AERO-THERMAL METHODS FOR ENGINE DESIGN: EVOLUTION AND CHALLENGES

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- A UNITED TECHNOLOGIES COMPANY

INTRODUCTION

Dr. Atul Kohli
Senior Technical Fellow
Heat Transfer – Analytical Methods
Pratt & Whitney

Fellow of the ASME

21 years in industry, all at Pratt & Whitney
More than 30 refereed publications, 15 issued patents with over 30 pending

Expertise in heat transfer and cooling for hot section components
Drive improvements in design system and analysis capabilities for prediction of metal temperatures

BSME from the Indian Institute of Technology
MSME and PhD in Mechanical Engineering from the University of Texas at Austin

SIMULATION HAS MADE SIGNIFICANT IMPACT ON ENGINE DESIGN

1960 1970 1980 1990 2000 2010 2020

3D Euler + Boundary Layer

3D RANS

Multi-stage RANS

Unsteady Multi-stage Euler, RANS

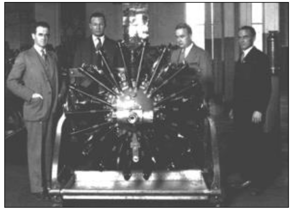
Unsteady Multi-stage RANS

HLES & Multi-discipline

JT8D

PW4000

GTF



Wasp

F100

F119

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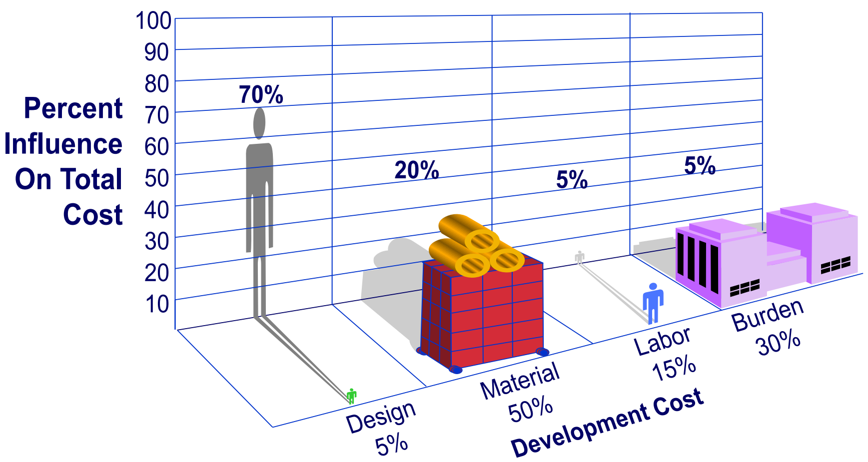
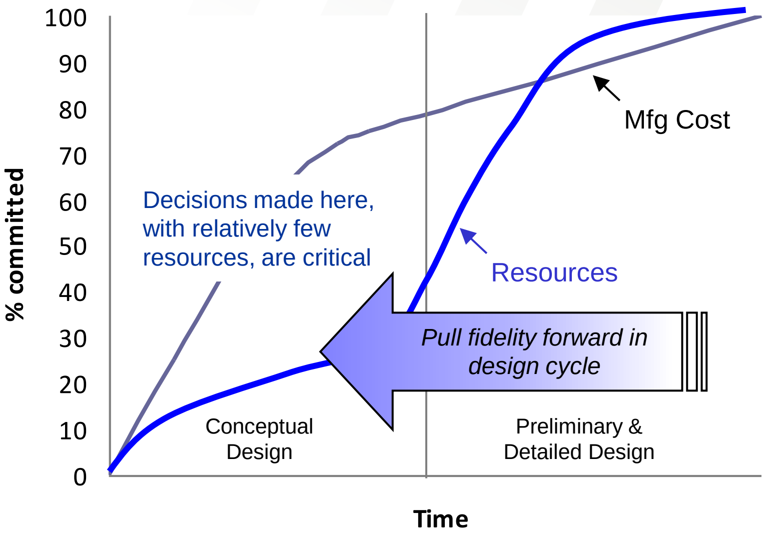
HUGE OPPORTUNITY FOR SIMULATION TOOLS

