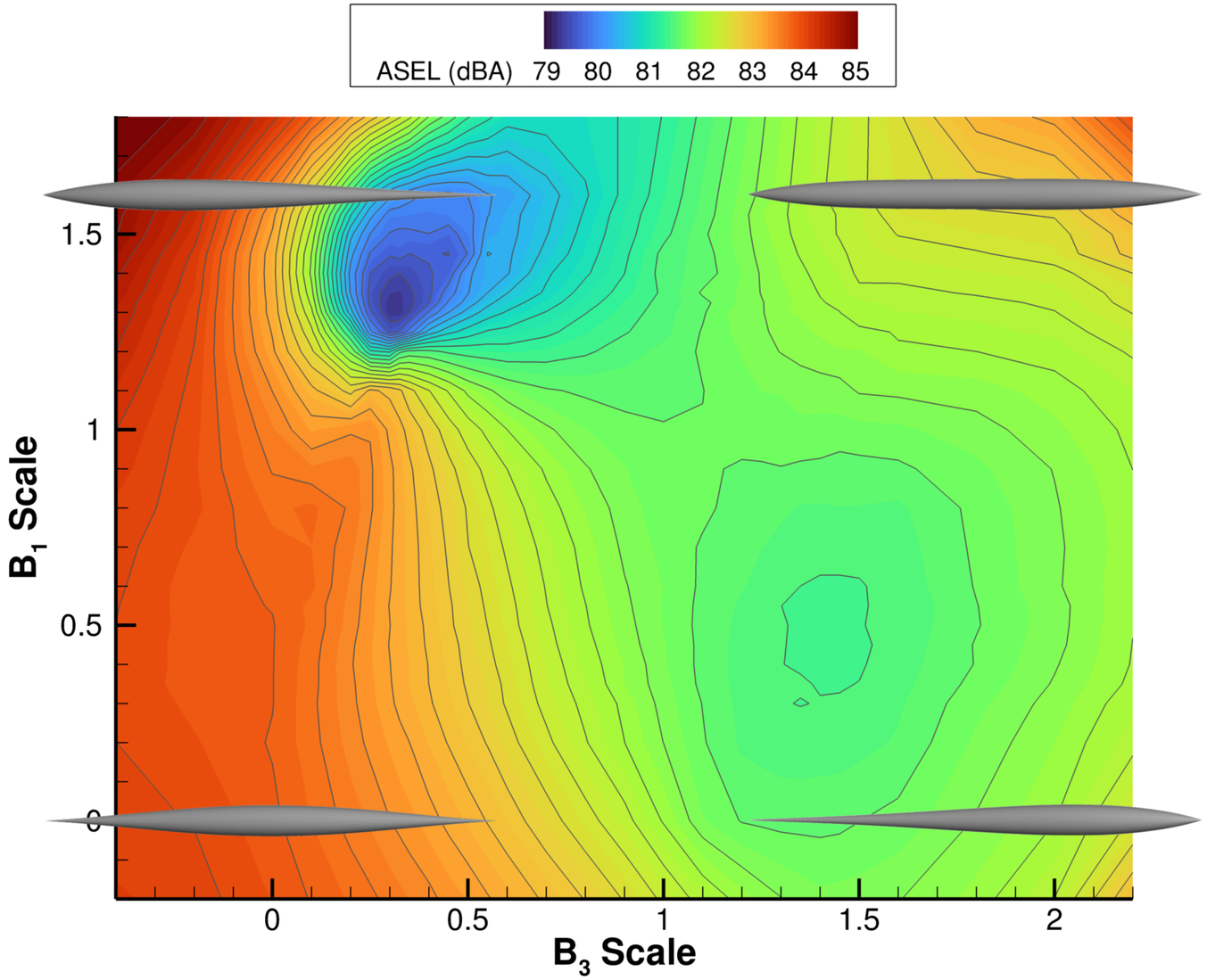






Simple Axisymmetric Body - Design Space Exploration

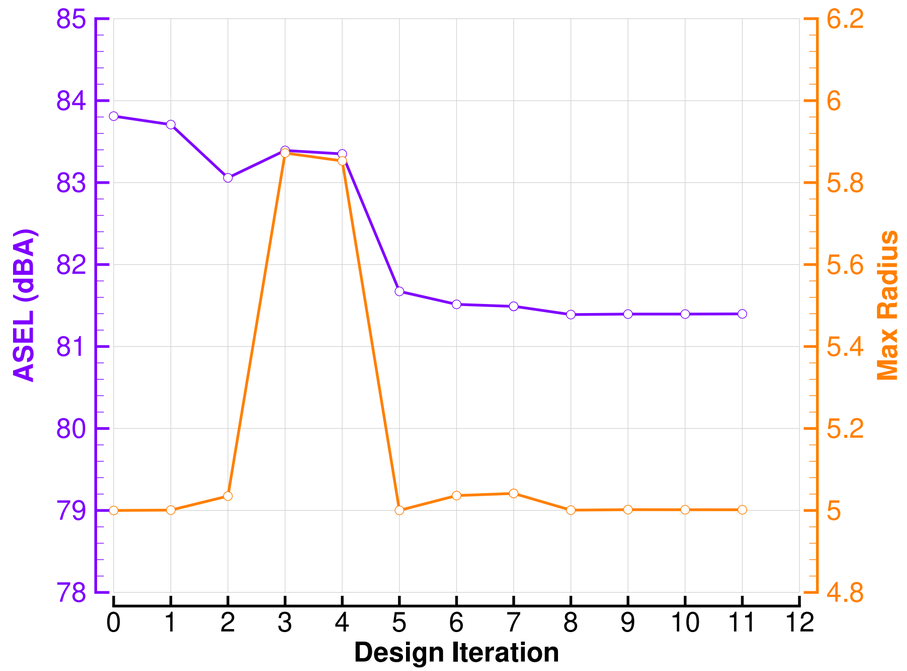
- 3 parameters and 1 constraint allows for design space exploration in 2 dimensions
- 780 analyses varying B_1 and B_3 scales, setting B_2 to keep maximum radius exactly 5 feet
- Space is clearly multimodal and yet quite smooth



