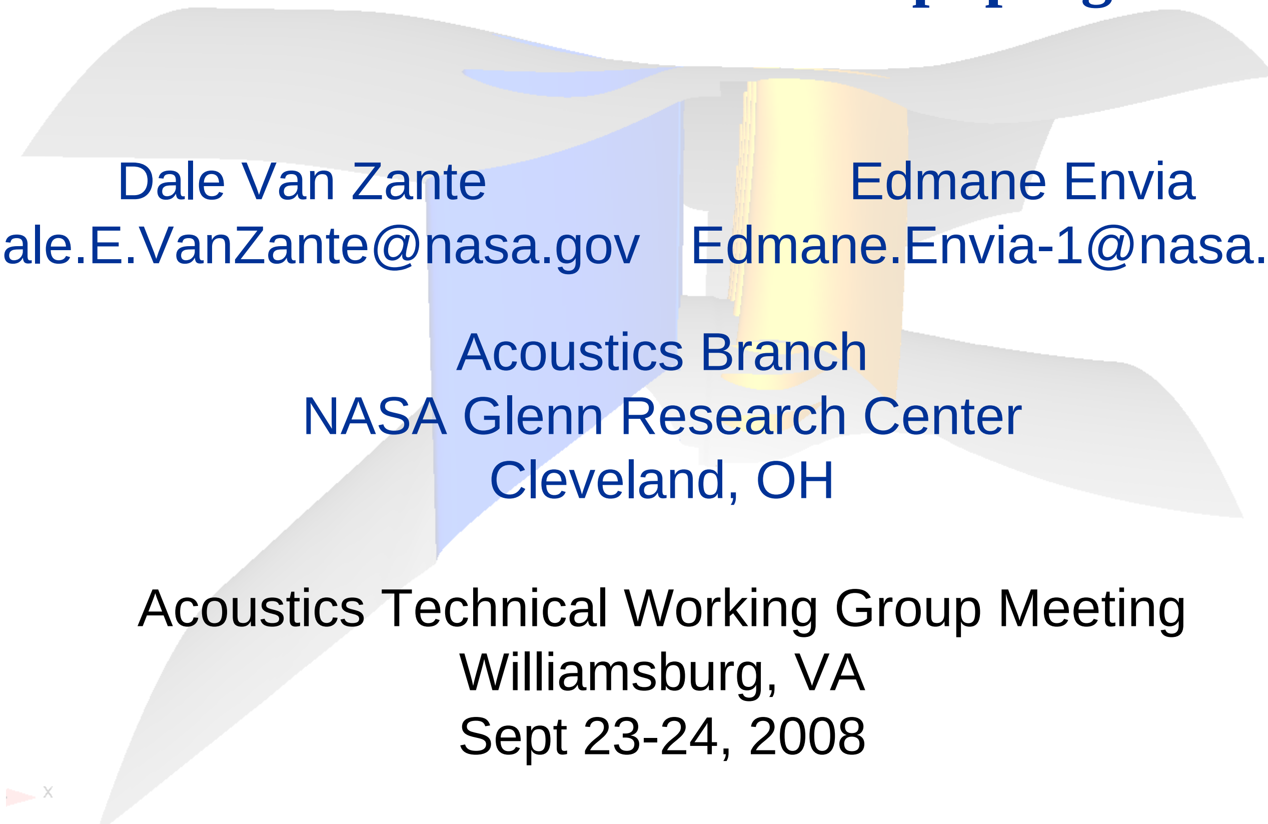
A Numerical Investigation of Turbine Noise Source Hierarchy and Its Acoustic Transmission Characteristics: Proof-of-concept progress

Abstract:
A CFD-based simulation of single-stage turbine was done using the TURBO code to assess its viability for determining acoustic transmission through blade rows. Temporal and spectral analysis of the unsteady pressure data from the numerical simulations showed the allowable Tyler-Sofrin modes that are consistent with expectations. This indicated that high-fidelity acoustic transmission calculations are feasible with TURBO.

A Numerical Investigation of Turbine Noise Source Hierarchy and Its Acoustic Transmission Characteristics: Proof-of-concept progress



Dale Van Zante
Dale.E.VanZante@nasa.gov

Edmane Envia
Edmane.Envia-1@nasa.gov

Acoustics Branch
NASA Glenn Research Center
Cleveland, OH

Acoustics Technical Working Group Meeting
Williamsburg, VA
Sept 23-24, 2008

Outline

- Motivation and Objectives
- Single and Multi-Stage Turbine Geometries
- Simulation Setup
- Noise Generation Mechanisms
- Results
- Future Work
- Summary

Acknowledgements:
This work is supported by SFW and SRW Projects.
Computer resources:
Columbia and RTJones at NAS
GX Cluster at GRC

Motivation and Objectives

Motivation:

As fan and jet noise are reduced, turbine noise is lurking just below surface. Robust first-principles-based models for turbine noise do not currently exist.

Approach:

