Advanced Core Engine Technology

Dr. James D. Heidmann
Chief, Turbomachinery & Heat Transfer Branch
NASA Glenn Research Center

Green Aviation Summit
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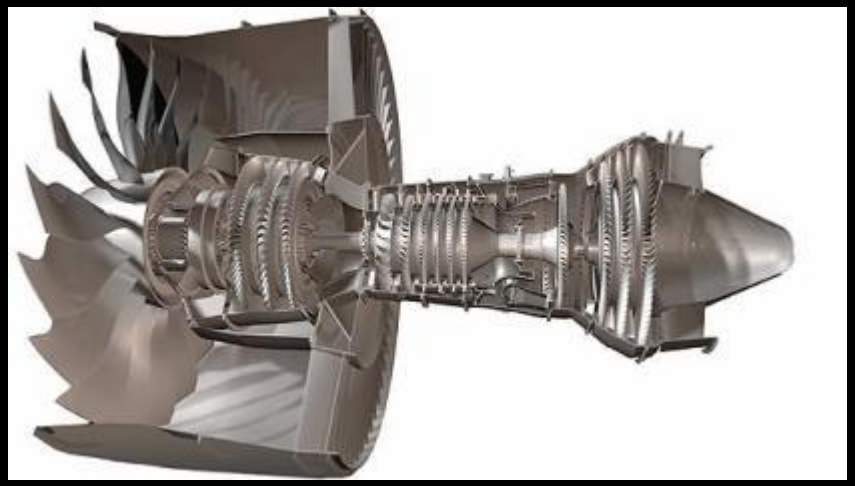
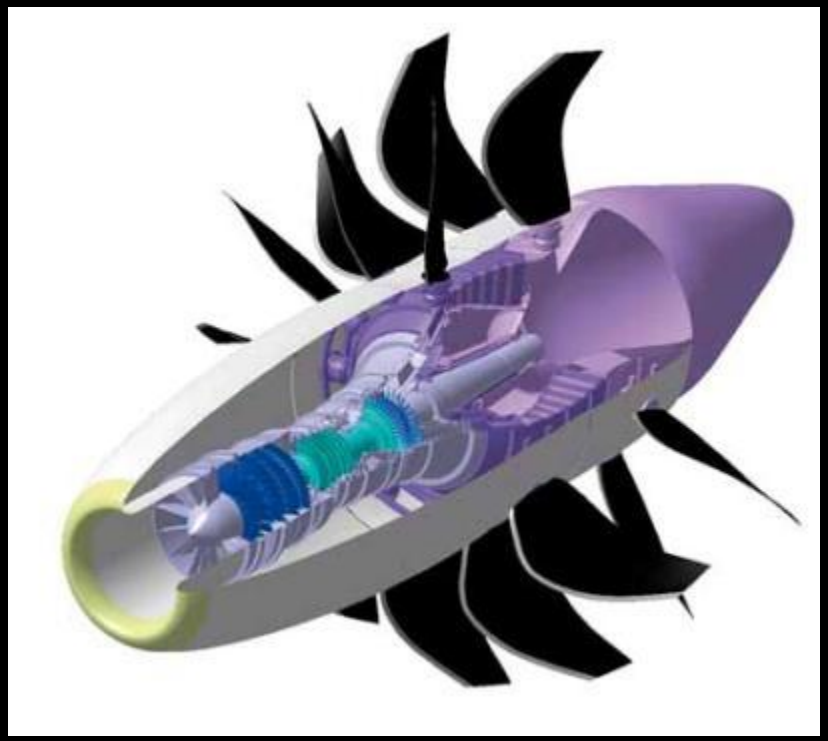




NASA's Subsonic Transport System Level Metrics

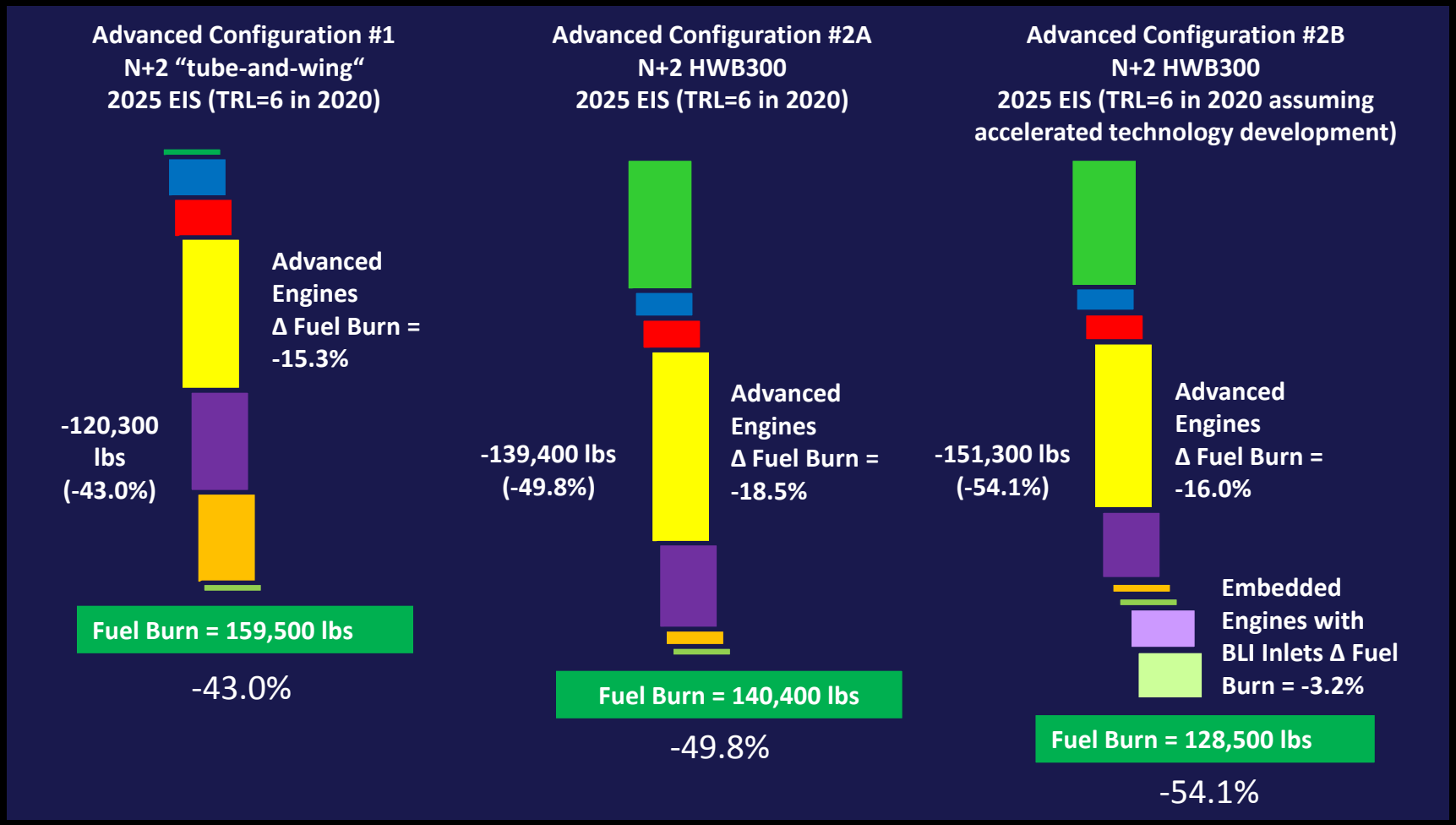
…. technology for dramatically improving noise, emissions, & performance

