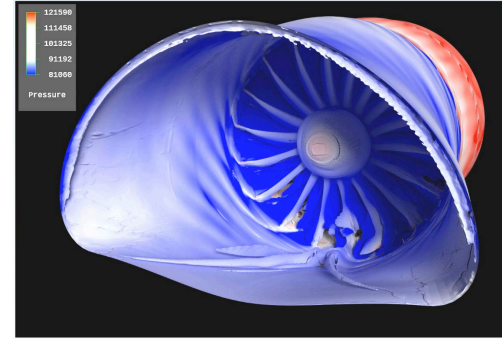
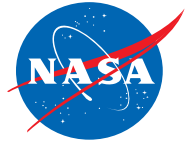


NASA Turbomachinery Capability for Simulation, Design, and Optimization

August 10, 2021

Presentation to NASIC

Mark G. Turner
NASA GRC



Contributions by:

Kenji Miki

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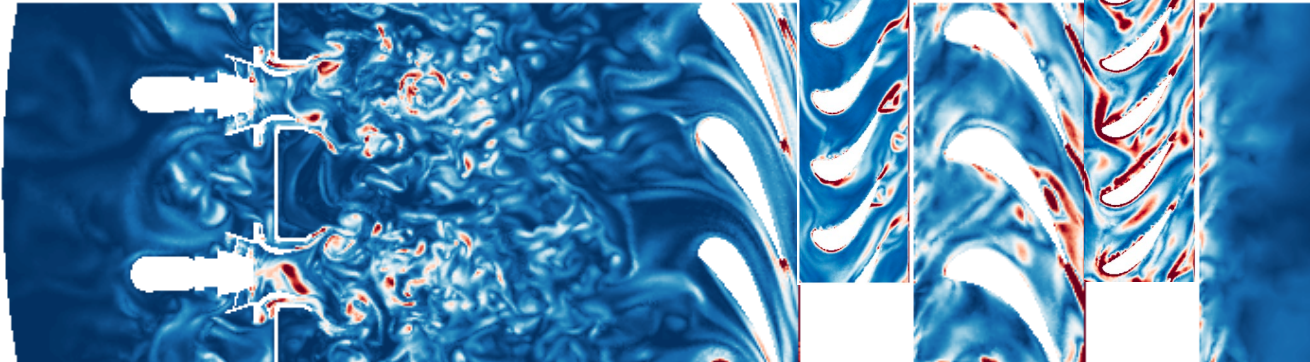
Ali Ameri

Mark Celestina

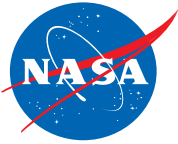
Jeff Moder

George Stefko

& many others



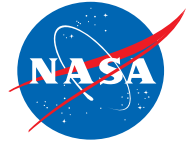
Complements Turbomachinery Efforts at AFRL



- Compressor
 - Connects to ESP (Engineering Sketch Pad) working with MDAO group
 - High speed fan, compressor, and centrifugal design capability
 - Still uses APNASA, a NASA code
- Turbine
 - ADS CFD code which NASA has looked into
 - Turbine Design Capability
 - Accounts for laminar to turbulent transition
- Combustion modeling collaboration limited

NASA has great relationships with Turbomachinery Experts at AFRL

My background is Aero - What I've Learned is:



- Other Disciplines are of Equal Importance to Aero Performance
 - If it breaks, it's not useful
 - Most CFD is run adiabatic even for turbines – Measure the casing temperature
 - Integrate with MDAO
 - Need to have real features such as fillets, shrouds, and disks
 - Need Campbell Diagram early
 - Need an automatic way to get CAD
- Multi-Discipline is critical (structures, aero, heat transfer, acoustics, aeromechanics, operability, controls, ...)
 - Human Factors, cost, maintenance???
- Need a Gradient Based Optimization Capability in 3D -> Adjoint
 - Optimizing for off-design is essential
 - Define the Right Objective Function

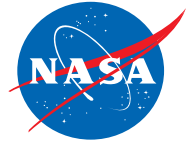
Break Down the Silos!