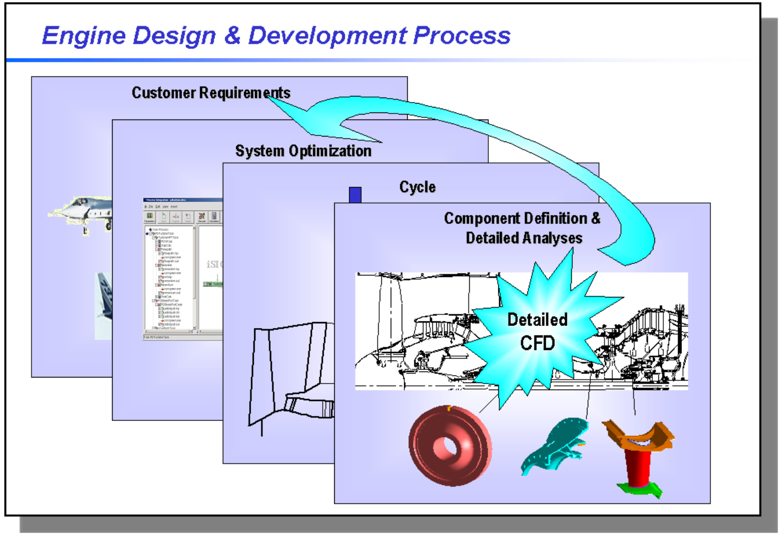


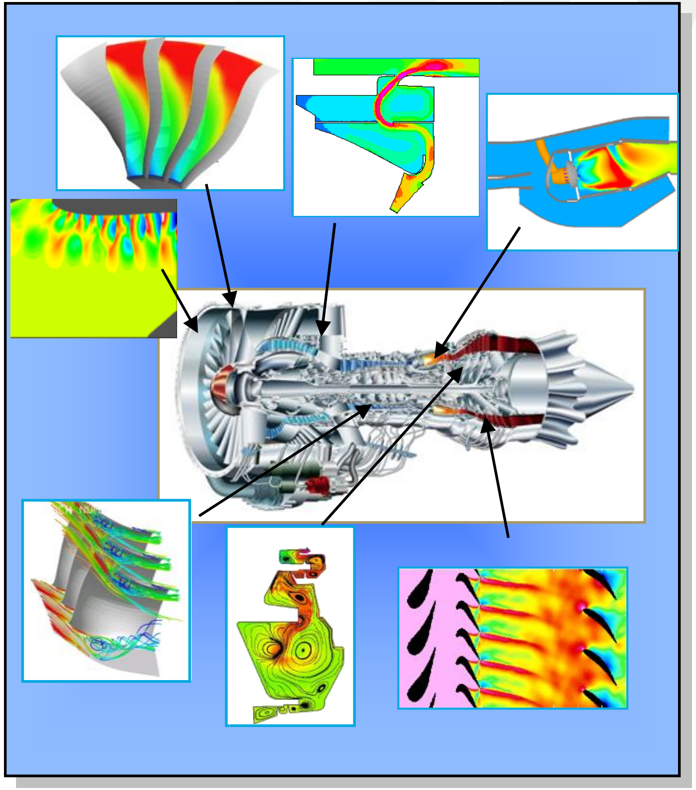
"75 percent of the manufacturing cost is committed by the end of conceptual phase of the design process"[1]