CORNERS OF THE TRADE SPACE	N+1 = 2015 Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020 Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025 Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%	**-50%****	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

Goals are relative to reaching TRL 6 by the timeframe indicated
Better chance to reach all goals simultaneously for N+2 and N+3

POTENTIAL REDUCTION IN FUEL CONSUMPTION

Advanced N+2 Configurations



Propulsion Technology Enablers

Fuel Burn

- reduced SFC (increased BPR, OPR & turbine inlet temperature, potential embedding benefit)

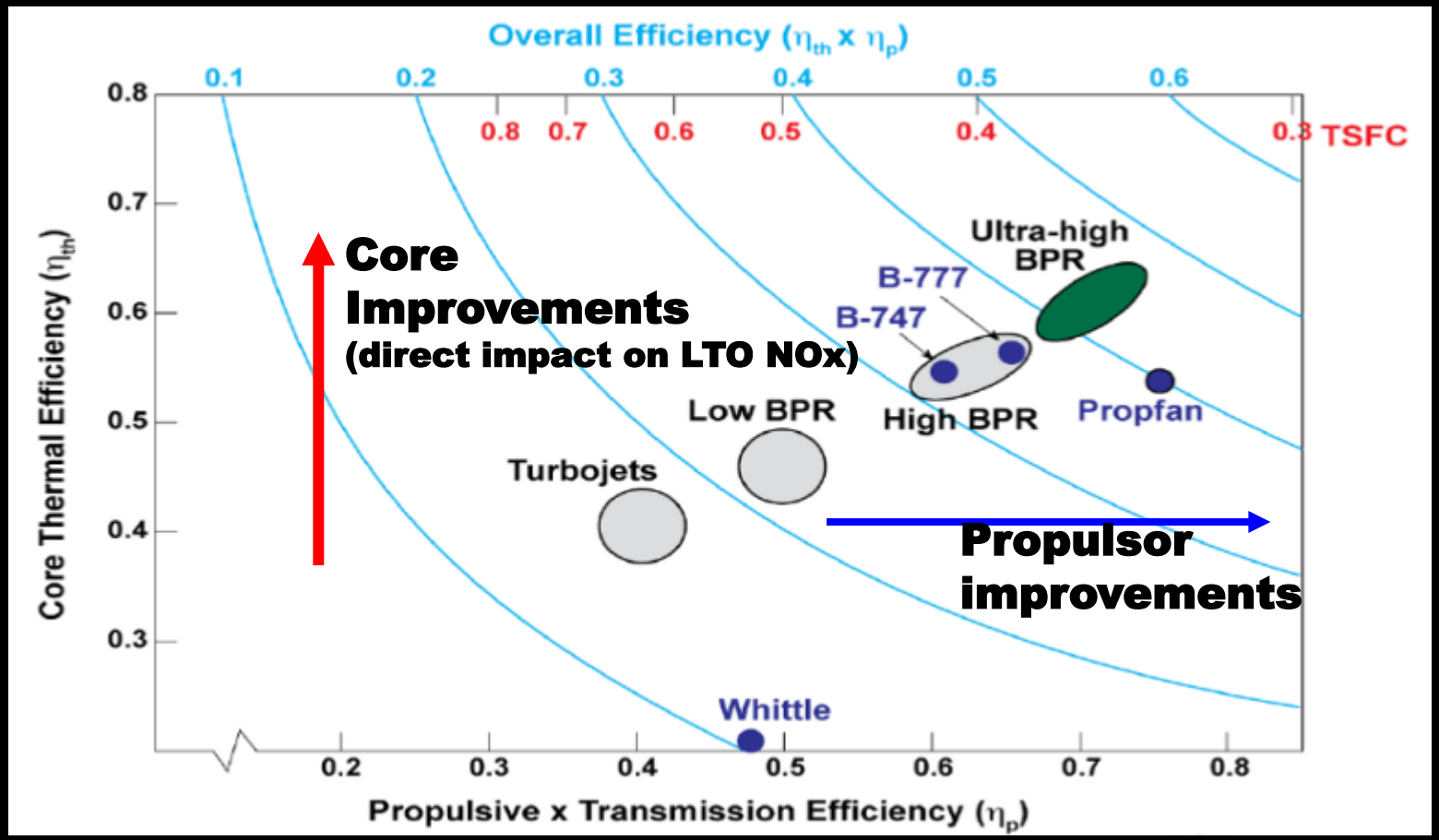
$$\text{Aircraft Range} = \frac{\text{Velocity}}{\text{TSFC}} \left(\frac{\text{Lift}}{\text{Drag}}\right) \ln\left(1 + \frac{W_{fuel}}{W_{PL} + W_O}\right)$$