Outline

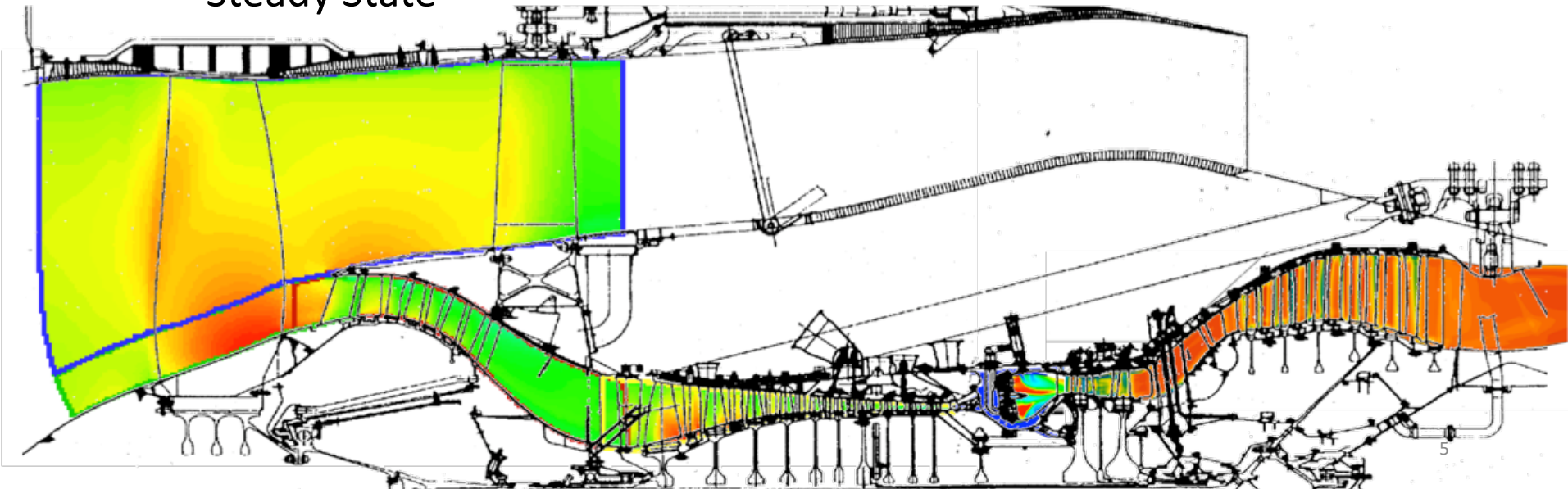


- Overall NASA Capability for Turbomachinery Simulation
 - Multistage Simulation
 - Unsteady Simulation
 - Inlet Distortion
 - Aeromechanics
 - LES of LPT blade
 - LES Combustor with Turbine
 - Acoustics (won't show)
 - Heat Transfer
 - OpenMDAO
- Future Direction
 - Further Multi-Discipline focus
 - Speed up Preprocessing for conventional and innovative turbomachinery
 - Design improvements with Optimization and Machine Learning
- Collaboration Opportunities

