CFD @ GE … Usage & Trends

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Overview of CFD at GE

Wide penetration

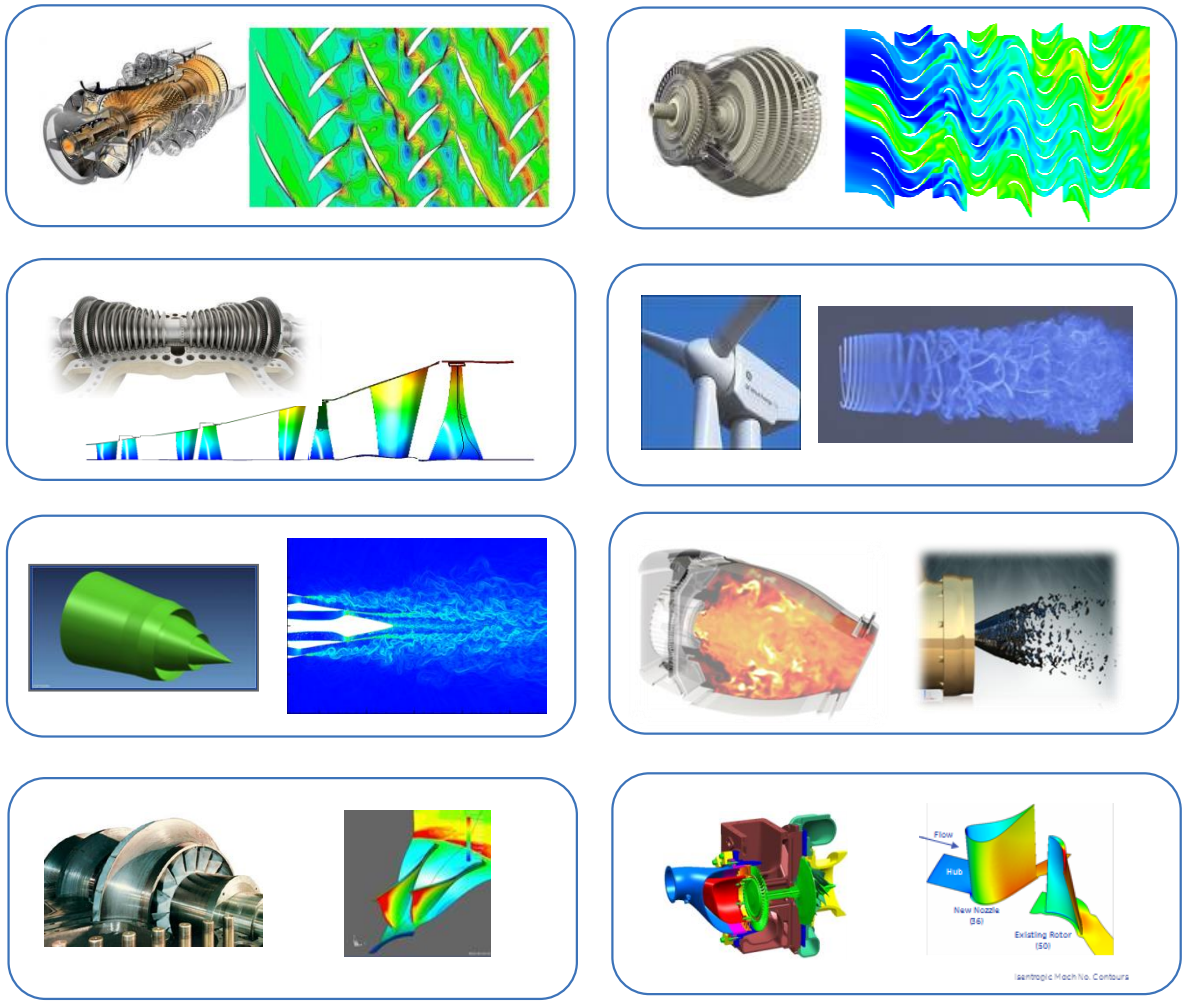
- Aviation, Power, Oil & Gas, Renewables
- Aerodynamics, heat transfer, aero-mechanics, aero-acoustics, combustion
- Every new product

Long term investment in software

- In house turbomachinery solver (TACOMA™)
- ISV solvers: ANSYS CFX & Fluent, CharLES
- LES solvers: FDL3DI, HipStar, etc.

