Experimental Results of the First Two Stages of an Advanced Transonic Core Compressor Under Isolated and Multi-Stage Conditions

GT2015-42727

Patricia S. Prahst
Zin Technologies, Inc
Cleveland, OH, USA

Sameer Kulkarni
NASA Glenn Research Center
Cleveland, OH, USA

Ki H. Sohn
The General Electric Company
Cincinnati, OH, USA

ASME Turbo Expo 2015
June 15 – 19, 2015, Montréal, Canada

Outline

- Introduction
- Objective
- Facility and Rig Overview
- Results
- Conclusion

Introduction

v2013.1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_2e per MJ for fuel and/or energy source used

- NASA Environmentally Responsible Aviation Project (ERA) goal: Identify and mature technologies that together can simultaneously meet the metrics above (noise, emissions, and fuel burn) in the N+2 timeframe

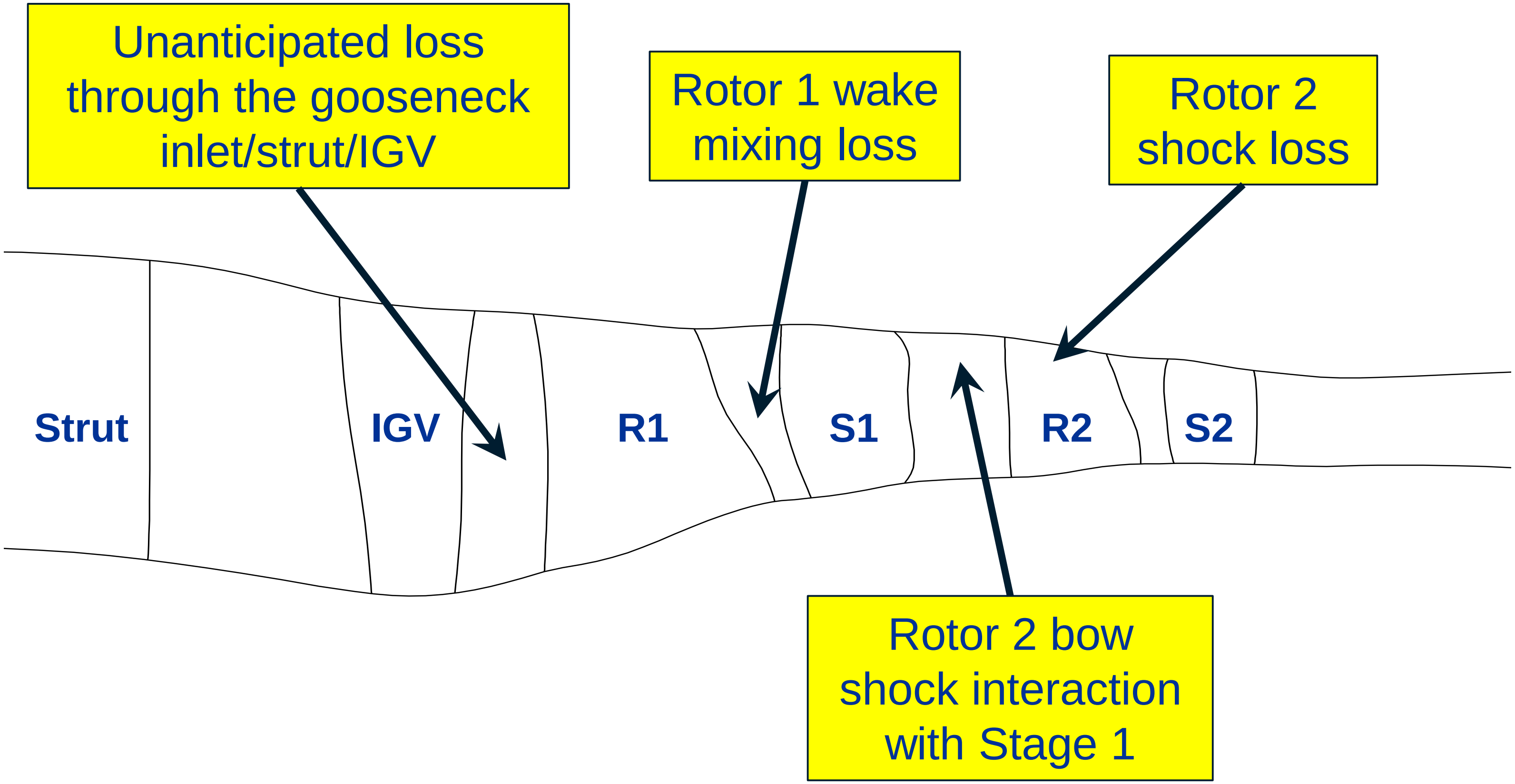
- ERA system studies have shown potential for up to 2.5% reduction in Thrust Specific Fuel Consumption by increasing core compressor pressure ratio by 30%

Introduction

- Increased loading of the core compressor introduces aerodynamic losses and decreased efficiency in the front stages
- NASA partnered with General Electric to test the front stages of a legacy advanced, highly loaded, transonic core compressor to identify loss mechanisms
- Previous test experience of a compressor which included these front stages indicated a performance deficit relative to design at high speed which was not captured by RANS/URANS CFD

Introduction

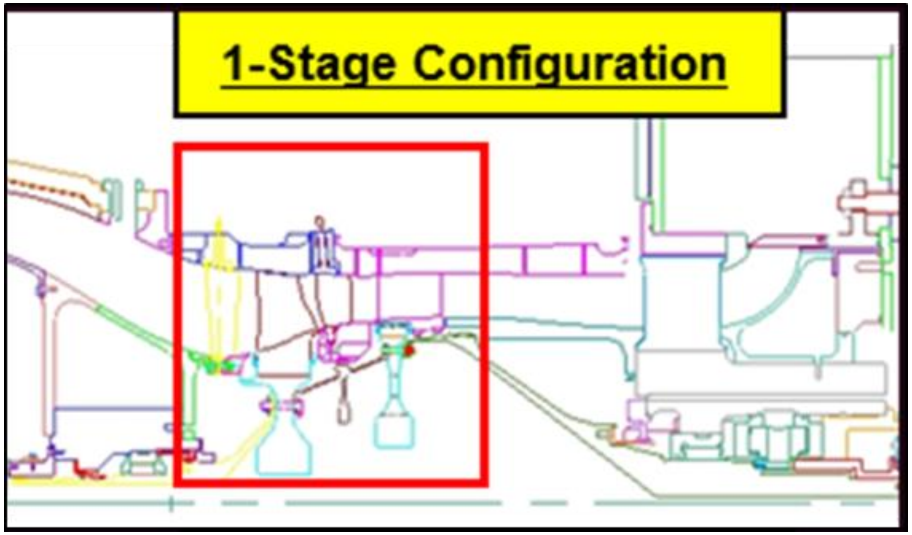
- Potential explanations of the previously measured performance deficit:

