AERO-THERMAL METHODS FOR ENGINE DESIGN: EVOLUTION AND CHALLENGES

ATUL KOHLI, NOVEMBER 8TH 2018

PREPARED FOR THE 17TH JET ENGINES SYMPOSIUM, TECHNION UNIVERSITY
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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>3D Euler + Boundary Layer</td>
<td>3D RANS</td>
<td>Multi-stage RANS</td>
<td>Unsteady Multi-stage Euler, RANS</td>
<td>Unsteady Multi-stage RANS</td>
<td>HLES &amp; Multi-discipline</td>
<td></td>
</tr>
</tbody>
</table>

*Images: JT8D, PW4000, GTF, F100, F119, F135*  
*Image credits unless mentioned: Pratt & Whitney*
HUGE OPPORTUNITY FOR SIMULATION TOOLS

“75 percent of the manufacturing cost is committed by the end of conceptual phase of the design process”

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

- DFV on High Fidelity Models
- Small-to-Mid Scale Design for Variation (DFV)
- Faster, Higher Fidelity Analysis
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

AERO-THERMAL METHODS FOR ENGINE DESIGN: EVOLUTION AND CHALLENGES
MDO ENABLES GOOD DECISION MAKING EARLIER IN DESIGN CYCLE

**DOE**
- Parametric Flowpath
- Meanline Analysis
- Rotor Sizing
- Cooling Air / Life
- Cost
- Weight

**System Metrics**

**Airfoil Optimization**
- Parametric Airfoil
- CFD (Aero-Thermal)
- FEA (Structures)
- Lifing

**Part-Level Metrics**

**Flowpath Selection**

1000s of analyses/day

10s to 100s of analyses/day

---

AEROTHERMAL METHODS FOR ENGINE DESIGN: EVOLUTION AND CHALLENGES
PART LEVEL CHALLENGE: PREDICTION OF FILM COOLING FLOWS

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

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

© ASME, from Wang et al., GT2012-68193

Full-wheel domain for analysis

Complicated pressure field changes with time/position

Complex interaction between gaspath/ingested/purge flow
MULTI COMPONENT CHALLENGE – COMBUSTOR TURBINE INTERACTION

- 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