Acoustics of a Supersonic Mach 1.4 Axisymmetric Spike Inlet

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AIAA Aviation 2023

Supported by the NASA Commercial Supersonic Technology Project

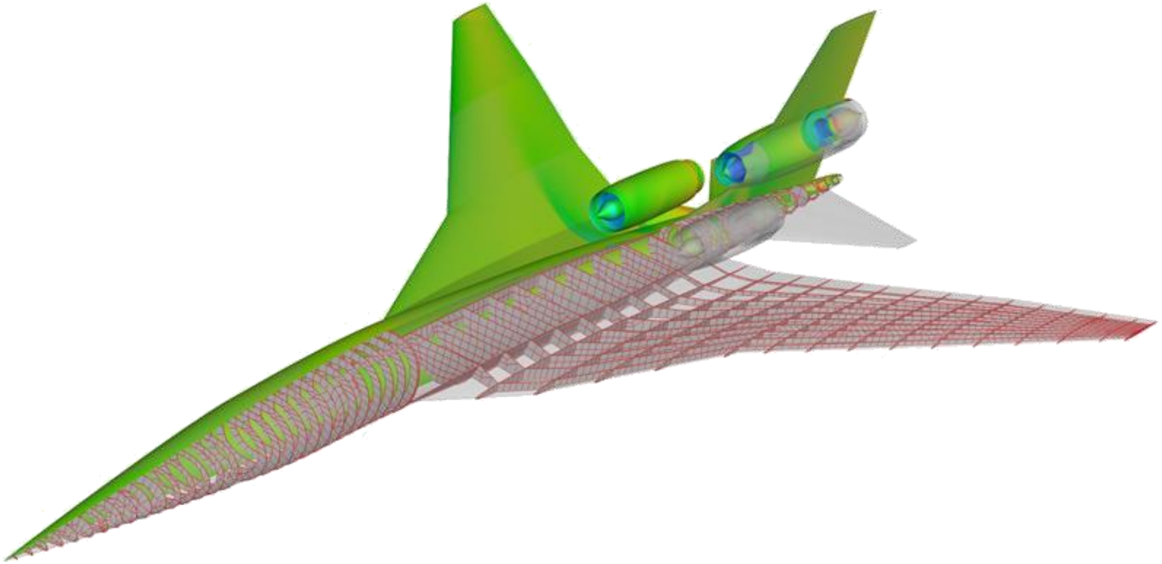
Airport noise for supersonics

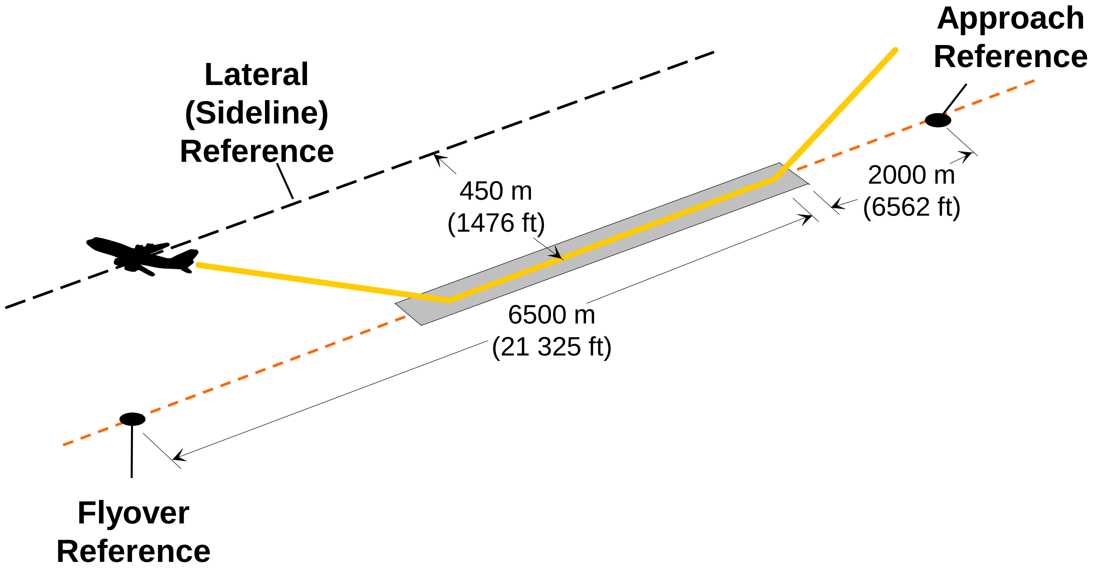
The NASA Commercial Supersonic Technology project includes an Airport Noise research area

– Airport noise a recognized challenge
– Separate from the sonic boom challenge

Different features than subsonic aircraft

– System study motivates research in engine noise





Supersonic Technology Concept Aeroplanes for Environmental Studies (AIAA 2020-0263)

Prediction Uncertainty Reduction

Currently no certification noise rule for commercial supersonic aircraft.

Regulatory Catch-22:

- OEMs have no international noise rule for product requirements.
- Regulators have no existing product for technical feasibility assessment.