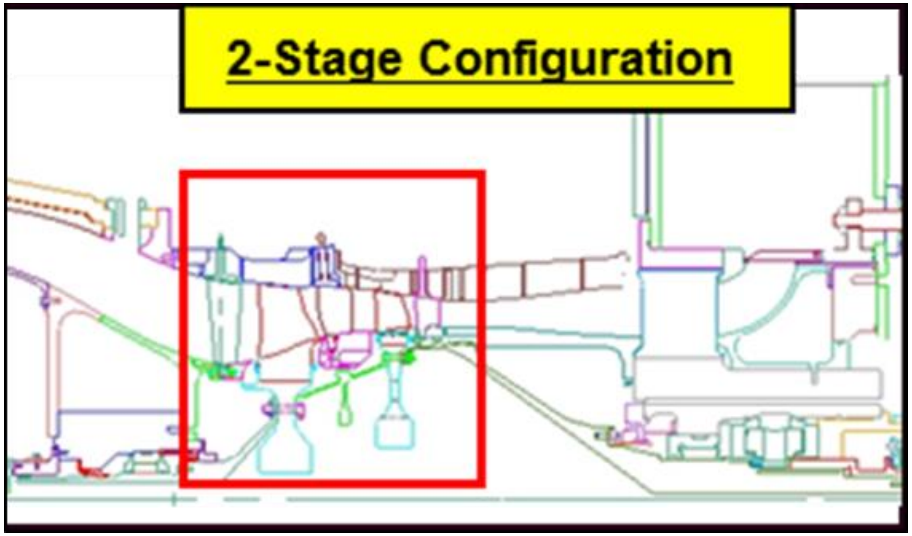


Objective

- Document high-speed performance of a highly loaded front block core compressor under isolated and multi-stage conditions to understand any differences
  - Provide detailed aero data for CFD validation

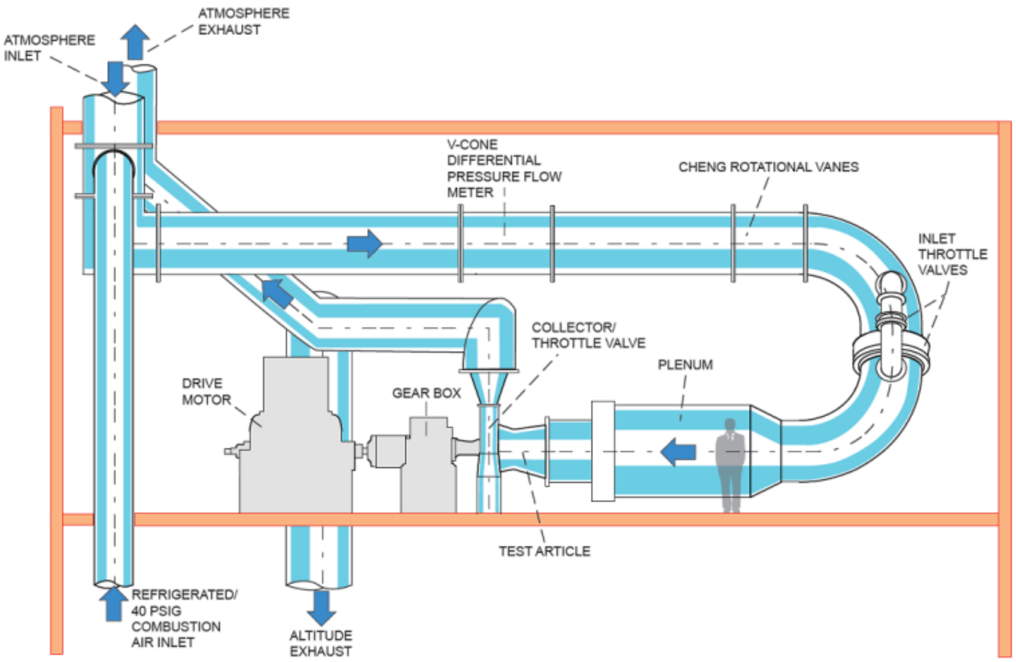
- Rig was operated in 1-stage and 2-stage configurations in separate tests to isolate the effect of the Rotor 2 bow shock on Stage 1





Facility and Rig Overview

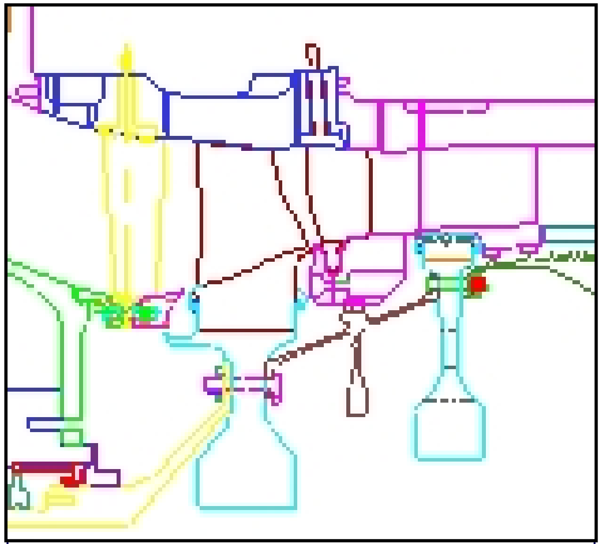
- Testing was conducted at NASA Glenn Research Center in the W-7 High Speed Multi-Stage Axial Compressor Facility
- Atmospheric inlet and exhaust were used during testing
- ESP data acquisition system for steady state pressures up to 150 PSIA
- ESCORT data recording system to obtain and display steady state parameters
- GE supplied proprietary data acquisition and probe actuation systems were used for traversing probe data, dynamic pressure data, and rotor tip clearance measurements.



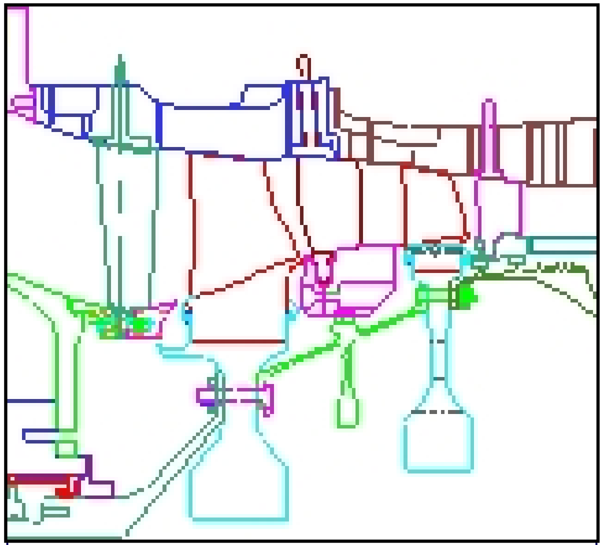
W-7 Facility Capabilities	
Parameter	**Operating value**
Inlet air pressure	atm to 20 psig
Inlet airflow	10-100 lb_m/s
Atmospheric exhaust	0.8 psid blowers
Altitude exhaust	26 in. Hg (vacuum)
Rotor speed	0-18,700 ± 0.5 rpm
Rotor size	20 to 22 in.
Drive motor	15,000 hp

Facility and Rig Overview

- 1-stage configuration
  - Strut, IGV, Rotor 1, Stator 1, de-swirl vane
- 2-stage configuration
  - Strut, IGV, Rotor 1, Stator 1, Rotor 2, Stator 2
- IGV, Stator 1, and Stator 2 are variable stagger vanes
  - Data was acquired at off-schedule vane angles but the current work is focused on nominal vane settings



