National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Overview of progress in SRW/Engine research effort

Dr. Gerard E. Welch, GRC/RTT
SRW/Engines Technical Lead

2012 Technical Conference
March 13-15, 2012

Research team

GRC in-house

- ARL-VTD / G. Skoch, D. Thurman
- NASA RTT / E. Braunscheidel, S. Kulkarni, B. Lucci, A. McVetta, Dr. G. Welch
- NASA RTM / C. Snyder
- NASA RXN / Dr. S. Howard
- NASA DER / M. Stevens
- ASRC Aerospace/ Dr. P. Giel
- U. Toledo / Dr. W. To
- Ohio State U. / Dr. A. Ameri
- Coyote Hollow Corporation / T. Beach

NRA partner United Technologies Research Center — Drs. A. Shabbir, W. Cousins, E. Lurie, P. Van Slooten

RTAPS contracts Rolls-Royce — A. Ford, M. Bloxham, E. Turner, S. Gegg, B. King, C. Harris, M. Bell, E. Clemens, C. Nordstrom, D. Eames

Williams International — M. Suchezky, G. S. Cruzen

Research on engines for LCTR variable-speed capability reflects …

Sensitivity of vehicle GTOW and fuel burn to engine weight & SFC – drives high efficiency / power density

- High OPR, T_3, T_4
- High component η
- Compact

Gas generator research

- Aerodynamics of low-corrected flows
- Compressor exit temperatures at high OPR
- Impact of variable-speed PT shaft sizes on LP/HP turbomachinery aero

Sensitivity of LCTR propulsive efficiency to main-rotor speed change

Variable speed power turbine research (VSPT)

- Aerodynamics
- Rotordynamics

Content

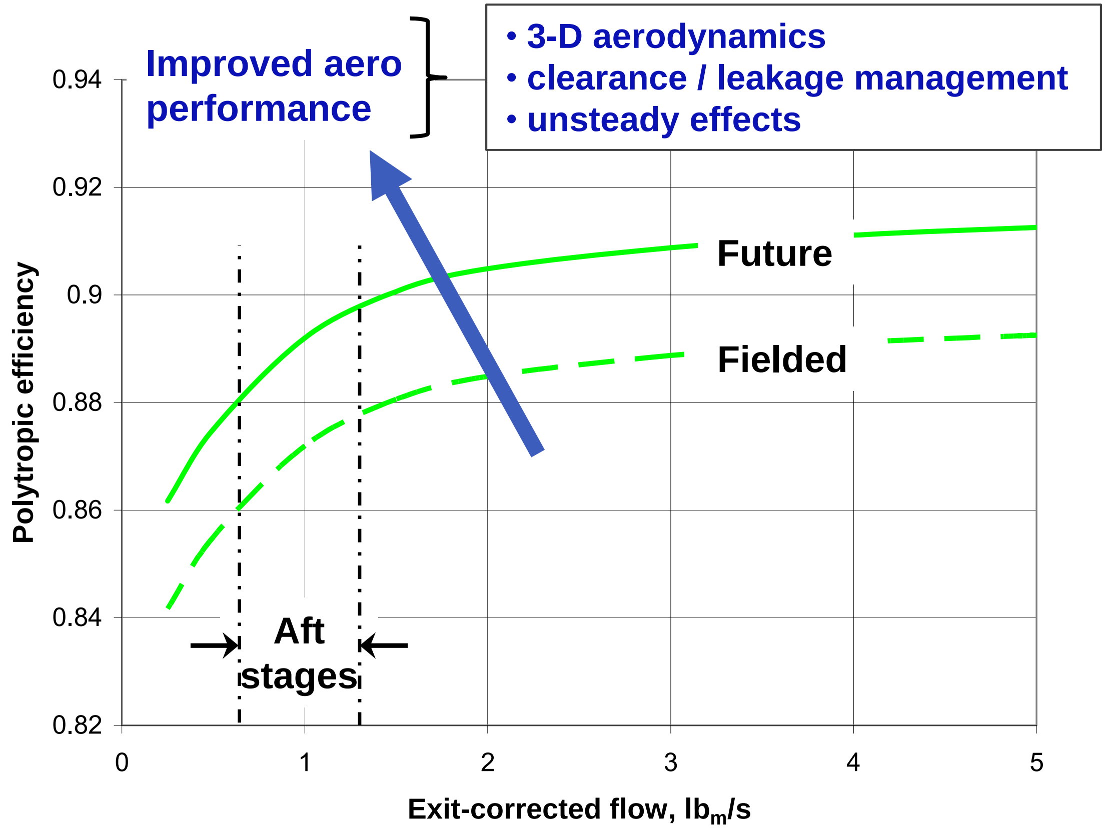
Gas Generator & VSPT research efforts

- Technical Challenges
- Research agenda
- Progress on research elements
- Next steps

GAS GENERATOR RESEARCH

Technical Challenge – Aft-stage HPC aero

- 7,500 SHP-class engines for the LCTR2 concept vehicle
  - OPR > 35:1
  - Physical flow of 25 to 30 lb_m/s
- Small aft-stage blading at exit-corrected flows of ≈ 1 lb_m/s



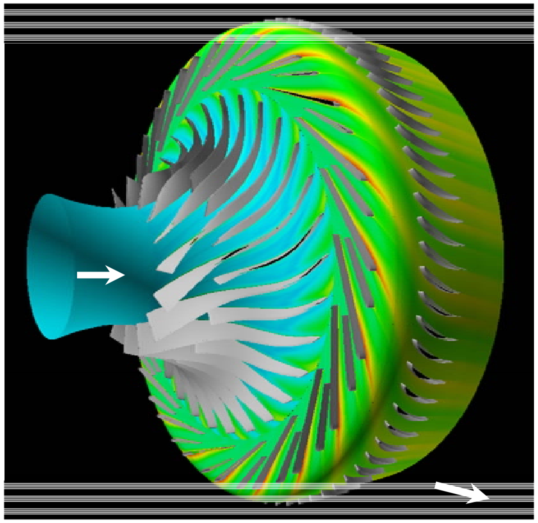
Technology challenge: Improve efficiency of low-exit-corrected flow centrifugal compressors with compact diffusers

Gas generator research agenda

- **NASA/UTRC High Efficiency Centrifugal Compressor (HECC)** – 3 yr. NRA cost-share contract
  - ID key technical barriers & research
  - Design, fab, assembly, test
  - CFD – performance / flow physics
- **HECC component testing**
  - Aero mapping / clearance sensitivities
  - Impeller / diffuser / EGV rating
  - Unsteady pressure fields
- **In-house CFD effort – SOA grids for centrifugals & URANS computations**
- **Multistage HPC** – axial, transition duct, centrifugal
  - Industry consensus tech challenges
  - Research needs
  - Component experiment (2A + 1C)

Metric	Intent (rig scale)	CFD*
Exit-corr. flow	$2.1 < W_{c,ex} < 3.1$ lb_m/s	2.98
Work factor	$0.60 < \Delta H_0/U^2_{tip} < 0.75$	0.68
η_{TT} (poly)	≥ 0.88	0.888
Diam. ratio	$D_{max} / D_{tip} \leq 1.45$	1.45
Design SM	13%	12%
M_{exit}	0.15	0.15
α_{exit}	15º	14º

HECC stage 3-D URANS computation (UTRC)*



*Lurie, E. A. *et al.*," AHS Int. Forum 67, May 2011.