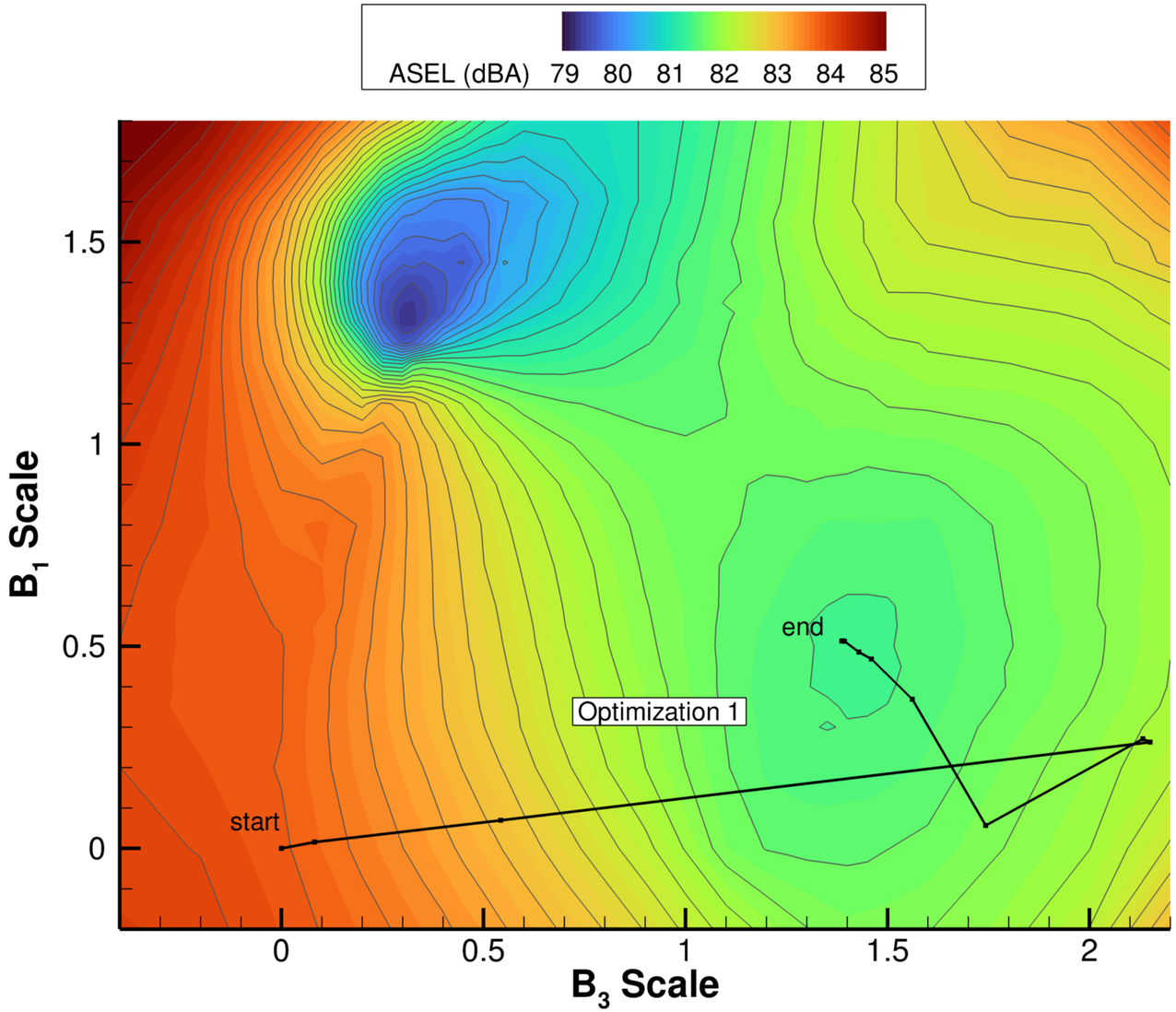
Simple Axisymmetric Body - First Optimization

- Start near lower left hand corner of sampled space

initial



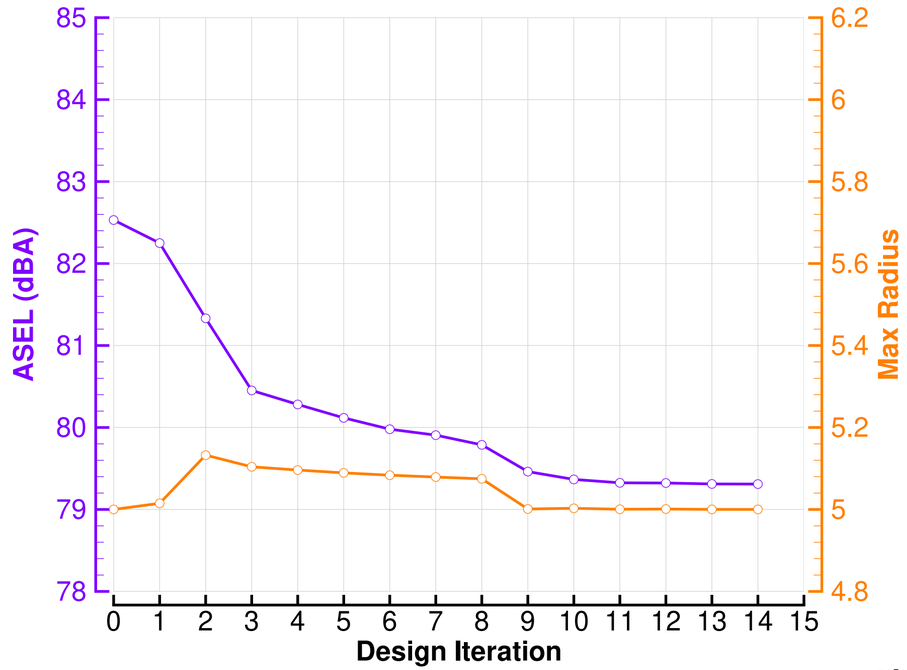
optimized



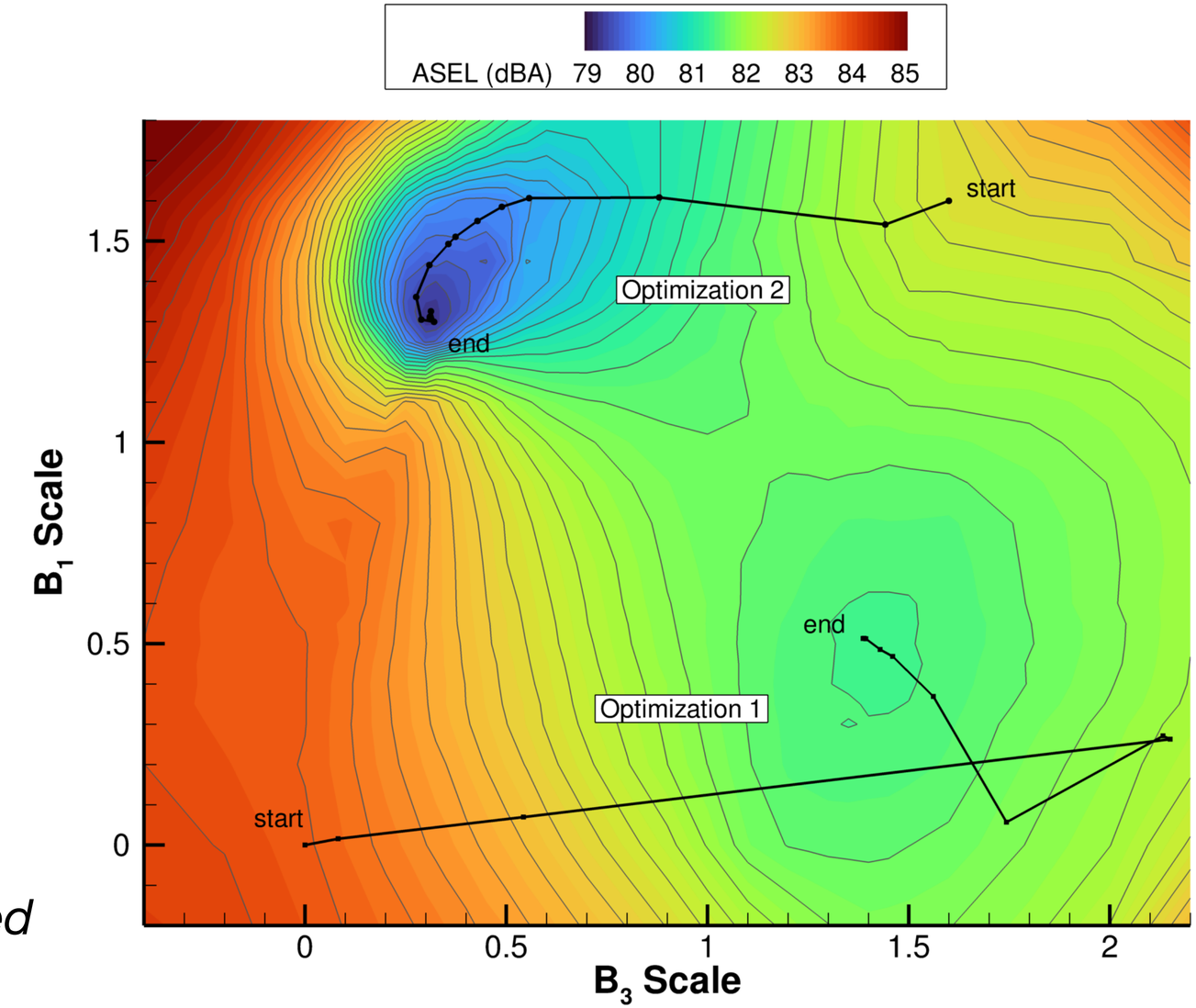
Simple Axisymmetric Body - Second Optimization