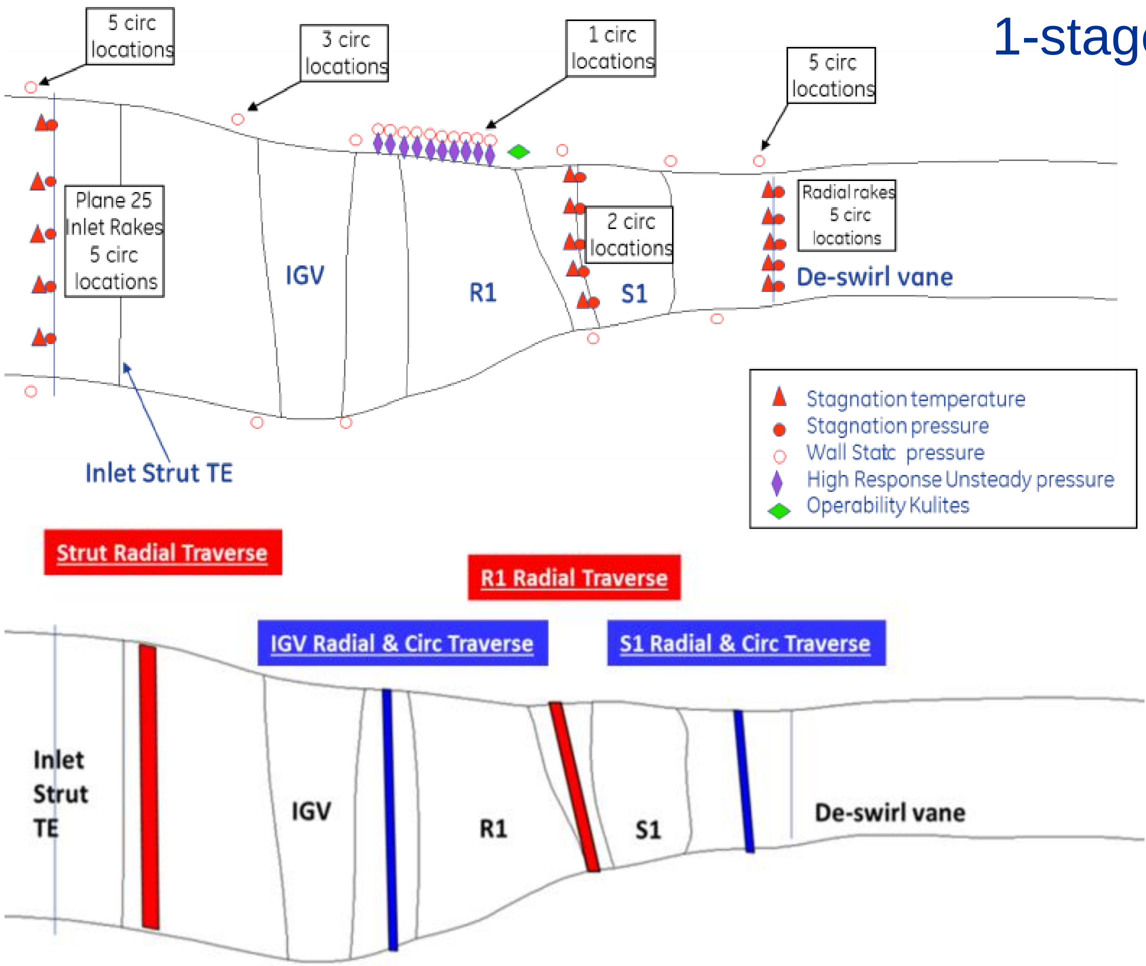
1-stage config.



2-stage config.

Facility and Rig Overview

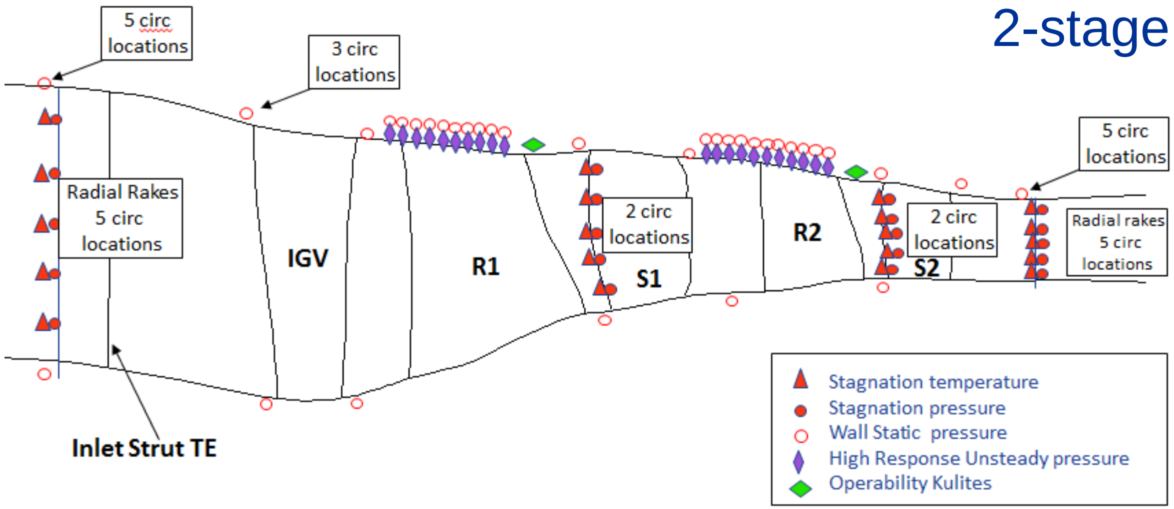
1-stage configuration

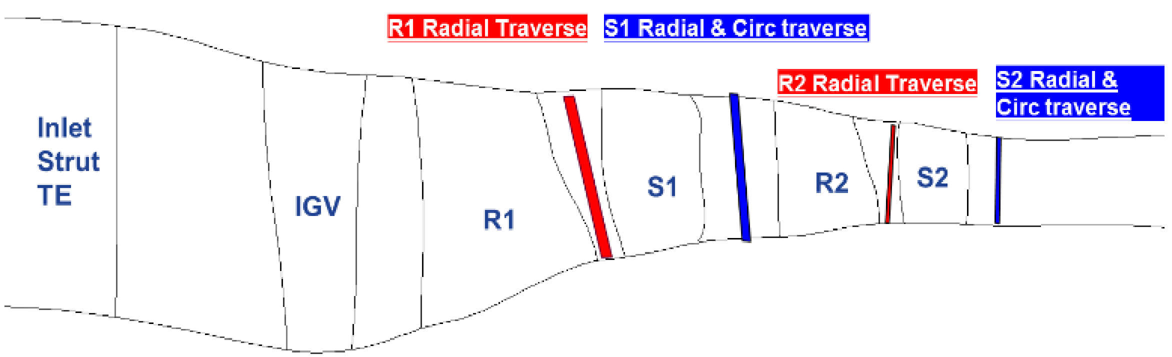


- Inlet and Exit Rakes: 5 circumferential positions with 5 radial locations
- Vane Leading Edges: 2 vanes/stage with P0 probes, 2 vanes/stage with T0 probes at 5 radial locations
- Casing and hub static pressures along the flow path
- Detailed traverses at 4 positions shown above: 5-hole probe, Kulite, hot wire