GE90 Full Engine Simulation

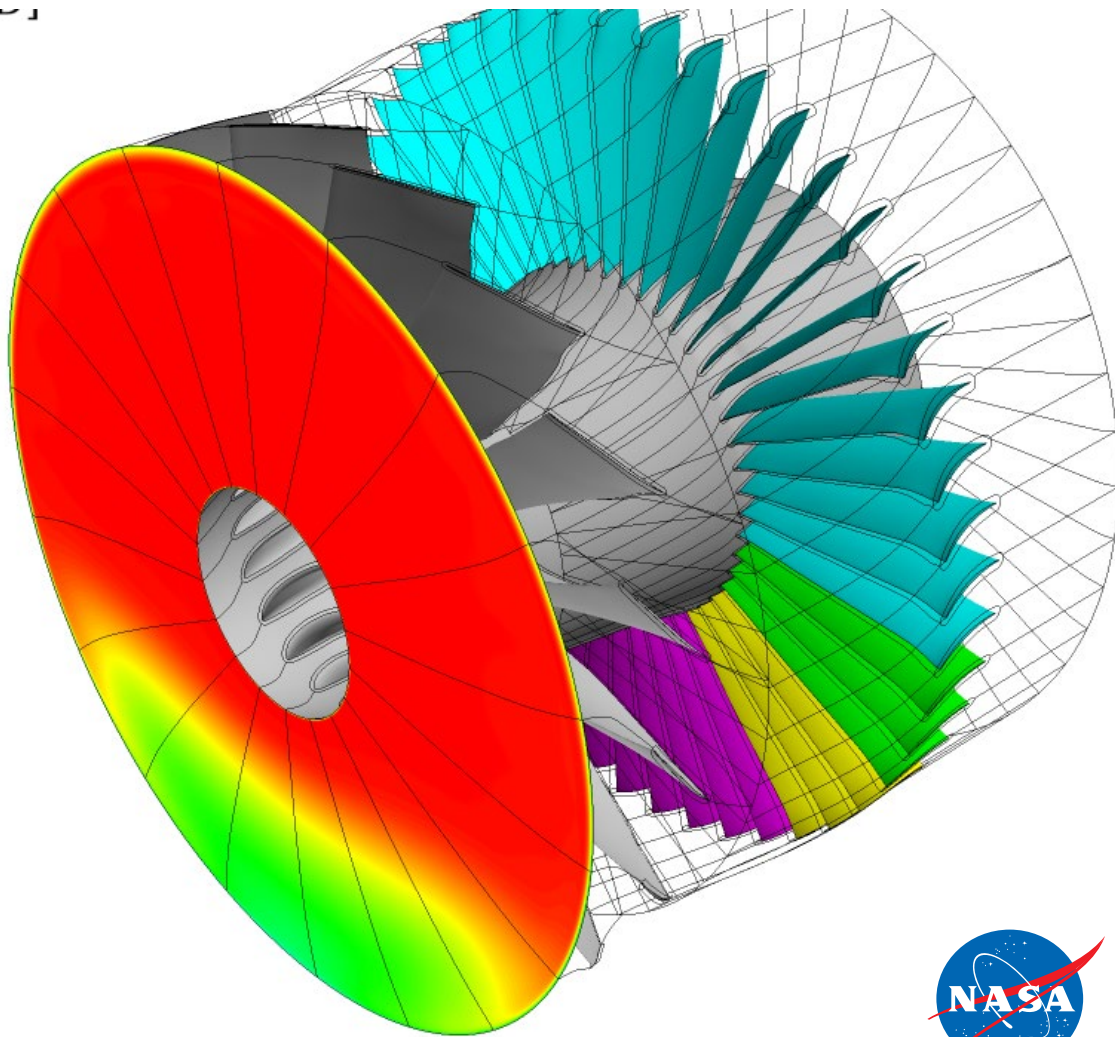
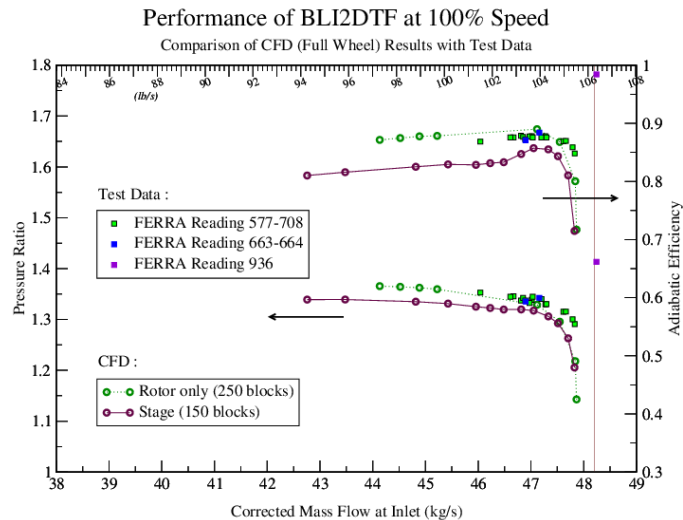


- Used APNASA for turbomachinery (50 blade rows)
- Used National Combustor Code (NCC) for combustor
- First Full Engine Simulation in 3D
- Completed in 2000
- Steady State

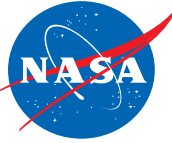


Distortion: BLI2DTF fan stage with TURBO code

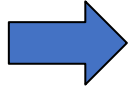
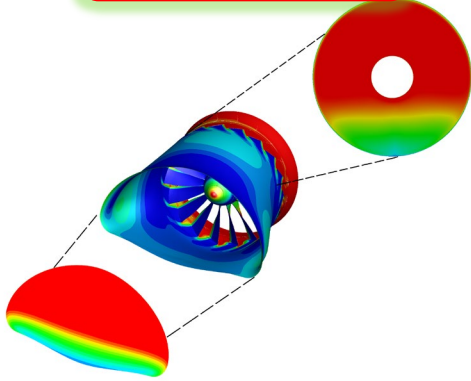
Distortion from inlet and fuselage modeled through fan – compared to test