Sustained investments in HPC

- In house Linux and Cray resources
- Access to US & EU Leadership facilities
- Leverage partners



GE Products … Pushing the boundaries

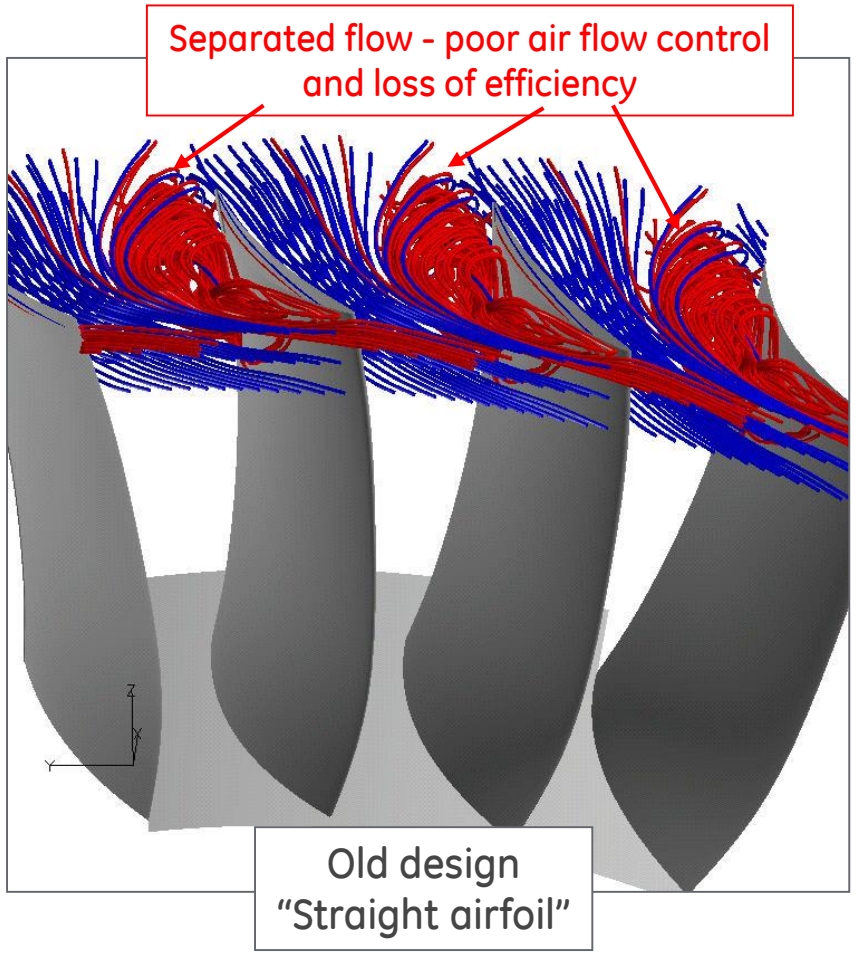
Next generation single aisle … B737, A320
15% reduction in fuel burn (GE/Safran CFM56)

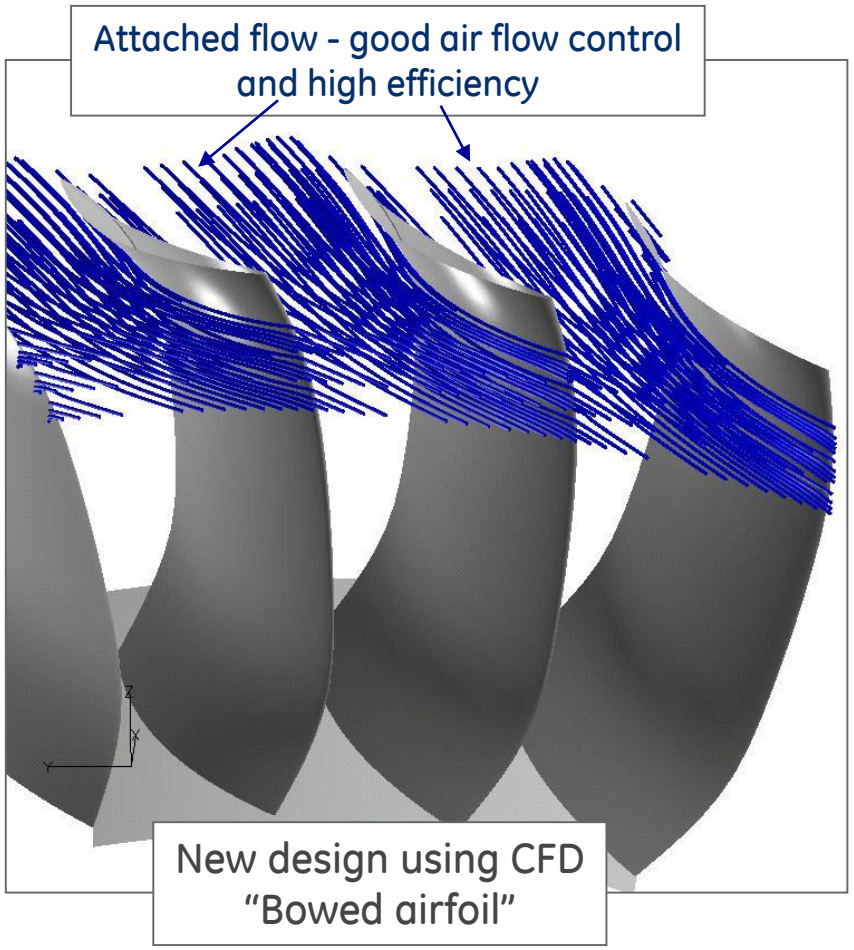
Next generation B777
10% reduction in fuel burn (GE90)