Progress

United Technologies
Research Center

- **High Efficiency Centrifugal Compressor (HECC)**
  - Completed design / fab / assembly
  - Completed test cell readiness
  - Mechanical checkout – Mar 2012

- **Documentation of CC3 centrifugal compressor** underway – historical data & 2010 re-baseline

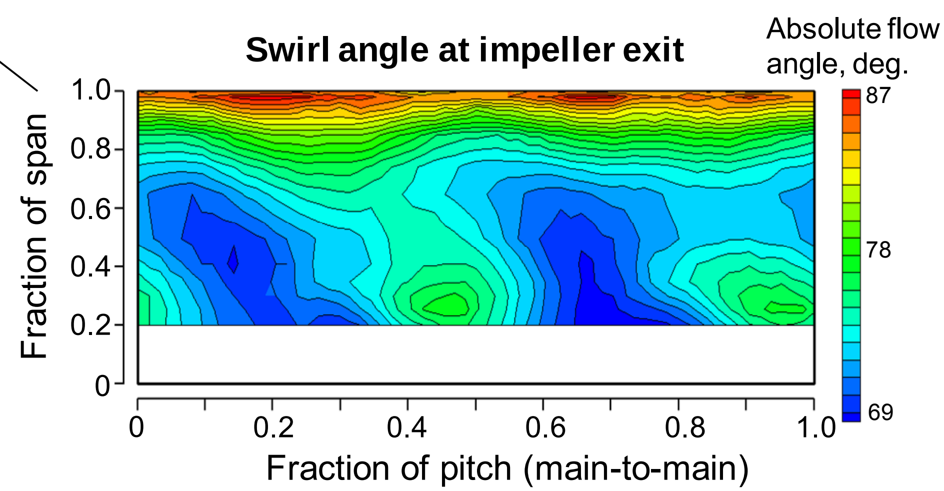
- **High-response (4 BPF) p_0 Kulite-probe development** – impeller exit $p_0(t)$ and $\alpha(t)$

- **NASA computational work**
  - Multiblock grid gen. for centrifugal compressor geometries
  - CC3 vaned & vaneless stages w/ data
  - HECC stage – test predictions

HECC impeller (15 main/splitter)

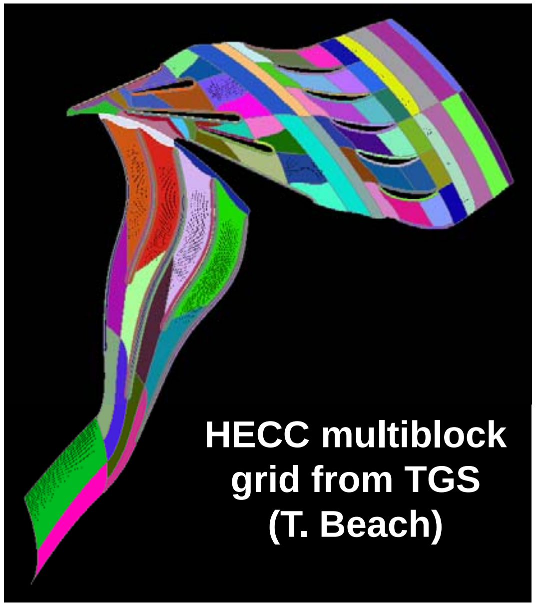
Diffuser (20 main/splitter)

Kulite probe (Lepicovsky)



Flow angle from high-response p_0 probe data (E. Braunscheidel / J. Lepicovsky)

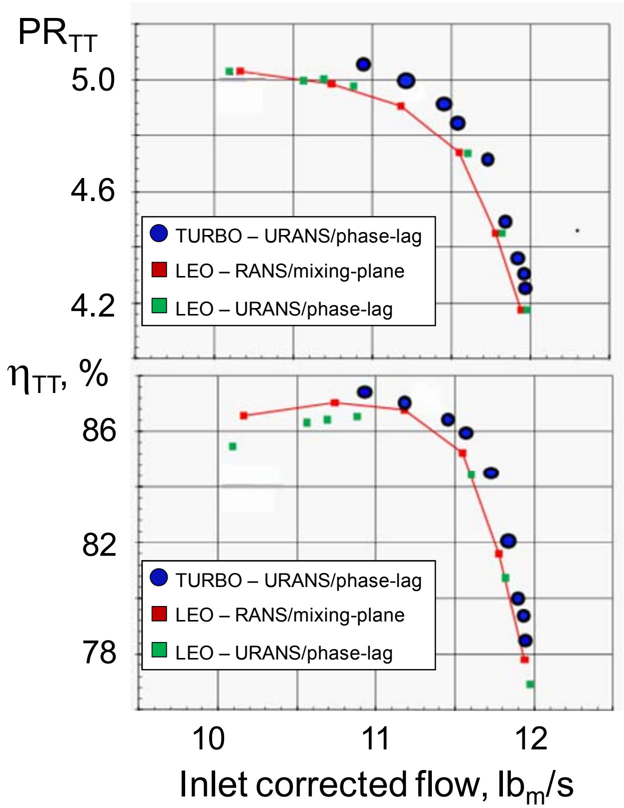
In-house HECC grid generation and TURBO phase-lagged URANS simulations

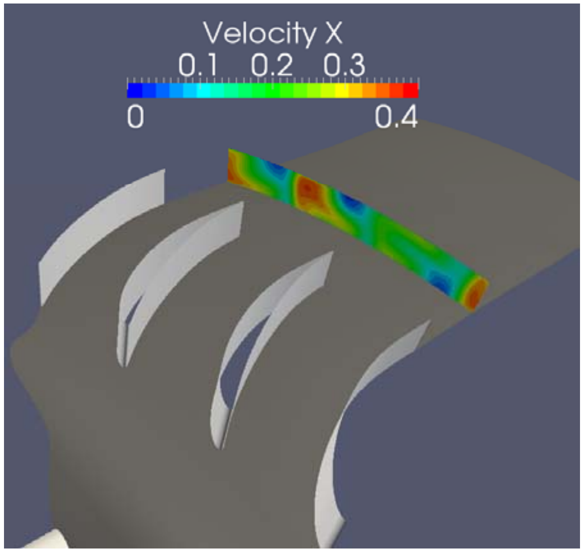


HECC multiblock grid from TGS (T. Beach)