- Engine Fuel Consumption
- Aerodynamics
- Empty Weight

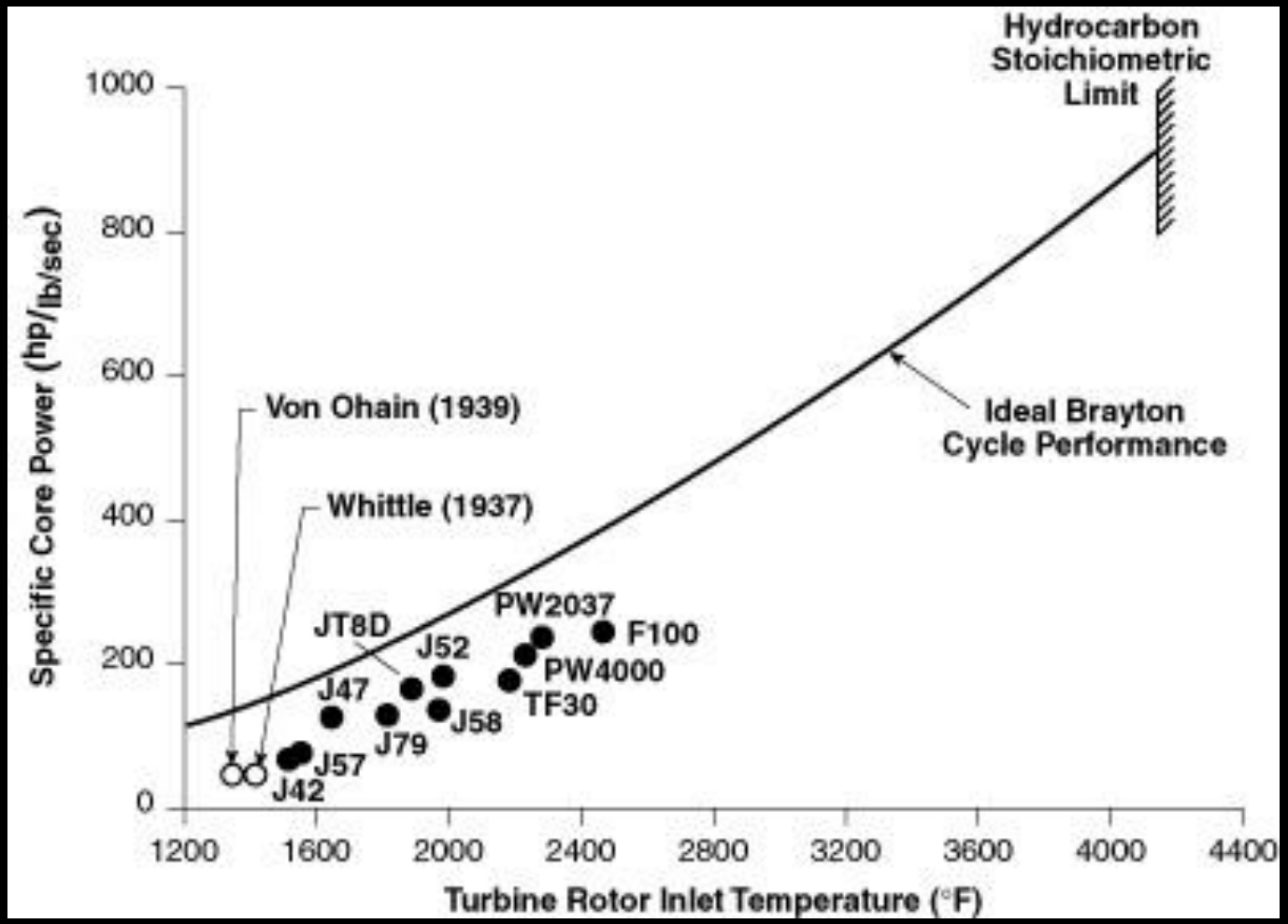
$$\text{TSFC} = \text{Velocity} / (\eta_{overall})(\text{fuel energy per unit mass})$$

$$\eta_{overall} = (\eta_{thermal})(\eta_{propulsive})(\eta_{transmission})(\eta_{combustion})$$