9HA.02 Gas Turbine
Record setting 64% combined cycle efficiency @ 826 MW

Pushing the state of the art … today and for next generation products
$1BB of fuel burned in GE products … Aircraft Engines, Gas Turbines, Locomotives

CFD provides insights to drive design





In house software for blade row simulations

GE does not rely solely on commercial software

Turbomachinery blade design … TACOMA™

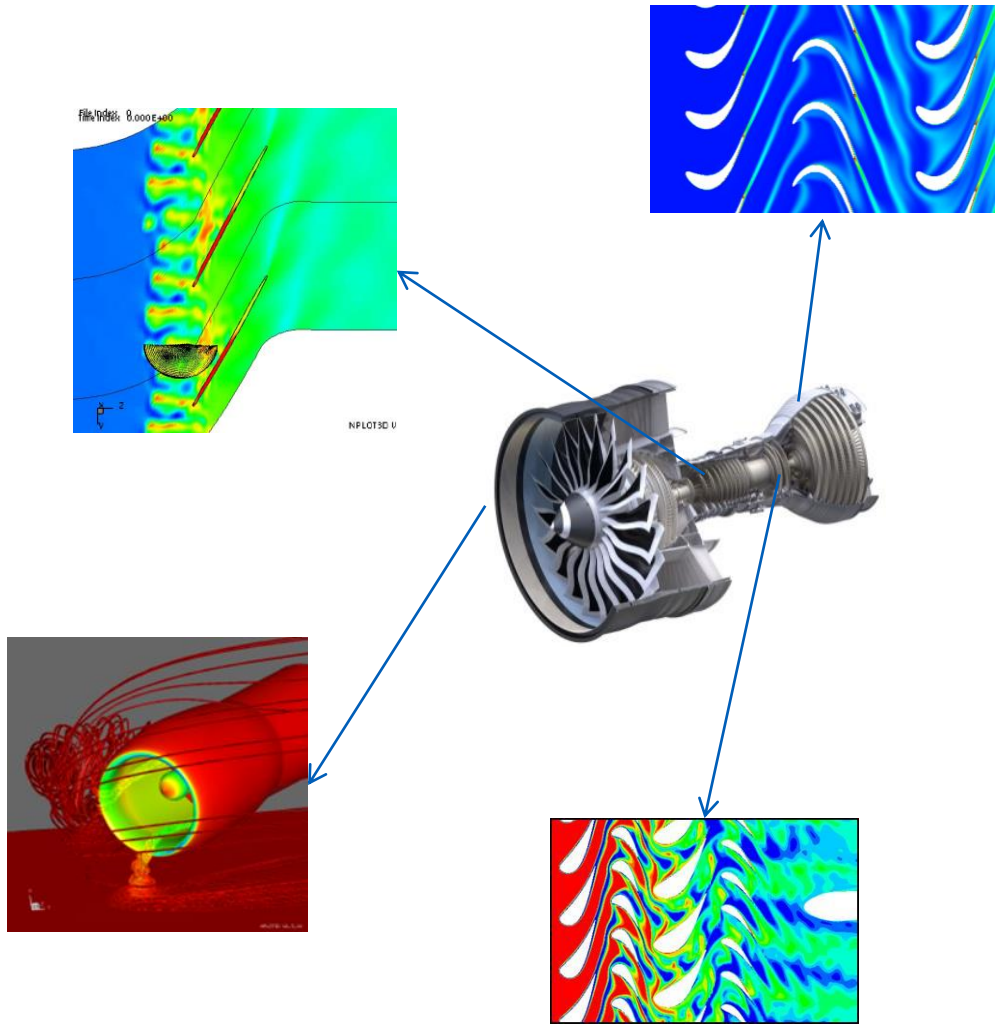
- 2nd order accuracy … “explicit”, FV, multi-grid
- Block structured & unstructured meshes
- RANS, URANS, HLES
- 20+ years of development & use; ~1MM lines of modern Fortran

LES efforts also leverage SW brought in house

Why?