Facility and Rig Overview

2-stage configuration

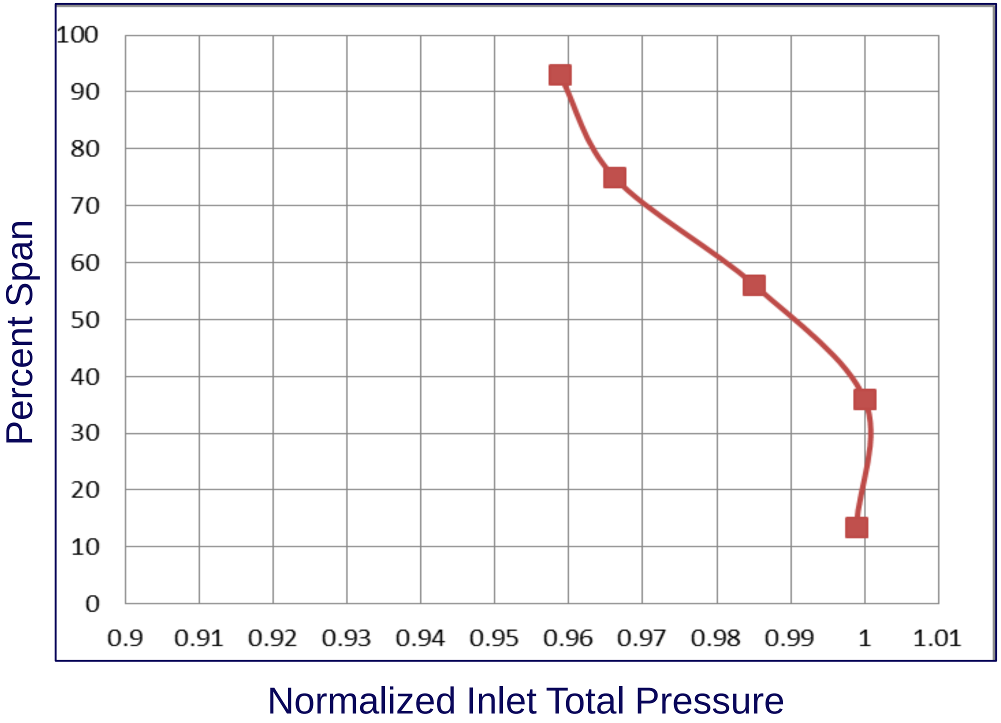


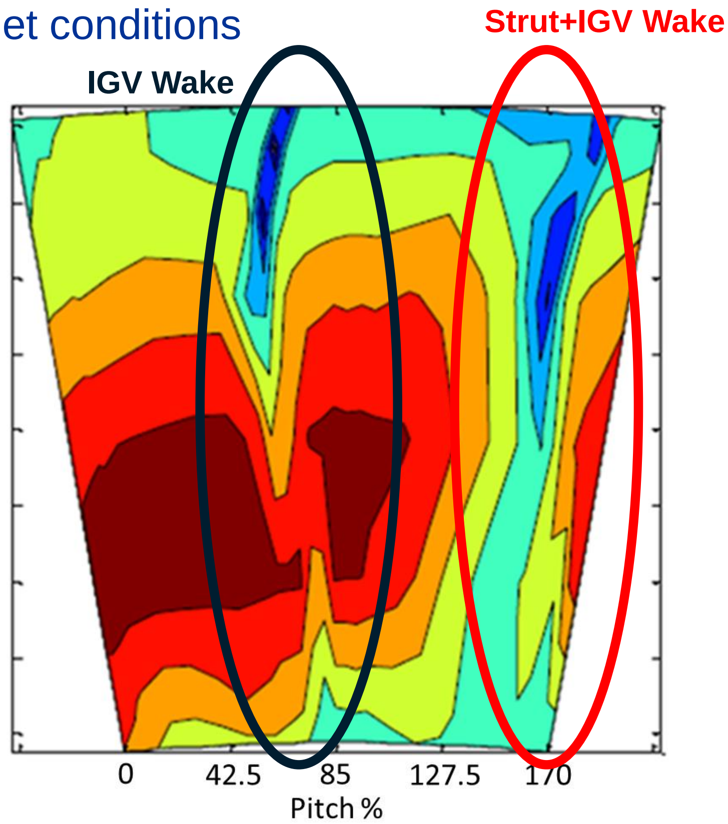


- Inlet and Exit Rakes: 5 circumferential positions with 5 radial locations
- Vane Leading Edges: 2 vanes/stage with P0 probes, 2 vanes/stage with T0 probes at 5 radial locations
- Casing and hub static pressures along the flow path
- Detailed traverses at 4 positions shown above: 5-hole probe, Kulite, hot wire

Results: Inlet P0 Profile

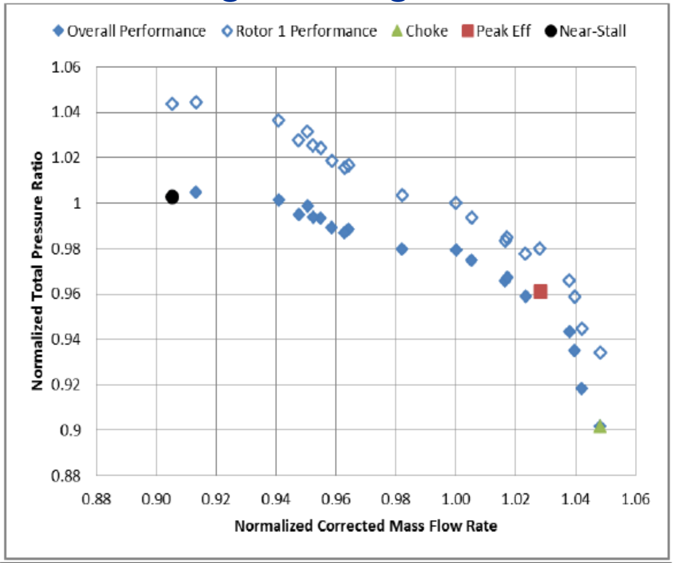
- Inlet total pressure profile aft of inlet screen (within strut passage) below was typical for all run conditions
- Radial-circumferential 5-hole probe survey characterizing IGV wake (black) and strut+IGV wake (red) is shown below
- These data ruled out unanticipated loss due to inlet conditions