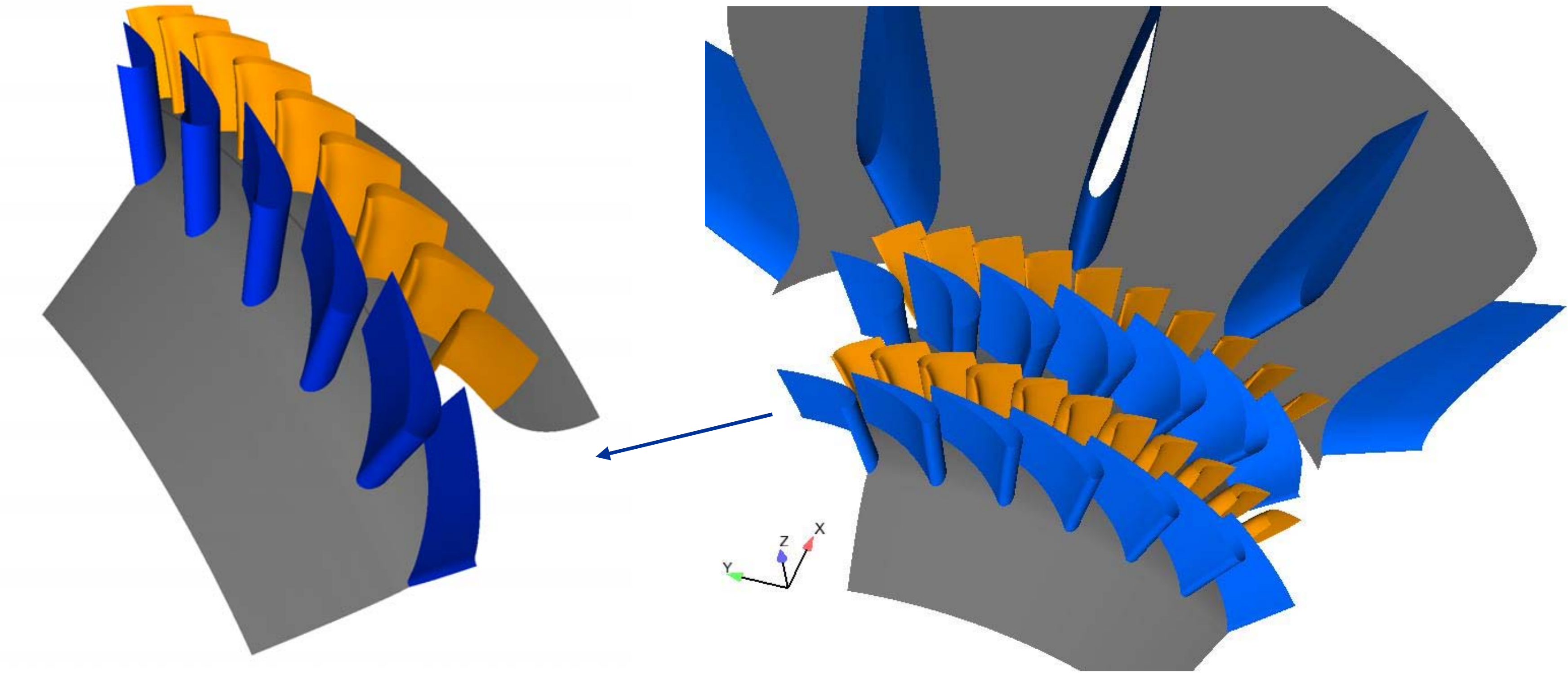
Appropriately apply an aerodynamic solver to produce highly detailed numerical simulations of a modern high pressure turbine.

Objectives:

- Estimate of the relative importance of the contributions to the coherent part of the acoustic signature of a turbine from the three possible sources of turbine noise generation; blade-row viscous interaction, potential field interaction, and entropic sources
- Understand the turbine acoustic transmission characteristics
- Develop reduced order models for turbine noise generation and transmission

Preliminary analysis of the results obtained so far is presented in order to assess the validity of such an approach.

Single and Multi-Stage Geometries



1st stage HPT
1/8th annulus (80 million nodes)
40V-64B count (5-8 sector)
Cooling flows are included.

Entire HPT + strut
1/7th annulus (200 million nodes)
42V-70B-42V-63B-2V count
Cooling flows are included.
(calculation is 30% complete)

The Numerical Code

TURBO:

3D multi-stage, turbomachinery URANS solver
Temporal discretization is second-order accurate backward differencing
Spatial discretization is a modified upwind scheme, 3rd order accurate
NASA/CMOTT κ-ε turbulence model

Mesh:

Domain is meshed to resolve 2BPF using 40 nodes per wavelength as accepted practice for a 2nd order code
Total node count is 10x an aero simulation:

- Single stage case: 80 million nodes
- Multi-stage case: 200 million nodes

Operating point:

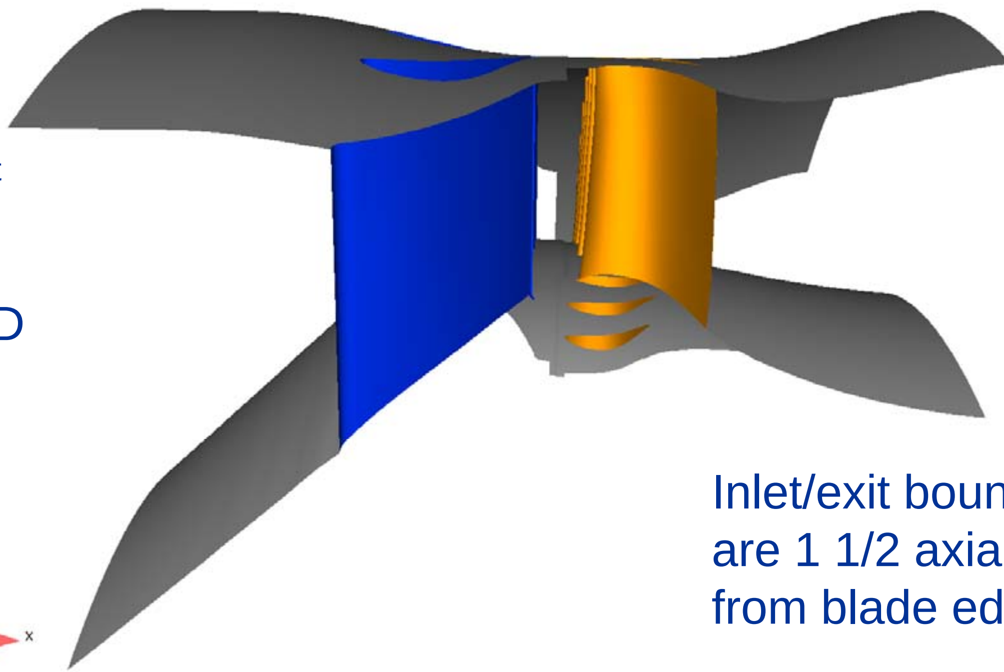
Full scale, takeoff condition (*get proof-of-concept results in a shorter time due to experience base*)

The Computation Domain

Vanes, rotors, hub and casing have cooling flows included using source terms.

Combustor exit radial profile of P_t and T_t applied to start solution and then change to 1D non-reflecting.