Aeromechanics couples CFD with FEA



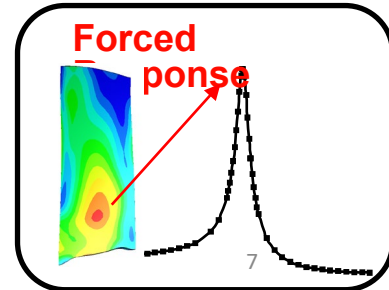
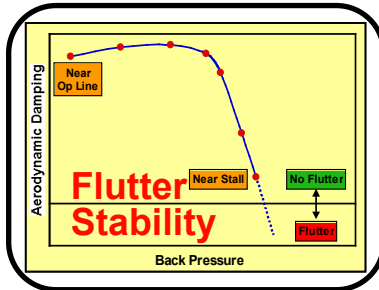
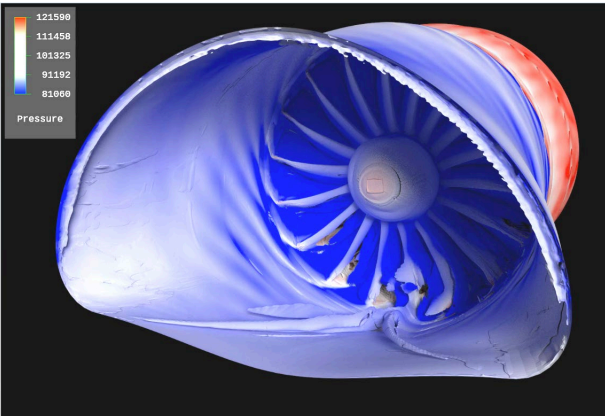
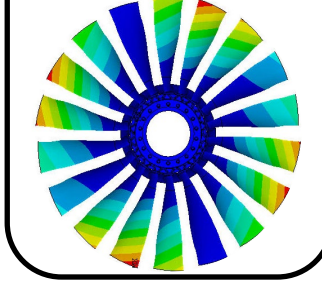
Coupled Inlet-Fan
Modeling