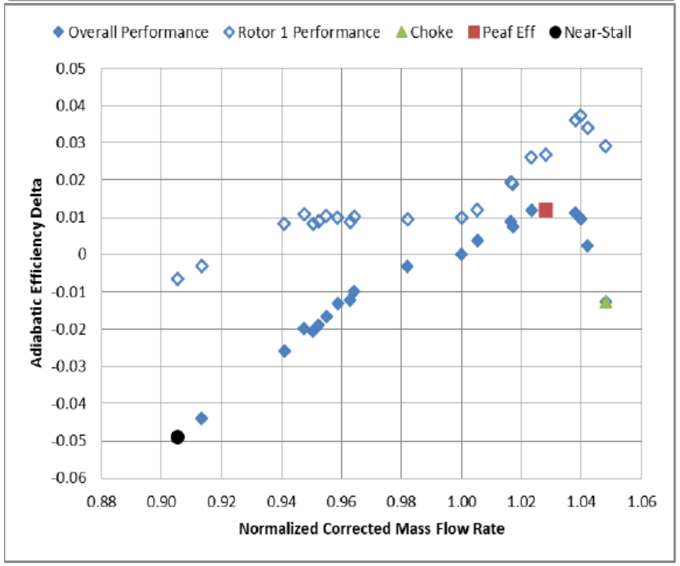




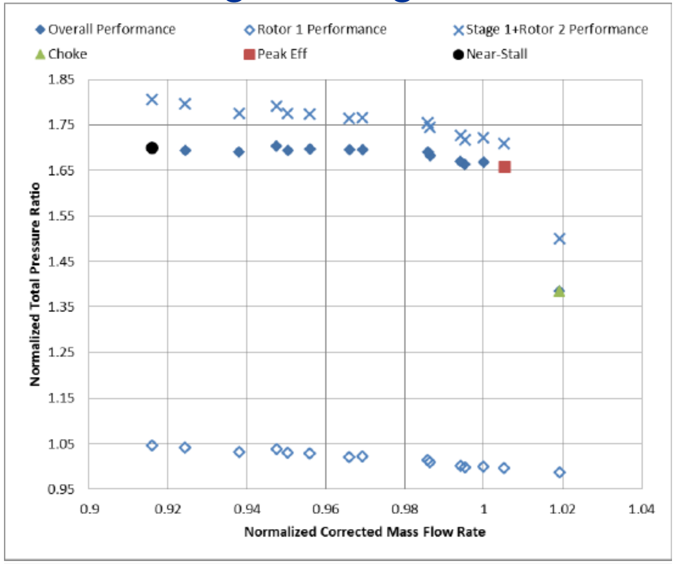
Results: 97% Nc Speedlines

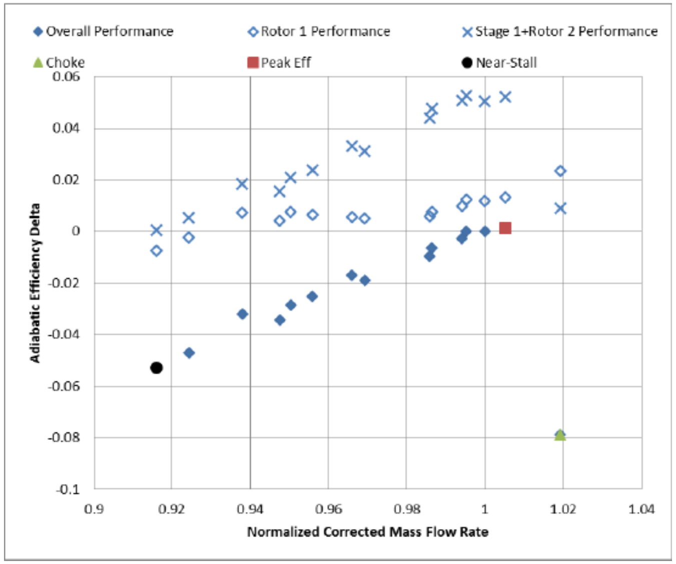
1-stage configuration



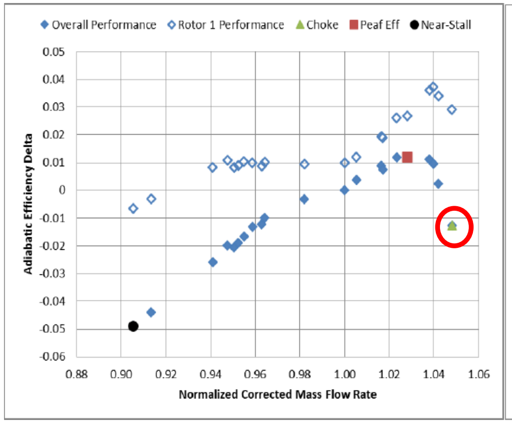


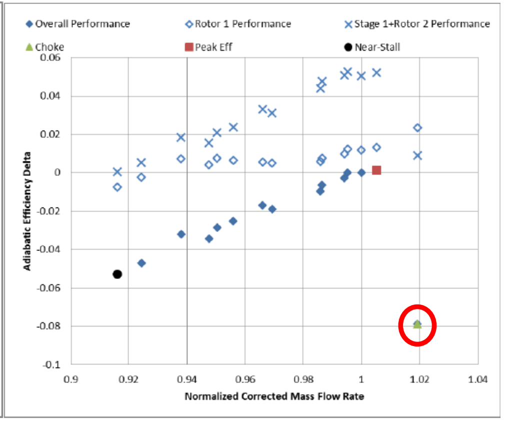
2-stage configuration

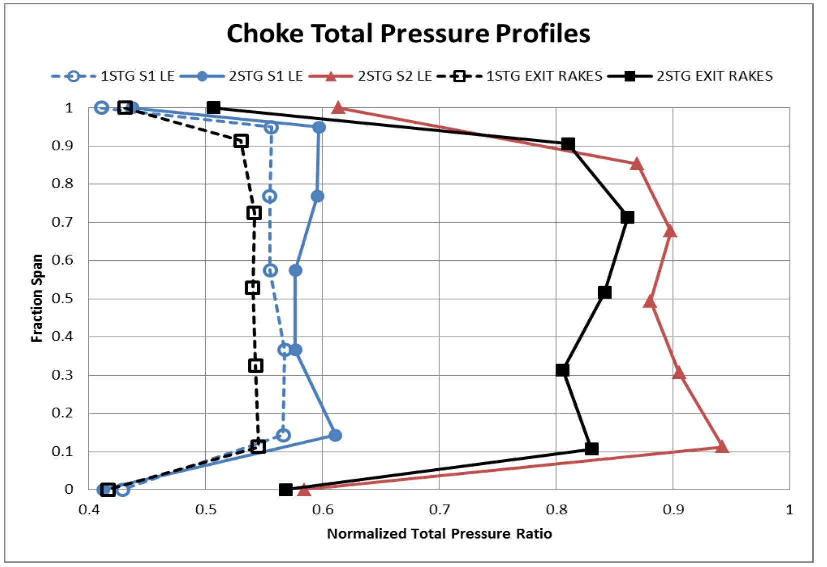


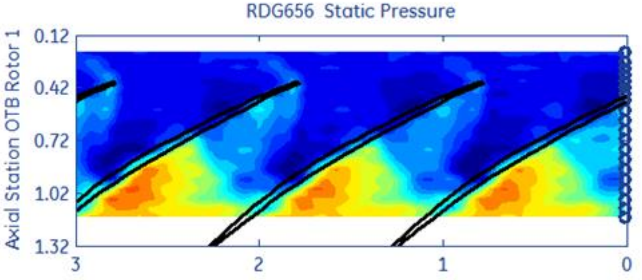


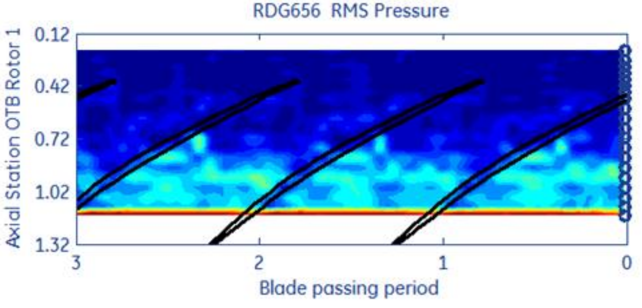
Results: Choke

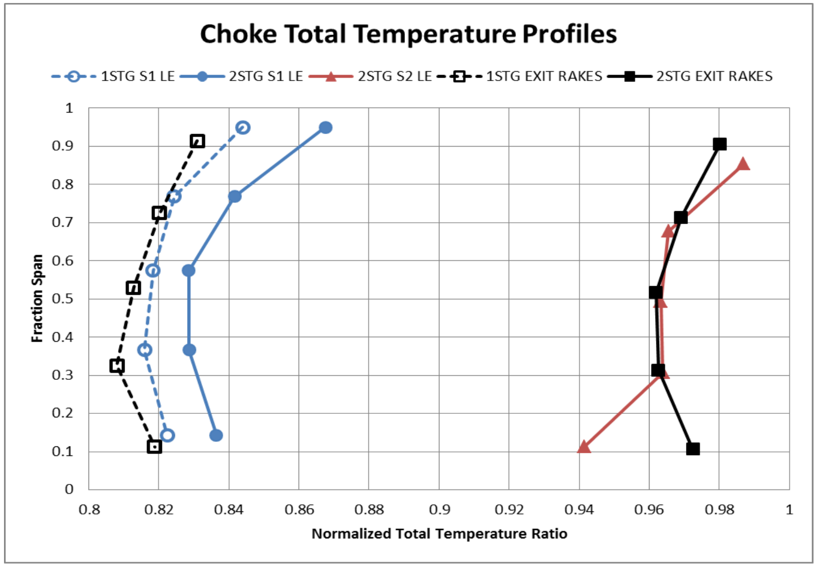






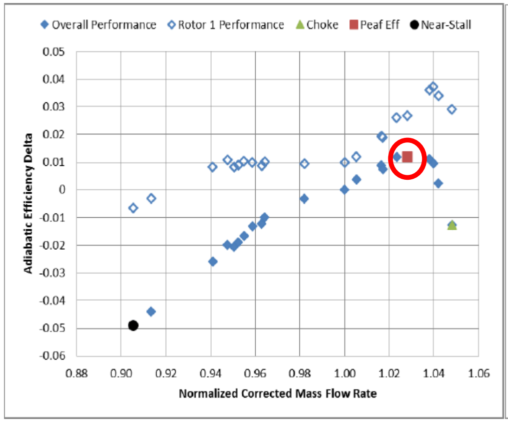


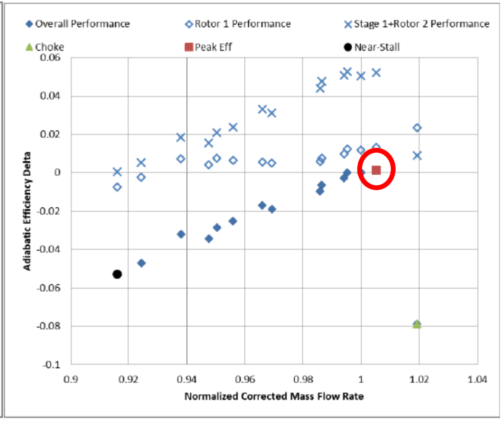


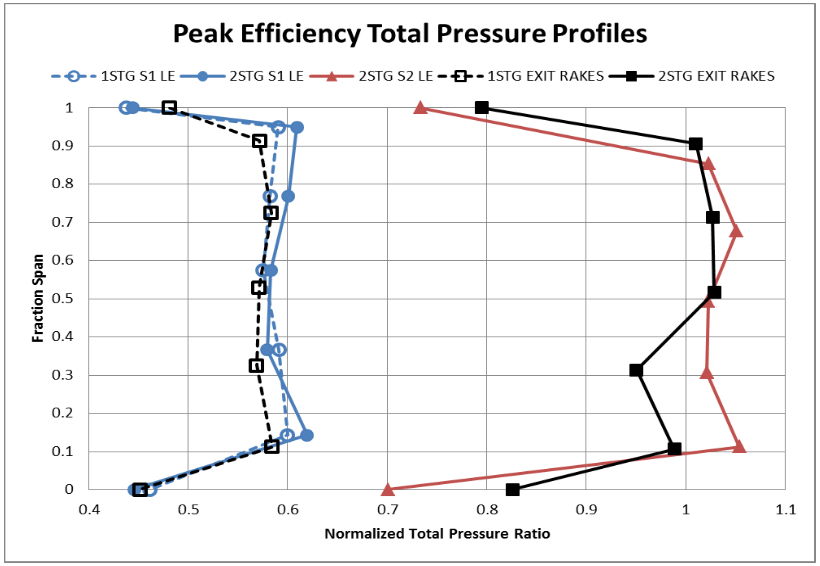


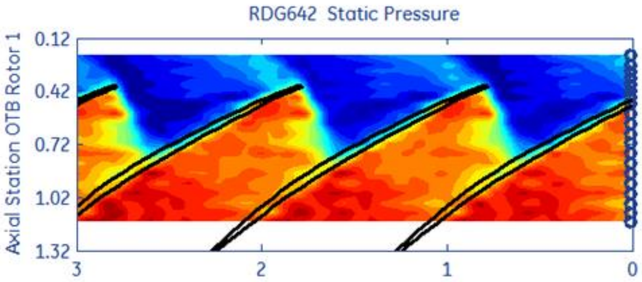
2-stage config. chokes at lower flow than 1-stage config.