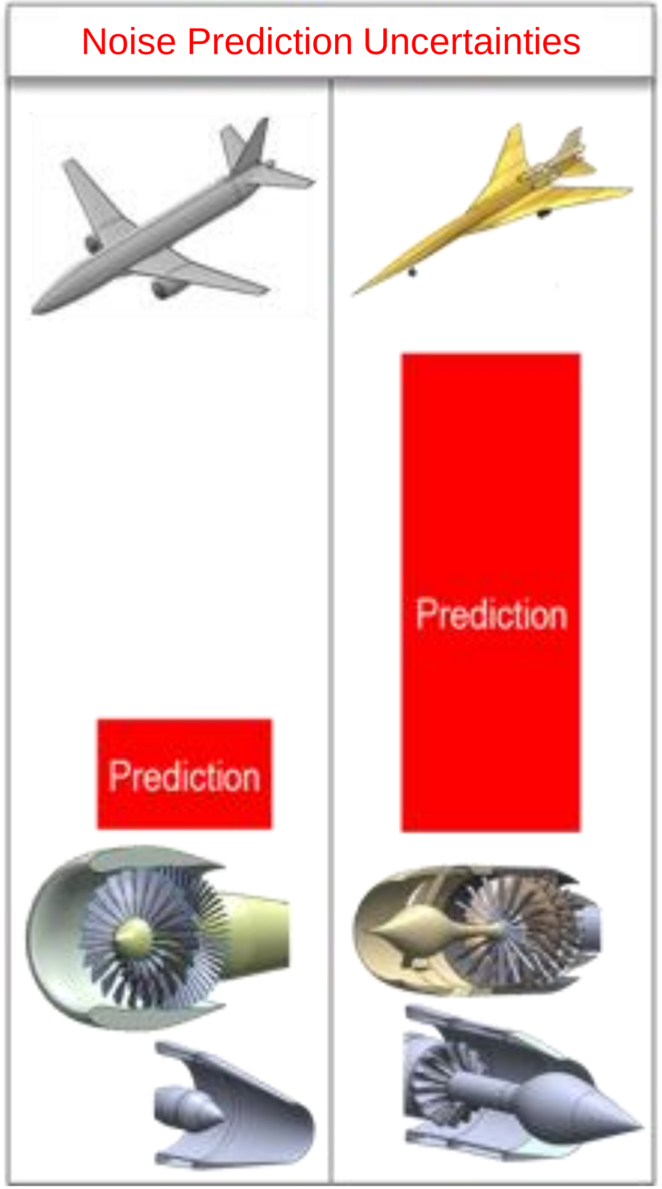
FAA has led with issuance of with ‘Notice of Proposed Rule-Making’ (NPRM)

- Technical assessment influenced by NASA system studies. Uncertainties of study?
- Further progress requires international collaboration.

In June 2021, NASA initiated a Tech Challenge to **reduce uncertainty in prediction** of airport noise for supersonic aircraft.

Prior work on subsonic fan presented at 2022 Aeroacoustics conference

- *Inlet Radiated Noise Predictions for the NASA Source Diagnostic Test Fan Using Physics-Based Simulations (AIAA 2022-2941)*



Two-stage fan for commercial supersonic application

Fan system designed by GE Aviation under NASA contract

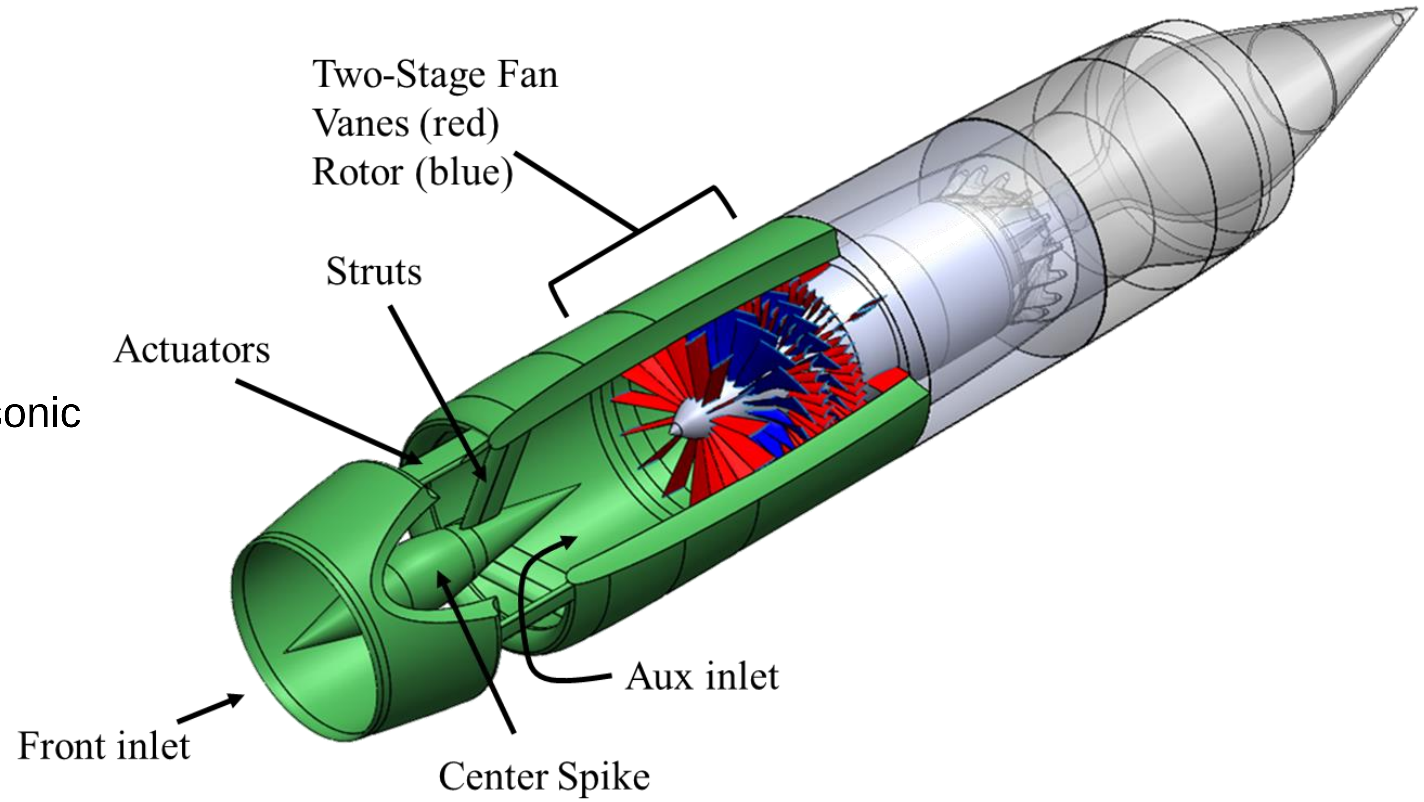
- Inlet guide vanes
- Two rotor/stator stages
- Aerodynamic and acoustic design