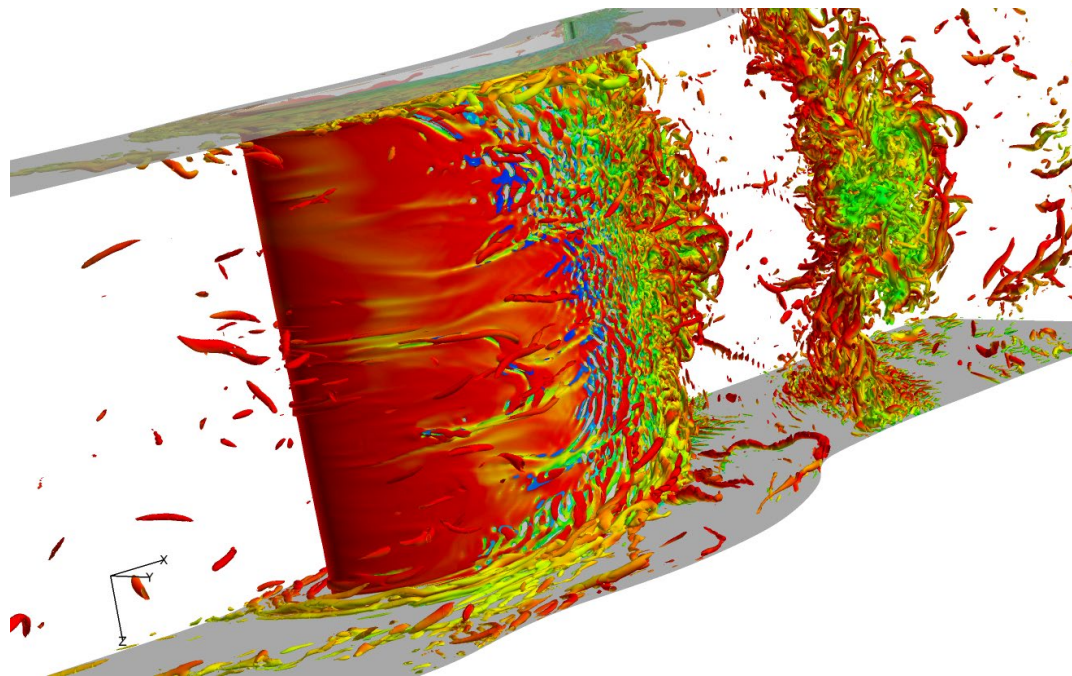
*Steady & Unsteady
Aerodynamics*



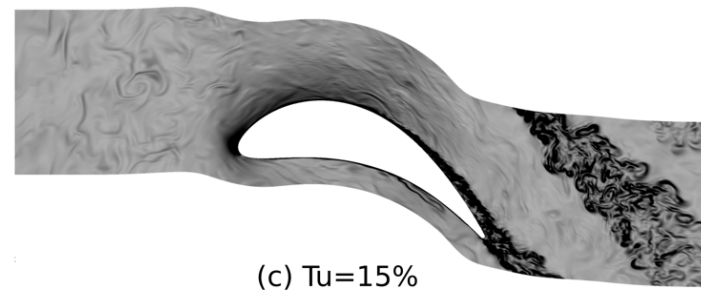
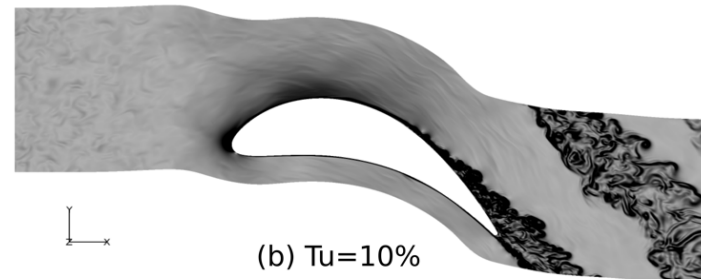
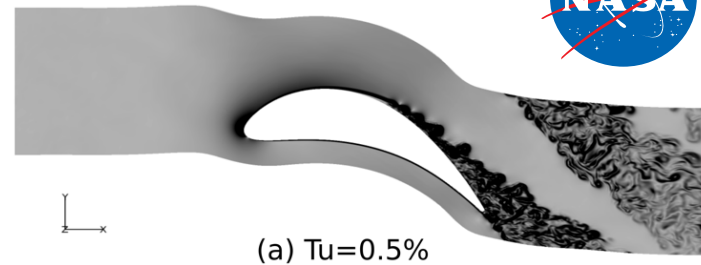
*Structural
Dynamics*



LES of LPT with GlennHT



Instantaneous Iso-Surface of Q-Criterion

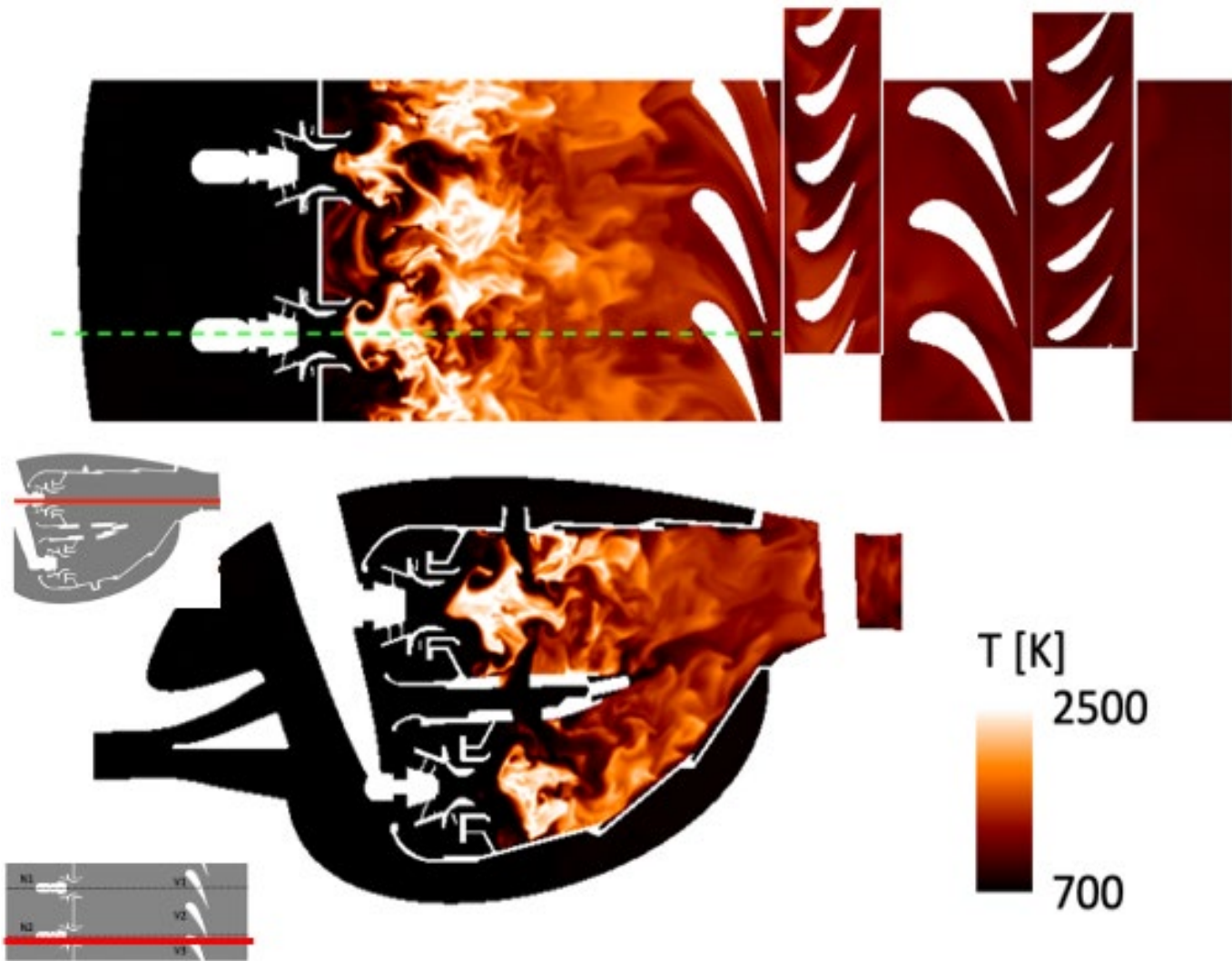


Instantaneous Density Gradient

LES of EEE
Combustor &
HPT (uncooled)