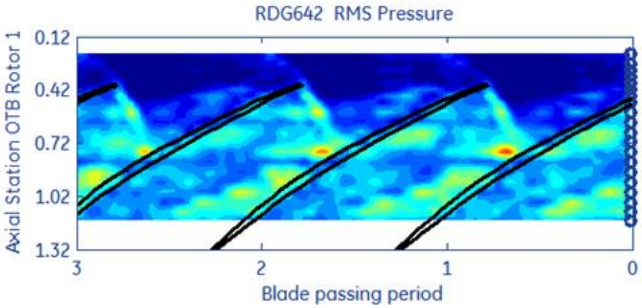
Results: Peak Efficiency

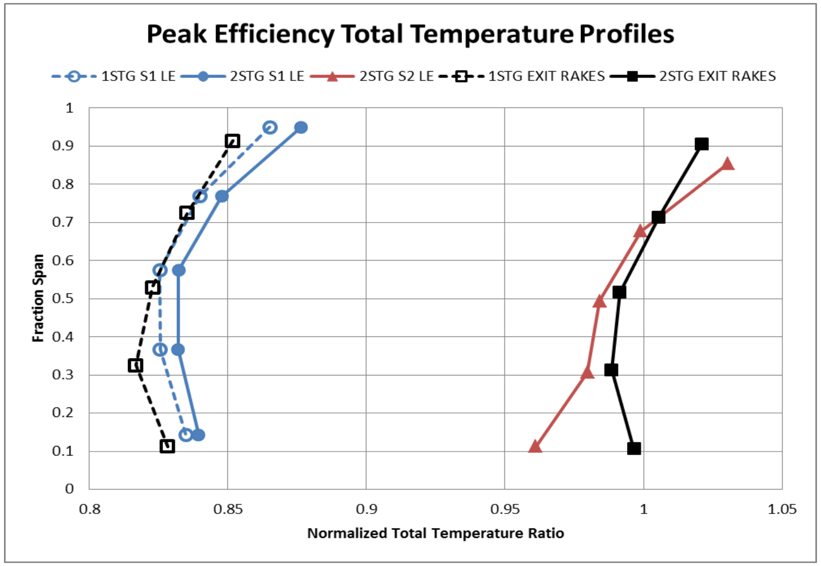






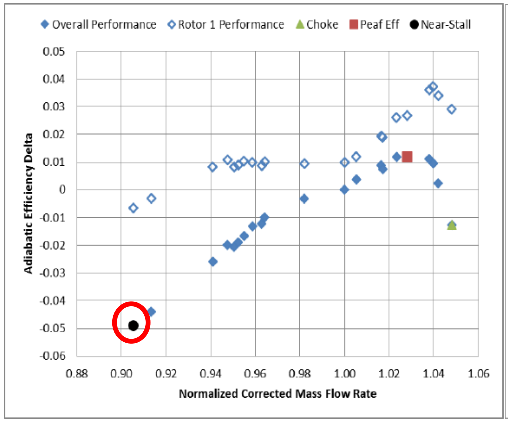


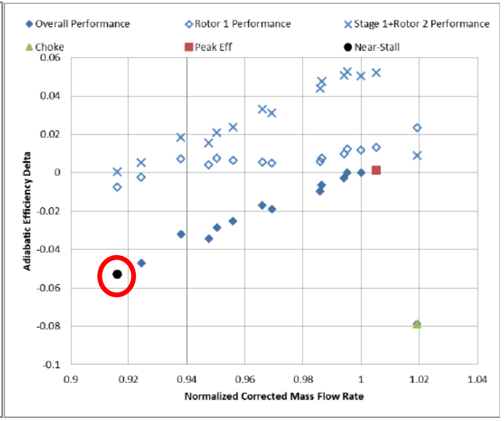


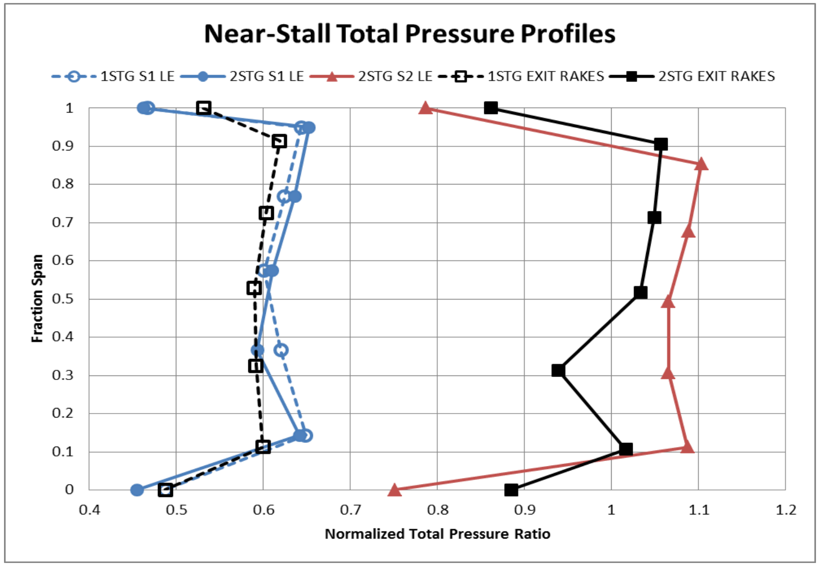


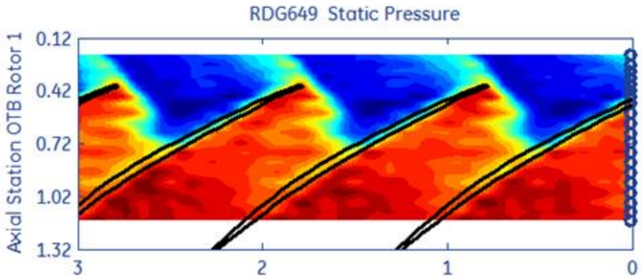
Rotor 1 throttled past peak efficiency in 2-stage config.