- Moving fluids is critical to GE’s success
- Need to control our fate, push SOA
- Specialize to t/m; integrate with design system
- Affordable at GE’s scale

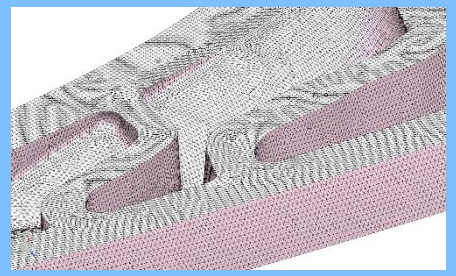
Software / tool systems … not just solvers



CFD systems … not just “silo” tools

Geometry & Meshing

- Meshing systems for block structured and unstructured meshes
- Support for very complex geometries
- Common CAD representation

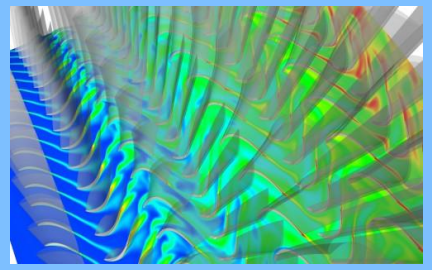


Flow Solvers

- 40+ year history of CFD
- TACOMA™
- ANSYS, Cascade solvers
- Aero / heat transfer LES solvers

Post Processing

- NPLOT3D … legacy tool for bread and butter applications … customized for GE’s designers
- EnSight … visualization of very large cases



Meshing capabilities influence solvers

Where to compute quantities of interest … solver or post processor?

GE's CFD is responding to inter-connected trends

1. Products are relentlessly improving

2. Simulations getting more complex

3. CFD used earlier & later in the design process

4. External computer hardware & software trends

1 Products relentless improving

Reduced fuel burn, reduced emissions, reduced noise, more durable, lighter

Component & airfoil efficiencies improving … difficulty scales like $1 - \eta$

Pushing into new corners of the design space

New architectural implications … Open Rotor, CMCs, etc.

