Gas Turbine Industrial Fellowship Program 2005

Survey of National Combustor Testing Facilities and Selection of AVC Testing Conditions

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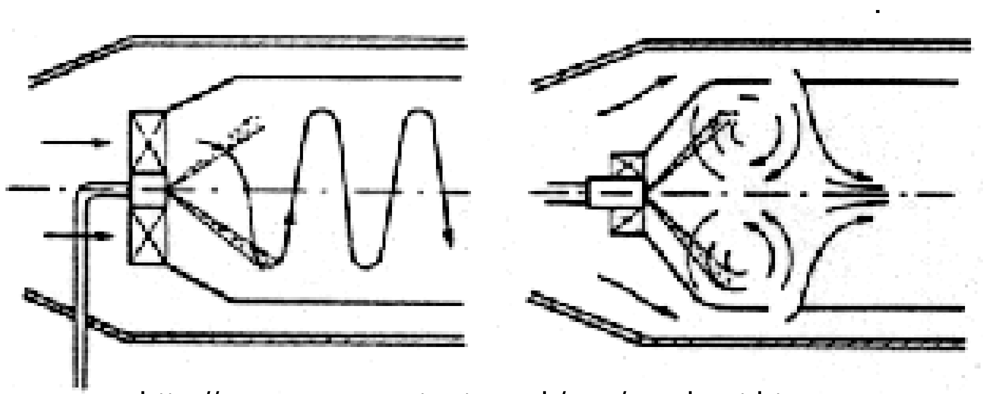
Premium gas turbine performance is critical in today's competitive power generation Market

Air quality standards for gas turbine emissions are becoming increasingly stringent

- Achieving single digit ppm NOx emissions is pushing the low limit of swirl stabilized combustion

The ever-rising cost of fuel demands maximum gas turbine efficiency

- Current combustion technology has reached an efficiency limit based on the required flow geometry



http://www.users.zetnet.co.uk/gas/combust.htm

Trapped Vortex technology provides significant advantages over traditional swirl stabilized combustion for land based gas turbines

The work presented supports continued development of Trapped Vortex Combustion technology

Trapped Vortex technology has demonstrated the capability of single digit ppm NOx and CO emissions

Trapped Vortex technology has also been shown to provide increased combustion efficiency over current methods

Recommendations requested for Advanced Vortex Combustor (AVC) testing conditions and a testing facility

- The Ramgen Combustion Team is evaluating the potential for AVC product insertion into a variety of industrial applications including:

  -*gas turbines*
  -chemical process heating
  -incineration
  -manufacturing
  -steam boilers

- Want to select AVC testing conditions similar to industrial gas turbine operating conditions allowing performance comparison

- Testing facility should be economical with capabilities greater than the recommended

Study of industrial gas turbine operating conditions to recommend AVC test conditions


Solar Turbines
A Caterpillar Company

MARS 100
Gas Turbine Mechanical-Drive Package

OIL & GAS

General Specifications

Mars® 100 Gas Turbine
- Industrial, Two-Shaft
- Axial Compressor
  - 15-Stage
  - Variable Inlet Guide Vanes and Stators
  - Compression Ratio: 17.4:1
  - Inlet Airflow: 41.3 kg/sec (91.0 lb/sec)
  - Max Speed: 11,168 rpm
  - Vertically Split Case
- Combustion Chamber
  - Annular-Type
  - Conventional or Lean-Premixed, Dry, Low Emission (*SoLoNOx*™)
  - 21 Fuel Injectors (Conventional)
  - 14 Fuel Injectors (*SoLoNOx*)
  - Torch Ignitor System
- Gas Producer Turbine
  - 2-Stage, Reaction
  - Max. Speed: 11,200 rpm
  - Thrust Bearing, Active: Tilting-Pad
  - Thrust Bearing, Inactive: Fixed Tapered Land
- Power Turbine
  - 2-Stage, Reaction
  - Max. Speed: 9500 rpm
  - Full Tilting-Pad Thrust Bearing
- Journal Bearings
  - Tilting-Pad
- Coatings
  - Compressor: Inorganic Aluminum
  - Turbine and Nozzle Blades: Platinum Aluminide
- Vibration Transducer Type
  - Proximity Probes
  - Velocity Pick-up