[1] D. Ullman, *The Mechanical Design Process*, McGraw-Hill, New York, 1992

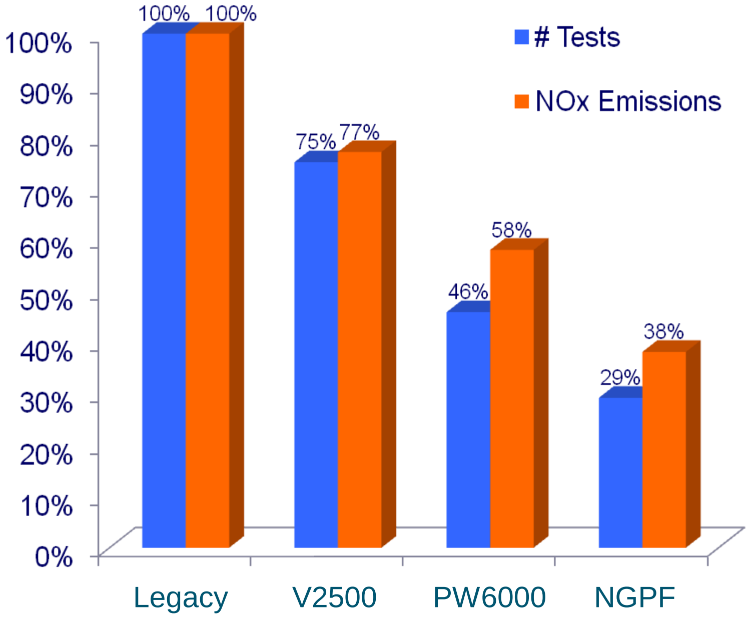
ENGINEERING SIMULATIONS ARE INTEGRAL PART OF ENGINE DESIGN

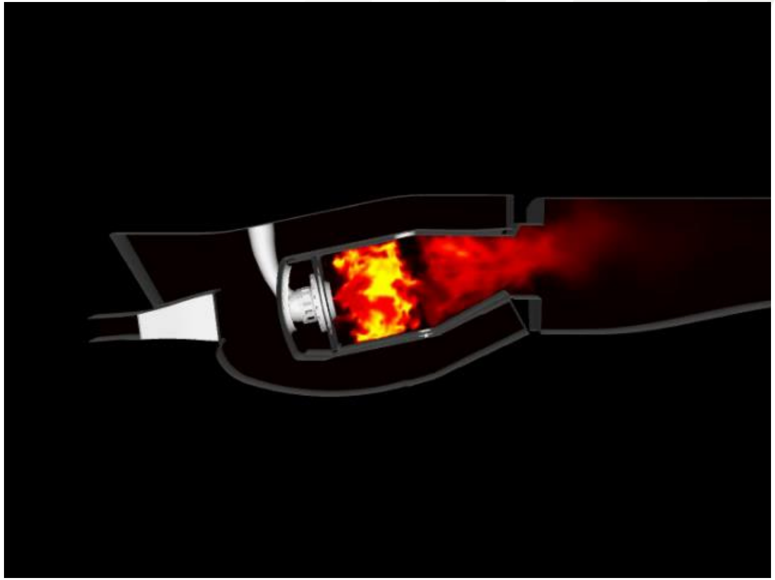




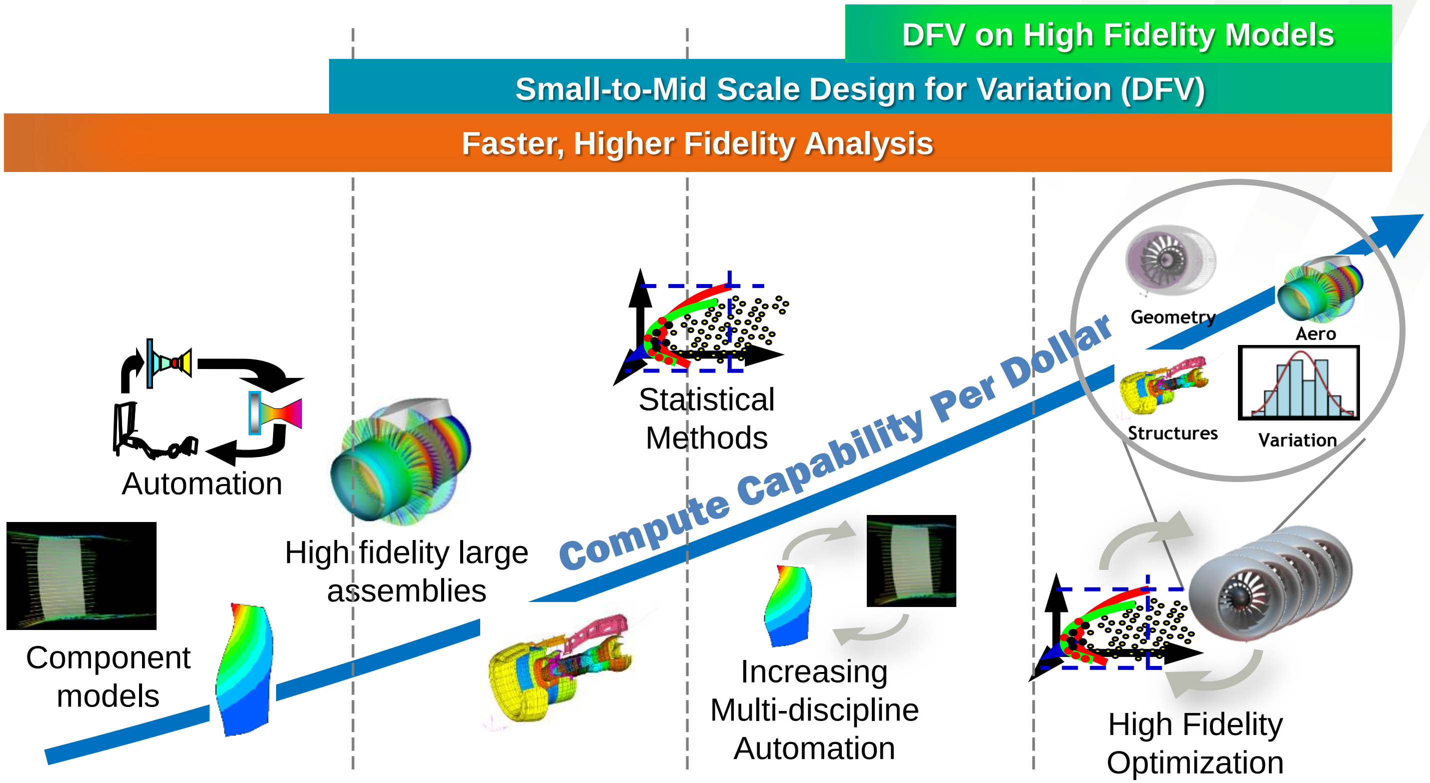
- CFD relatively mature for single component, on-design analysis.
- Going forward, we need to model component interactions and off-design flow physics.