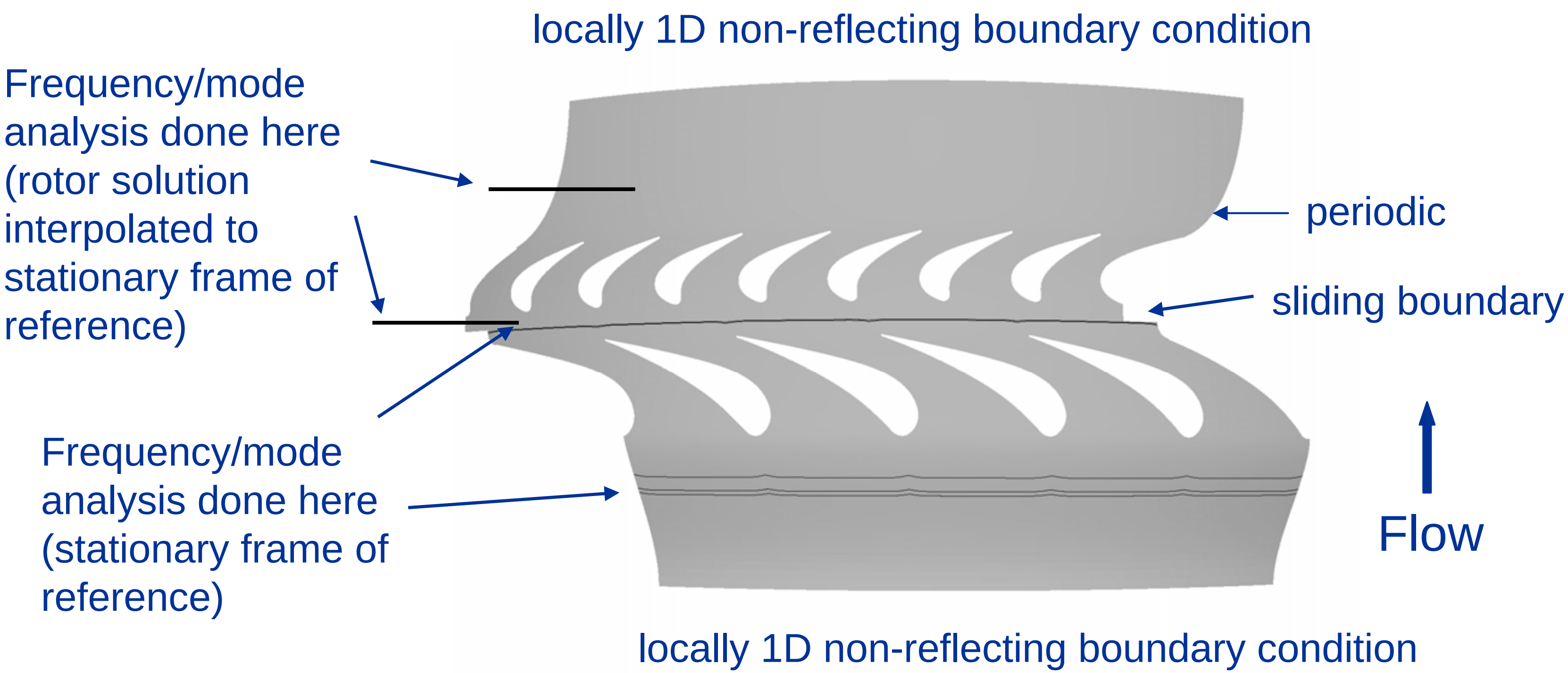
Inlet condition is circumferentially uniform.



Inlet/exit boundaries are 1 1/2 axial chords from blade edges

Side view of domain showing flowpath contraction for single-stage geometry

The Computation Domain



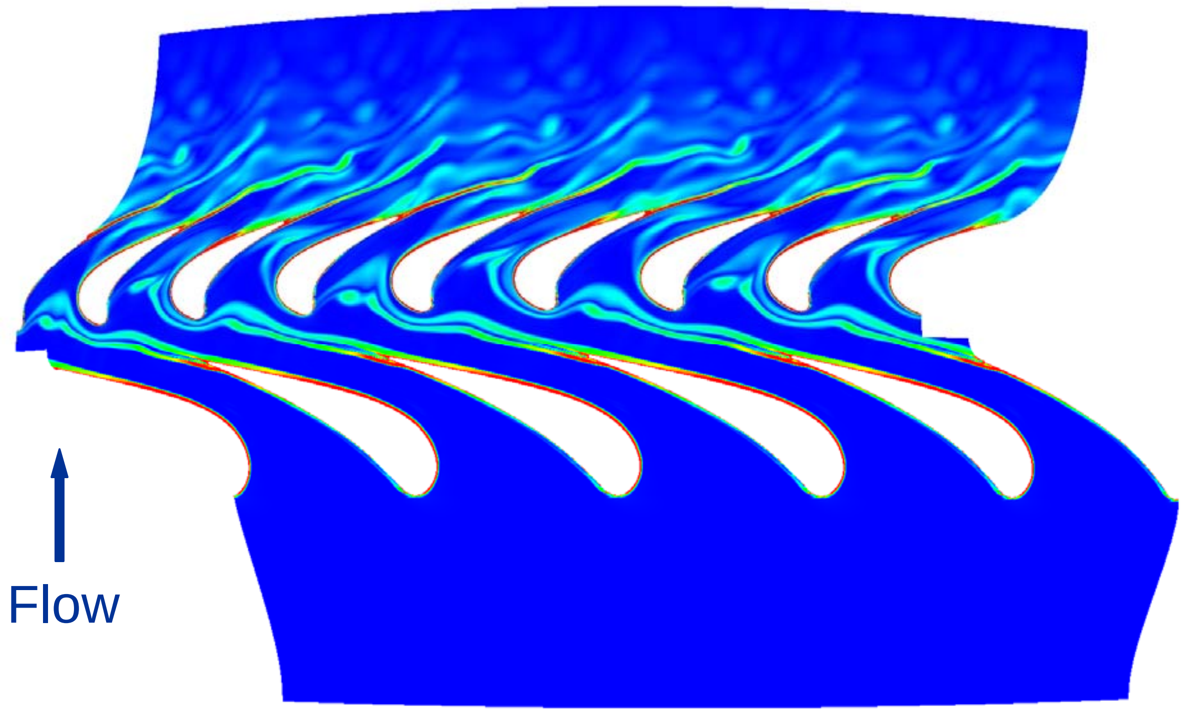
1/8th annulus with 40V-64B blade count (5-8 for sector)

Results
Instantaneous views of the flow field

Noise Generation Mechanisms

Velocity non-uniformities are the primary tone noise generator for fans but are only one of the mechanisms at work in turbines. Contributors also include entropic and potential field interactions.