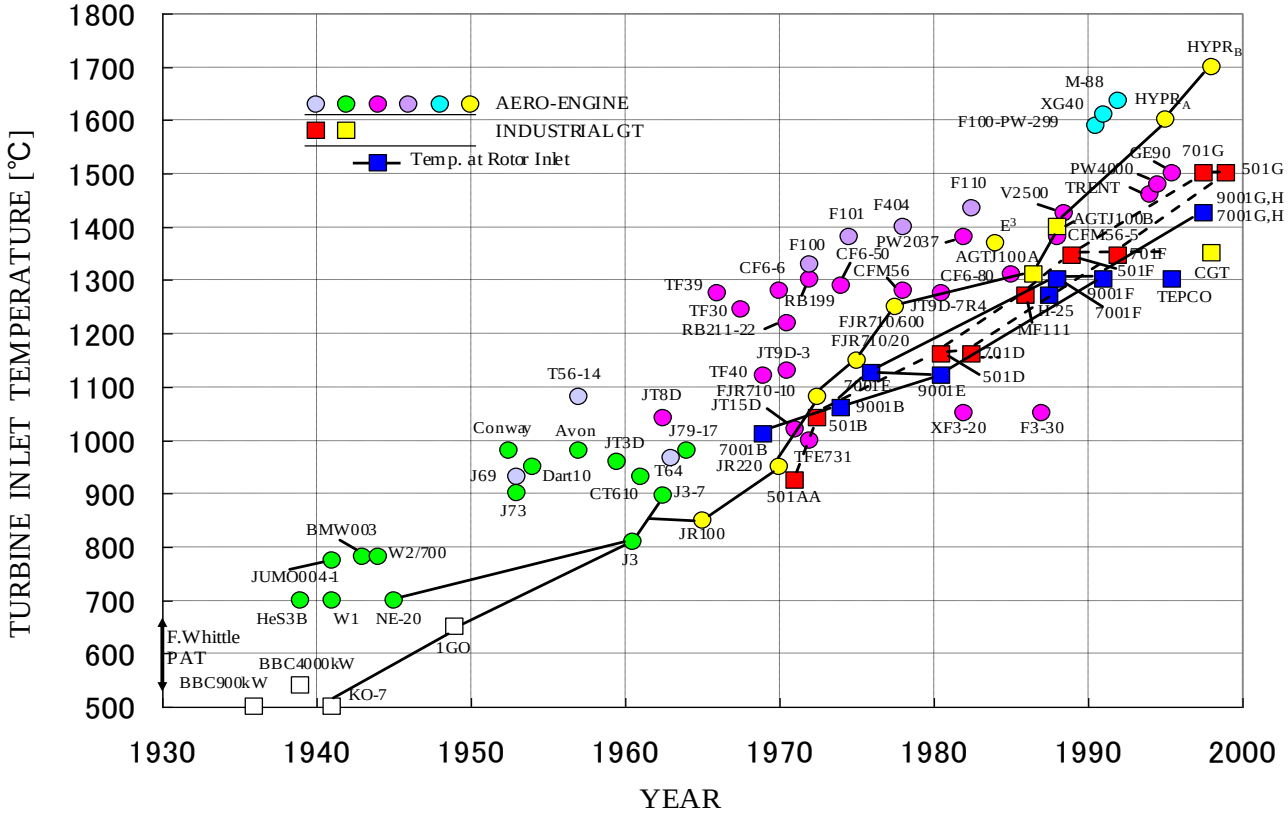
Propulsion Technology Opportunity



Cycle Performance Improves with Temperature

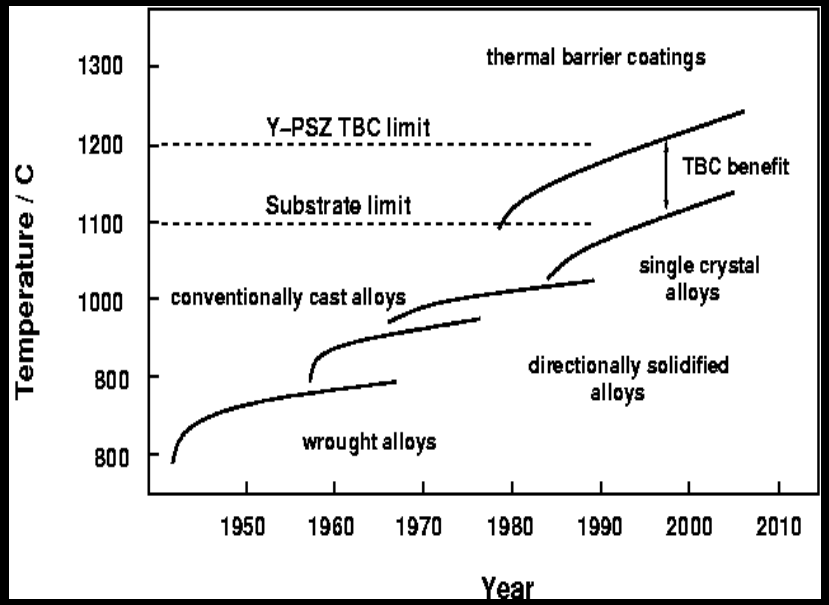


Engine Thermal Trends



From Dr. Toyoaki Yoshida, National Aerospace Laboratory, Japan

Materials and Cooling Improvements



Increase in operational temperature of turbine components. After Schulz *et al*, Aero. Sci. Techn.**7:2003, p73-80.**

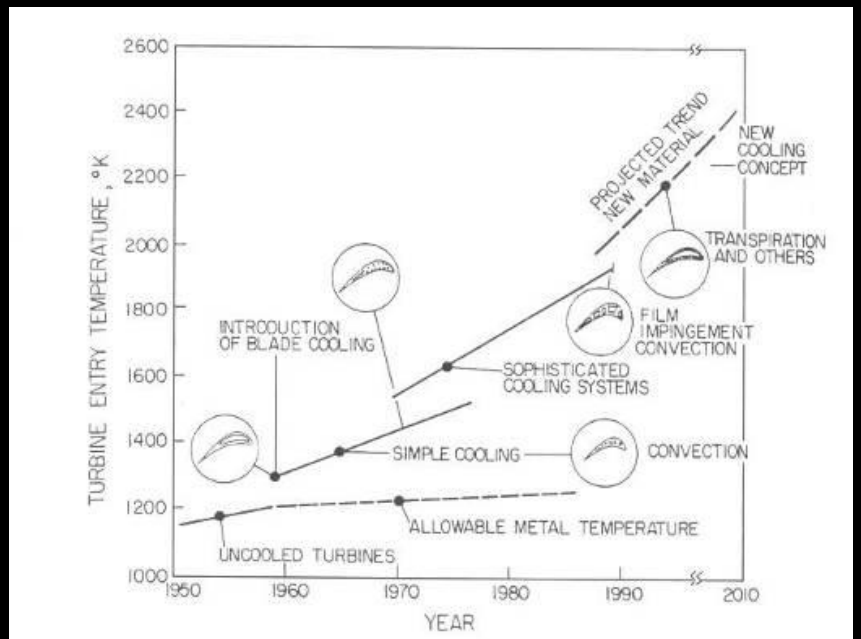
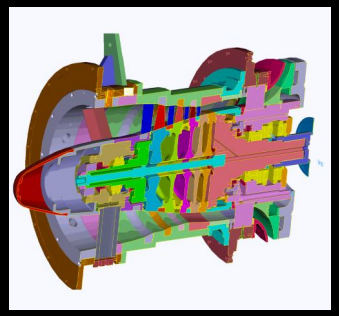