Key Package Features
- Driver Skid with Drip Pans
- 316L Stainless Steel Piping ≤4"
- Compression-Type Tube Fittings
- Digital Display Panel
- Electrical System Options
  - NEC, Class I, Group D, Div 1
  - ATEX, Zone 2
  - CENELEC, Zone 1
- *Turbotronic*® Microprocessor Control System
  - Onskid Control System (Div 2 or ATEX, Zone 2)
  - Freestanding Control Console
  - Color Video Display
  - Vibration Monitoring
- Control Options
  - 120-Vdc Battery Charger System
  - Gas Turbine and Package Temperature Monitoring
  - Serial Link Supervisory Interface
  - Turbine Performance Map
  - Compressor Performance Map
  - Historical Displays
  - Remote Monitoring and Diagnostic Option
  - Printer/Logger
  - Process Controls
  - Compressor Anti-Surge Control
  - Field Programming
- Start Systems
  - Pneumatic
  - Direct Drive AC
- Fuel System
  - Natural Gas
- Integrated Lube Oil System
  - Turbine-Driven Accessories
  - AC Motor-Driven Accessories
- Oil System Options
  - Oil Cooler
  - Oil Heater
  - Tank Vent Separator
  - Flame Trap
- Package Skid Design
  - Accommodates *Mars* and *Titan*™ Turbines
  - Optional Modifications for Floating Production Applications
  - Drop-In Lube Oil Tank
  - Modularized System Design
- Axial Compressor Cleaning Systems
  - On-Crank
  - On-Crank/On-Line
  - Portable Cleaning Tank
- Gearbox (if applicable)
  - Speed Increaser
  - Speed Decreaser
- Air Inlet and Exhaust System Options (Carbon or Stainless Steel)
- Enclosure and Associated Options
- Factory Testing of Turbine and Package
- Documentation
  - Drawings
  - Quality Control Data Book
  - Inspection and Test Plan
  - Test Reports
  - Operation and Maintenance Manuals

http://mysolar.cat.com/cda/files/126869/7/ds100md.pdf

Parameters of interest:
-compressor discharge temperature
-pressure ratio
-air mass flow per combustor can

Total of 23 engines evaluated including:
-Rolls Royce 501
-Kawasaki GPB-15D
-Solar Mars
-Siemens SGT Series
-Alstom family of engines

Most data gathered from manufacturer’s web sites: specifications and performance

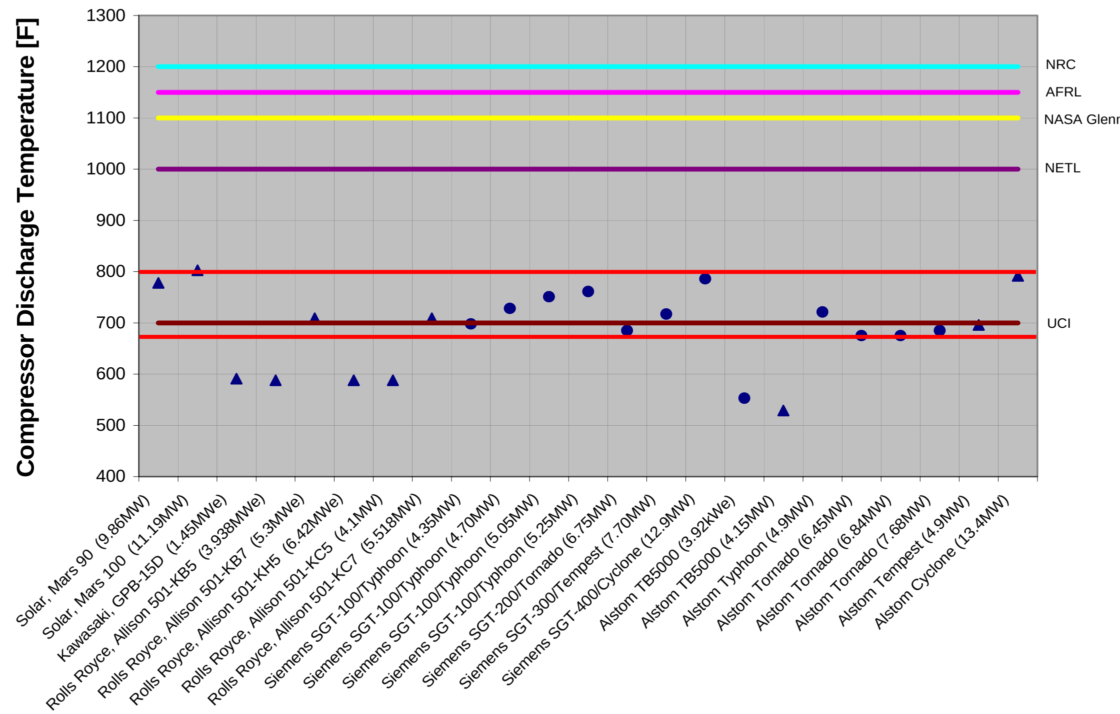
Extensive survey conducted of combustion testing facilities in Canada and the U.S.