Axisymmetric spike inlet

- Designed using NASA SUPIN code
  - (SUPersonic INlet design and analysis tool)
- Aerodynamic cruise design augmented for subsonic operation:
  - Upstream cowl split to create auxiliary inlet
  - Struts to support center spike
  - Actuators to support upstream cowl
  - Gap between center spike and fan spinner

Auxiliary inlet required for off-design operation

- Mode switch expected to be around Mach 0.6
- Open for noise certification



Inlet representation for acoustic simulation

Actran TM (turbomachinery) used for acoustic simulation

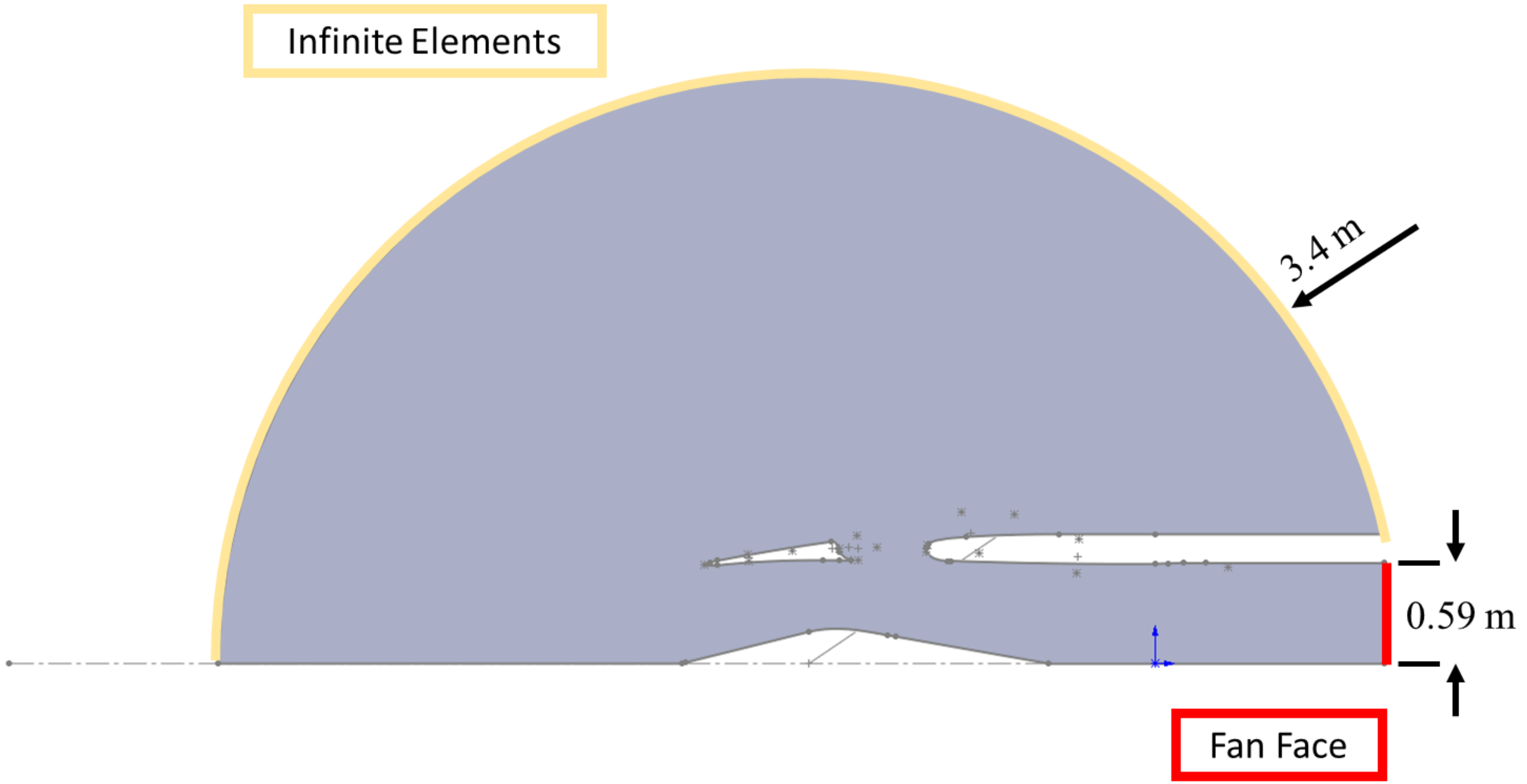
- Solves Möhring Analogy for convected wave equation
- Duct mode boundary condition for fan face
- Infinite elements for far field sound and non-reflecting boundary condition

Axisymmetric representation

- Fast simulation time
- All relevant frequencies
- Allows spinning modes
  - Periodicity specified in advance