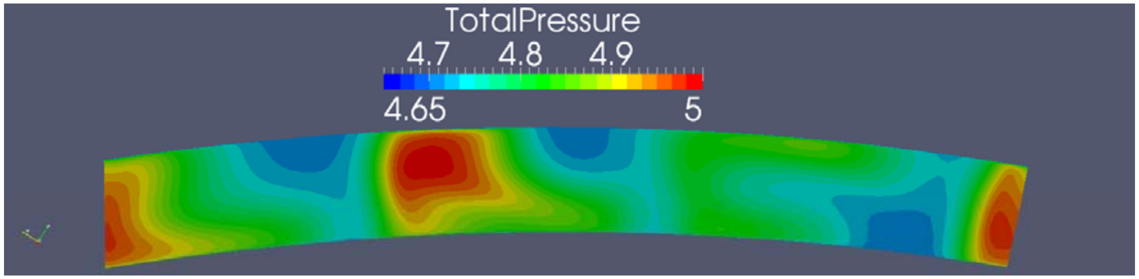
Performance predictions from UTRC* (WAND/LEO) and NASA (TGS/TURBO)

***Lurie, E. A. *et al*., AHS Int. Forum 67, May 2011.**





(S. Kulkarni, T. Beach)

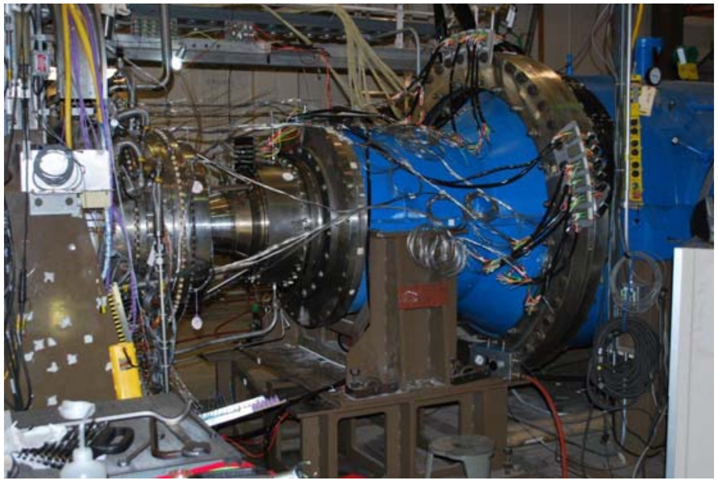


Contours of computed axial velocity and total pressure at exit rating plane (FLA) – time-averaged URANS results.

Next steps

United Technologies Research Center

- **HECC**
  - Aero performance (Apr-Jul, 2012)
    - Map compressor / clearance-sensitivities
    - Acquire unsteady pressures
  - UTRC CFD analyses & final report (Sept 2012)
  - Impeller and diffuser rating (FY13)



HECC installed in CE-18

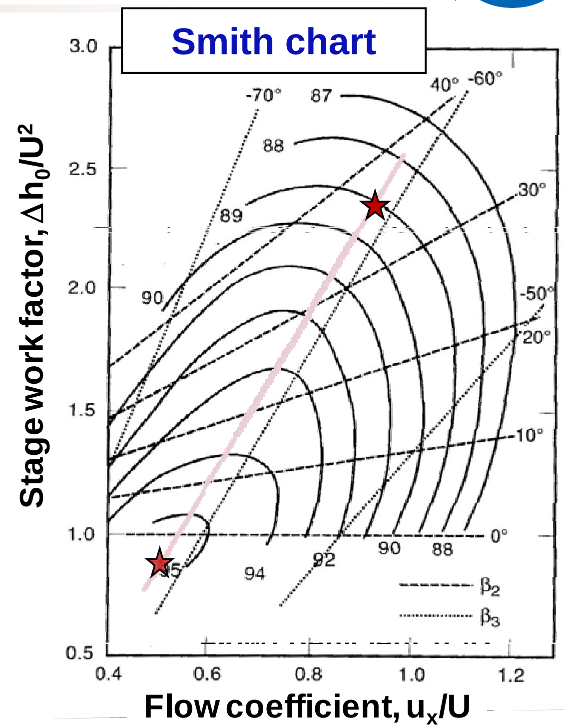
- **NASA CFD**
    - CC3 & HECC predictions & experimental support
    - HTML user's guide for TGS grid-generation python modules

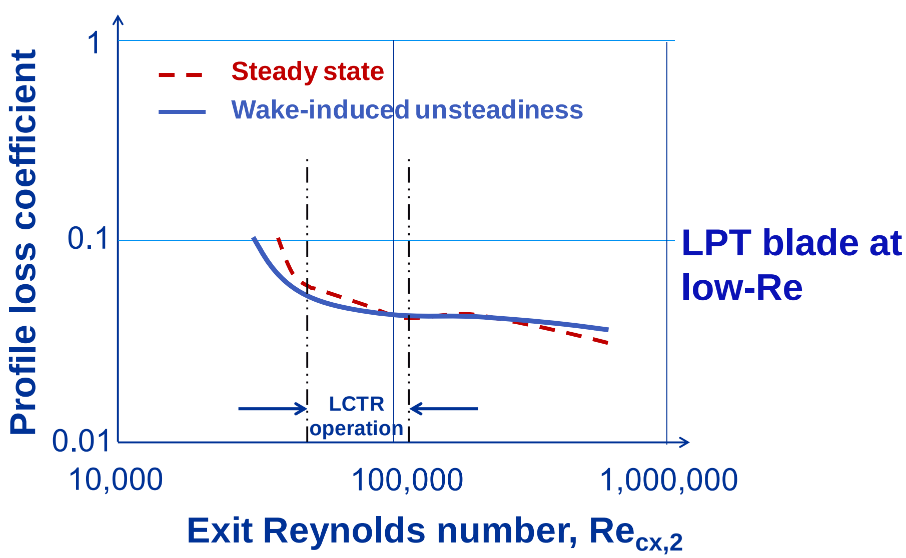
- **HPC axi-centrifugal**
  - Industry RFI/conversations (FY12) ➔ consensus technical challenges
  - Coordinate w/ FAP/SFW & Turbomachinery TWG on low $\dot{m}_{c,ex}$ aero challenges
  - FY15/16 – next-step experimental effort on axi-centrifugal – path?