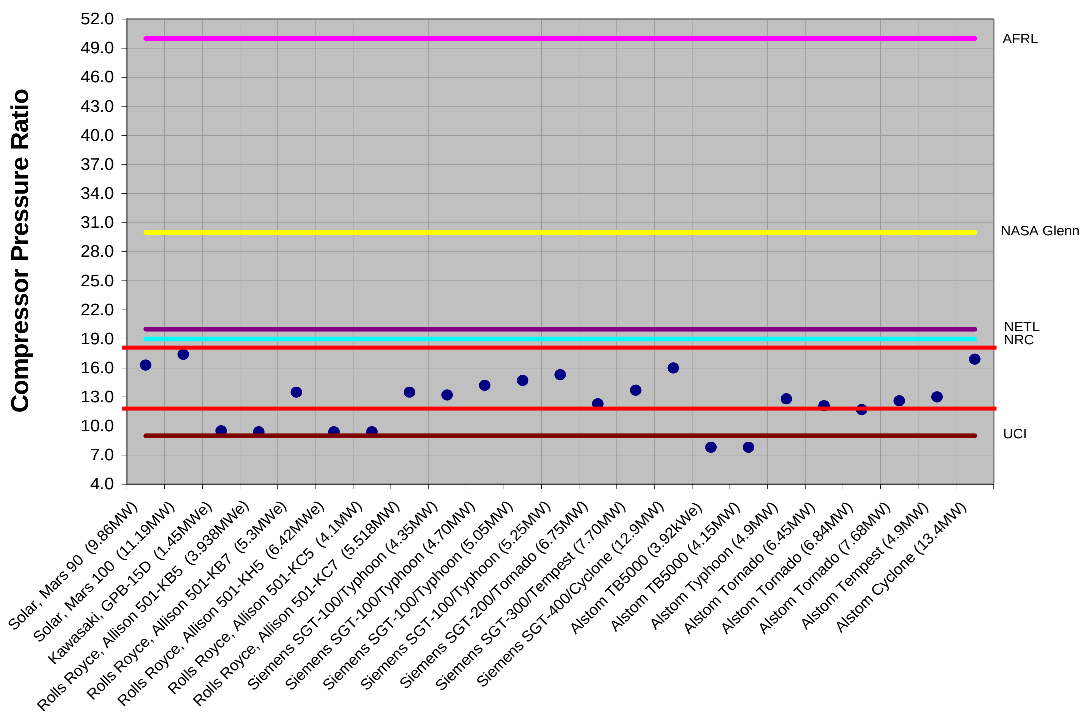
- Total of 36 facilities surveyed
- Facilities were asked to provide responses to the following set of basic questions

#	**Question**
1	What type of air supply/s do you have? What are their max flow rates and pressures?
2	What type of pre-heater/s do you have on that air supply/s, if any? Is the heater/s vitiated or non-vitiated? What is the max air temperature attainable and at what flow rate and pressure?
3	What type of natural gas supply do you have, if any? What is the max pressure and flow rate?
4	Do you have the equipment to measure NOx? CO? CO2? O2?
5	What is your facility's position on allowing outside groups to contract the use of your facility for testing?