Assumptions

- Neglects spike struts
- Neglects cowl actuators
- Angle of attack



Fan stage and operating conditions

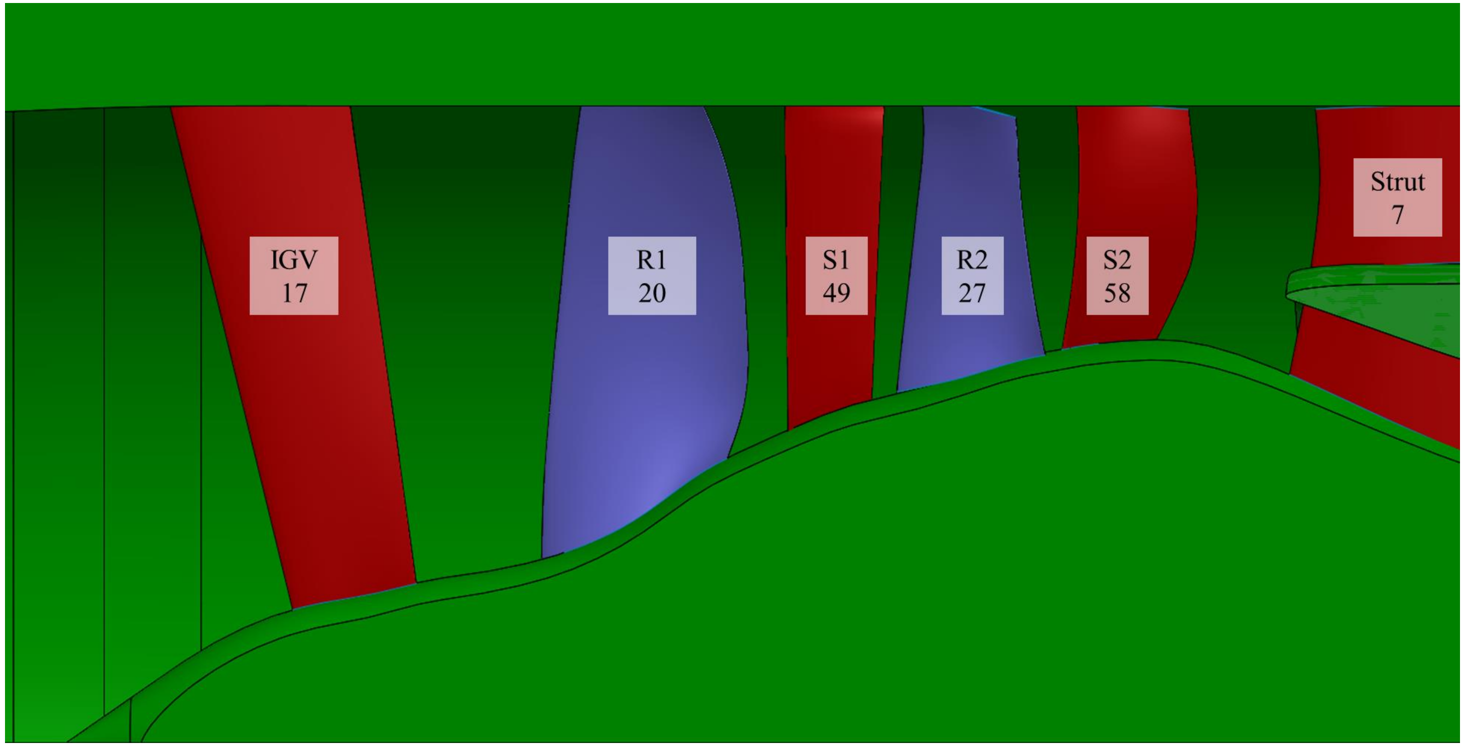
Contract delivery included fan design and main operating conditions

- Three noise rating points plus takeoff
- Fixed IGVs

	Approach	Cutback	Sideline	Takeoff
Flight Speed (m/s)	90	121	123	88
Fan Face Speed (m/s)	107	140	173	194
RPM	4533	5733	6672	7200
First Stage Fan BPF, Hz	1511	1911	2224	2400

Jet noise varies considerably with operating condition

- Expected to be dominate at cutback and sideline
- Not considered in present report