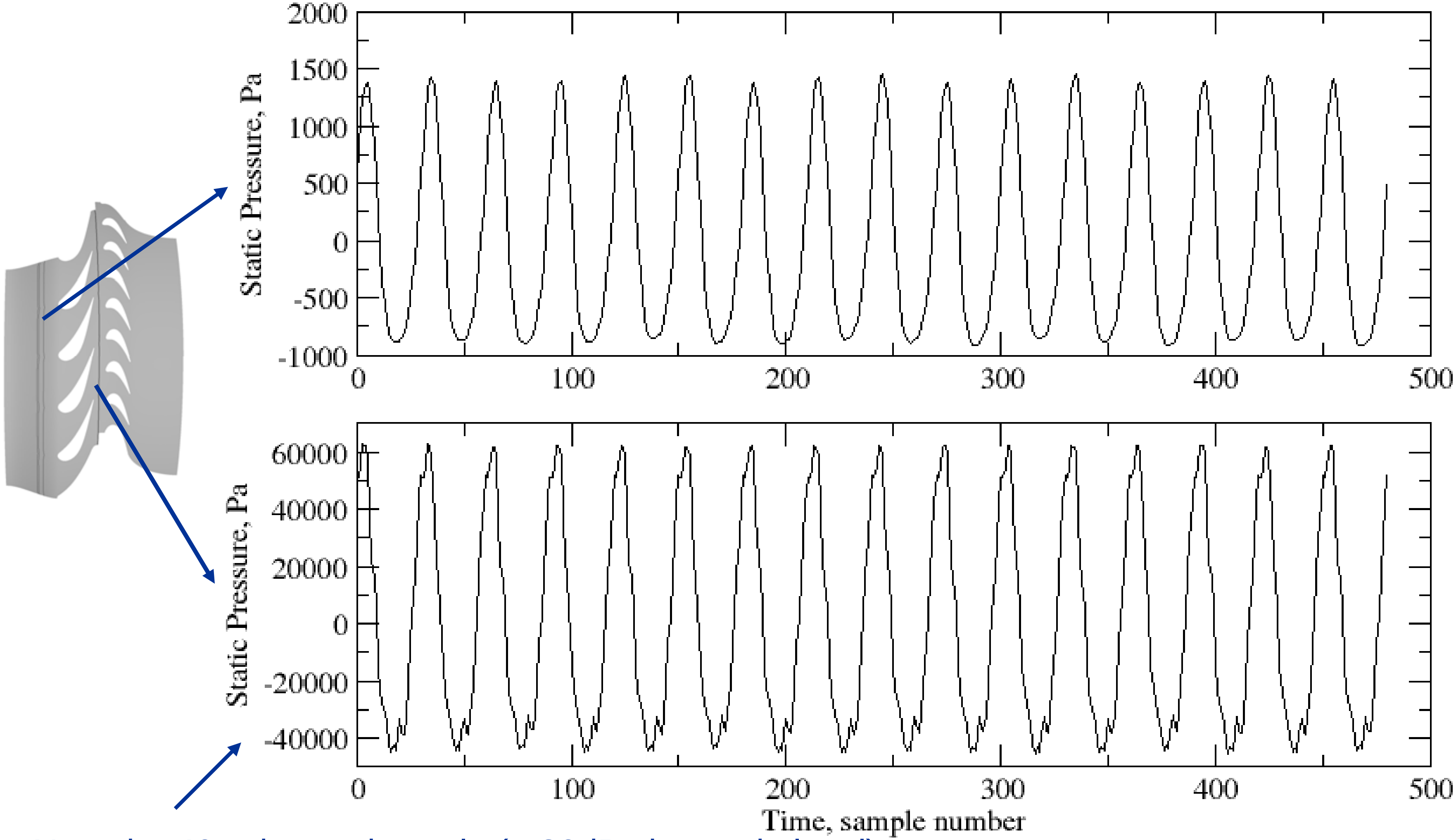
- The vane wakes are highly distorted by the velocity gradients of the rotor
- The potential field of the rotor extends forward to the vane trailing edge



Vorticity magnitude on a 50% span surface.
Vorticity tracks the velocity non-uniformities in the flow.

Pressure Time Histories Before and After Vane

16 rotor passings of data



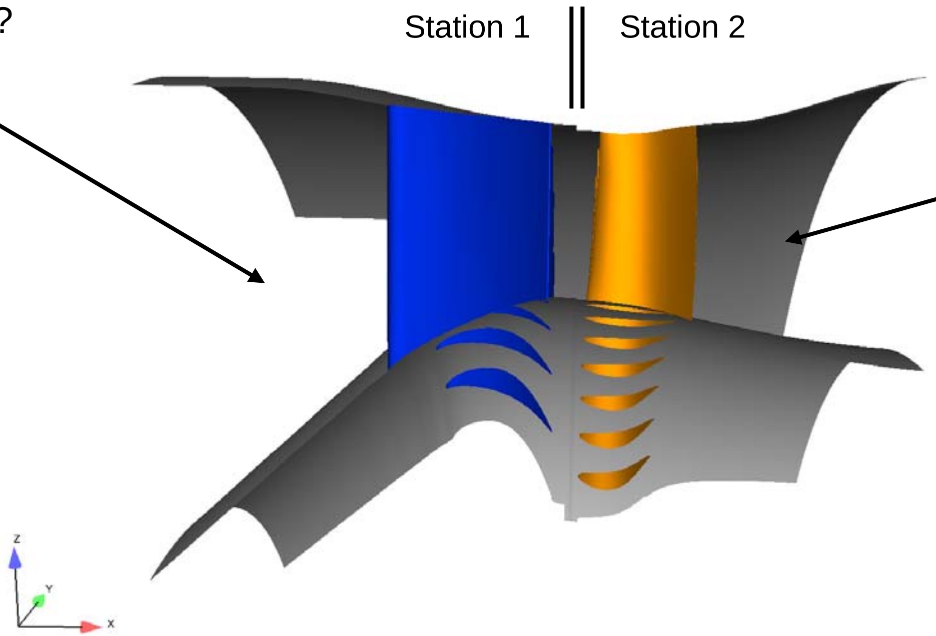
Note the 40x change in scale (>30dB change in level)

Results
Spectral and Modal Analysis

Vane inlet: Are the correct modes present where pressure fluctuations should be at acoustic levels?

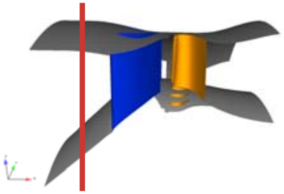
Sliding Interface: Does the interface transmit the pressure waves without attenuation?