SUCCESSFUL COMPONENT SIMULATIONS DRIVE METRICS AND COST

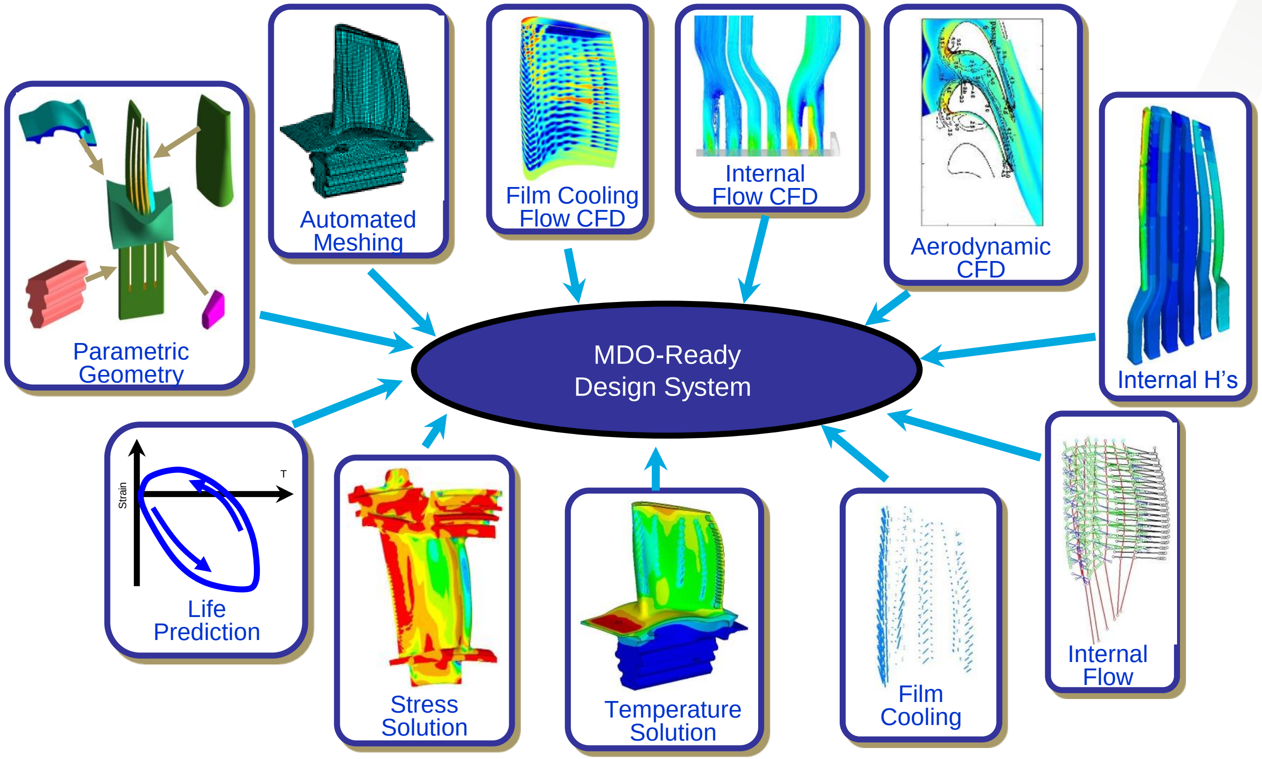




DESIGN PROCESS HAS EVOLVED WITH COMPUTING CAPABILITY