Figure 1.2: Variation of turbine entry temperature over recent years (Clifford, 1985; AGARD CP 390; collected in Lakshminarayana, 1996).

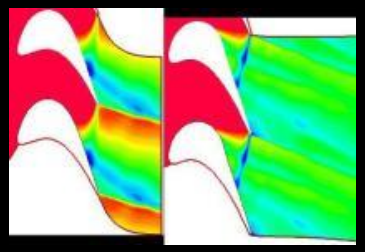
approximately two-thirds of turbine temperature increase has historically been enabled by cooling improvements

Turbomachinery Aero Design-Based Tech Enablers

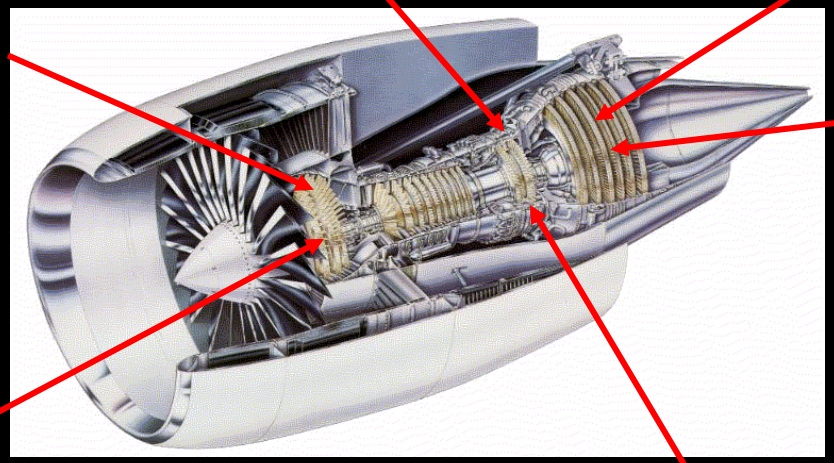


Highly-Loaded, Multistage Compressor (higher efficiency and operability)

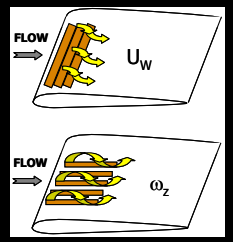
Low-Shock Design, High Efficiency, High Pressure Turbine



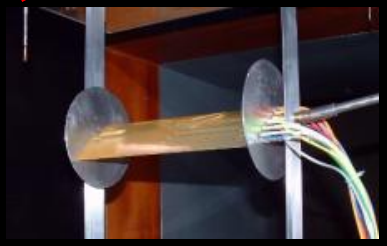
Aspiration Flow Controlled, Highly-Loaded, Low Pressure Turbine

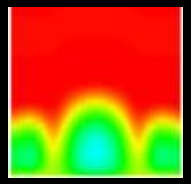


Low Pressure Turbine Plasma Flow Control

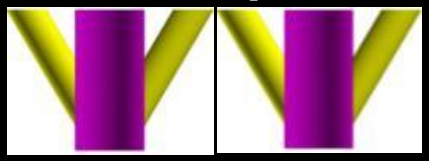


Compressor Synthetic Jet Flow Control (reduced flow losses)





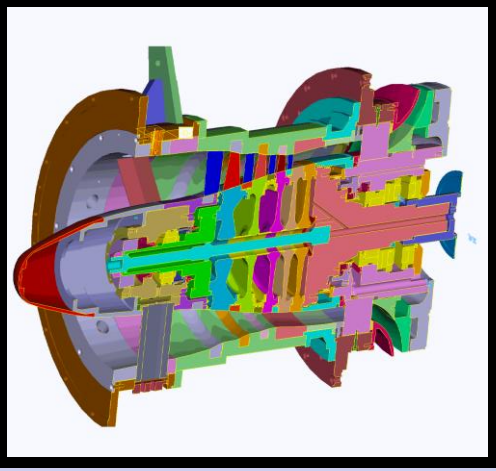
Novel Turbine Cooling Concepts



Multi-Stage Axial Compressor (W7)

Objective: To produce benchmark quality validation test data on a state-of-the-art multi-stage axial compressor featuring swept axial rotors and stators. The test will provide improved understanding of issues relative to optimal matching of highly loaded compressor blade rows to achieve high efficiency and surge margin.

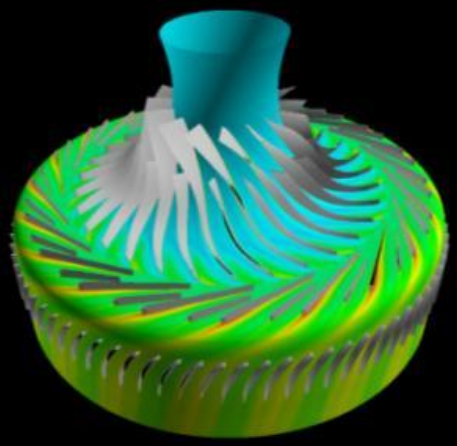
ERB Test Cell W7



76B 3-Stage Axial Compressor
PR=4.7,TR=1.63, ha=88.5, Utip =1400 ft/s

Approach: Acquire and test a modern axial compressor representative of the first three stages of a commercial engine high pressure compressor with an engine company.