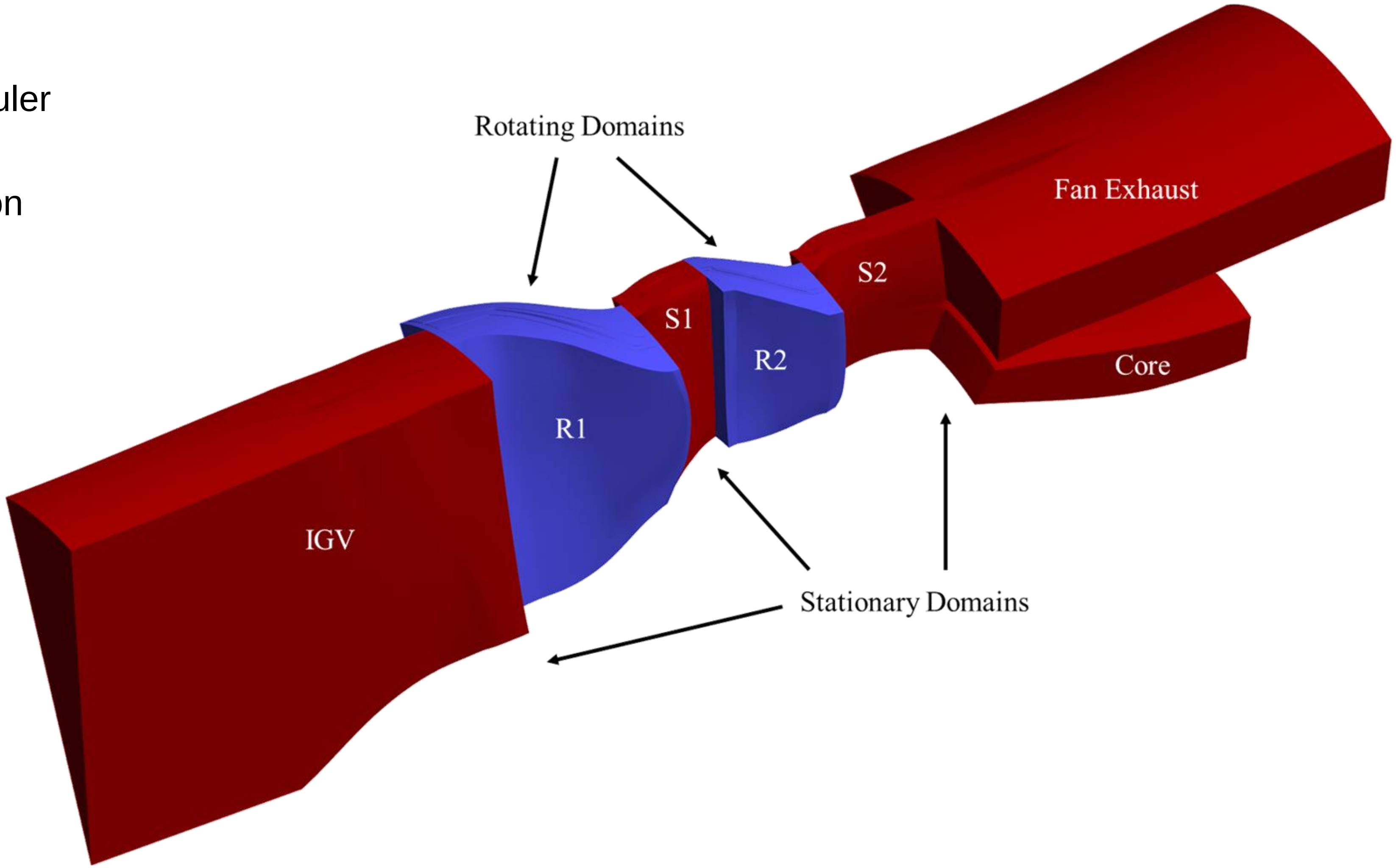
Turbomachinery simulation method

Unsteady Reynolds Averaged Navier-Stokes (URANS) approach

- Fewer assumptions than linearized Euler
- Faster than LBM or LES
- Commercial turbomachinery simulation package FINE^{TM}/Turbo

Non-Linear Harmonic (NLH) approximation

- Pre-selected set of frequencies
- Savings compared to full wheel
  - Memory O(10)
  - CPU time O(100)
- Steady simulations run to specified performance conditions
- Unsteady simulations to get perturbations



Acoustic pressure perturbation

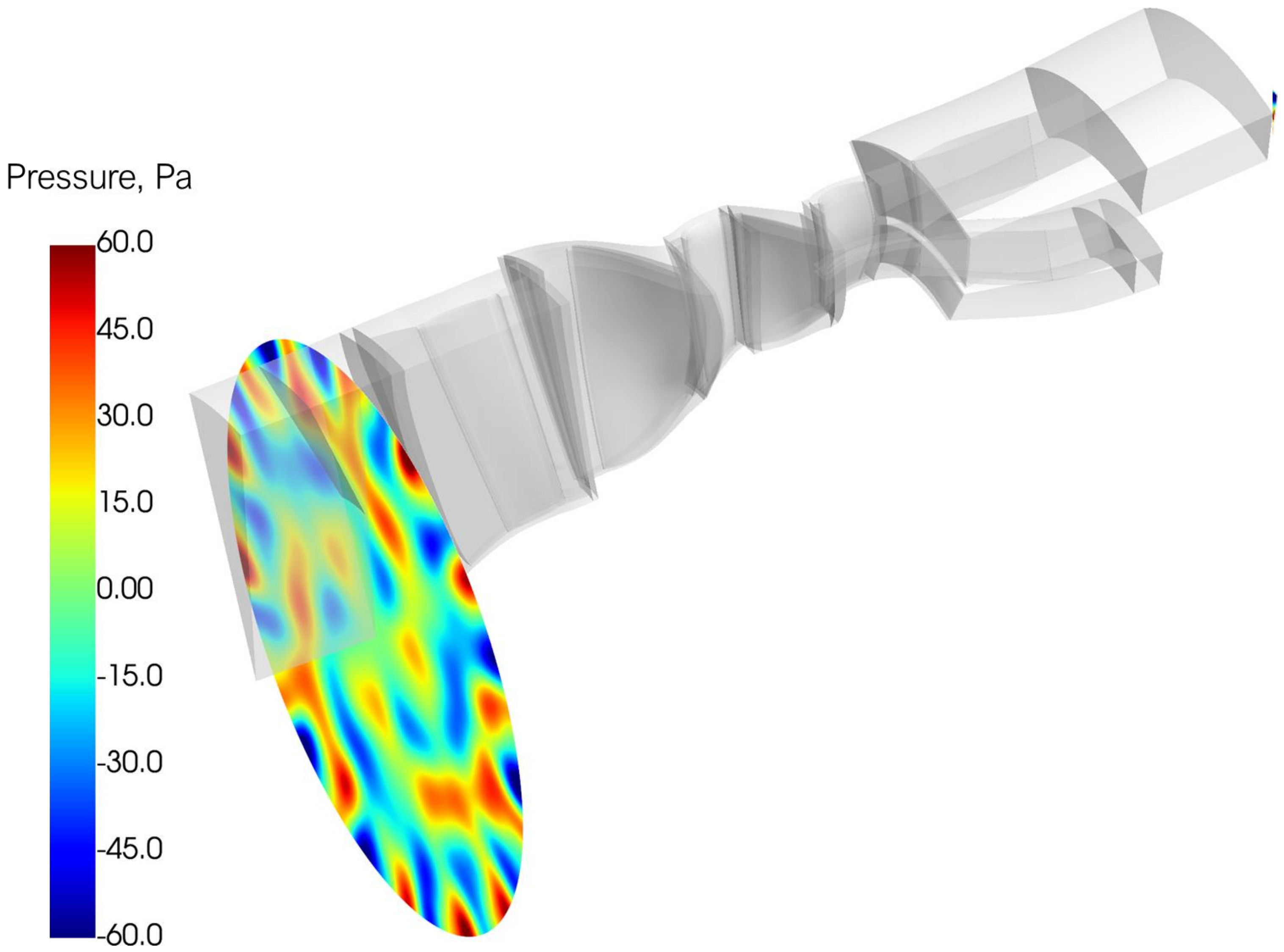
NLH simulation → complex pressure

Desired output is duct mode amplitudes

- Eigenfunction solution to wave equation in the inlet duct with flow
- Hand-off between turbomachinery and acoustic codes