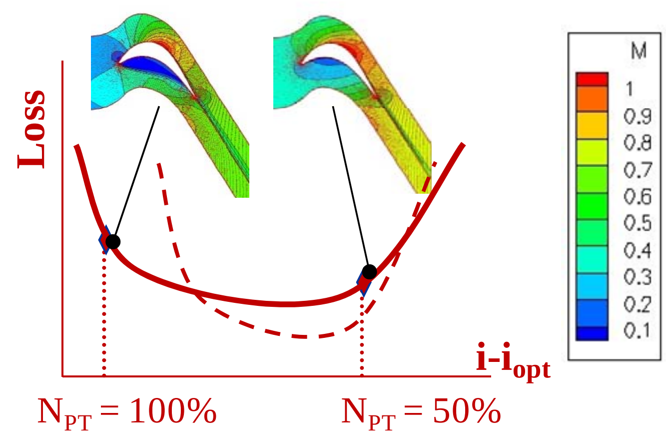
VARIABLE-SPEED POWER TURBINE

Key technical challenges for VSPT

- Aerodynamics
  - Efficiency at high cruise work factor
    - $\Delta h_0 = \Delta(u_\theta \cdot r\Omega) \approx$ const. at cruise and take-off
    - $\Delta h_0/U^2$ cruise is 3.5 x takeoff
  - 40^o to $60\ ^o$ incidence swings with speed change
  - Operation at low Re – transitional flow
- Rotordynamics – Avoidance / management of shaft modes through speed range







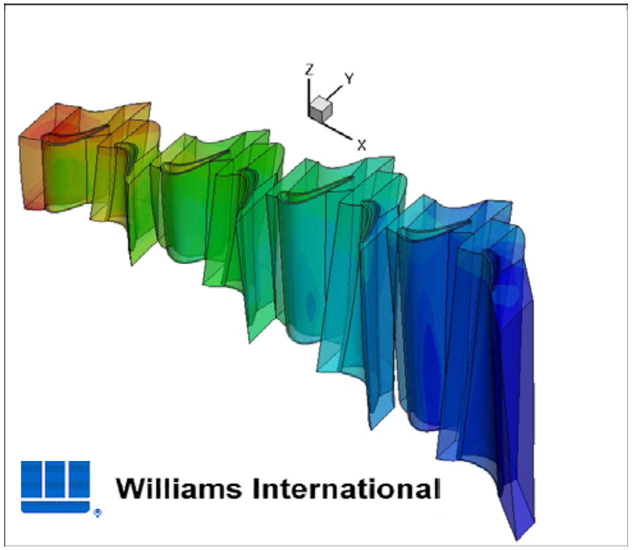
Blade-row loss versus incidence

VSPT research agenda

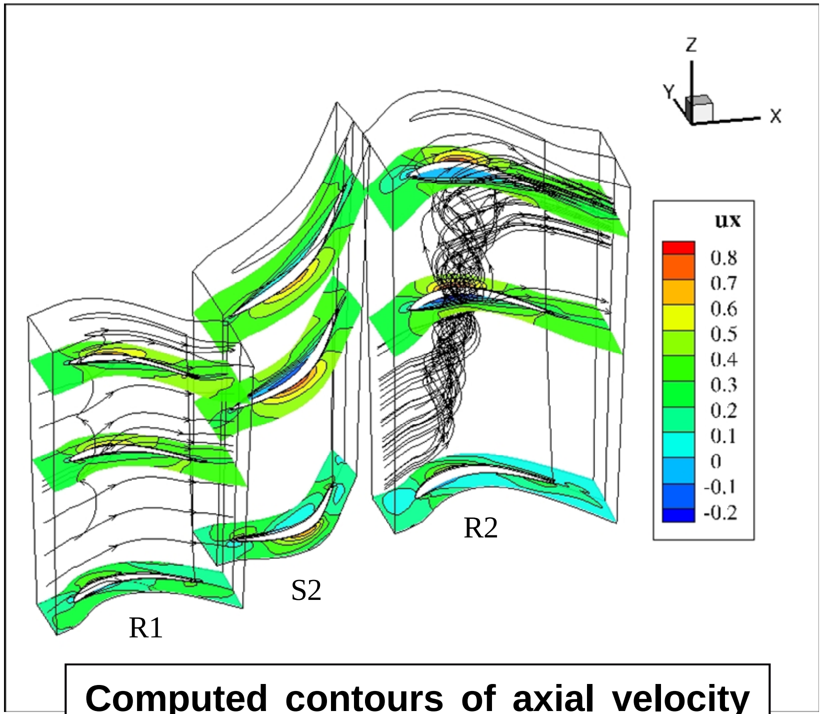
- Conceptual aero-design / analysis
- Incidence-tolerant blade development
  - 3-D design
  - Experiments – in-house / external
- Computational tools – multistage / transitional-flows
- Rotordynamics
- VSPT component testing - in-house & external paths

Progress – aero-design / analysis

- Documented conceptual designs
  - In-house* & external thru 3 RTAPS contracts**
  - 3- & 4-stage solutions w/ fixed geometry
- 3-D blade design / analyses