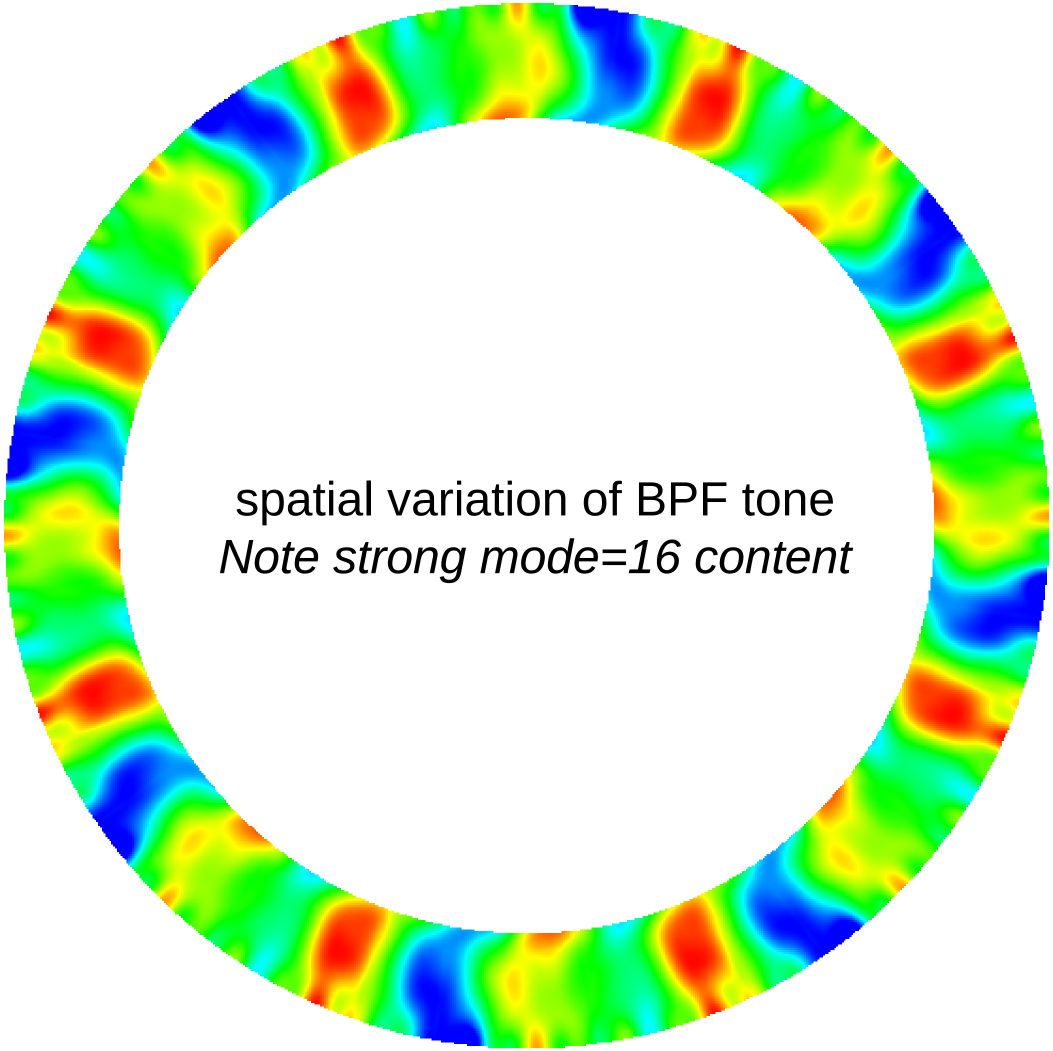
Rotor Exit: What is the modal content going into the next blade row?



Transmission Loss: What is a estimate of mode-by-mode transmission loss?