Actran iTM

- Reads cgns output file from FINE™/Turbo
- Construct full wheel complex pressure
  - Specify plane to extract
  - Periodicity based on blade count
- Least-squares fit duct modes
- Output is table of mode amplitudes
  - Complex pressure values
    - Preserve relative phase
  - Incident and reflected
  - Azimuthal and radial



Results: Duct mode amplitudes

Tyler-Sofrin modes

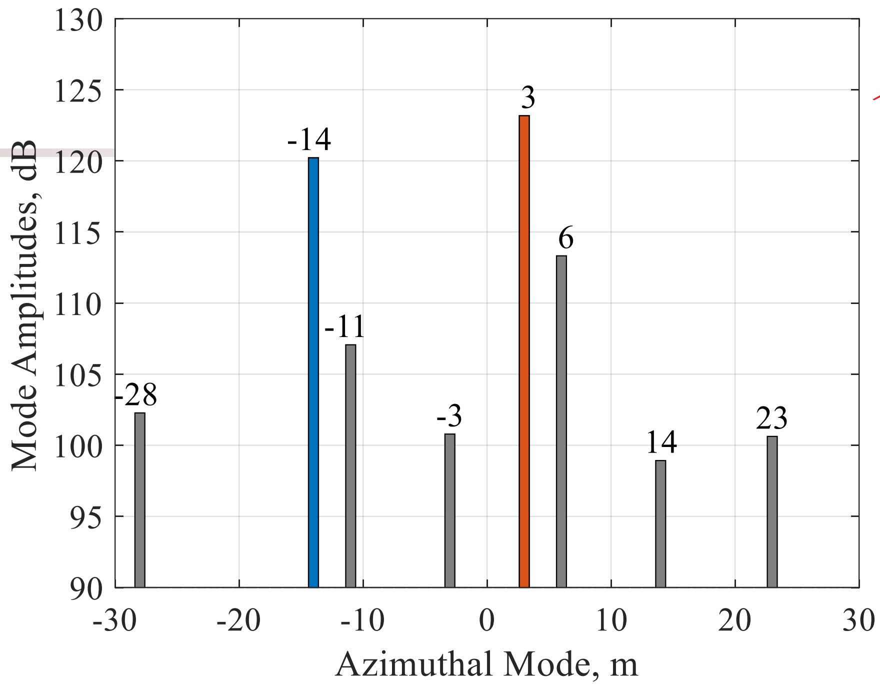
- Rotor/stator interaction (RSI) noise
- IGV wakes interacting with Rotor 1
- Potential field of Rotor 1 scattered by IGVs
  - Produces a sound field with mode order m

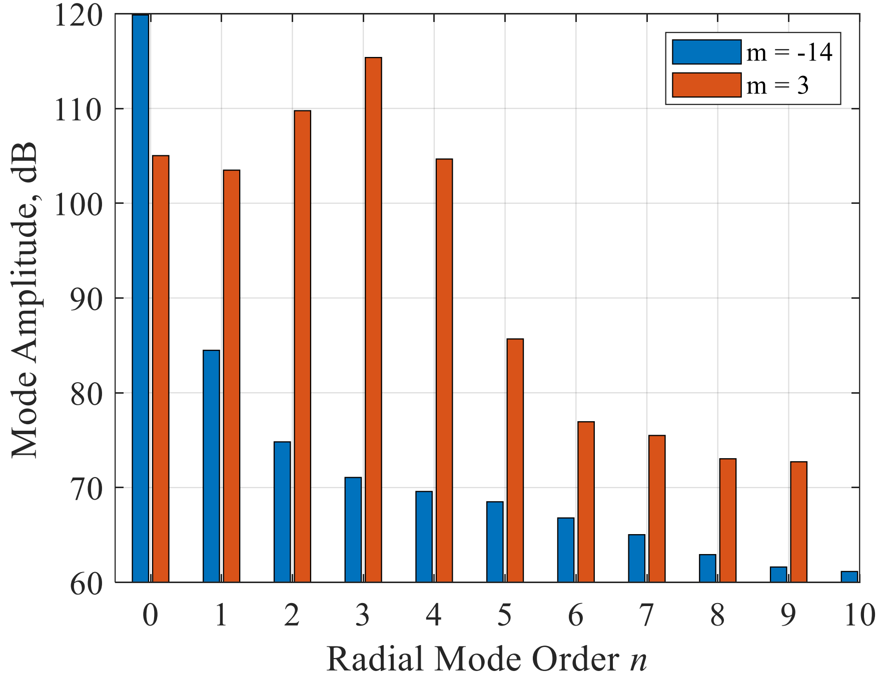
$m = n\, N_B - k\, N_V$

IGVs: N_V=17

Rotor 1: N_B=20

		Harmonic in static frame (n)				
		1xBPF	2xBPF	3xBPF	4xBPF	5xBPF
Harmonic in rotating frame (*k*)	*k* = 0	*20*	*40*	*60*	*80*	*100*
	k = 1	*3*	*23*	*43*	*63*	*83*
	k = 2	*-14*	*6*	*26*	*46*	*66*
	k = 3	*-31*	*-11*	*9*	*29*	*49*
	k = 4	*-48*	*-28*	*-8*	*12*	*32*