- Start near upper right hand corner of sampled space

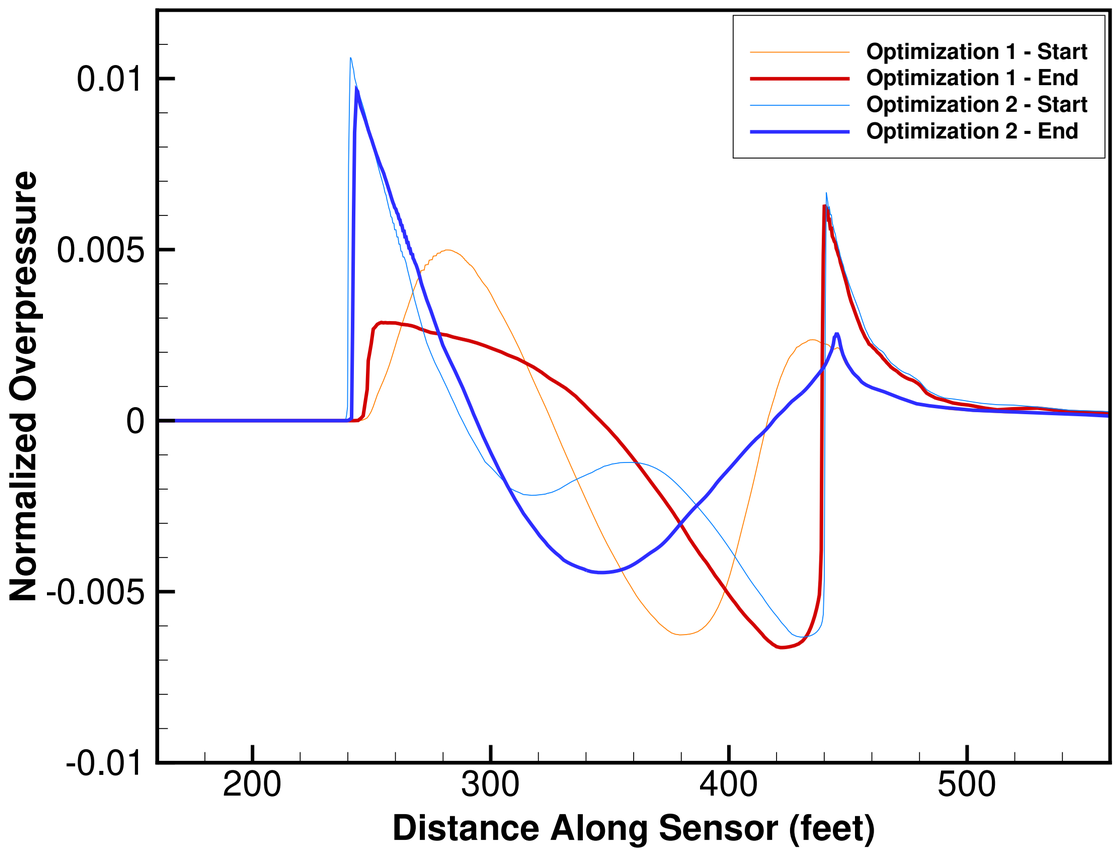
initial



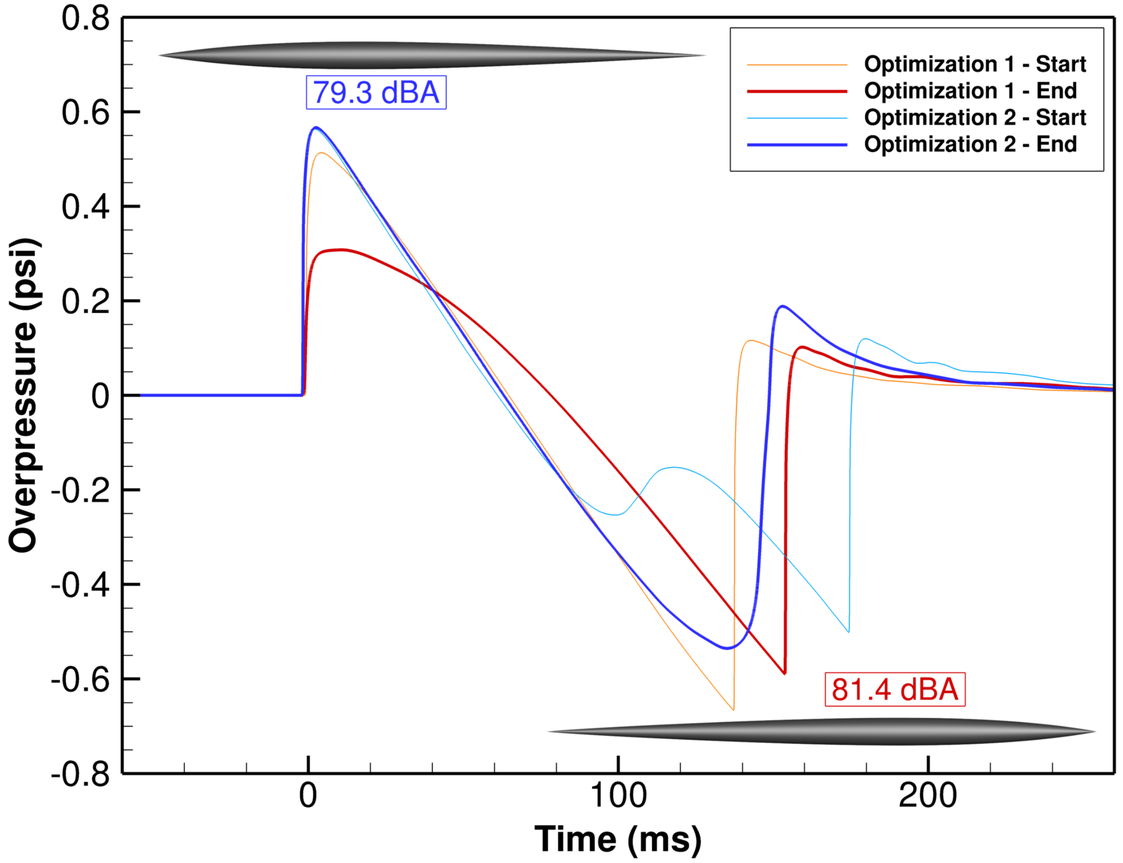
optimized



Simple Axisymmetric Body - Pressure Signatures

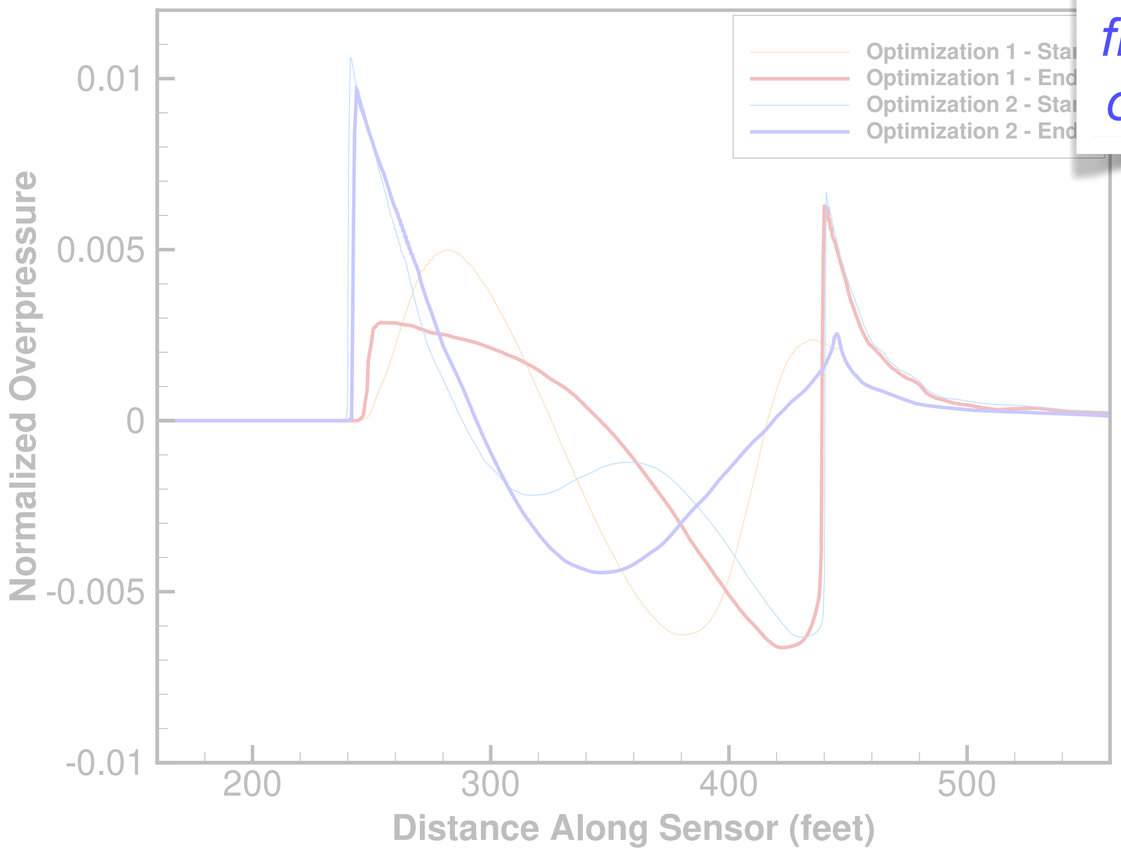


Near-field



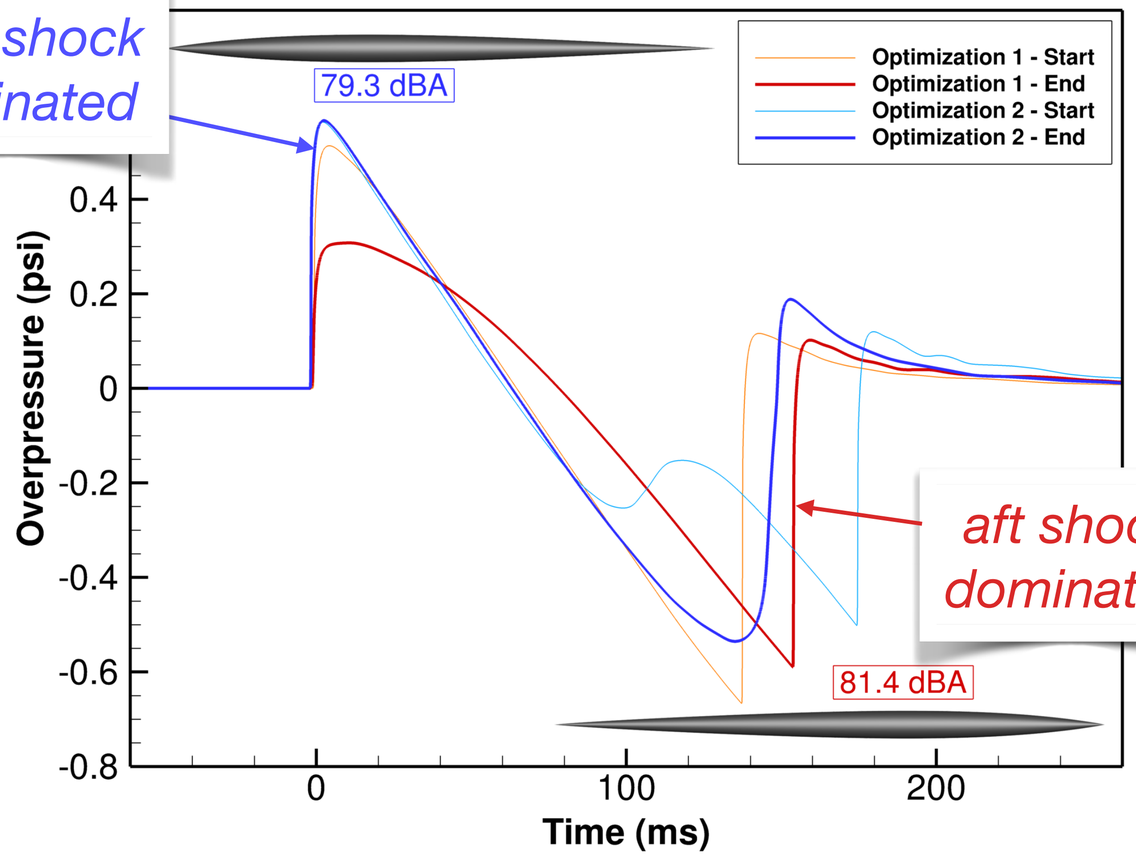