Upstream of vane

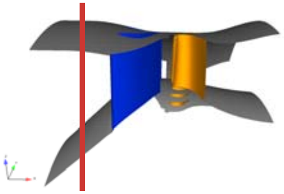


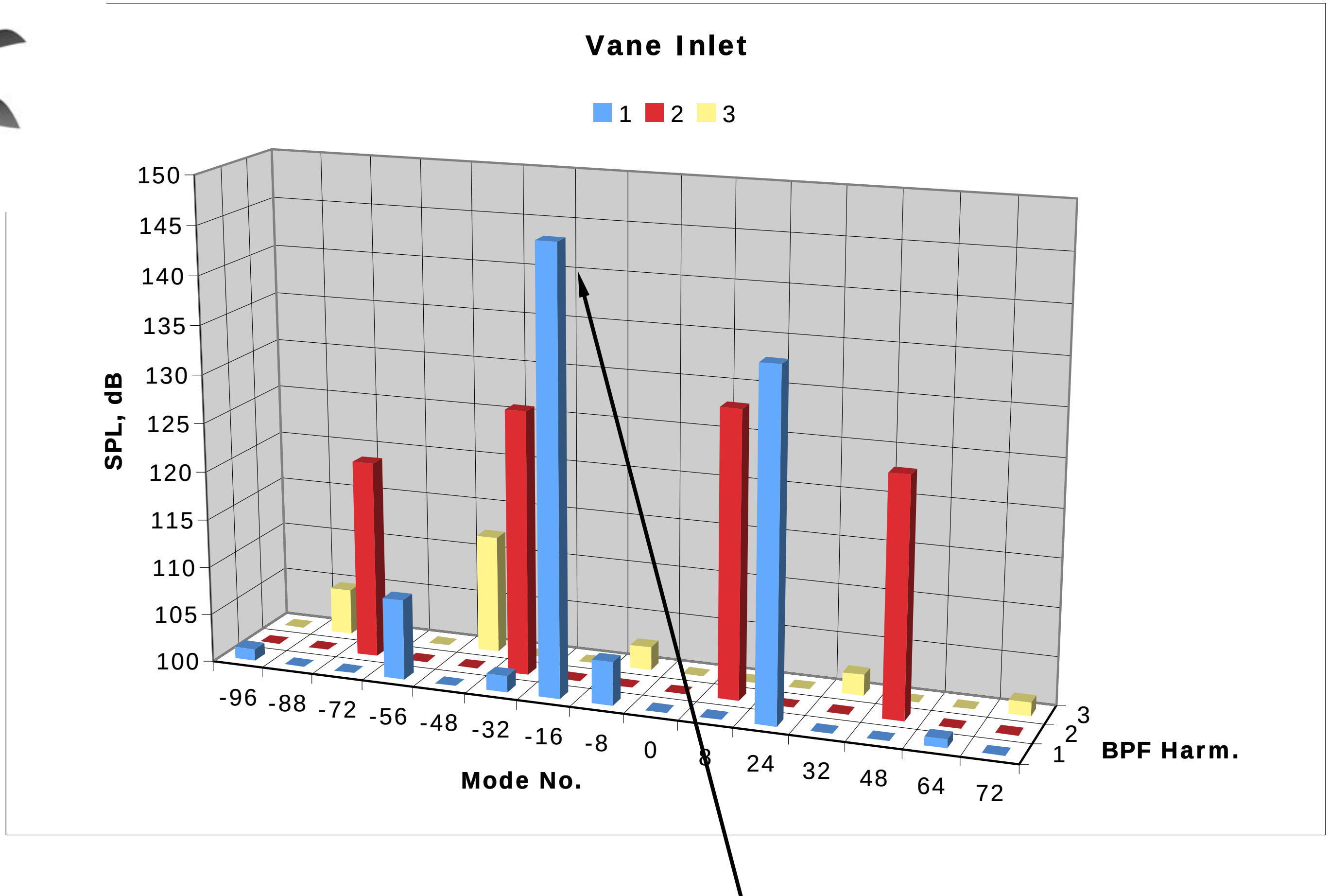


spatial variation of BPF tone

Note strong mode=16 content

Frequency/Mode Plot Upstream of Vane: 50% Span

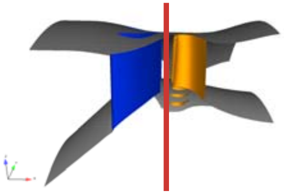


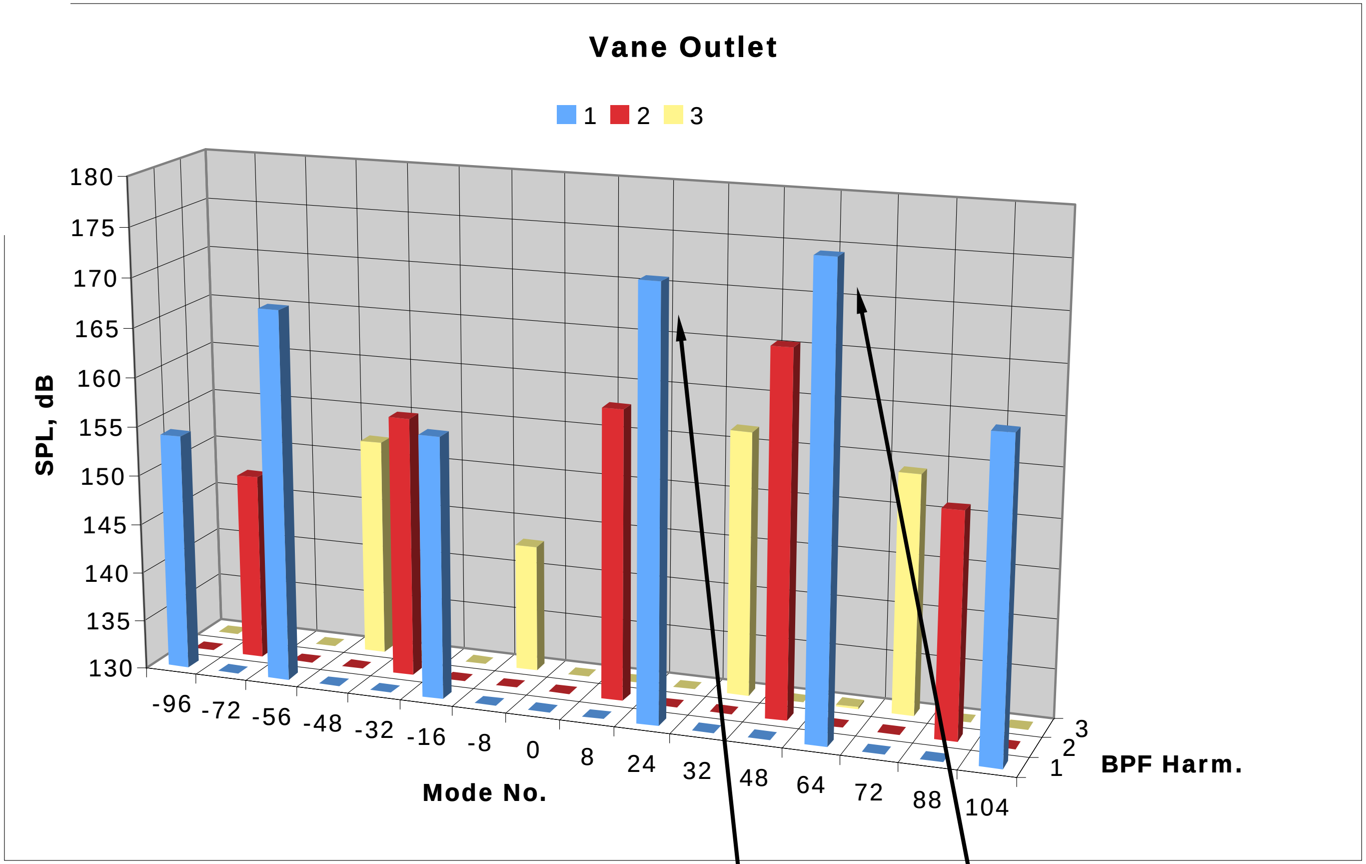


Most significant cut-on modes present:
@ 1xBPF: m = -56 -16 +24
@ 2xBPF: m = -72 -32 +8 +48
@ 3xBPF: m = -88 -48

Peak mode level: 145.6 dB (m= -16)