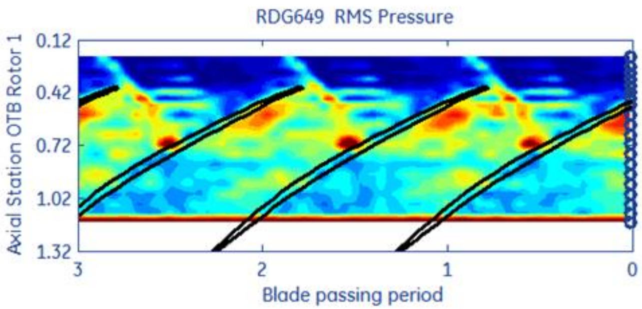
Results: Near-Stall

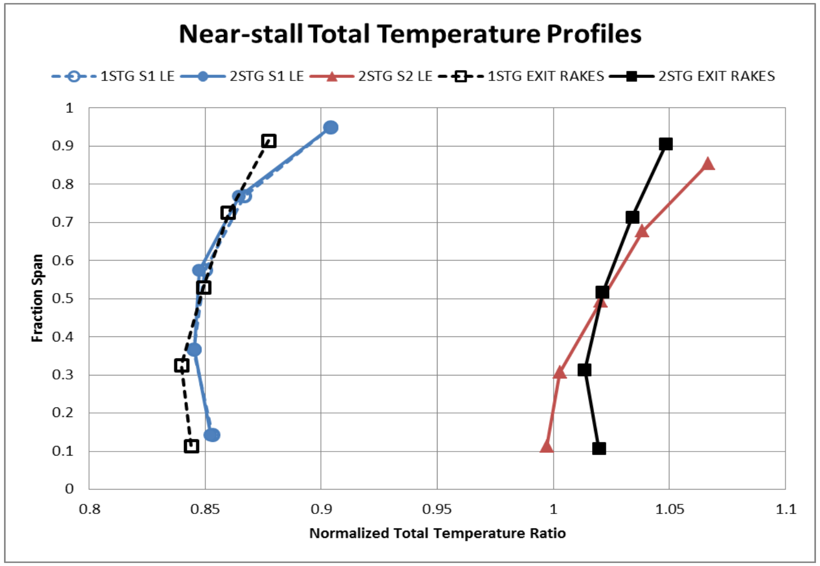








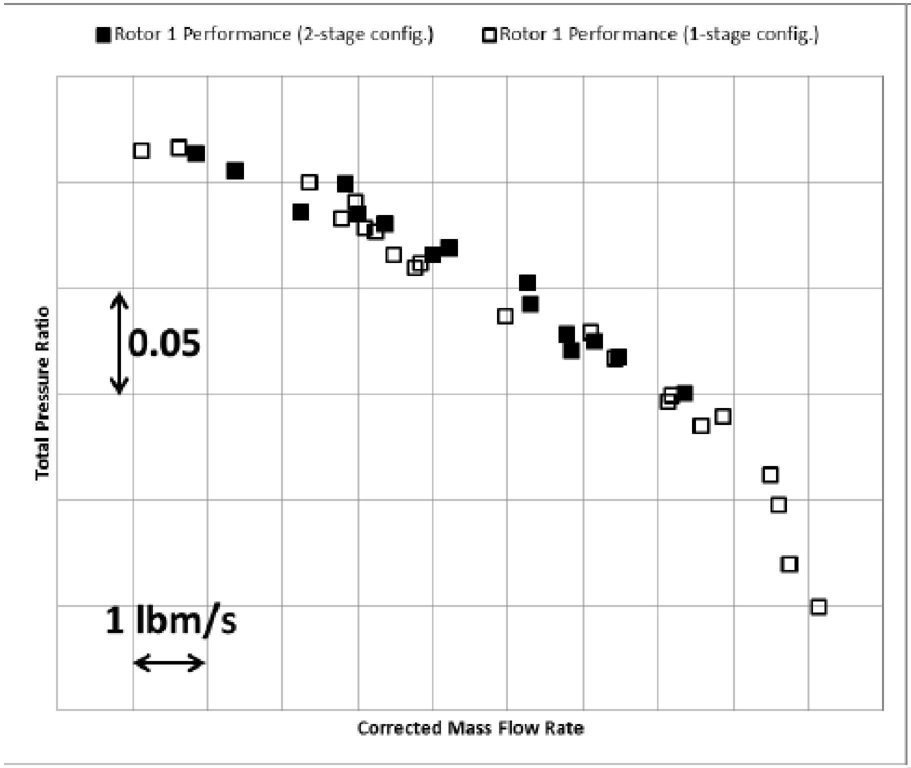


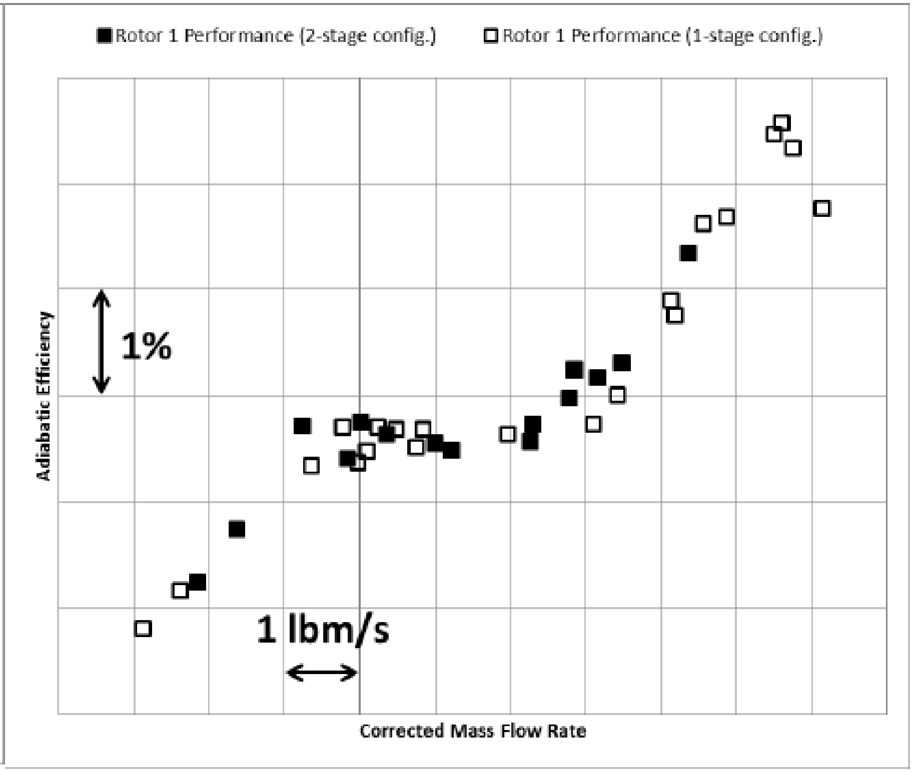


Stage 2 stalls before Stage 1

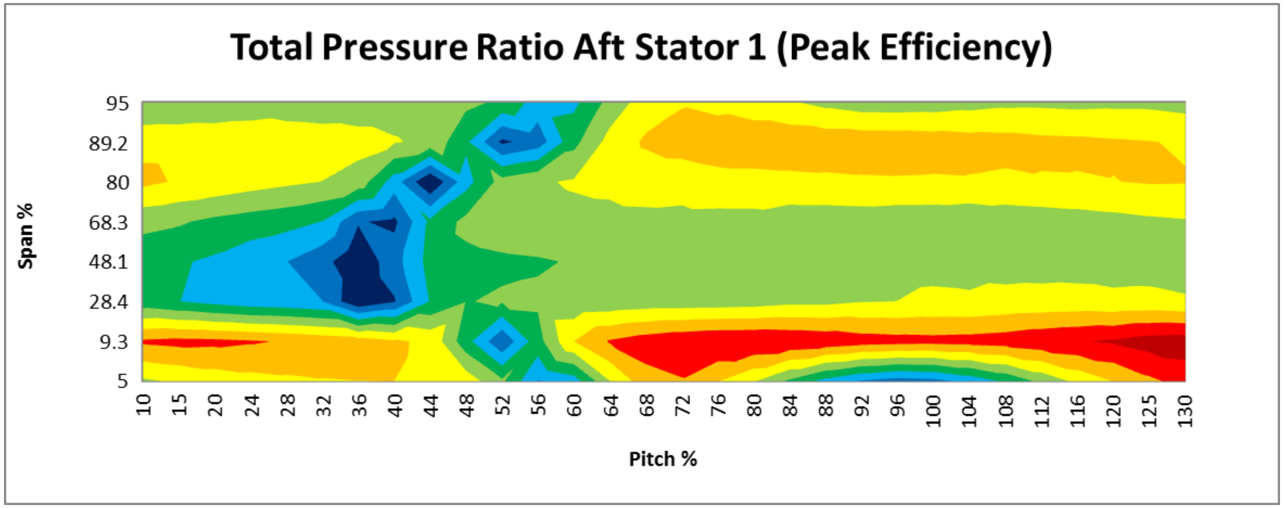
Results: Rotor 1 Performance

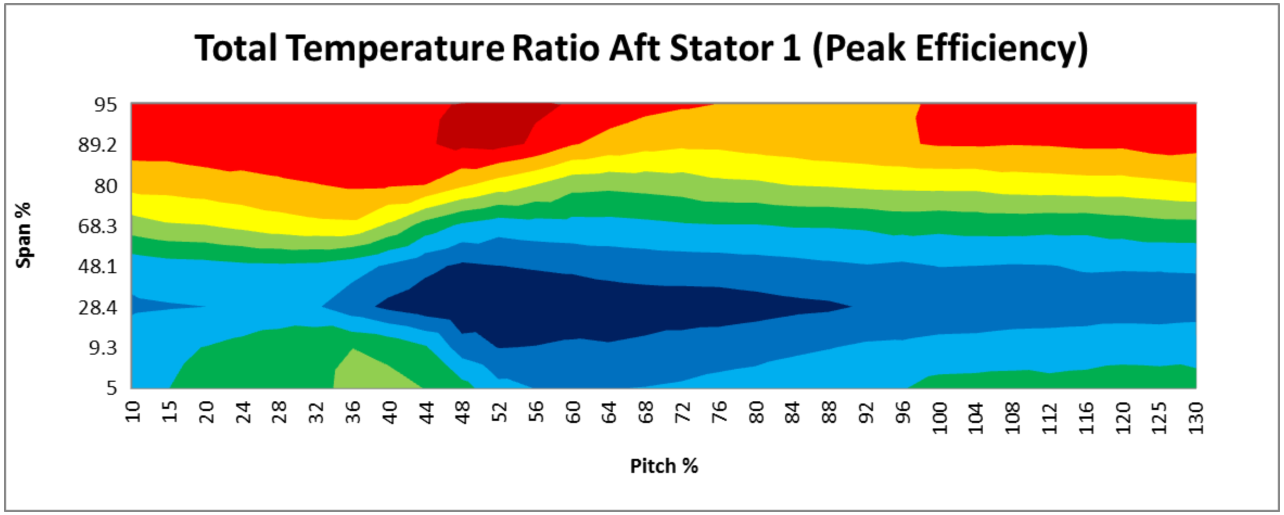
- 2-stage config. choked at lower flow than 1-stage config.
  - Rotor 1 does not reach peak efficiency in 2-stage config.
- Negligible change in Rotor 1 performance between 1-stage and 2-stage configs.





Results: 5-Hole Probe Traverse Aft Stator 1





- Stage 1 efficiency (1-stage config.) is low relative to design intent

Conclusion

- Data collected upstream of Rotor 1 did not indicate sources of unanticipated loss