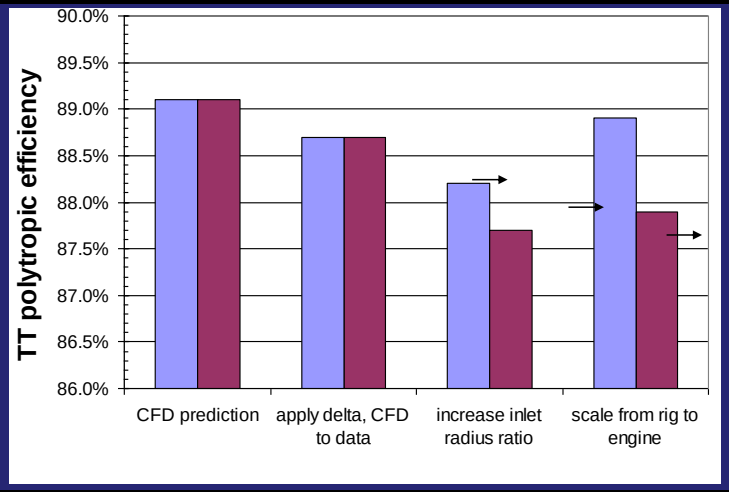
UTRC NRA – High Efficiency Centrifugal Compressor (HECC)



m = 10.1 lbm/s

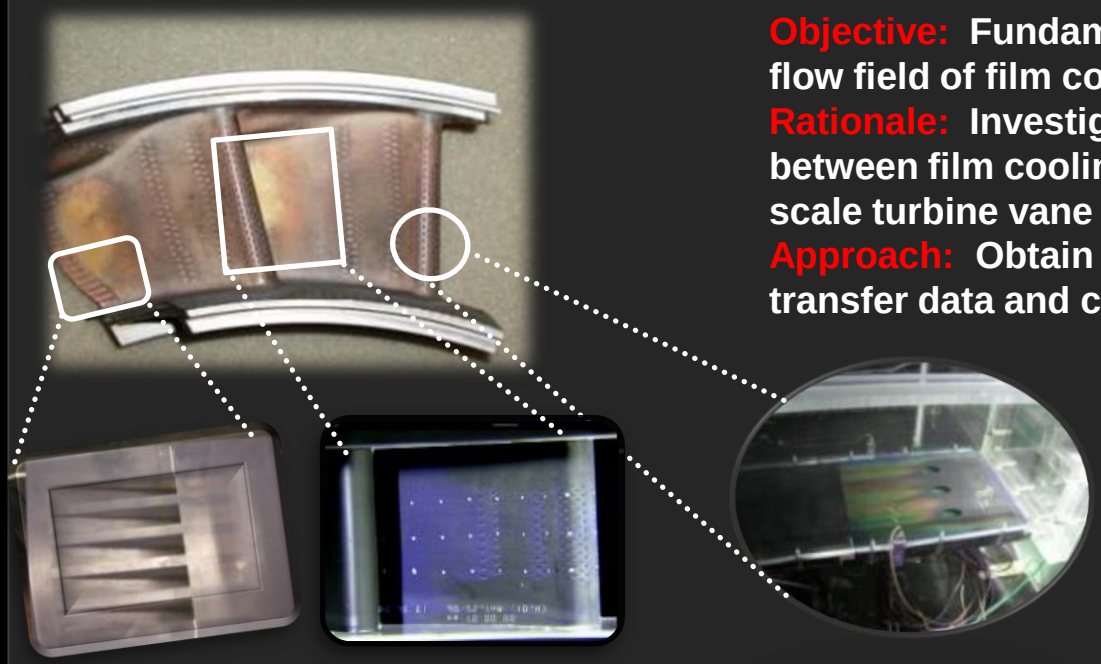
Metric	CC3+ Iteration 2	
	target	CFD predicted
Stage Pr	4.0 - 5.0	4.32
Inlet Corrected Flow (lbm/s)	10.0	10.1
Exit Corrected Flow (lbm/s)	2.6 - 3.1	2.95
Work Factor (DH_0/U_2^2)	0.58 - 0.7	0.69
Poly Eff TT	≥ 88%	89.1%
T3 (°F)	350-410	366
Dmax/Dtip	1.45	1.45
Stability Margin	13%	~13%
M_{exit}	0.15	0.15
α_{exit}	15°	14°

Opportunity for improved rotary wing vehicle engine performance as well as rear stages for high OPR fixed wing application



Engine scale polytropic efficiency is estimated as 87.9 - 88.9%

Turbine Film Cooling Experiments

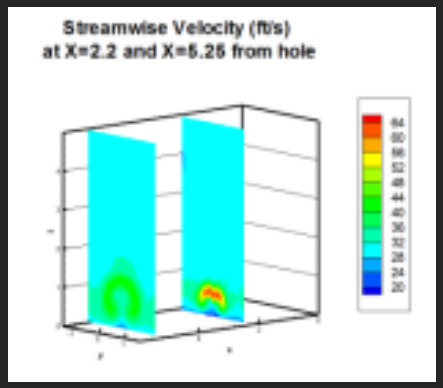


Objective: Fundamental study of heat transfer and flow field of film cooled turbine components

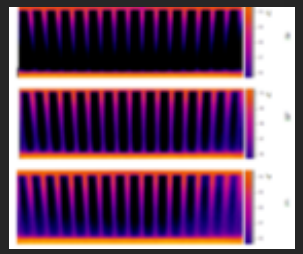
Rationale: Investigate surface and flow interactions between film cooling and core flow for various large scale turbine vane models