MULTI DISCIPLINARY DESIGN OPTIMIZATION IS KEY



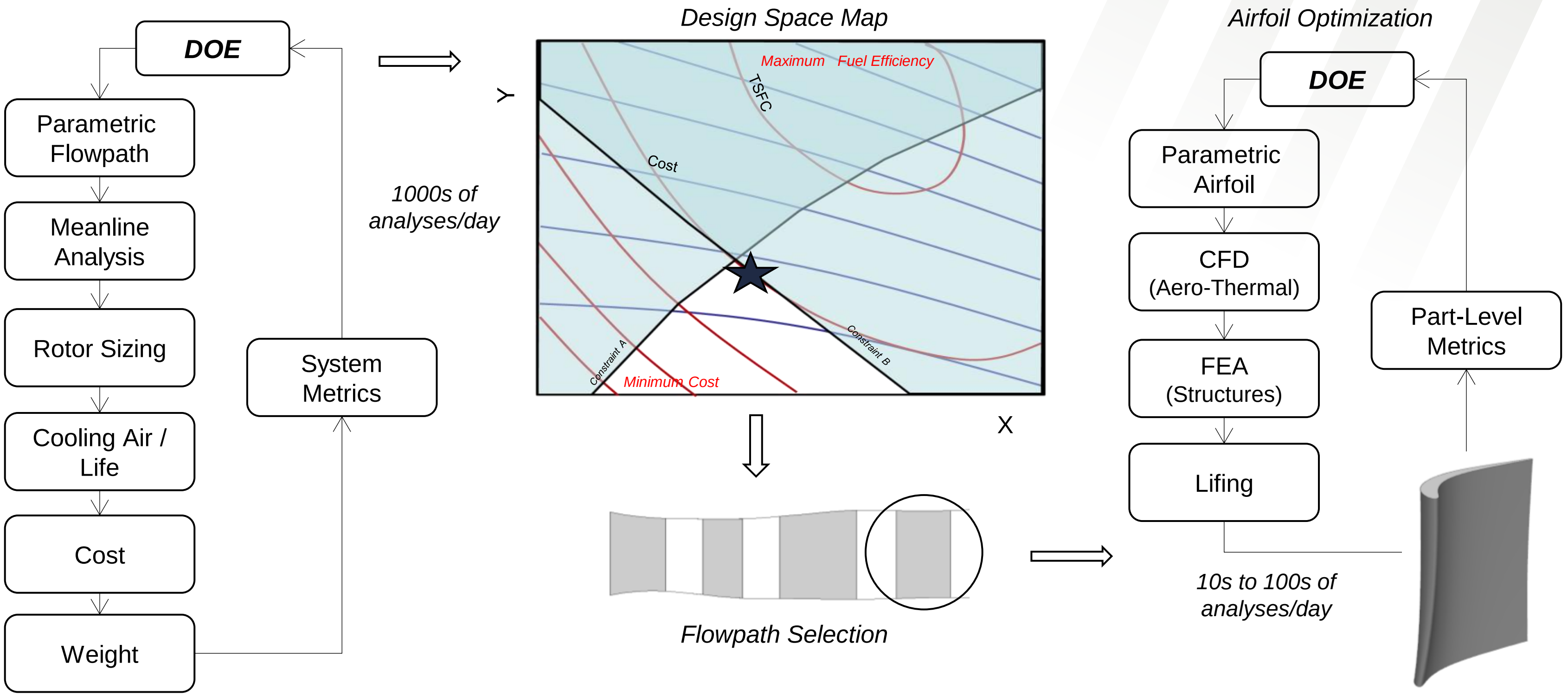
MODELING
- Accuracy
- Parametric models
- Fidelity level vs run-time