Uses OpenNCC

Temperature
Contours

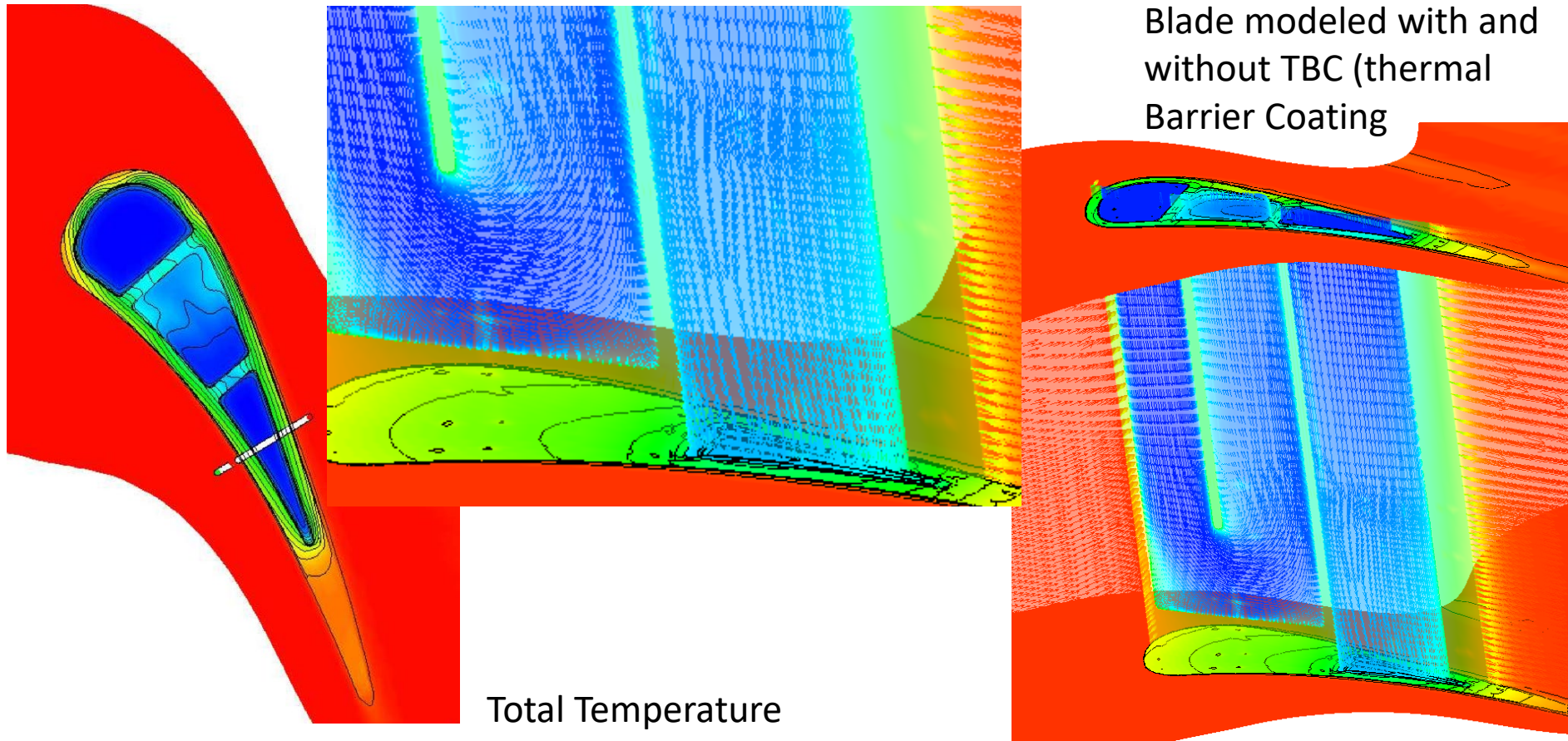




Conjugate Heat Transfer with GlennHT

Fluid and Solid modeled

Blade modeled with and
without TBC (thermal
Barrier Coating)