Ground

Simple Axisymmetric Body - Pressure Signatures



Near-field

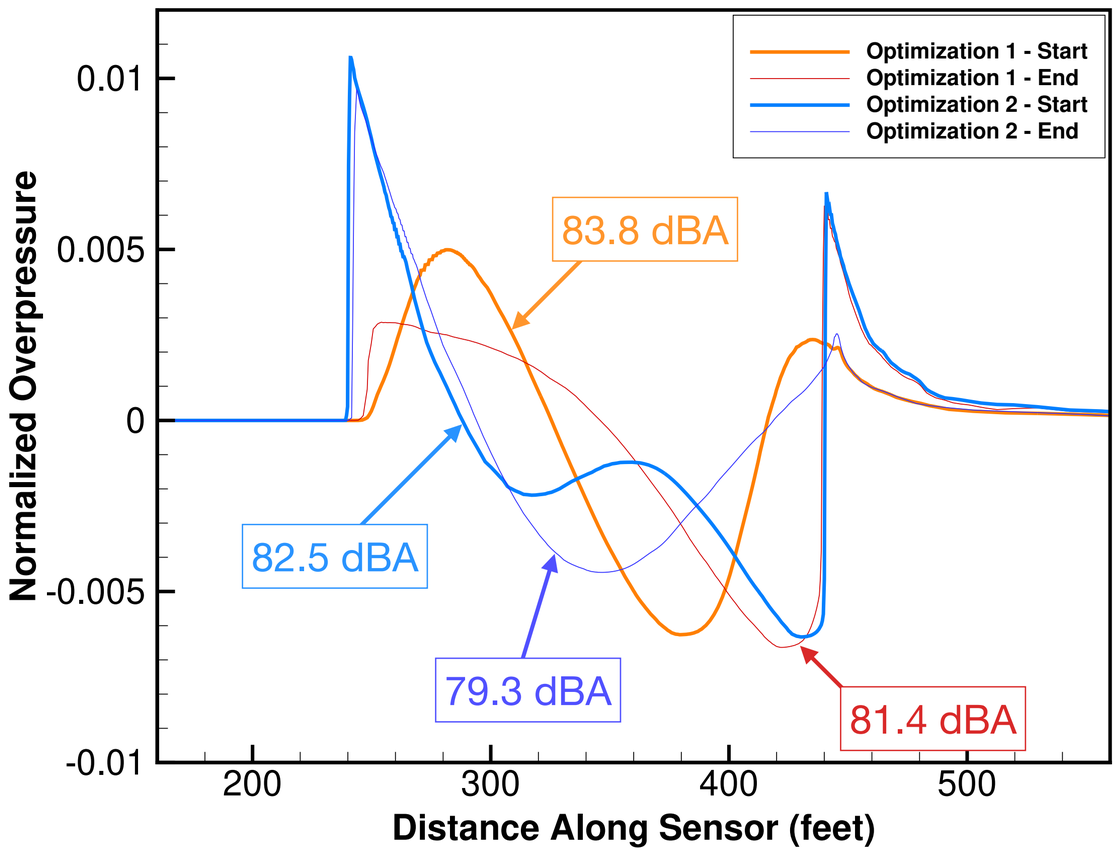
front shock dominated



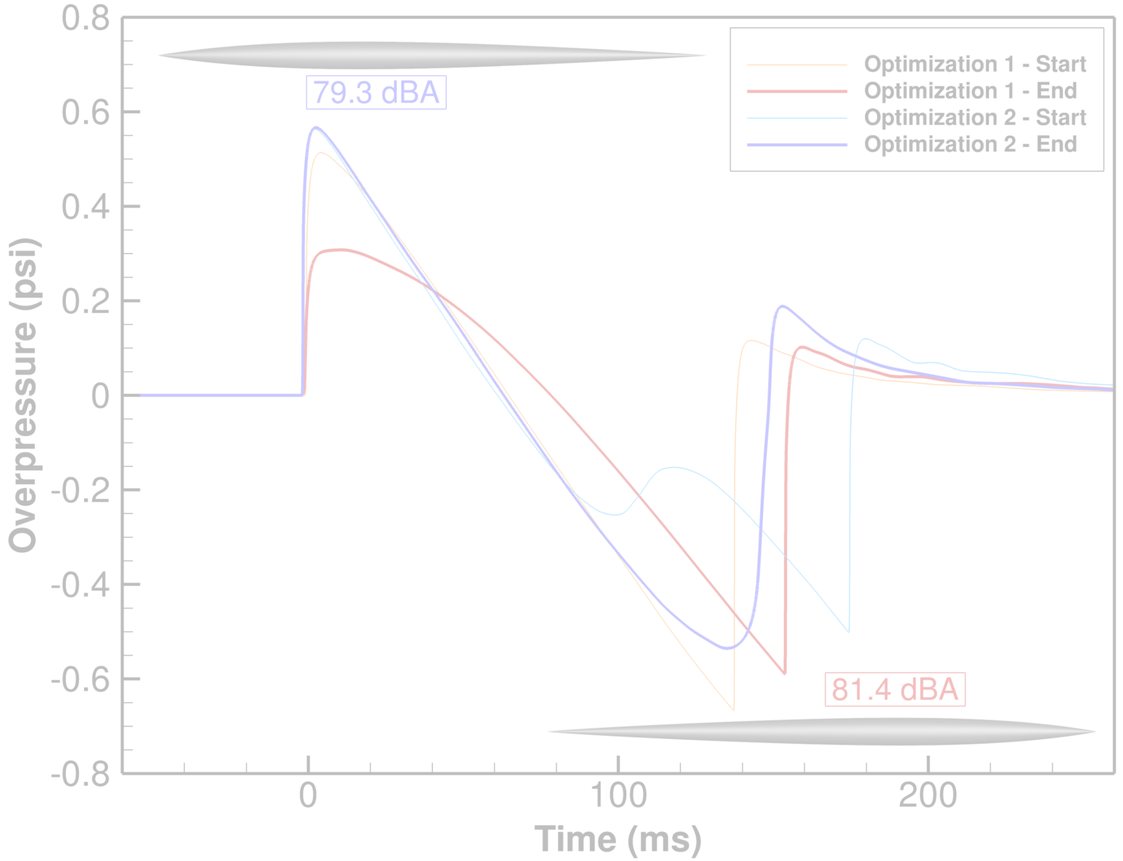
aft shock dominated

Ground

Simple Axisymmetric Body - Pressure Signatures



Near-field



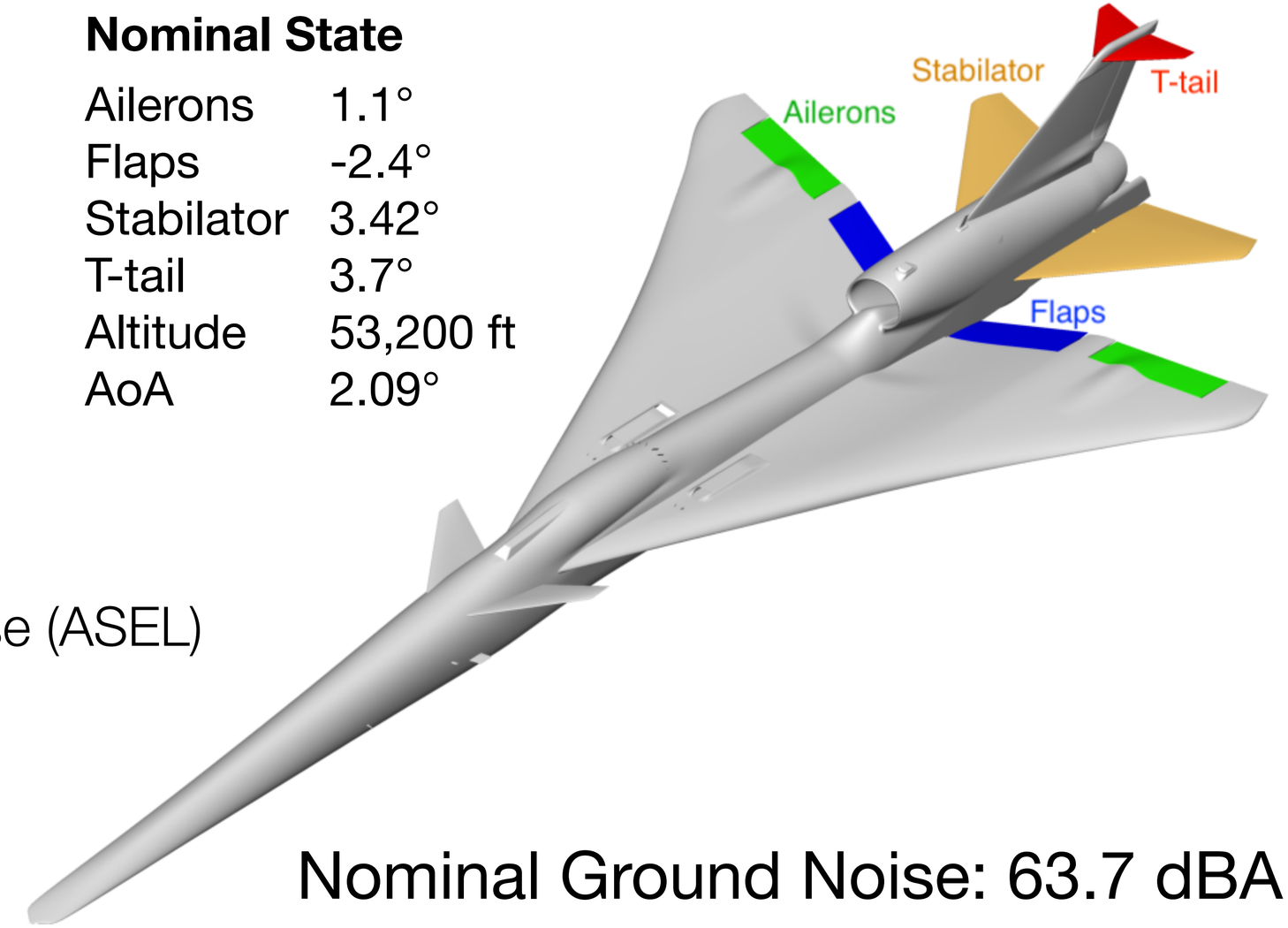
Ground

X-59 QueSST Aircraft - Control Surface Optimization

- Cruise condition
  - Mach 1.4
  - 52,000 - 54,000 feet altitude
- Design variables
  - control surface deflections
  - altitude
  - angle of attack
- Objective: minimize ground noise (ASEL)
- Constraints
  - cruise lift
  - longitudinal trim