Reducing design cycle time

Past experiences are an insufficient guide

Requires more detailed resolution of flow physics

Pushing boundaries of RANS applicability

Focus on solve time & engineering productivity

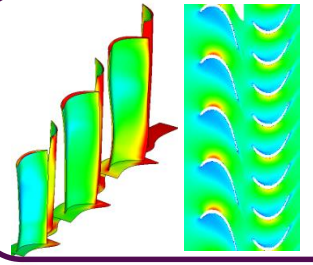
2 Simulations becoming more complex

Single blade row meshes … 100K → 5+MM over 20 years

Single blade row → components

RANS → URANS → (H)LES

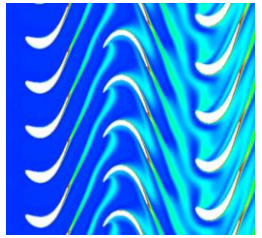
More detailed geometric resolution

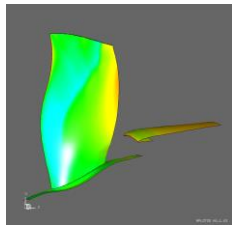


Unsteady Turbomachinery Design

From steady mixing plane to full unsteady

Benefit: Increased efficiency

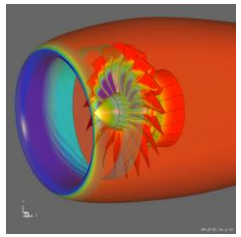


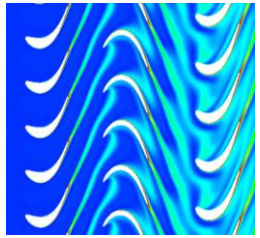


Inlet / Nacelle

From isolated blades to full components

Benefit: Fan operability

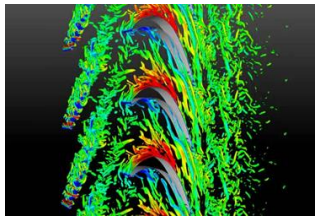


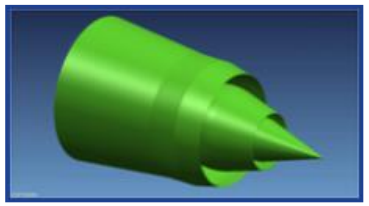


LPT Aero

URANS → LES & HLES

Benefits: Aero insights

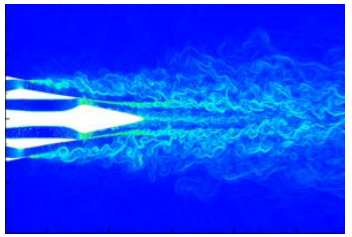




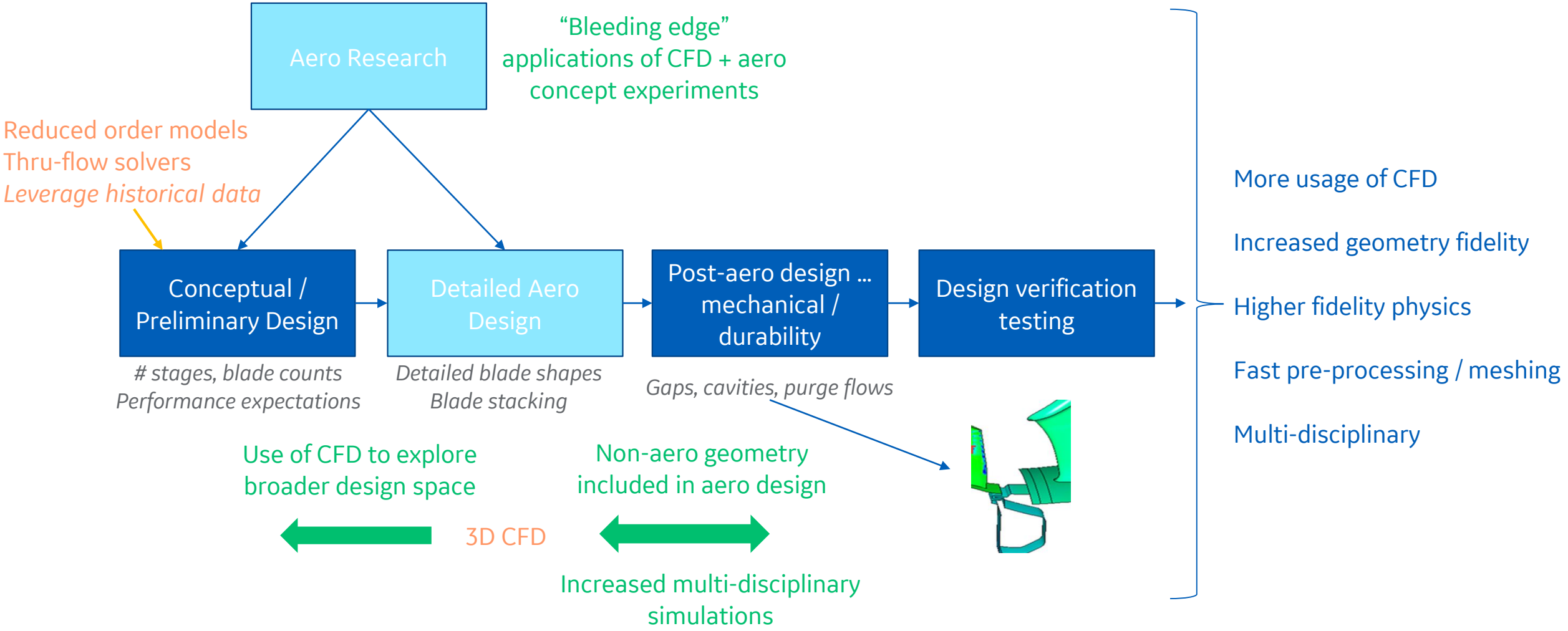
Jet Exhaust

From testing to LES CFD for noise

Benefit: Reduced noise



3 Expanded role of simulations in the design process



4 External Hardware & Software Trends

Challenge & Opportunity

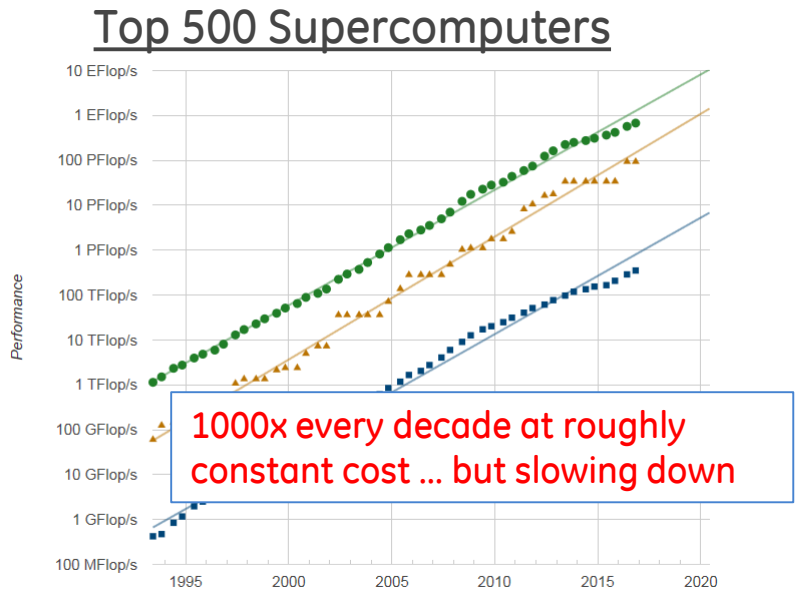
Scientific community's fate tied to wider trends