4-stage VSPT RANS/mixing-plane computation at design point

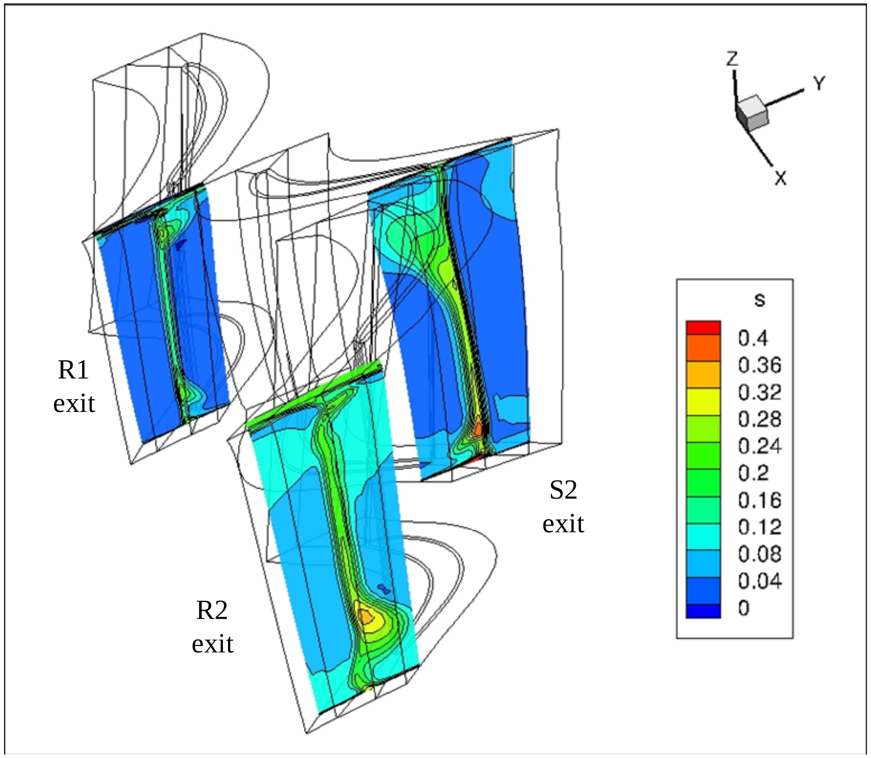


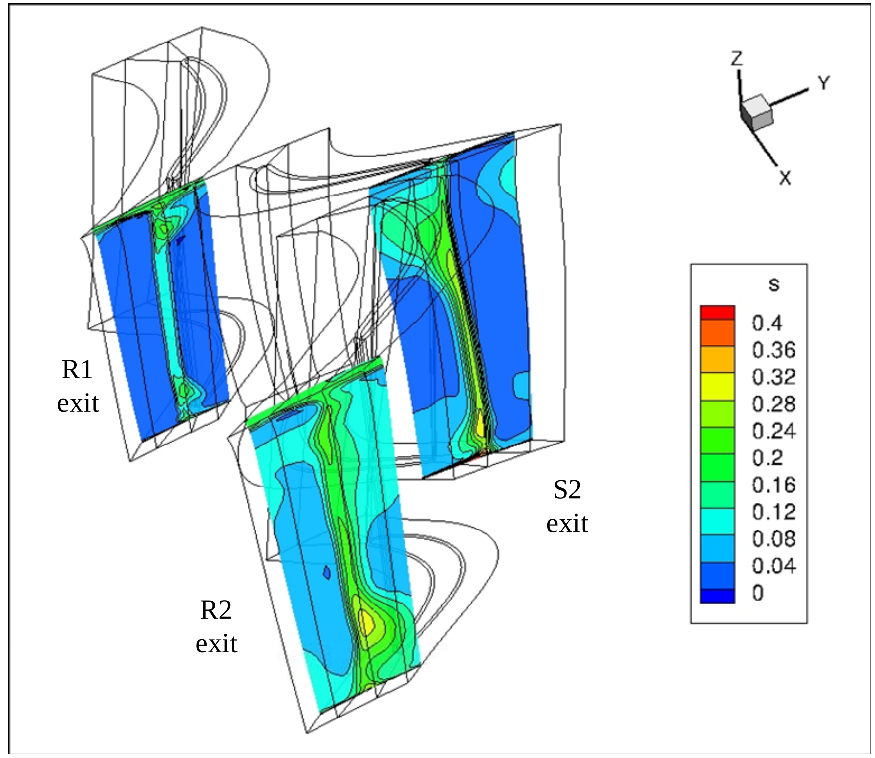
Computed contours of axial velocity and streamlines in Rotors 1 and 2 at the 100% N^* (off-design, takeoff).

Midspan section of incidence-tolerant blade

*NASA, AHS Int. Forum 67, 2011; NASA/TM-2011-217124
**Rolls-Royce, NASA/CR—2012-217016 & 217423
**Williams Int., NASA/CR—2012-217424

Progress (cont.) – impact of unsteadiness





a. LEO mixing-plane **b. LEO URANS TA/AP**

Computed contours of entropy at blade-row exit planes from LEO RANS/mixing-plane time-averaged, average passage URANS calculations at design point (54% *N**, 28 k-ft cruise)**

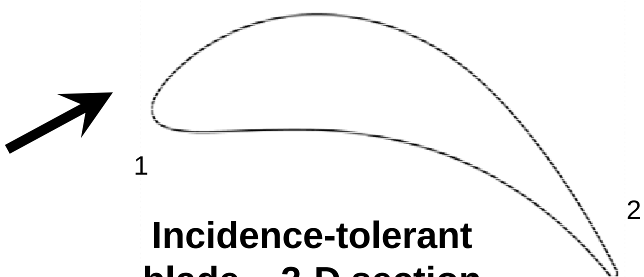
G. Welch, AIAA Aero Sci Meet., Jan 2012; NASA/TM—2012-217425
AeroDynamic Solutions flow solver, R-H. Ni

Linear cascade experiments – in-house

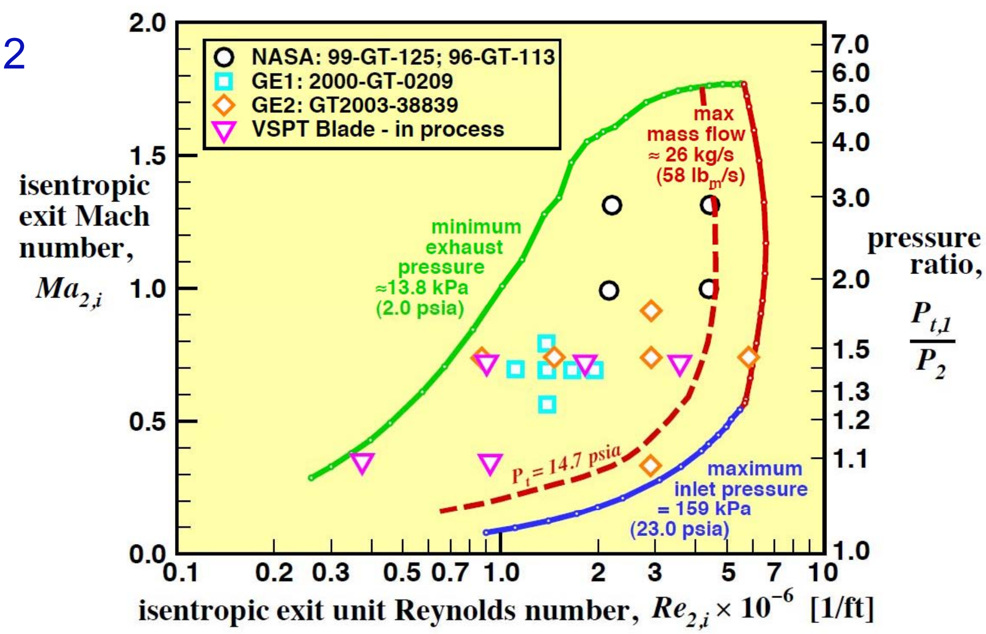
- Modified NASA GRC transonic linear cascade for VSPT negative incidence levels