Total Temperature

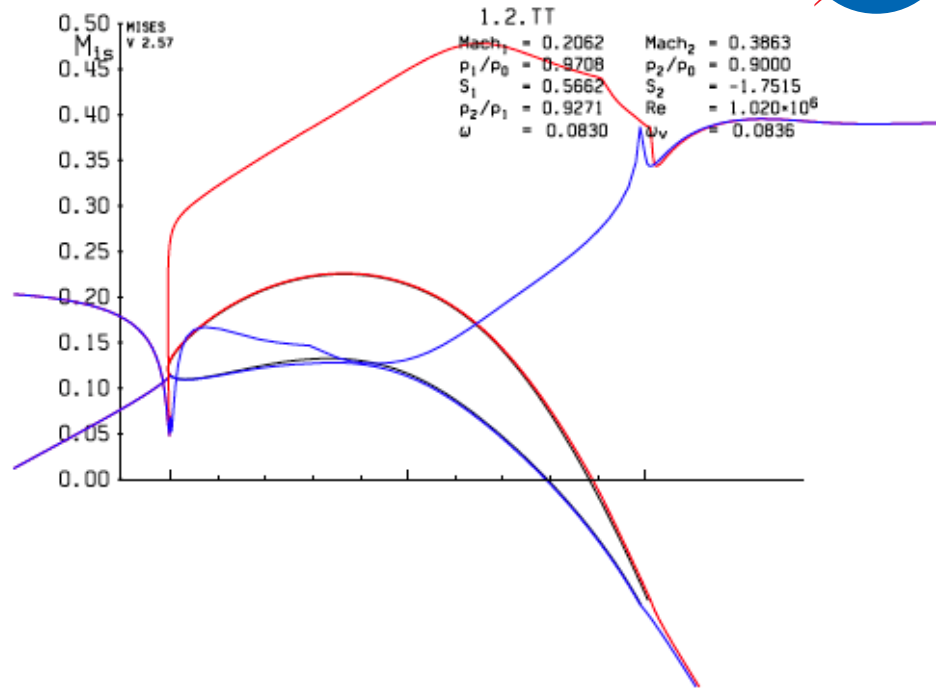


OpenMDAO:

OpenMDAO is an open-source optimization framework and a platform to building new analysis tools with analytic derivatives

Python code

Available to all



Turbine Section Constrained Optimization
Uses T-Blade3 & Mises

Future Direction: more Multi-Discipline Capability

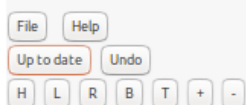
- Coupled Physics: loosely or tightly coupled
- Break down Silos: experts in design & simulation, not aero or structures
- Exploit ESP (Engineering Sketch Pad) for passing information, geometry generation, and sensitivities
- Exploit new frameworks, automated grid generators, faster less dissipative solvers
- Use Adjoint solvers for sensitivities and gradient-based optimization





Future for Turbomachinery: Engineering Sketch Pad (ESP)

- Developed by Bob Haimes of MIT and John Dannenhoffer of Syracuse
- Development largely funded by AFRL, mostly for airframe design and optimization
- Integrated with T-Blade3 (recent TurboExpo paper)
- Integration is part of T-Blade3 source
- Framework instead of CAD
- Analytic derivatives now available for gradient-based optimization



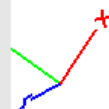
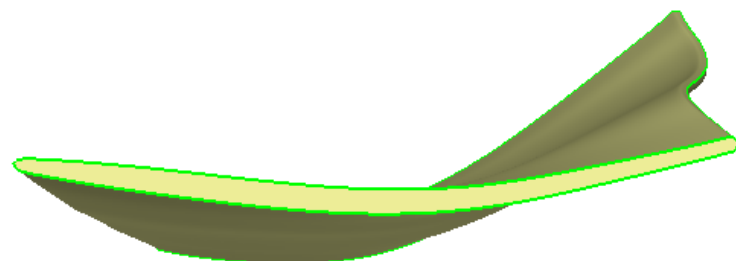
- Design Parameters

mrel1	[1x5]
chord	[1x5]
thk_c	[1x5]
inci	[1x5]
devn	[1x5]
in_beta	[1x5]
out_beta	[1x5]
u2	[1x4]
u3	[1x4]
u4	[1x4]
u5	[1x4]
u6	[1x4]
cur2	[1x4]
cur3	[1x4]
cur4	[1x4]
cur5	[1x4]
cur6	[1x4]