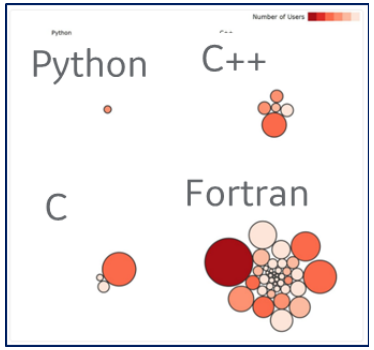
- Web servers → driving volume
- Gaming, AI → GPUs and accelerators
- Evolution of programming models & tools

HPC hardware directions are now multi-faceted and unclear … must be nimble

AI & Deep Learning

Fortran is not dead … but there is more than just Fortran & procedural-style software





Languages used at Archer

http://www.archer.ac.uk/status/codes/

Implications for CFD at GE

Increased usage of CFD

More complex geometry

Full component simulations

Increased use of unsteady simulations

RANS & HLES / LES

Focus on meshing for complex geometry

Focus on speed from algorithms

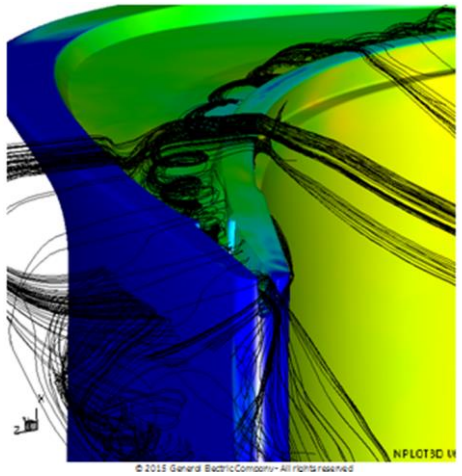
Focus on HPC performance

Focus on advanced turbulence models

Some CFD technology responses

Structured & unstructured capability

- Historically … block structured meshes
- Design trends → need for unstructured meshes
- Response → Convert TACOMA™ to unstructured … leverage 20 years of investment



Focus on HPC Performance

GE working with Intel, NVIDIA, Cray

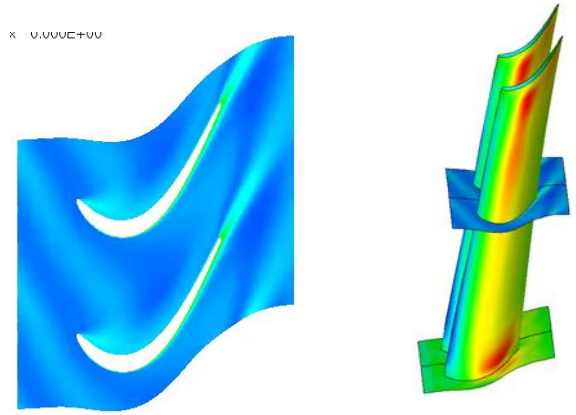
MPI + OpenMP + SIMD + OpenACC

TACOMA™ demonstrated on over 100K cores

Speed from algorithms

Harmonic Balance

- Exploit known harmonic content
- 4-50x speed-up

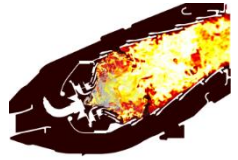


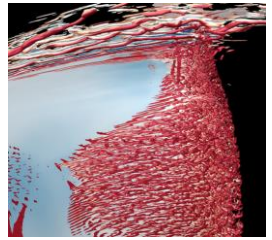
Entropy, 6 harmonics

Advanced Turbulence models

LES is now routinely used for combustion, exhaust jets

Being used for insights and modeling in core turbomachinery





GE leverages academic learnings, specializes to turbomachinery, selectively pushes the state of the art