Results: Sound field examples

Add flow field

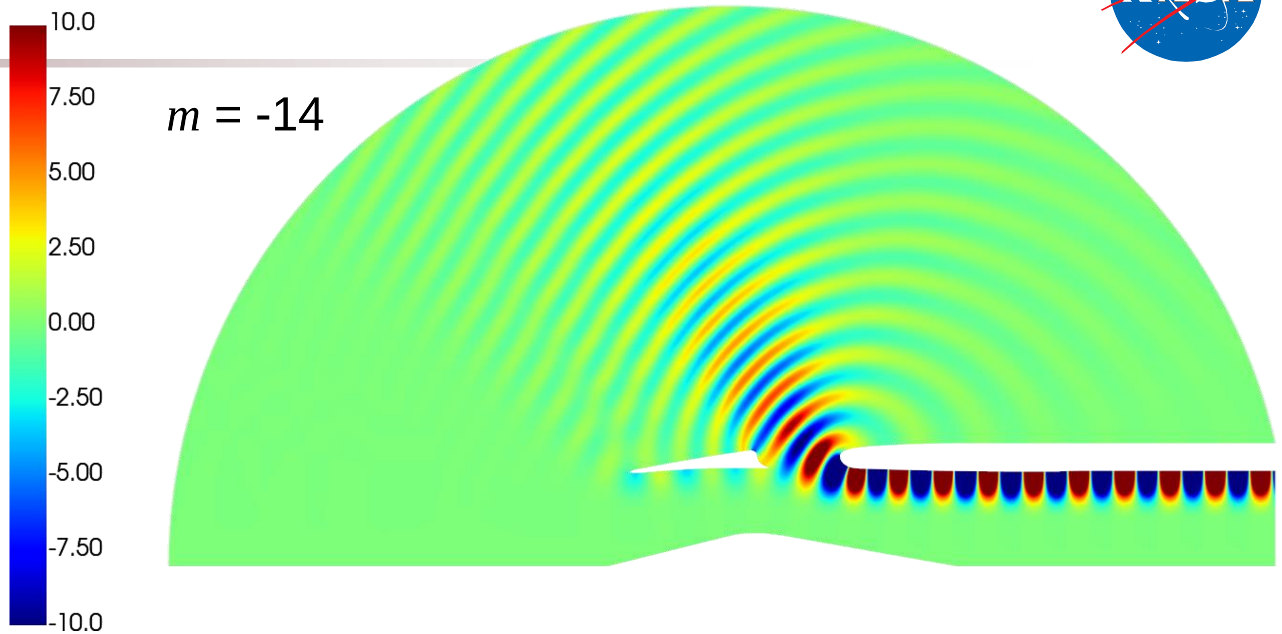
- Inviscid compressible potential flow

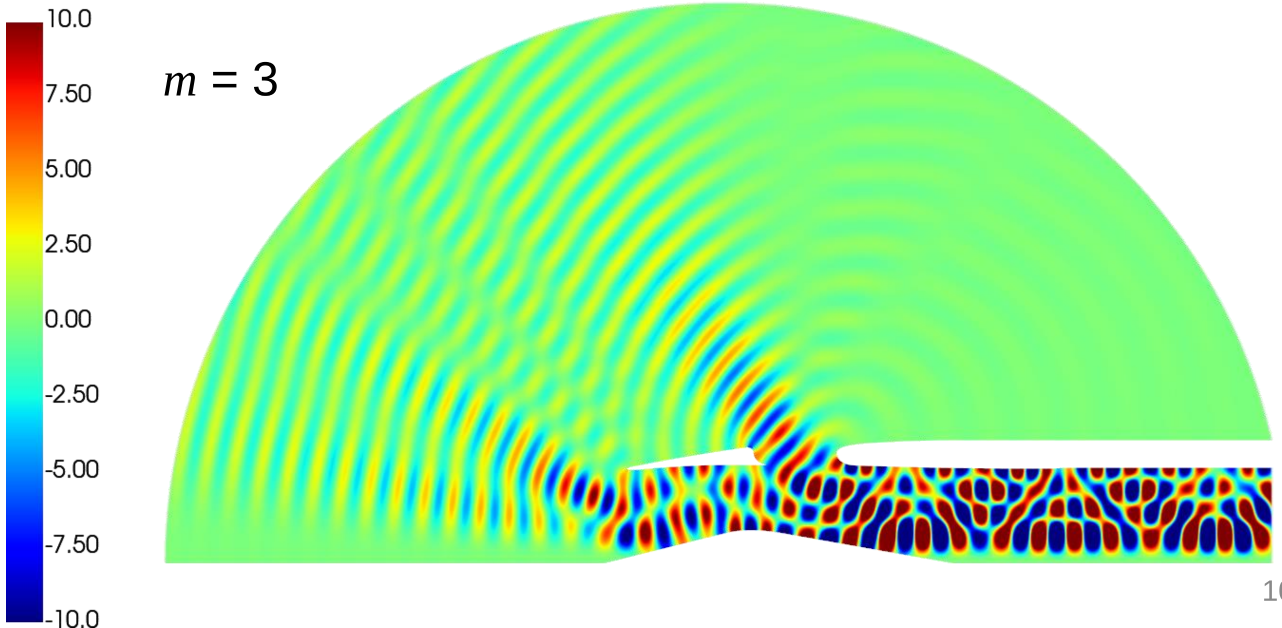
Approach conditions

- m = -14
  - One strong radial mode
  - High inclination
- m = 3
  - Five strong radial modes
  - Low inclination
- Radial modes injected with inter-mode phases preserved
- Cut-off modes are evanescent and decay