- Test entries (over Re_2, M_2 range)
  - Inlet hotwire characterization (Tu, ε)
  - E^3 tip-section blading – completed*
    ($-10^o < \beta_1 < +59^o$)
  - Incidence-tolerant blade – Q2FY12
    ($-12^o < \beta_1 < +55^o$)

Modified tunnel, showing new lead-out duct



Incidence-tolerant blade – 2-D section



Tunnel operating map

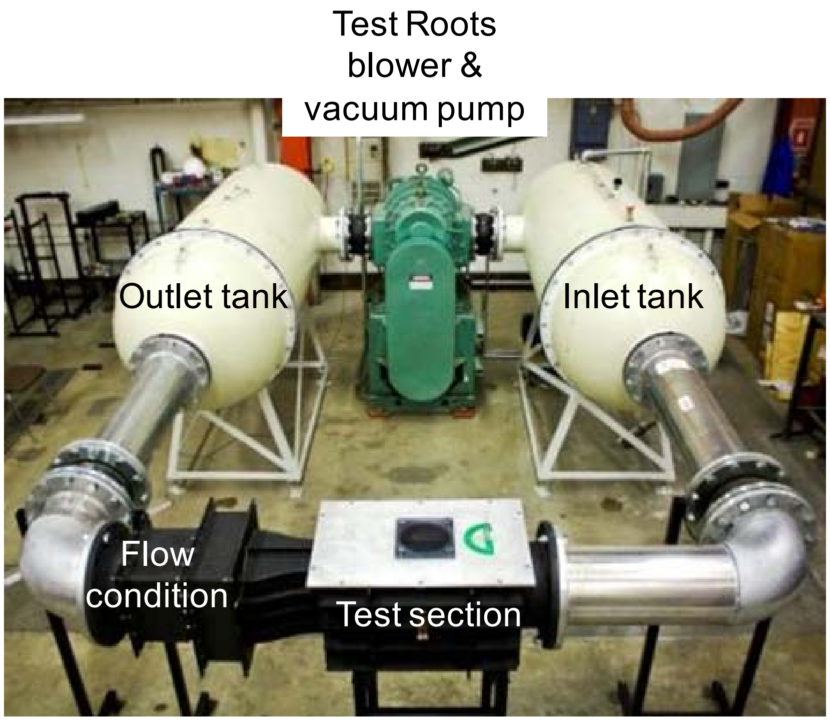
*A. McVetta, P. Giel – AIAA JPC 2012 paper

Linear cascade experiments – UND / NDSU

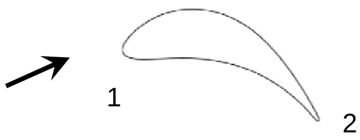
- Space Act Agreement with U. North Dakota – to extend NASA incidence-tolerant blade set to lower *Re*
  - Match M_2 and incidence angles
  - $40k < Re_2 < 400k$
  - p_0 surveys / heat transfer / PSP data

- 3-yr NASA EPSCoR* grant (FY12 start) to U. North Dakota and North Dakota State U.

- CFD element (North Dakota State U.)
  - 3-D URANS-SST and SAS-SST
  - γ-Re_θ transition model



U. North Dakota transonic linear turbine cascade test facility

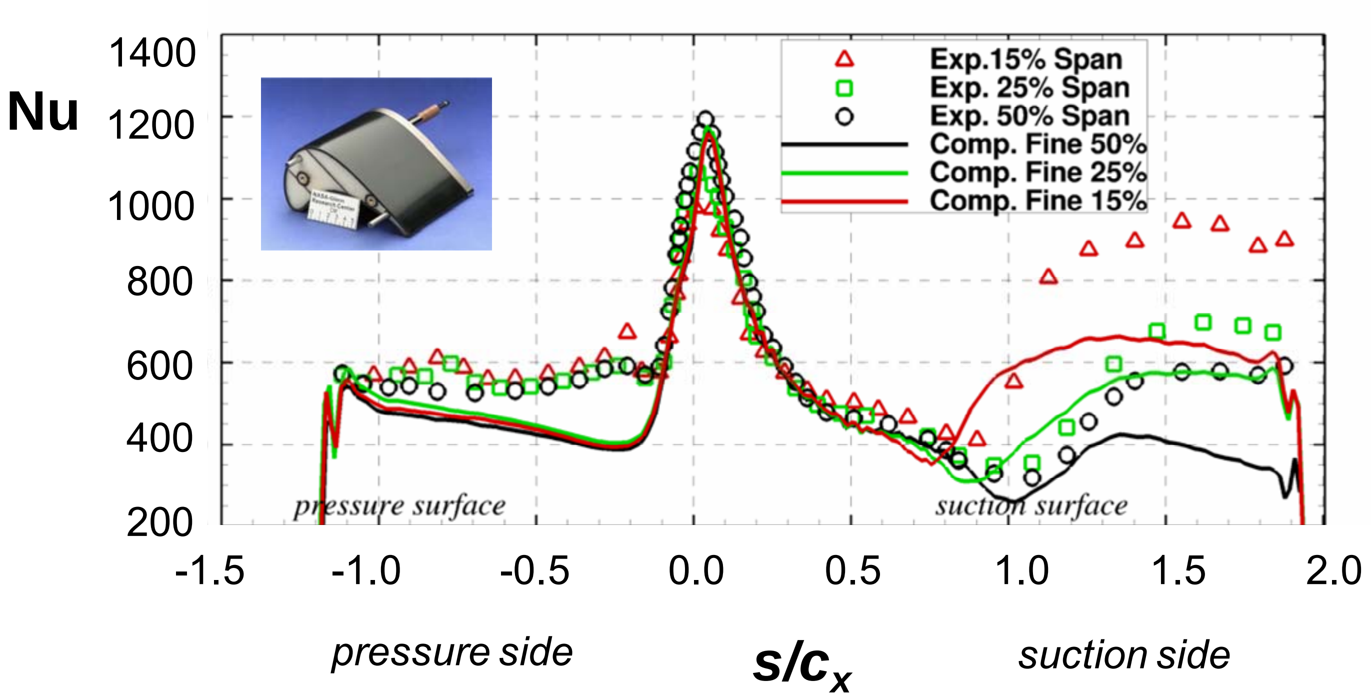


Incidence-tolerant blade section

*Experimental Program to Stimulate Competitive Research, Drs. F. Ames (UND) and Y. Bora Suzen (NDSU)

Computational work – W-L turbulence model for transitional flows in LPTs

- Walters-Leylek model implemented in NASA's GlennHT
- Assessed using NASA CW-22 data sets
  - Heat transfer using GE2 industrial PT blade (Giel *et al.*, 2004)
  - Aerodynamics using EEE tip-section blading / generation of loss bucket data