Nominal State

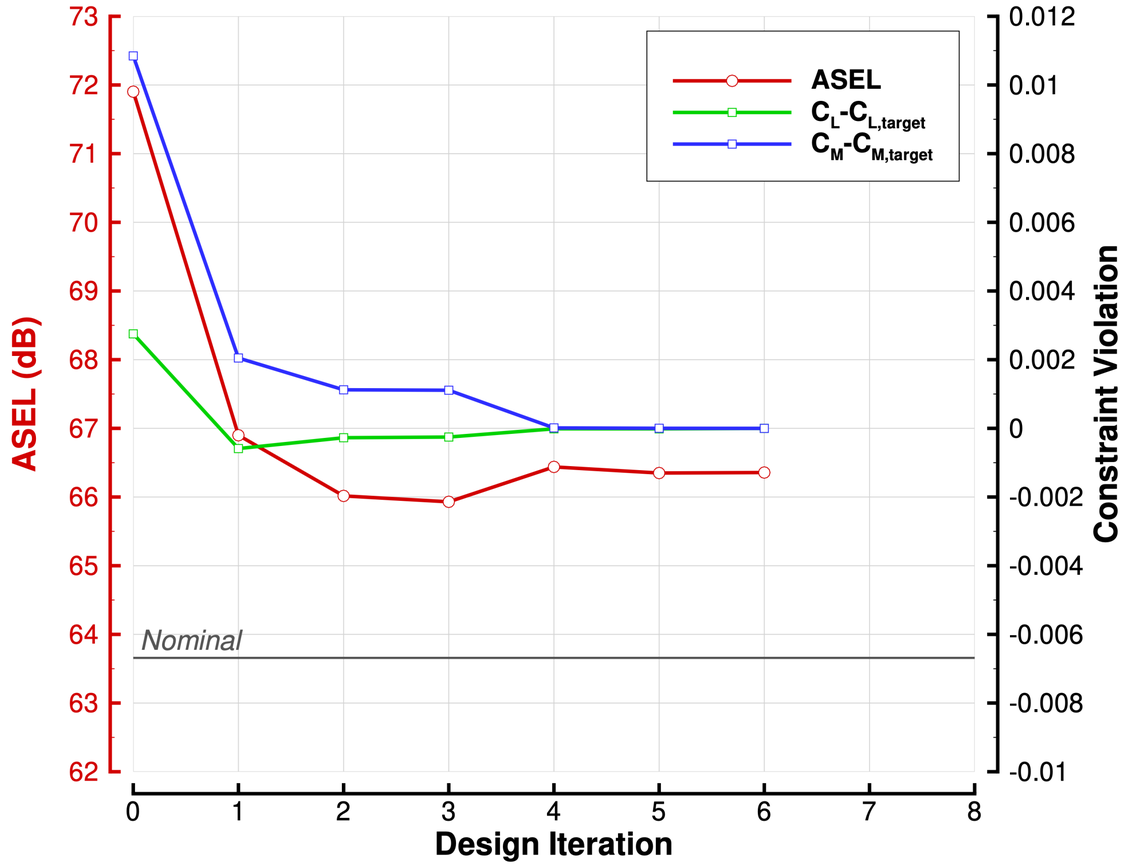
Ailerons	1.1°
Flaps	-2.4°
Stabilator	3.42°
T-tail	3.7°
Altitude	53,200 ft
AoA	2.09°

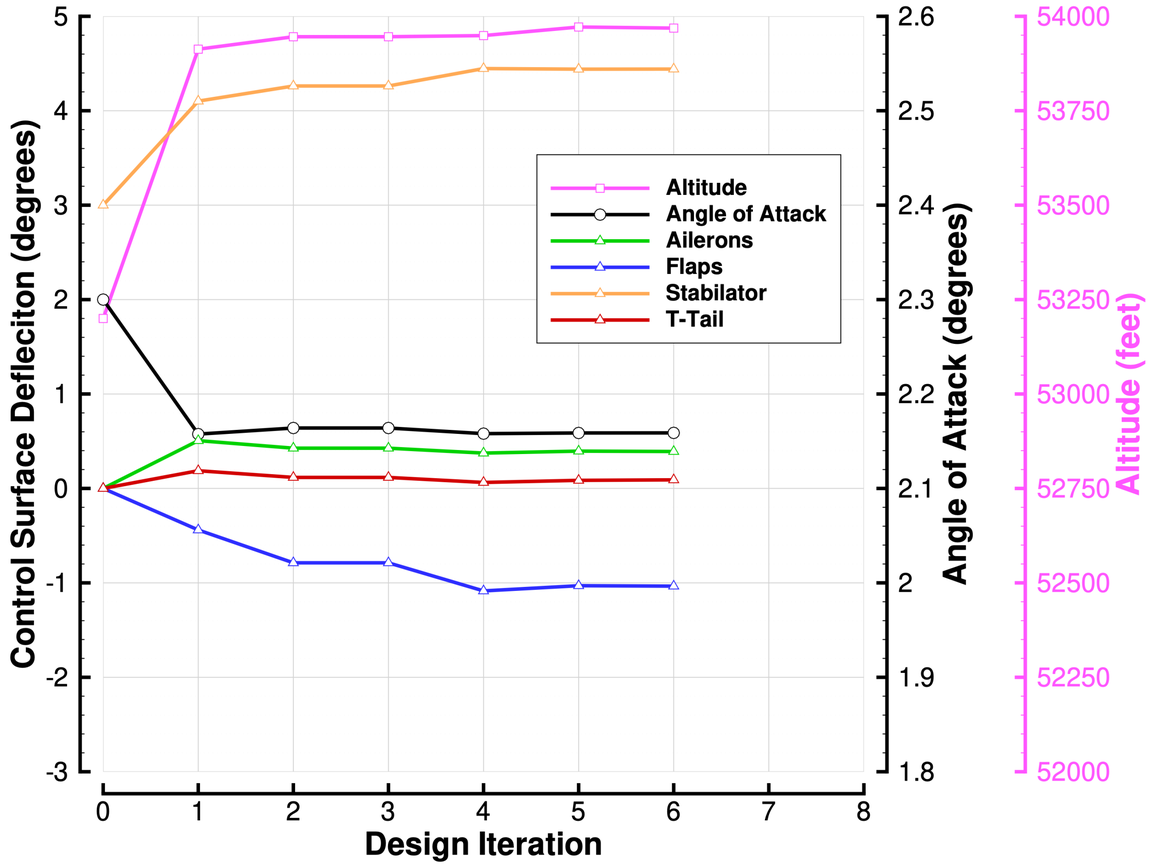


Nominal Ground Noise: 63.7 dBA

X-59 QueSST Aircraft - Optimization (first run)