AUTOMATED WORKFLOW
- Flexible
- Robust
- Easy to use
- Numerous variables/outputs

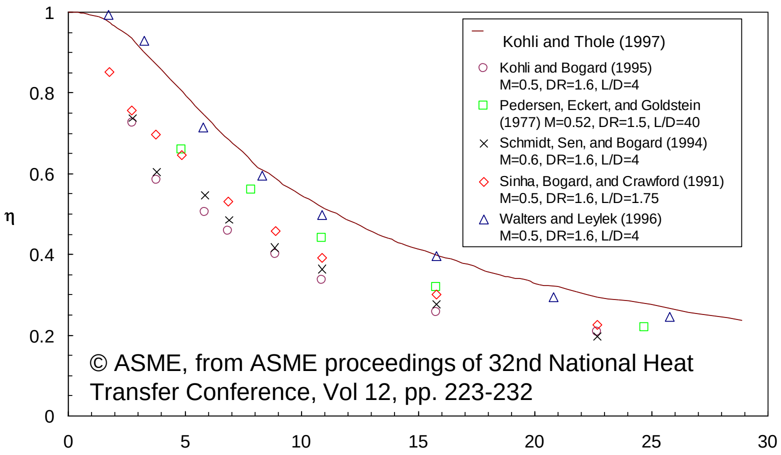
INFRASTRUCTURE
- Distributed, parallel computing
- Network reliability
- Data storage and search

CULTURE
- Alignment
- Up-front investment

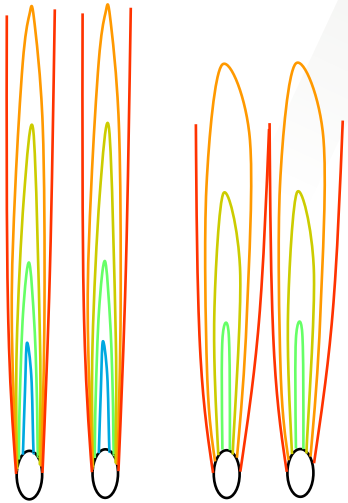
MDO ENABLES GOOD DECISION MAKING EARLIER IN DESIGN CYCLE



PART LEVEL CHALLENGE- PREDICTION OF FILM COOLING FLOWS

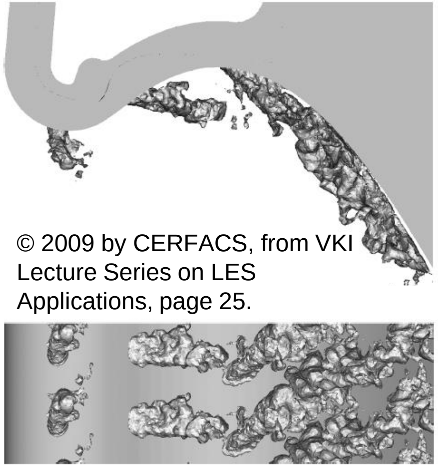


RANS vs. data



Notional RANS Prediction

Notional Data

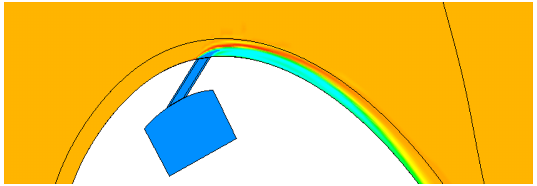


LES example

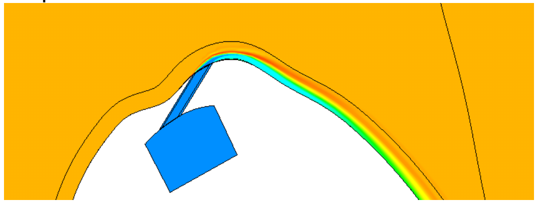
- RANS methods not capable of predicting film cooling effectiveness due to turbulence model limitations
- LES shows promise but not practical for design cycle