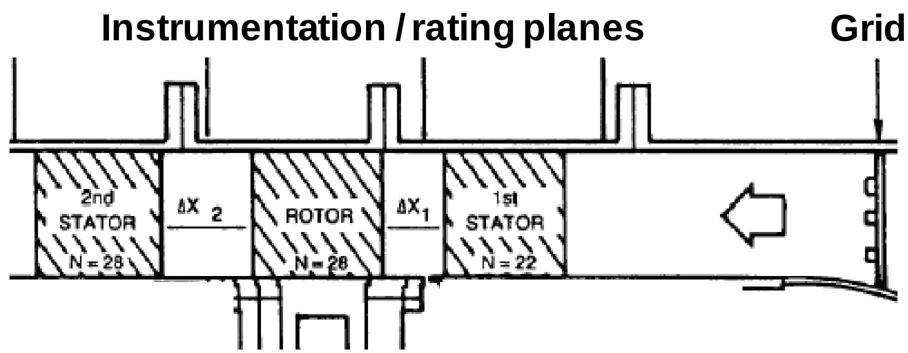


Comparison of computed & measured Nusselt number of GE2 blading at Re_2 = 375k.

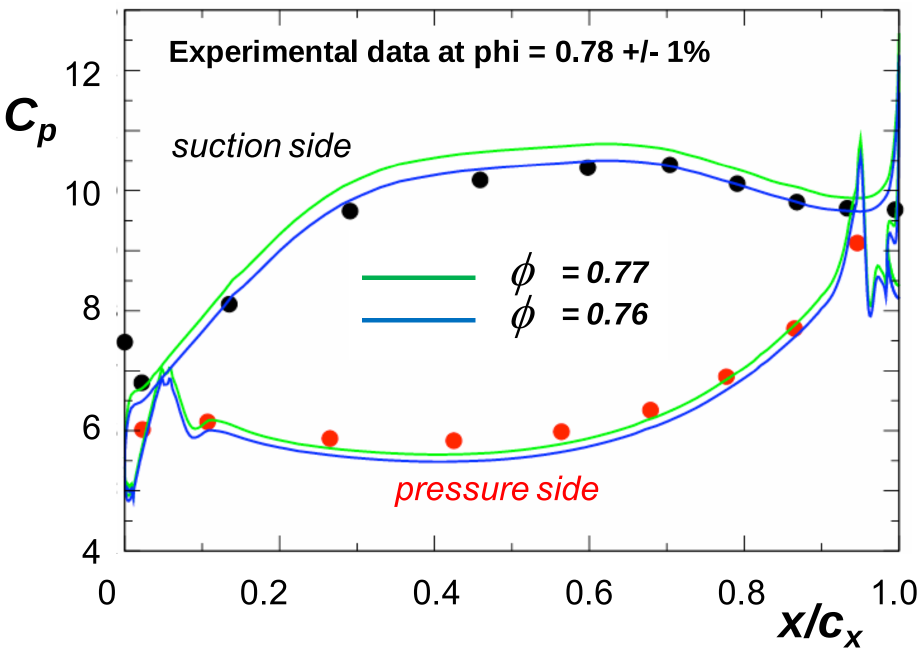
A. Ameri, ASME IGTI 2012 GT2012-69591, Jul, 2012

Multistage URANS simulation capability

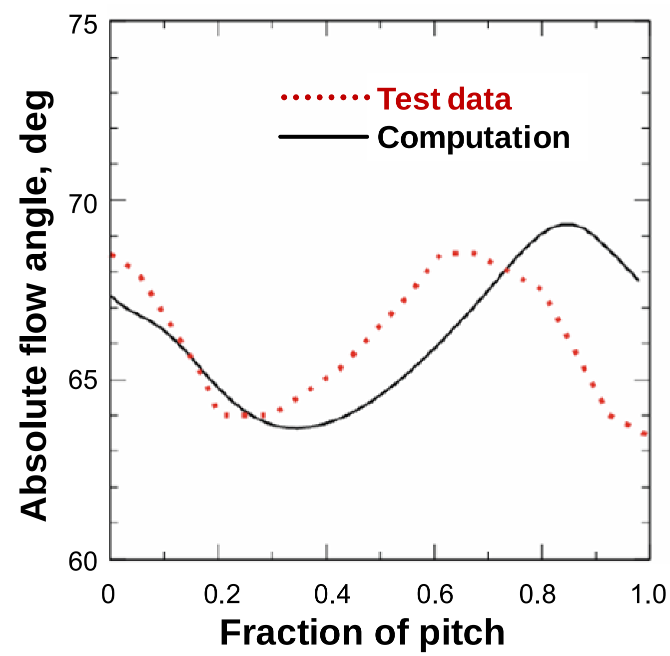
- TURBO code (J.P. Chen, OSU)
- Applied to 1.5-stage low-speed turbine (S1/R1/S2)
- Newly coded W-L model



UTC Low Speed Rotating Rig (Dring, UTC)