Frequency/Mode Plot Downstream of Vane: 50% Span



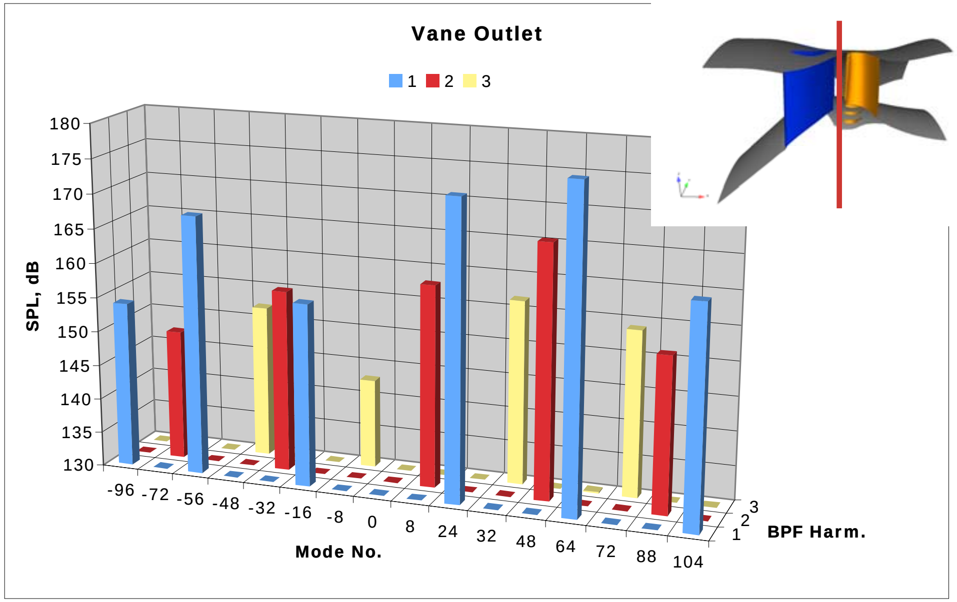


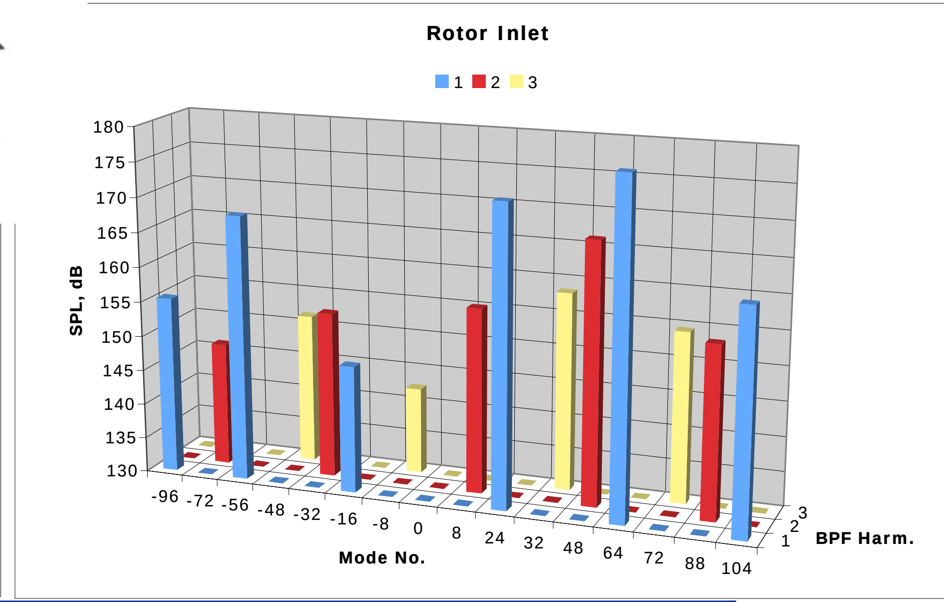
Peak mode level: 176.7 dB (m= +64)

173.2 dB (m= +24)

Modes present:
@ 1xBPF: -… -96 -56 -16 +24 +64 +104 …
@ 2xBPF: -… -112 -72 -32 +8 +48 +88 …
@ 3xBPF: -… -48 -8 +32 +72 …

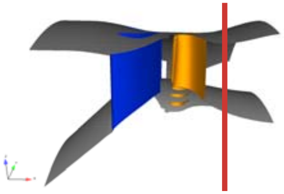
Frequency/Mode Plots across the sliding interface

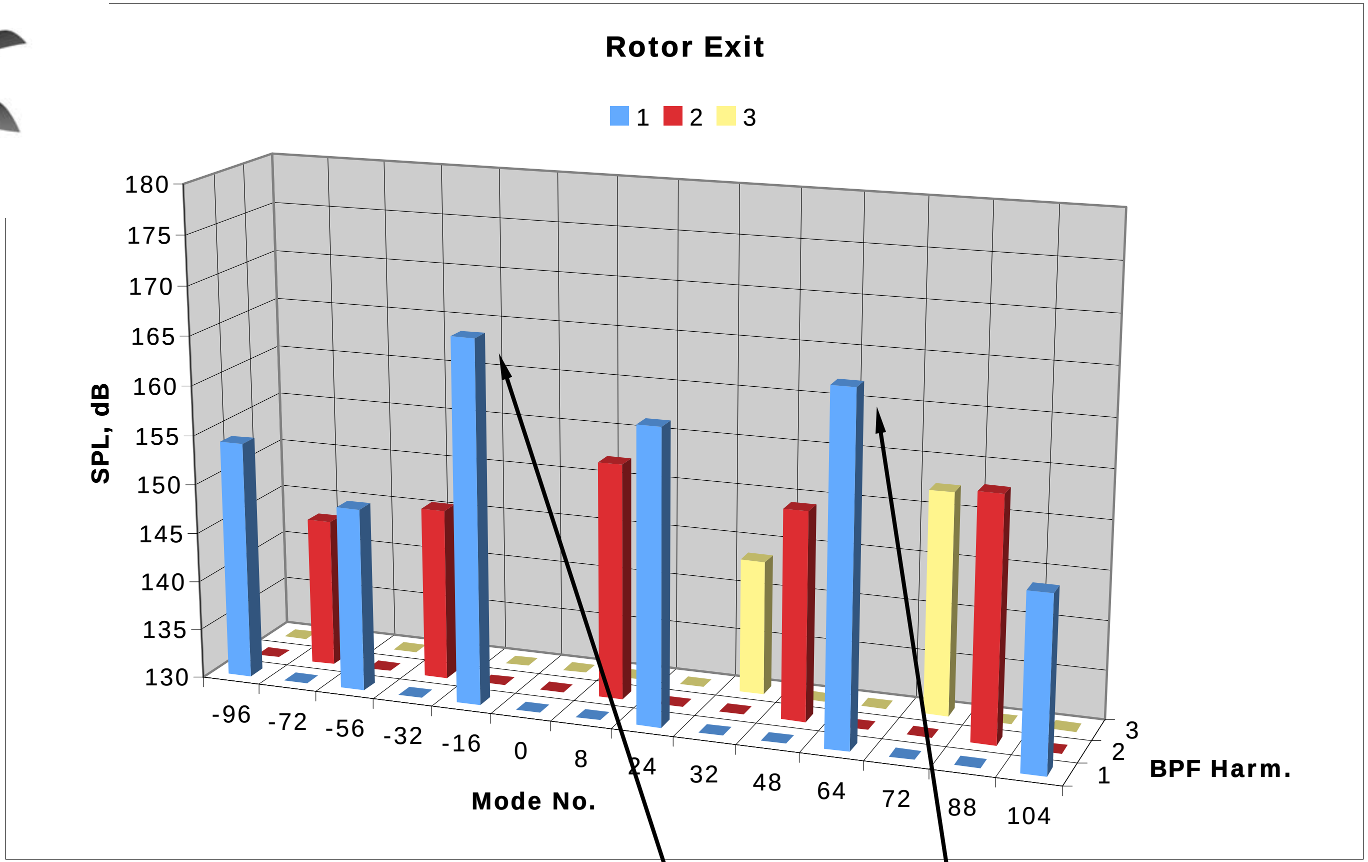




BPF Tone			
Mode No.	Station 1 (Vane) SPL, dB	Station 2 - Station 1 dB	Station 2 (Rotor) SPL, dB
-96	154.0	0.4	155.4
-56	167.6	0.5	168.1
-16	156.5	-8.3	148.2
24	173.2	-0.2	173.0
64	176.7	1.3	178.0
104	161.9	0.1	162.0