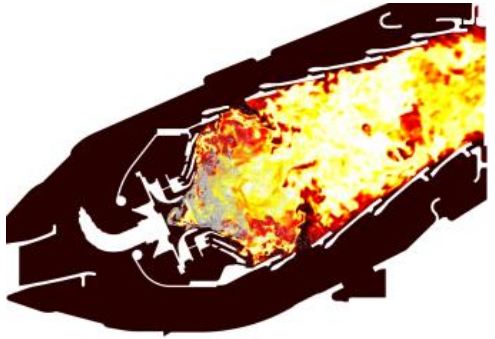
LES directly impact design process

Some problems can be directly tackled with LES

- Combustors
- Exhaust jets
- Film cooling

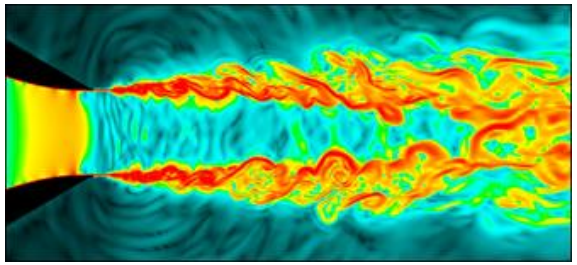
Common elements

- Free shear dominated
- Modest Re
- Baseline RANS is inadequate



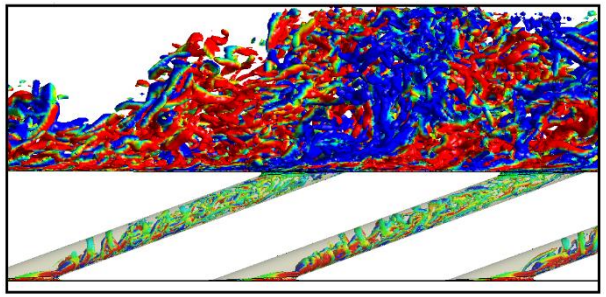
Combustion

- LES becoming routine
- Investigate emissions
- Investigate self-excited dynamics
- Improved prediction of turbine inlet



Exhaust Jets

- Demonstrated using US DOE grants
- Great match to data
- Replacing the need for testing
- Being used for design



IGTI 2016-56400

Film Cooling

- Demonstrated on a variety of file cooling unit configurations
- Being used to reduce coupon testing
- “Data” fed into design codes

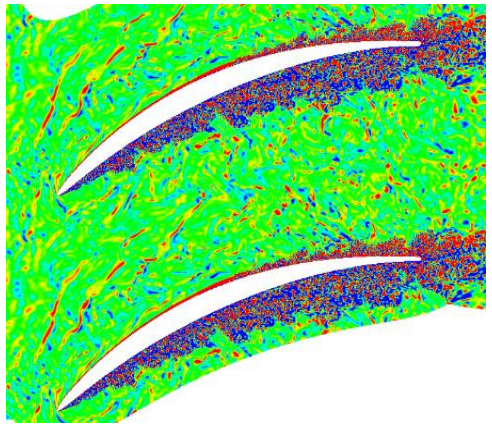
LES used for insight & modeling

Turbomachinery … LES much more expensive

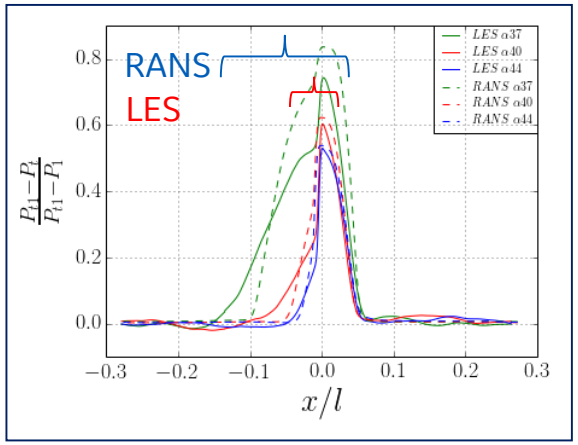
- Re … 10^4 to 10^6
- Wall bounded, but with shear layers (wakes)

How to use effectively

- Elucidate aerodynamic principles
- Focus on key challenging physics
- Obtain data to guide RANS modeling

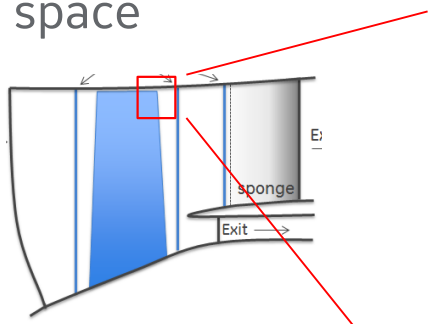


Q - criterion

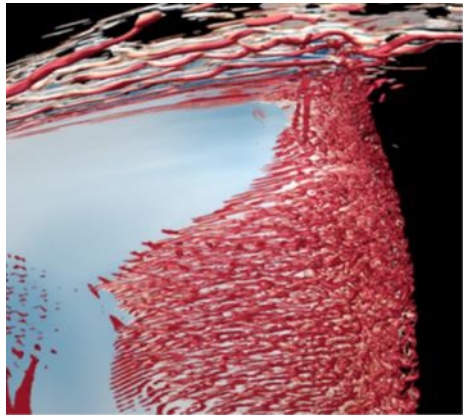


Improved wake prediction

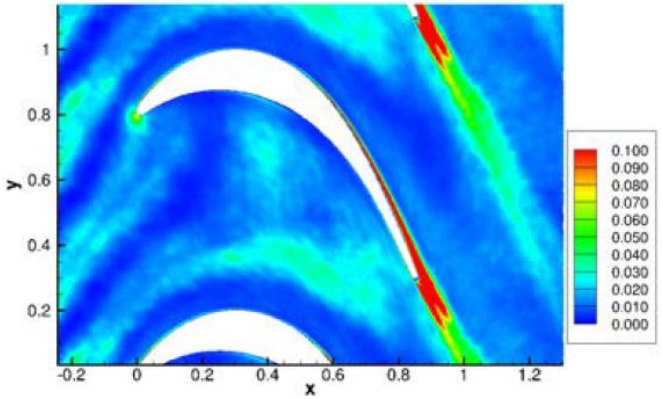
GE is using LES and HLES in the turbomachinery space