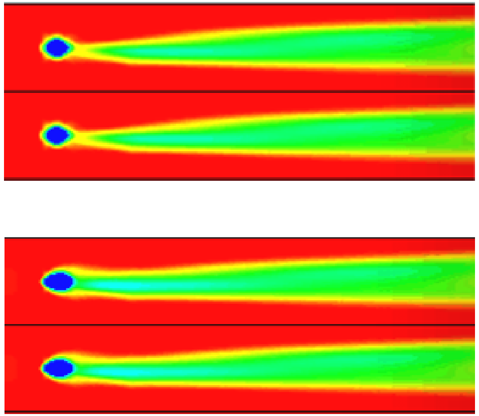
SOME SUCCESS USING OPTIMIZATION - TRENDWISE ACCURACY

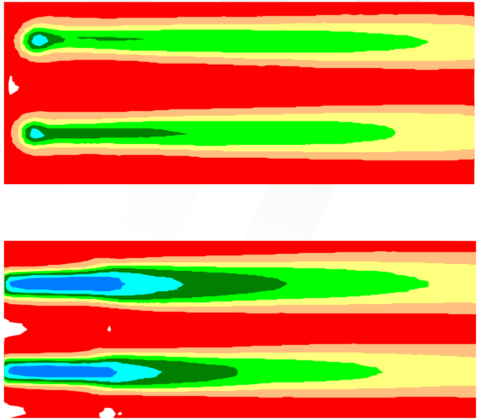
Baseline



Optimized





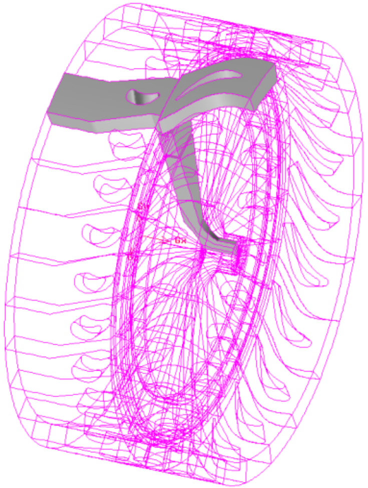


- An optimization procedure using RANS used to change airfoil shape with film cooling.
- Increase in adiabatic effectiveness with no impact on aerodynamic losses.

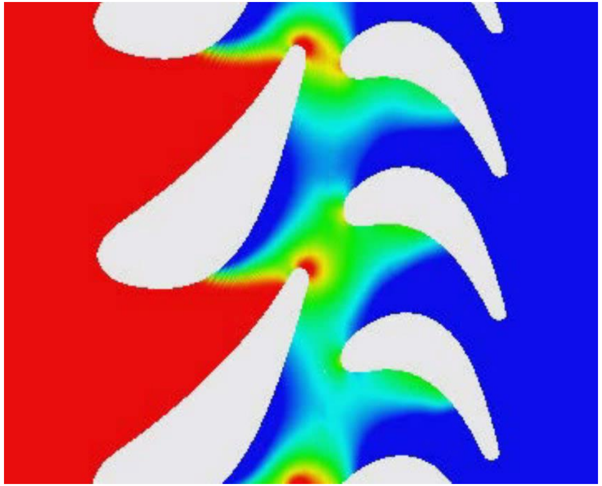
- Increased local acceleration and convex curvature reduced blow-off and improved lateral spreading.

- Test data showed similar trends as predictions but not absolute magnitudes.
- Despite its limitations, RANS methodology can be useful!