Frequency/Mode Plot Downstream of Rotor: 50% Span





Modes present:
@ 1xBPF: -… -96 -56 -16 +24 +64 +104 …
@ 2xBPF: -… -72 -32 +8 +48 +88 …
@ 3xBPF: -… +32 +72 …

Transmission Loss: A First Look

Mode	Vane Inlet SPL, dB	Interface (vane side) SPL, dB	Rotor Exit SPL, dB		Vane Pressure Transmission Loss, dB
-56	108.3	167.6	148.6		59.3
-16	145.6	156.5	166.7		10.9
24	135.6	173.2	159.7		37.7

Future Work

Near term work:

- Analysis of pressure wave transmission in the multi-stage HPT

Develop:

- Source hierarchy (vortical vs potential vs entropic)
- Transmission loss estimates
- Transmission loss model

Further simulations:

- Add pattern factor at turbine inlet
- Add combustor unsteadiness at turbine inlet
- Continue simulations through the LPT

Need help with:

- Change operating point from takeoff to approach
- Cooling flow definition (location, flow rate, P,T). Approach now is ad hoc.
- Validation data
- Another turbine geometry with a different aerodynamic design

Summary

Spetral and modal analysis of the unsteady pressure data from the numerical simulations show the allowable Tyler-Sofrin modes that are consistent with expectations.

Analysis will continue with the multi-stage simulation to further assess the validity of the methodology in a more complex modal environment.

More detailed results are scheduled to be published at the 2009 Aeroacoustics Meeting.

Acknowledgements:
This work is supported by SFW and SRW Projects.
Computer resources:
Columbia and RTJones at NAS
GX Cluster at GRC

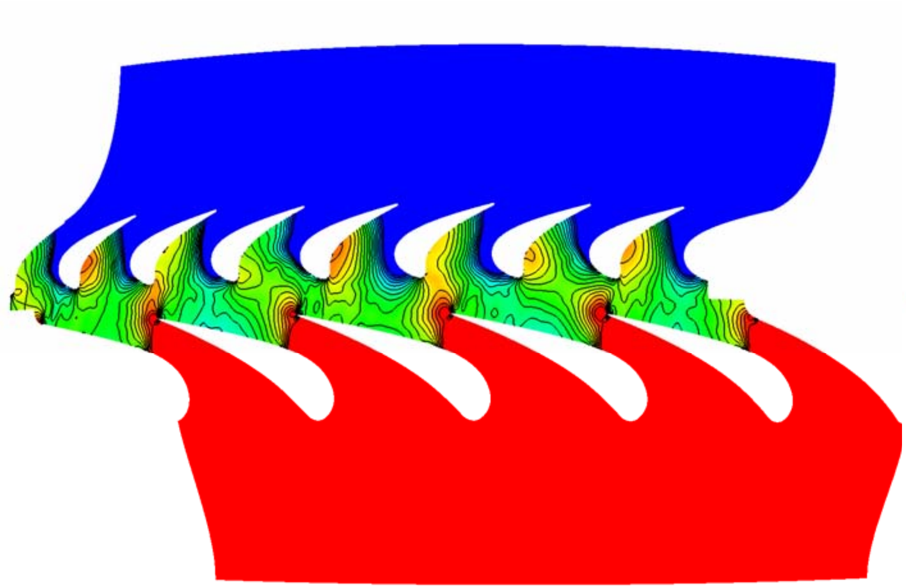
Flow Field Pressure Fluctuations

QuickTime™ and a
Motion JPEG OpenDML decompressor
are needed to see this picture.

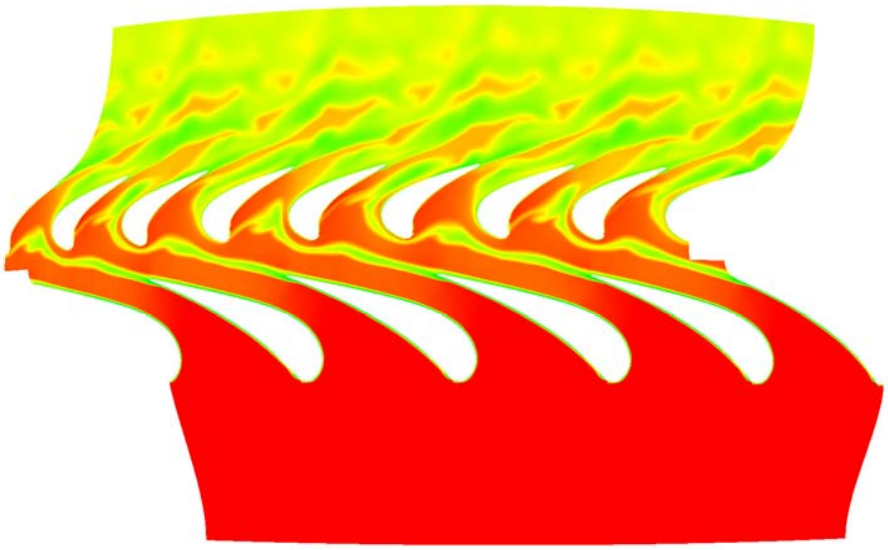
Animation showing pressure fluctuation propagating forward through vane
(coarse mesh solution)

Extra slides

Noise Generation Mechanisms (2)



Static pressure
(color scale adjusted to highlight
blade row interaction)



Static temperature

In turbines, tone noise generation mechanisms also include:
- potential field interactions due to close blade row spacing and large leading edge radii
- entropic interactions due to wake fluid which is hundreds of degrees cooler than the core flow

Downstream of Vane