+ Local Variables

+ Branches

- Display	Viz	Grd
+ Body 15	Viz	Grd
Axes	Viz	
DisplayType		



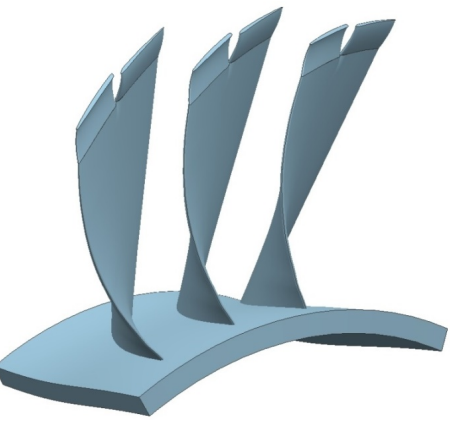
Parameter 'out_beta[1,1]' has been changed to 20 =====> Re-build is needed <=====

Parameter 'out_beta[1,2]' has been changed to 20 =====> Re-build is needed <=====

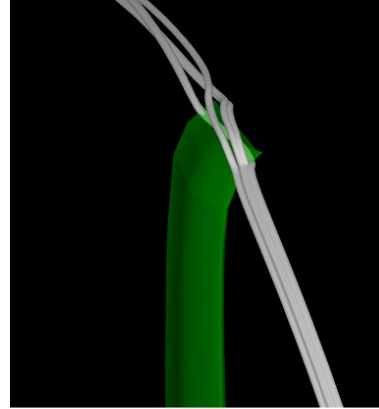
Parameter 'out_beta[1,3]' has been changed to 20 =====> Re-build is needed <=====

Parameter 'out_beta[1,4]' has been changed to 20 =====> Re-build is needed <=====

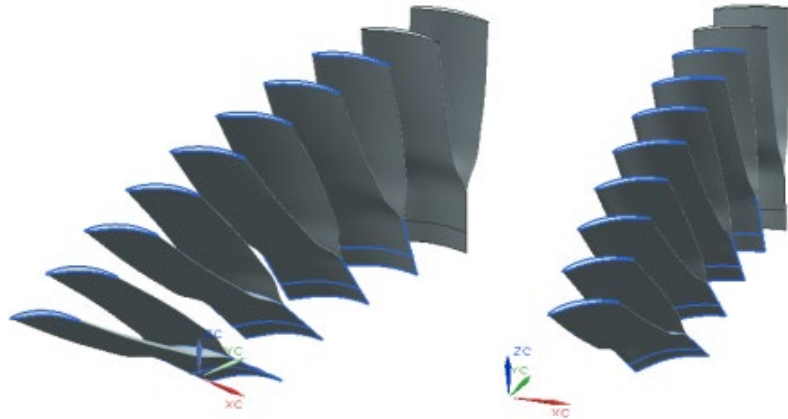
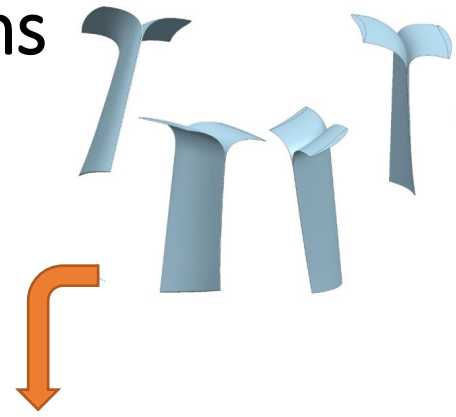
Future: Novel Geometry Designs



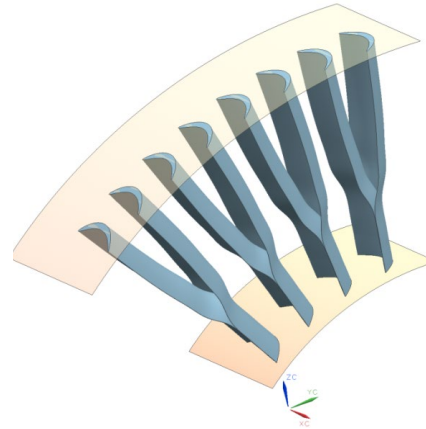
Combine T-Blade3 with CAD to enable Turbomachinery Innovation!



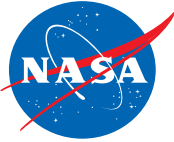
NREL-Winglet tip streamtubes.



***Outlet Guide Vane
(variable solidity)***



Collaborative Opportunities



- Very complementary to AFRL & NASIC efforts
- Multi-disciplinary is key
 - Design system needs to work with both aerodynamics, structures, acoustics, heat transfer ...
 - People need to be multi-disciplinary. – Remove Silos
- ESP integrated with T-Blade3 allows for automated CAD with Sensitivities can integrate with airframe
- Push for more Turbomachinery Innovation
- Have more discussions for even more common/complementary tools
- Coupled components:
 - Combustor – cooled turbine (planned for next year)
- SBIR/STTR code development, commercial codes, Air Force code collaboration

Questions?