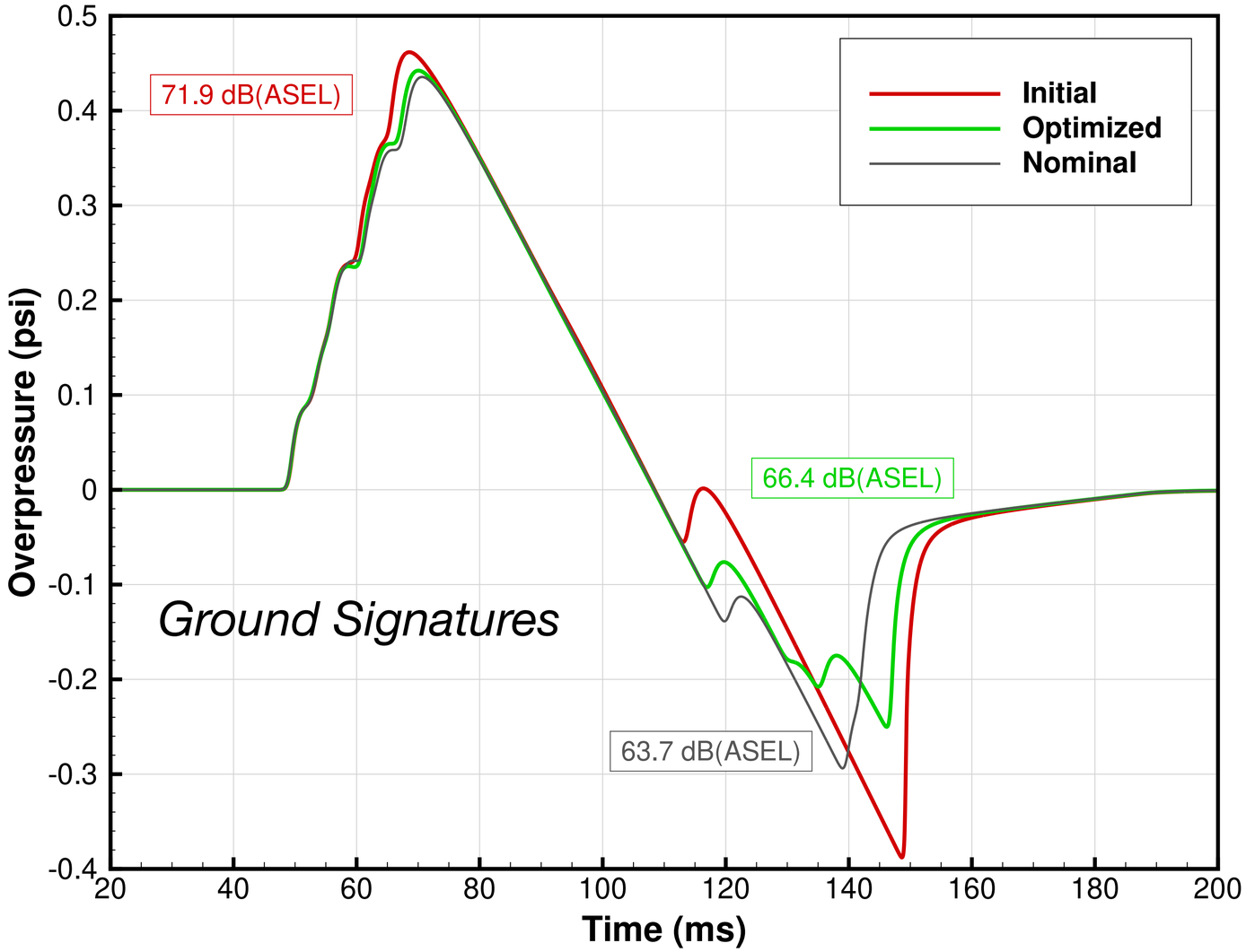
- Initial deflections far from nominal condition





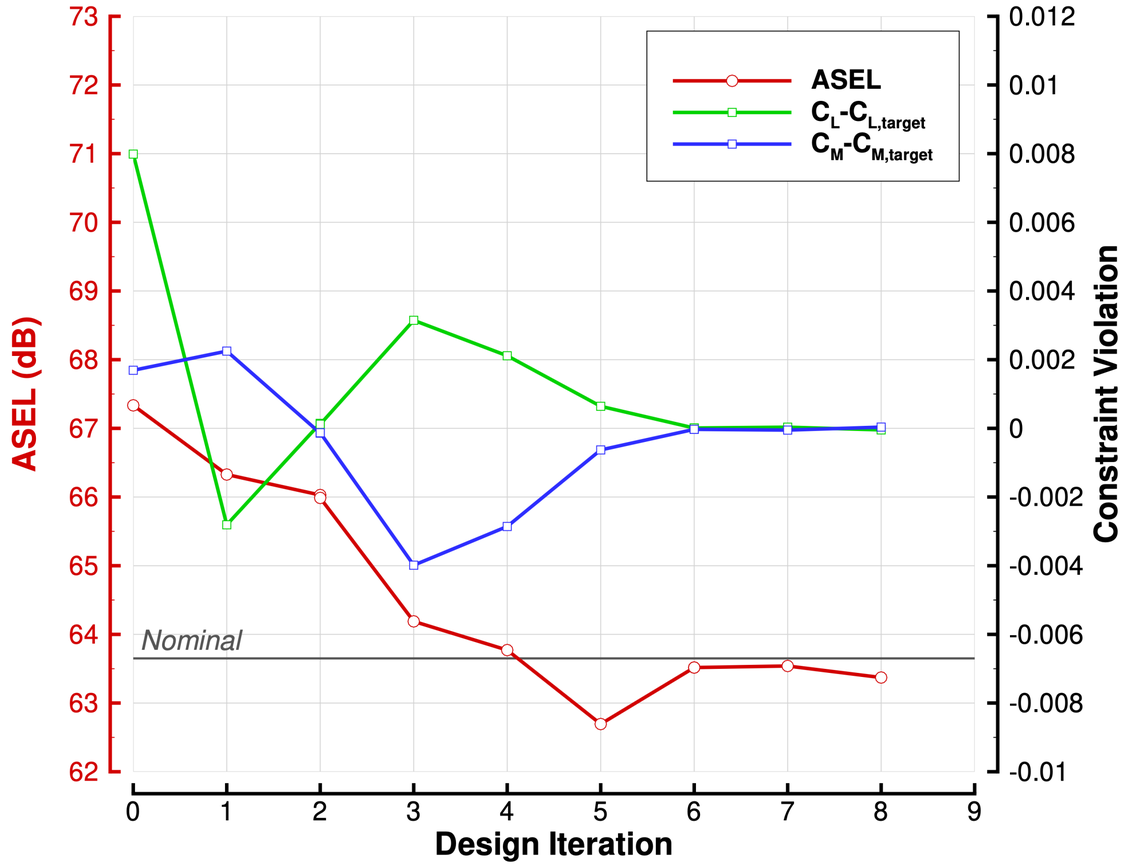
X-59 QueSST Aircraft - Ground Signature (first run)