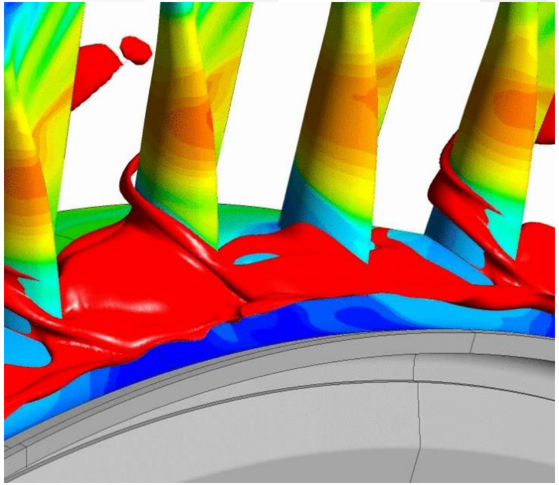
COMPONENT LEVEL CHALLENGE – PREDICTING INGESTION



Full-wheel domain for analysis



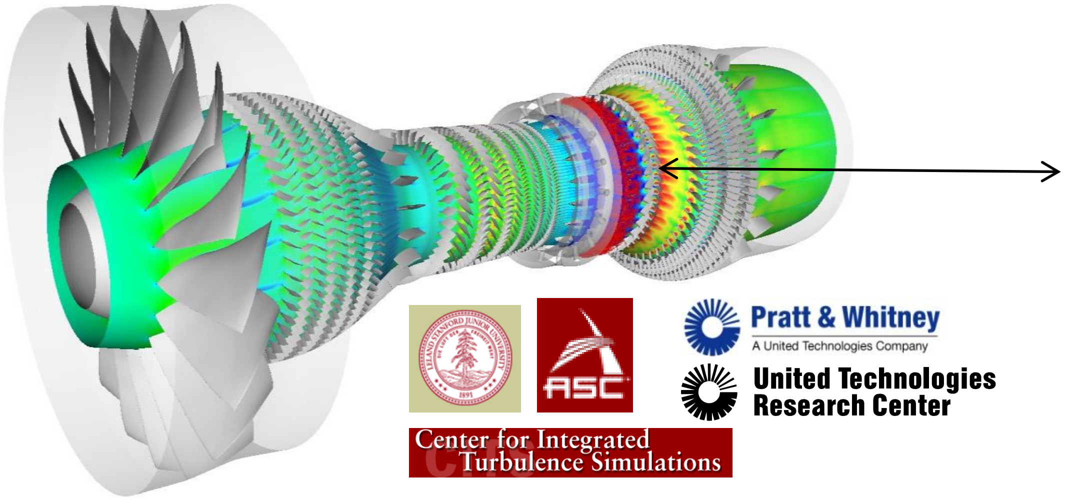
Complicated pressure field changes with time/position



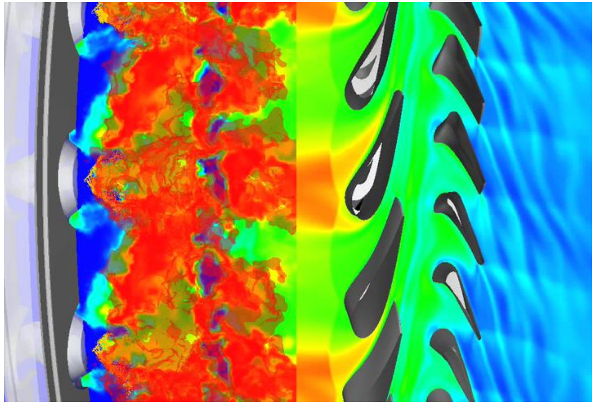
Complex interaction between gaspath/ingested/purge flow

- Understanding gas path – rim cavity interactions critical for both compressors & turbines
- Multi-row, ‘full-wheel’ time accurate simulations required to capture complex ingestion phenomena

MULTI COMPONENT CHALLENGE – COMBUSTOR TURBINE INTERACTION



Stanford University, 2006



- Different modeling fidelity used in individual components (LES in combustor vs. URANS in turbine)
- Large differences in length/time scales of interest (cooling air vs. gas path) makes full turbine LES simulation prohibitive

WHAT'S ON THE HORIZON?

- More reliance on simulations, from cradle to grave – digital thread/twin
- Need for both high and low fidelity modeling – machine learning
- Continued focus on multi-disciplinary and design for variation