AIAA 2016-3816



Transonic fan
Investigated post shock boundary layer

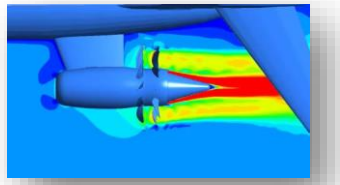


Error in RANS Reynolds Stress
T106 LPT … Southampton / Melbourne & GE Partnership

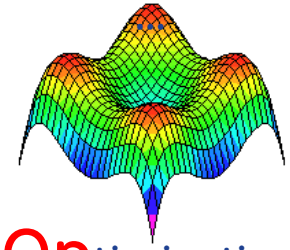
GT2014-25689
GT2016-57972

Organizational success requires integrated strategy

Microscope

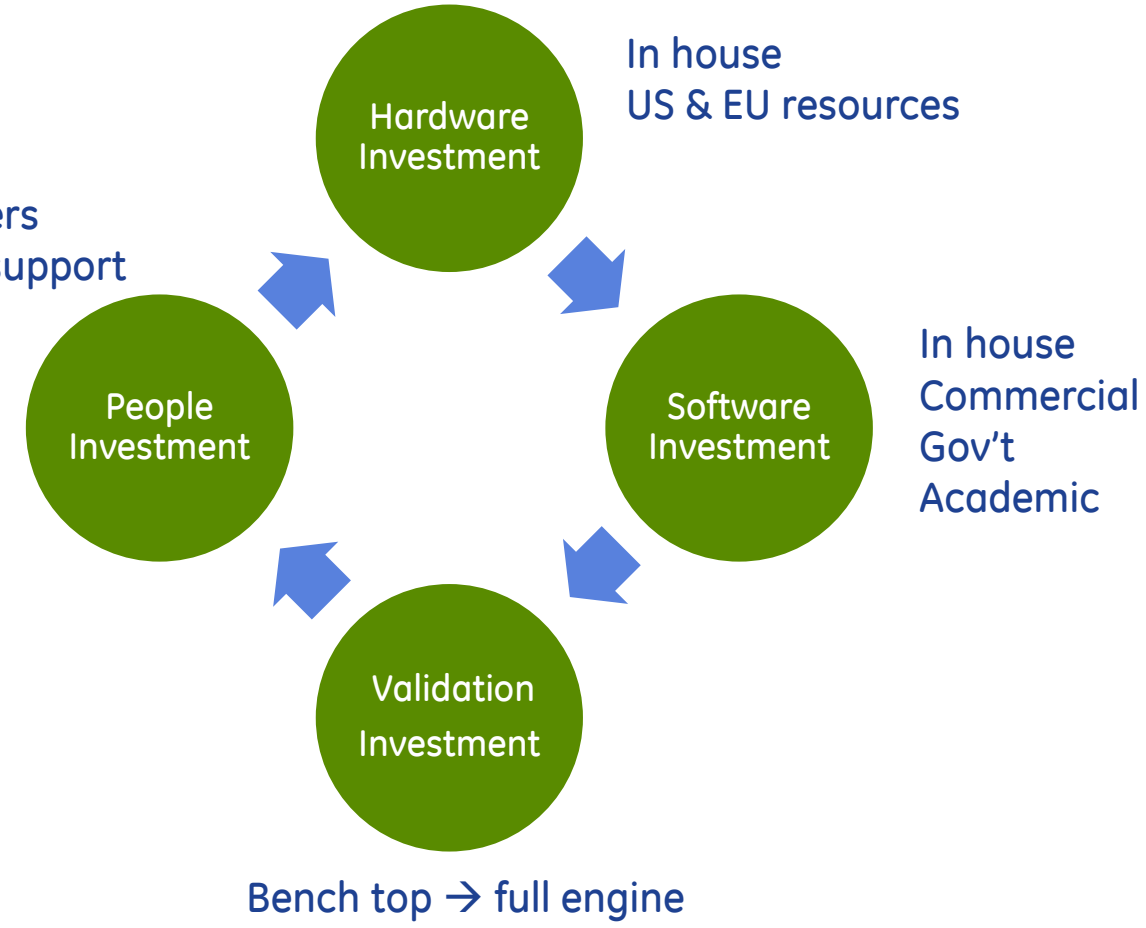


Macroscope



Optimization

Researchers
Methods support
Designers



Bench top → full engine