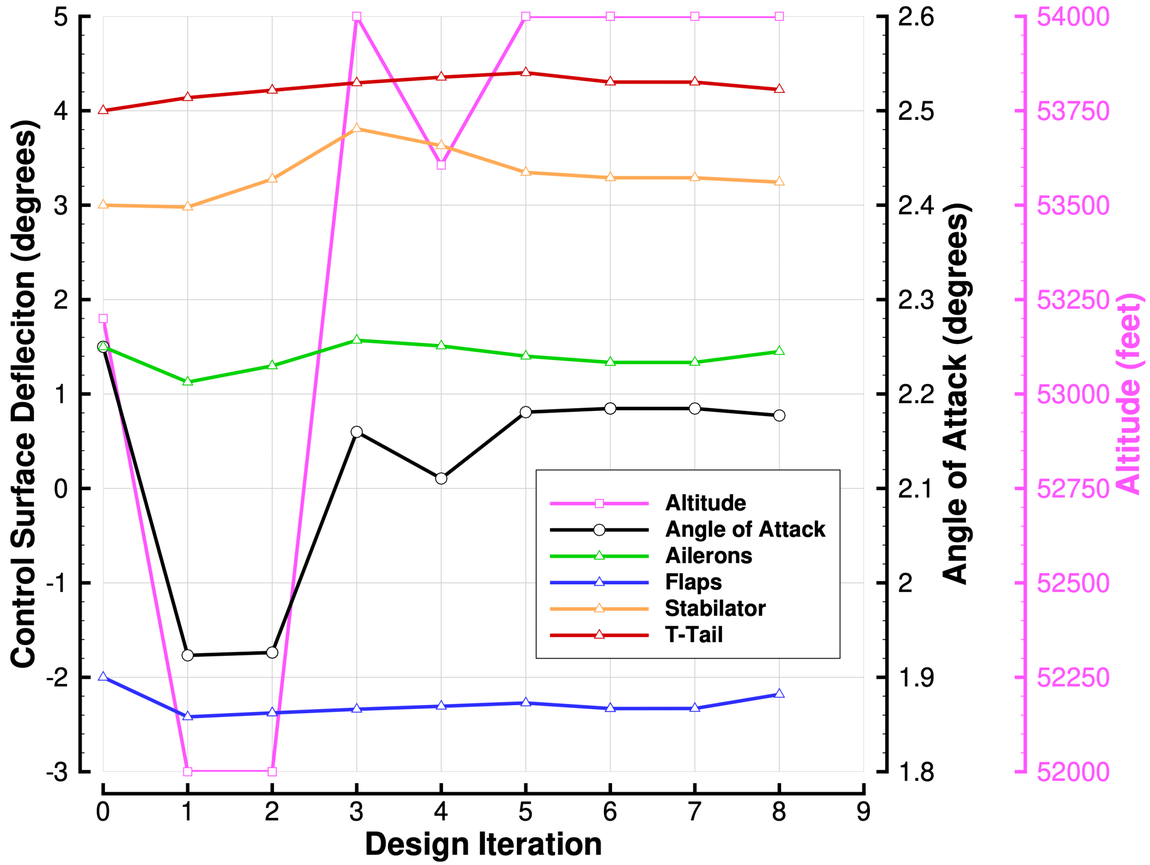
- Optimization resulted in significant improvement in ground noise (> 5 dBA)
- Stalled after 6 iterations
  - perhaps a local minimum has been found
  - larger meshes may be required to navigate flatter regions of design space
- Did not find solution better than nominal condition



X-59 QueSST Aircraft - Optimization (second run)

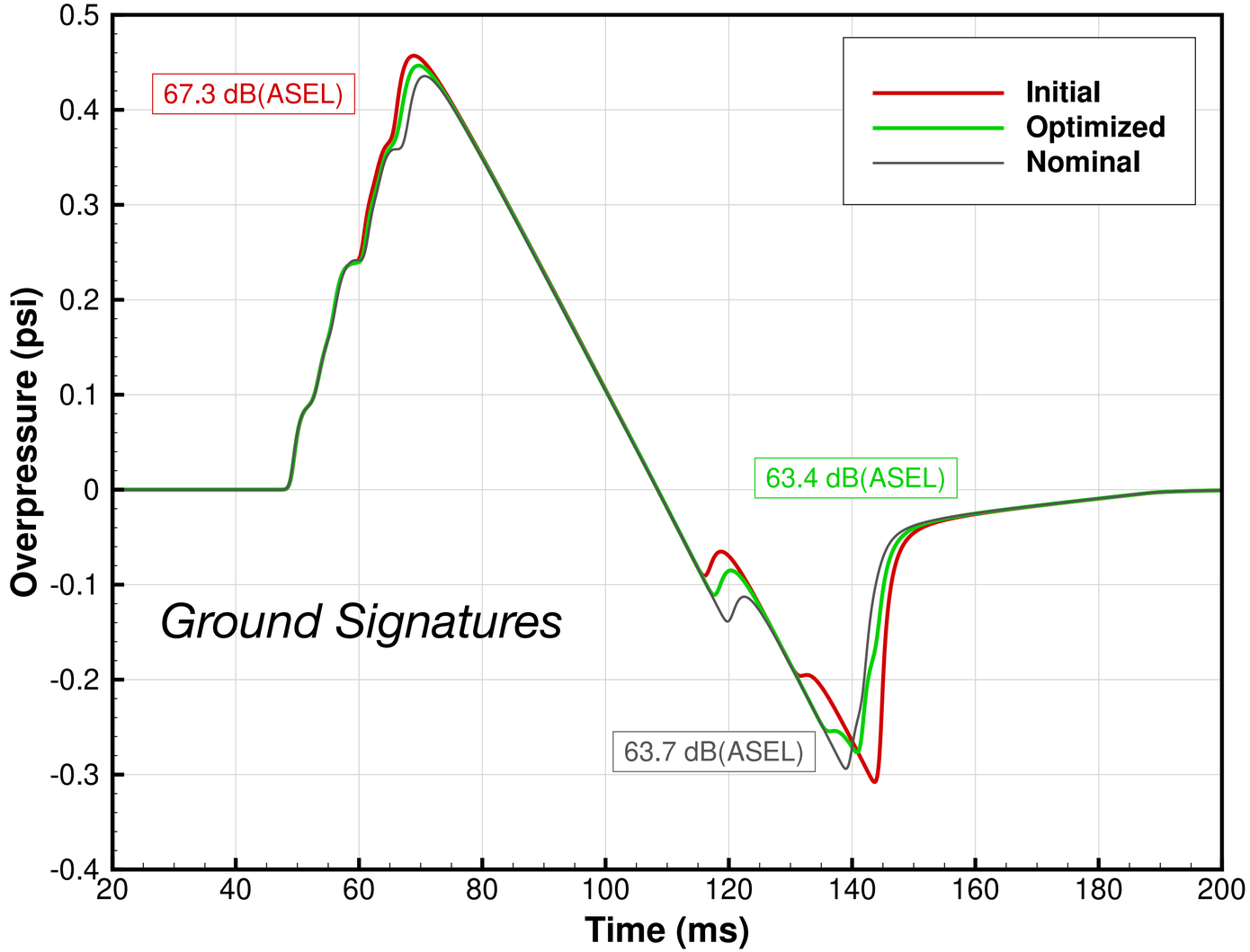
- Initial deflections closer to nominal condition





X-59 QueSST Aircraft - Ground Signature (second run)

- Optimization resulted in significant improvement in ground noise
- Stalled after 8 iterations
- Found solution slightly better than nominal condition
- Larger meshes may be required to navigate flatter regions of design space



Conclusions & Future Work

- Improved multidisciplinary design optimization method developed to directly optimize ground-level noise of supersonic aircraft
- Method applied to simple axisymmetric body
  - Design space found to be multimodal but smooth
  - Gradients verified and found to be vastly improved
  - Depending on starting point, method efficiently located local minima
- X-59 control surface deflection optimization revisited
- Explore hybrid optimization strategies (global + gradient-based) to navigate what may be highly multimodal design spaces
- Determine efficacy of applying method in the conceptual design phase

Acknowledgements

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