- Stage 2 choked at a mass flow rate which prevented Stage 1 from reaching its peak efficiency point, causing a stage mismatch
- Level of Rotor 1 performance is otherwise unaffected by presence of the Stage 2
  - i.e. Losses due to Rotor 2 shock loss or bow shock interaction with Stage 1 is unlikely
- Stage 1 performance is down relative to design intent

Following Papers

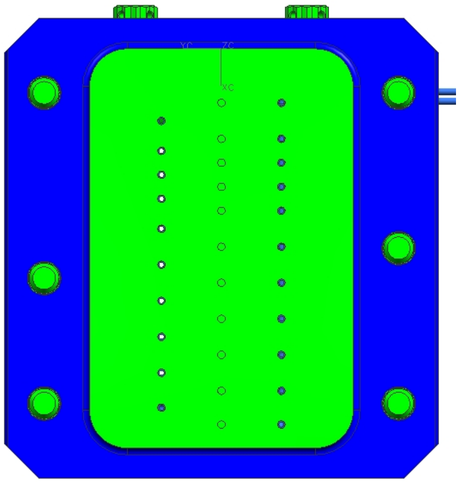
- GT2015-42526: Lurie and Breeze-Stringfellow present GE interpretation of the data at the 1-stage peak efficiency point

- GT2015-43389: Hah presents LES results of the 1-stage configuration

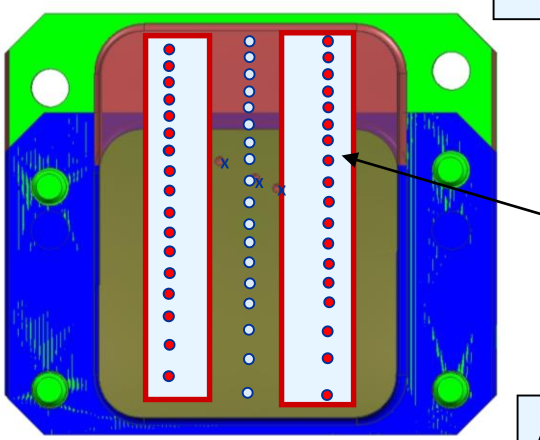
Backup Slides

Over Rotor Tip Pressure Blocks

Rotor 1



Rotor 2



Top case inside looking up