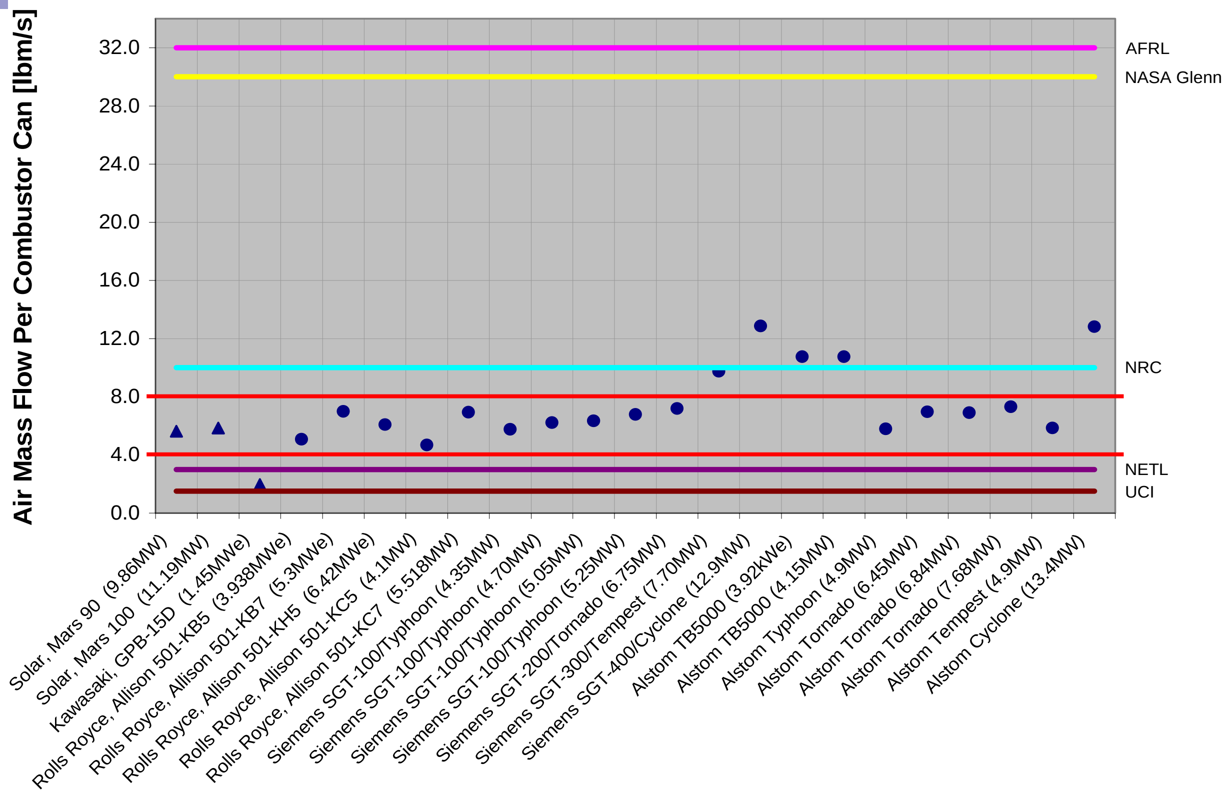
Parameters of interest are plotted to facilitate selection of AVC testing conditions

Industrial engine compressor discharge temperatures analyzed to recommend a range of 675-800°F





17 of 23 industrial engines operate within the recommended range of 12-18 atmospheres



Note: Triangle data points indicate mass flow per fuel injector for single can and annular engines.

The recommended range of testing air flows, 4pps to 8pps simulates 17 of 23 engines

Cost was evaluated to select the AFRL as the final facility recommendation

The top 3 facilities have competitive air supply systems so Rough Order of Magnitude (ROM) cost estimates were evaluated

-NASA Glenn ~$65,000 /week

-AFRL ~$20,000 /week

-NRC (not provided)

http://www.rl.af.mil/

In conclusion, an optimal AVC testing facility and testing conditions have been recommended to support development of Trapped Vortex technology

Testing facility:

AFRL, economic with above required performance

Testing Conditions:

Air supply pressure, 12 to 18 atmospheres

Air mass flow per combustor can, 4 to 8 pps

Air preheat temperature, 675 to 800°F

Many thanks to Rob Steele, Joe Williams, and Ryan Edmonds for their patience, flexibility and advice regarding my projects this summer.