Time-mean Stator 2 loading

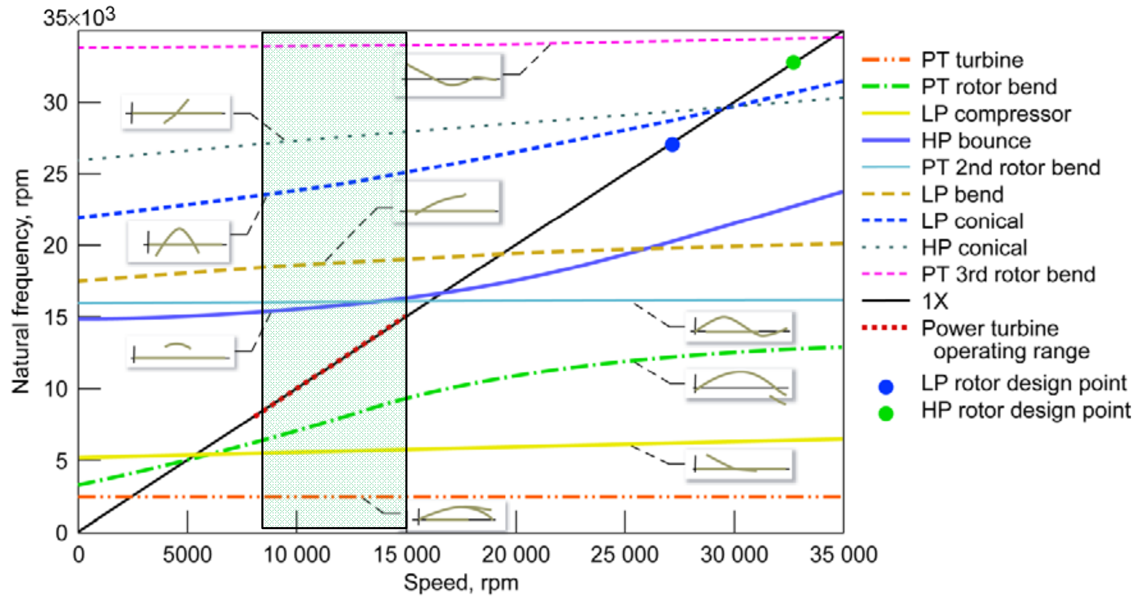


Computed and experimental Stator 2 exit flow angle

*W-M. To, NASA/CR—2012-2174382, 2012

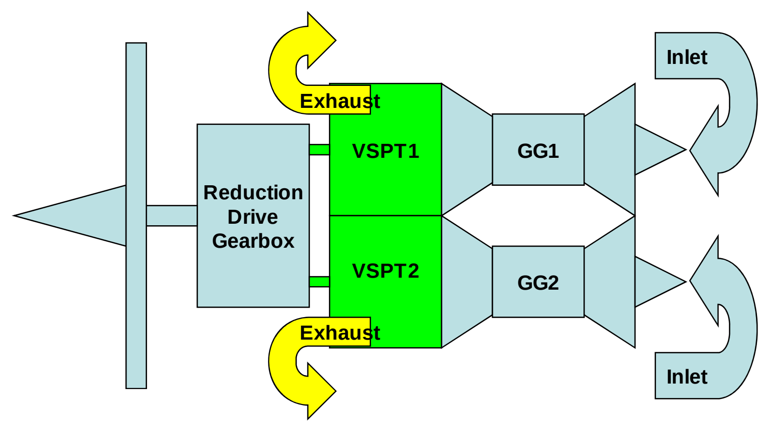
Rotordynamics for 50% shaft-speed range

- Rotordynamics model (DyRoBeS) for LCTR with 50% speed range*
  - Modeled HP, LP, & VSPT rotors
  - Critical-speed, stability, & unbalance-response analyses



Campbell diagram for three rotors of LCTR concept engine*

- Rotordynamics assessment in RTAPS contracts – viable engines
  - Rolls-Royce – growth AE1107C
  - Williams Int. – aft-drive



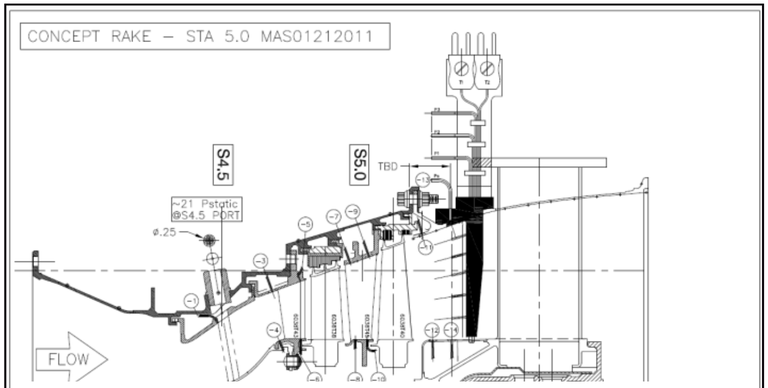
Aft-drive engine configuration for LCTR with VSPT directly coupled to the reduction drive gearbox**

*A. Howard, AHS Int. Forum 68, May 2012

**M. Suchezky & G. S. Cruzen, NASA/CR—2012-217424

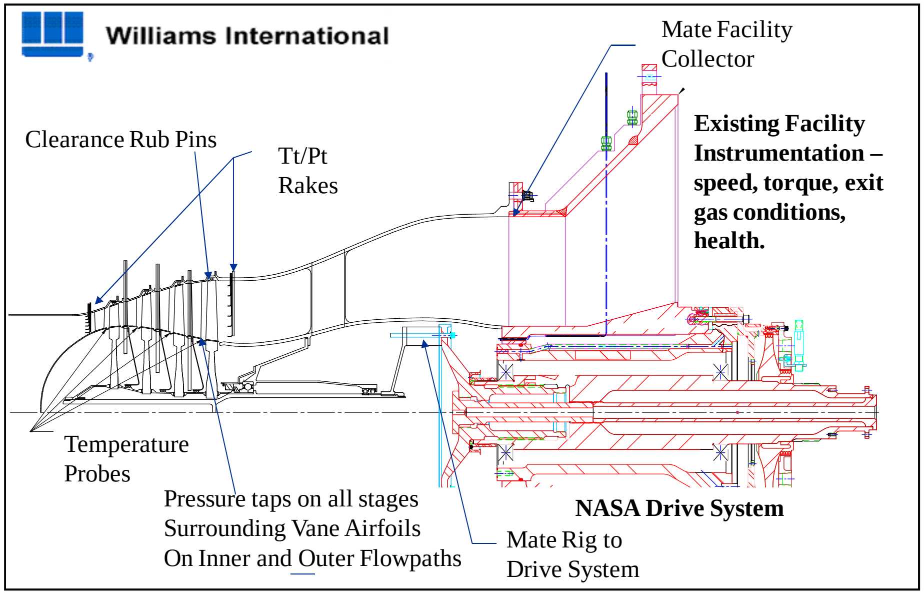
Progress toward VSPT component test

- Assessment of in-house VSPT test capability*
  - T700-700 engine in the NASA ECRL
  - NASA GRC single-spool turbine facility (W-6)



Notional instrumentation layout for VSPT component test in T700*

- RTAPS study contracts
  - Williams International
    - 4-stage VSPT in W-6
    - Match mission *Re*
  - Rolls-Royce NAT
    - Growth AE1107C
    - 3.5-stage VSPT/EGV in W-6
    - Match mission *Re*



**Williams Int. 4-stage LCTR VSPT component in NASA GRC W-6 single-spool facility

*G. Skoch, M. Stevens, *et al*., NASA/TM—2012-217422
**M. Suchezky et al., NASA/CR—2012-217424

Next steps for VSPT

- Complete CW-22 aero testing of incidence-tolerant blading
  - Reports at AIAA JPC 2012 & ASME IGTI 2013
  - Heat-transfer experiments with incidence-tolerant blade pack
- Computational analysis
  - Report W-L / heat-transfer work at IGTI 2012
  - Support CW-22 experimental data synthesis
  - Apply TURBO with W-L model to high-speed multistage LPT
- Rotordynamics – done
  - Report at AHS Int. Forum 68
- U.S. Army Aviation Applied Technology Directorate (AATD) partnership efforts
  - 6.3 FATE engine program, NASA-$ VSPT option (FY12 start)
  - 6.2 VSPT component test, NASA-$ award (FY12 award & start)