Approach: Obtain detailed flow field and heat transfer data and compare with CFD simulations

Large Scale Film Hole:
Film cooling jet downstream of hole

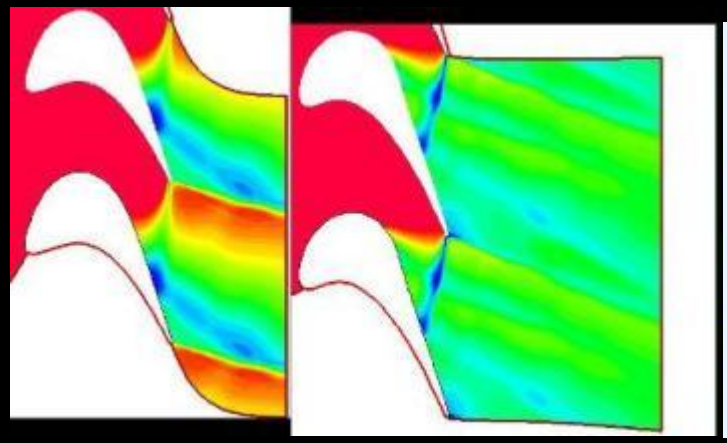


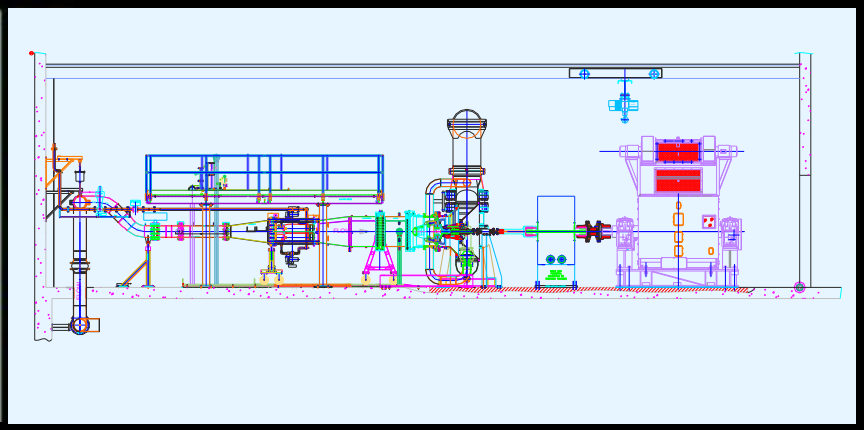
Trailing Edge Film Ejection:
IR images



Vane Heat Transfer:
Good agreement between GlennHT and experiment

NASA/General Electric Highly-Loaded Turbine Tests





Conventional HPT Reduced Shock Design

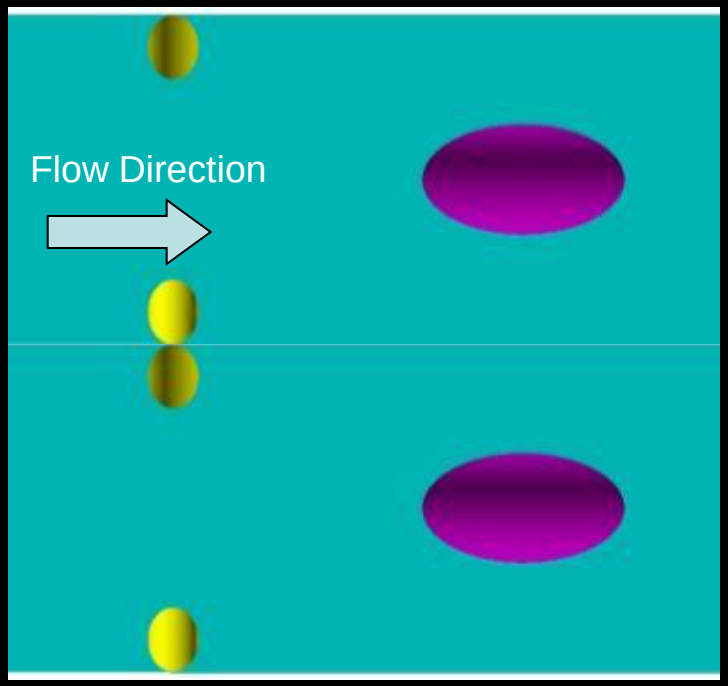
Pressure Ratio (PTR/PS) = 3.25
Stage Pressure Ratio = 5.5

HPT: Reduced Shock Design
LPT: Flow-Controlled Stator
& Contoured Endwall

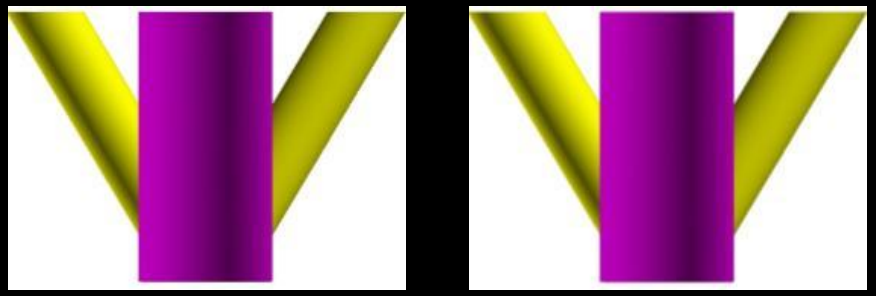
High and Low Pressure Turbine Testing in NASA
Glenn Single Spool Turbine Facility (W6)