Solved separately in Actran TM

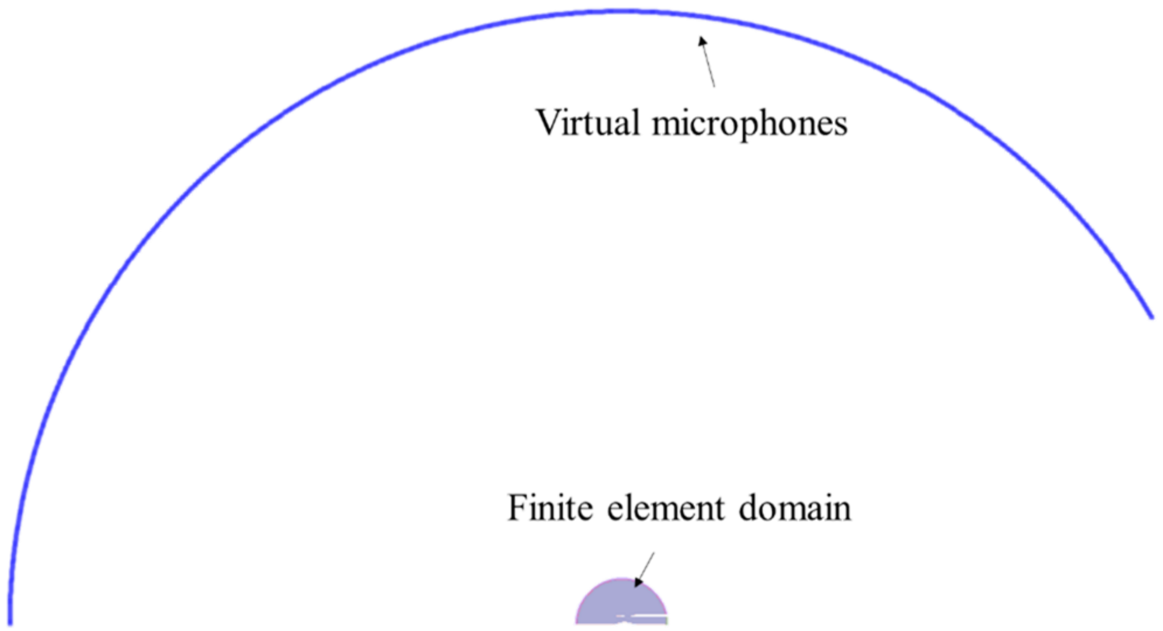
- Total sound field is the complex sum



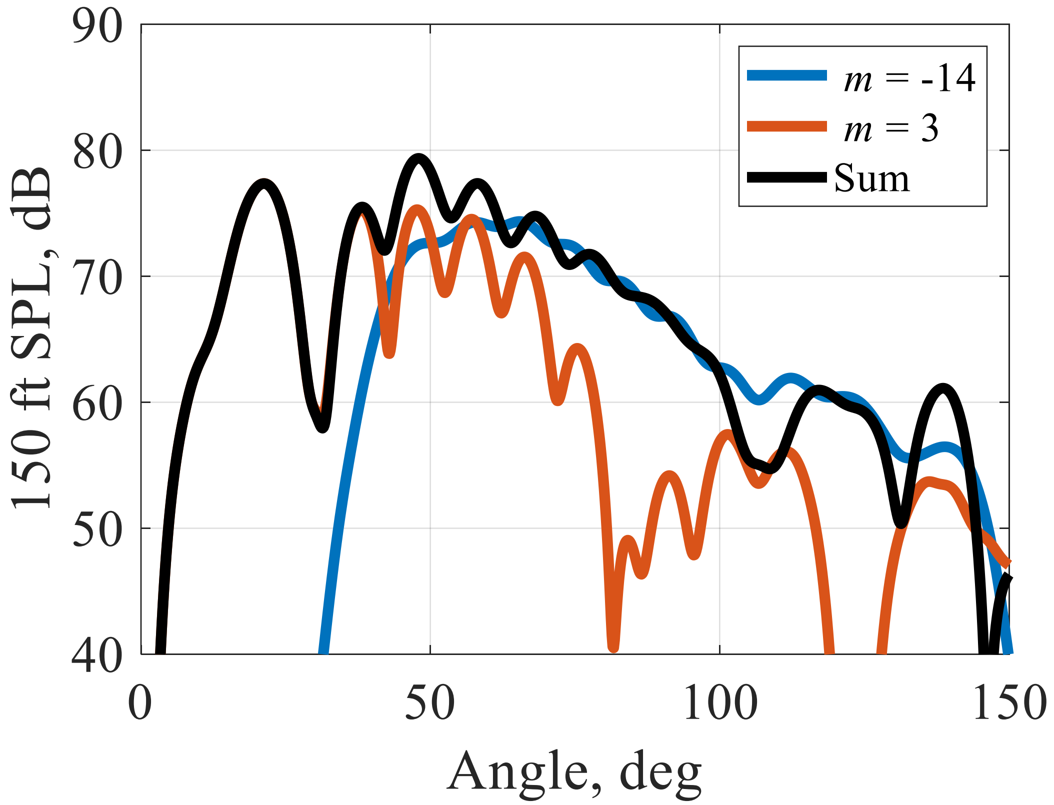


Results: Far field prediction

Virtual Microphones
- 150’ (46 m) arc
- Finite elements only needed in nearfield
- Sound propagates through uniform flow



Combined radiation pattern
m = -14, radiates out auxiliary inlet
m = 3, radiates forward



Conclusions

Noise predictions made for 1x BPF inlet radiated tone

- Four operating conditions
  - Cutback and sideline about 20 dB higher than approach
  - Physics-based solutions on workstations
    - Hours for turbomachinery, minutes for acoustics
  - Higher harmonics from post-processing same data set
  - Aft fan noise subject to bypass and mixing geometry

Limitations to current method

- Missing broadband
  - Likely to be predicted by analytical methods

Future work

– 3D vs 2D comparison
– Viscous flow solution
– Angle of attack
– Other distortion

In-duct amplitude