Anti-Vortex Film Cooling Concept

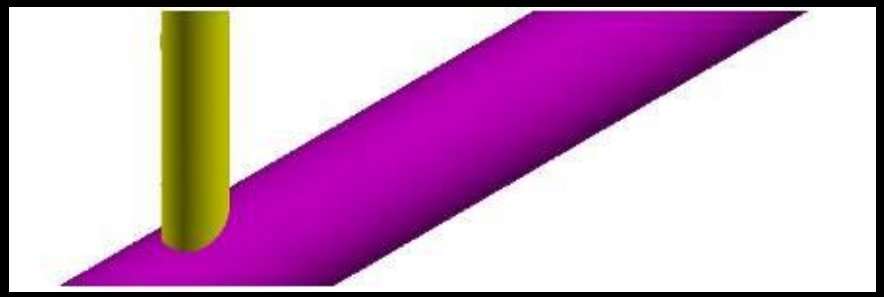
Top View



Front View



Side View



Auxiliary holes (yellow) produce counter-vorticity to promote jet attachment
Advantages: Inexpensive due to use of only round holes, hole inlet area unchanged

CMC Turbine Vanes

Objective: Reduce emissions in high bypass ratio turbine engines by utilizing high temperature Ceramic Matrix Composites (CMCs) for high pressure turbine vanes applications

Approach: Demonstrate fabricability of CMCs in vane shape using two or more processing methods and evaluate current state of the art materials in a relevant environment

Proposed Vane Shape for Evaluations

SiC/SiC – Hi-Nic type S fibers

Variable-Speed Power Turbine for Large Civil Tilt-Rotor

NASA FAP/SRW Large Civil Tilt-Rotor Notional Vehicle

Need for variable-speed power-turbine with range of operation 54% < N_{PT} < 100%

Research addresses key technical challenges:
- High efficiency at high stage work factor
- Wide (50º) incidence range requirement
- Low Reynolds number operation

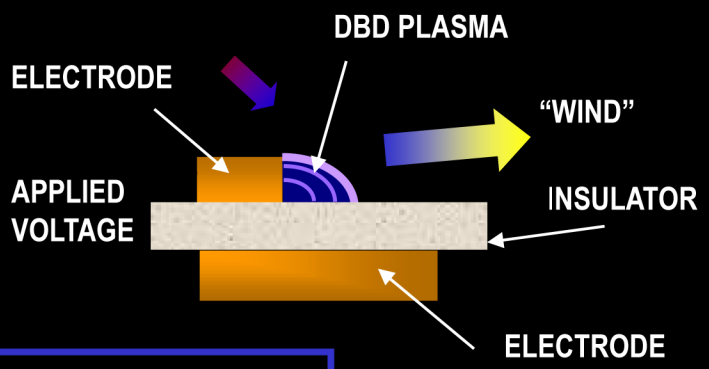
Large Civil Tilt-Rotor	
TOGW	108k lb_f
Payload	90 PAX
Engines	4 x 7500 SHP
Range	> 1,000 nm
Cruise speed	> 300 kn
Cruise altitude	28 – 30 kft

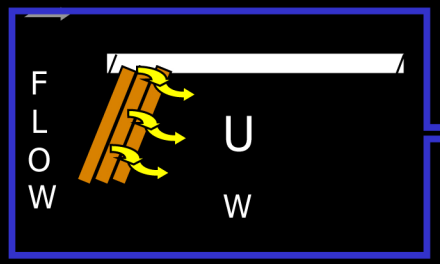
Goal – to enhance airport throughput capacity by utilizing VTOL capable rotary wing vehicles.

Principal challenge for LCTR – required variability in main-rotor speed:
– 650 ft/s at take-off
– 350 ft/s at Mn 0.5 cruise

Dielectric Barrier Discharge Plasma Actuators

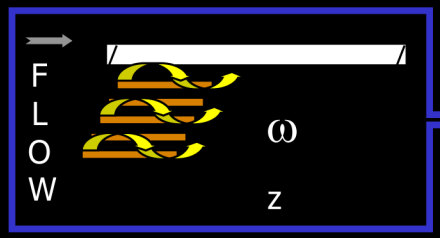
Potential application for low pressure turbine flow control and improved efficiency





Electrode perpendicular to flow

Active Flow Control via Oscillating wall jet



Electrode parallel to flow

Active Flow Control via Streamwise vortices

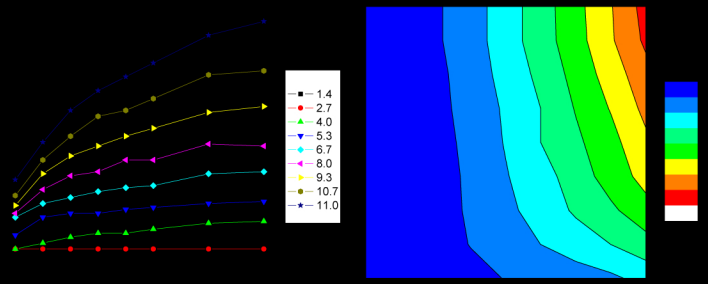
Advantages of GDP actuators:

- Pure solid state device
- Simple, no moving parts
- Flexible operation, good for varying operating conditions
- Low power
- Heat resistance – w/ proper materials

Force Versus Pulse Repetition Rate & Bias

Princeton Nanosecond Pulsing NRA

Large force induced with voltage bias



Core Engine Research Summary

Turbomachinery research directly impacts fuel burn reduction goals of NASA Aeronautics projects

Compressor research focused on increasing overall pressure ratio while maintaining or improving aerodynamic efficiency

Centrifugal compressor research can meet multiple project architecture needs

Turbine research focused on increased loading, reduced cooling flows, and improved aerodynamic efficiency

Fundamental testing of turbine cooling flows to improve effectiveness

Low pressure turbine flow control and rotating testing

Computational fluid dynamic development and assessment across all components, including advanced turbulence models such as LES and DNS