IAGT Fall Course

2012

October 18 & 19, 2012
Delta Toronto Airport West

Fuel flexibility and its impact on gas turbines

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Fuel flexibility

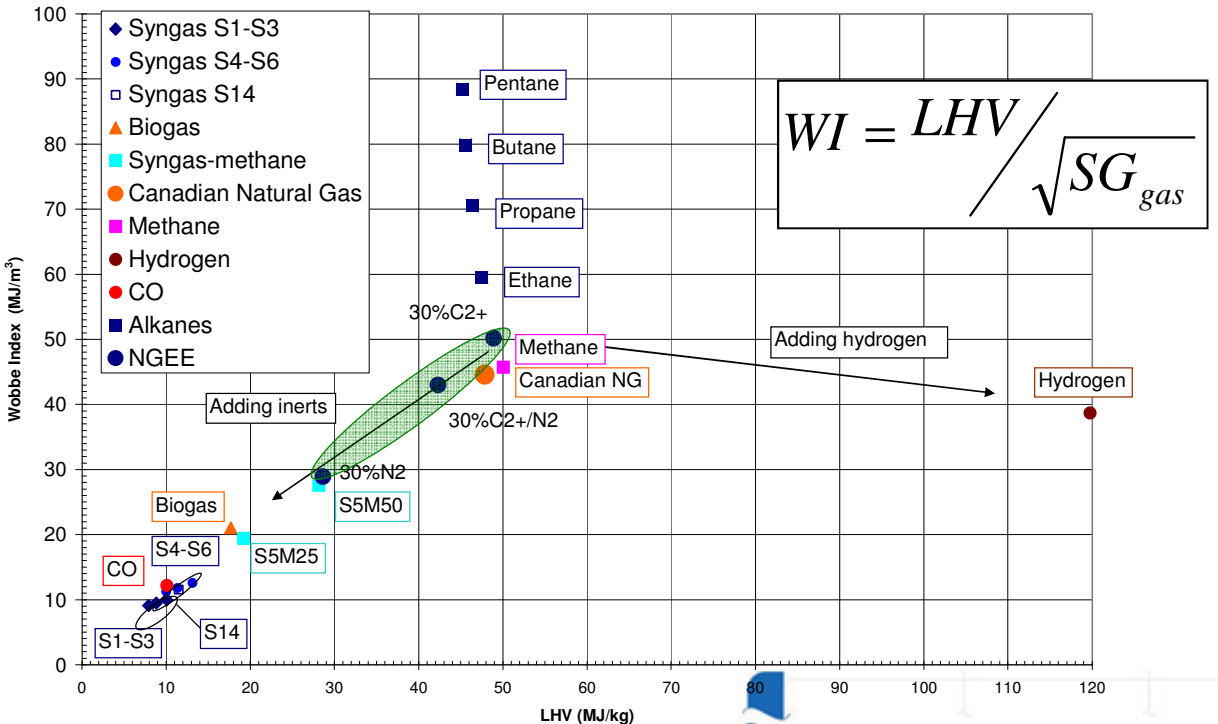
- Fuel flexibility means the ability to burn a wide range of fuels.

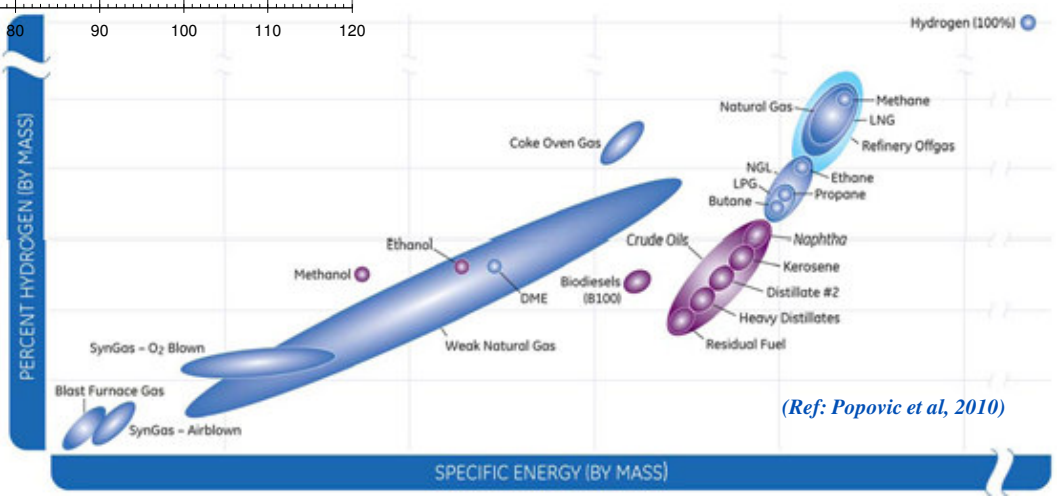
- The requirement for industrial gas turbine - burn anything!

- For Large Frame GT used in power generation the trend is toward
  - LNG + NG
  - Coal derived H2 and Syngas
- For Aeroderivatives GT, especially in Oil and Gas applications, the trend is toward process NG and associated gases.
  - Diversification of NG sources
  - Multiplication of LNG plants
  - Restrictions on flaring
- Obviously for the industrial GT the requirement is to burn anything available but at the same time not compromise on operational characteristics .

- OEMs have been developing the GTs to handle wide range of fuels.

Fuel Flexibility Trends





(Ref: Popovic et al, 2010)

Rolls Royce Combustion systems

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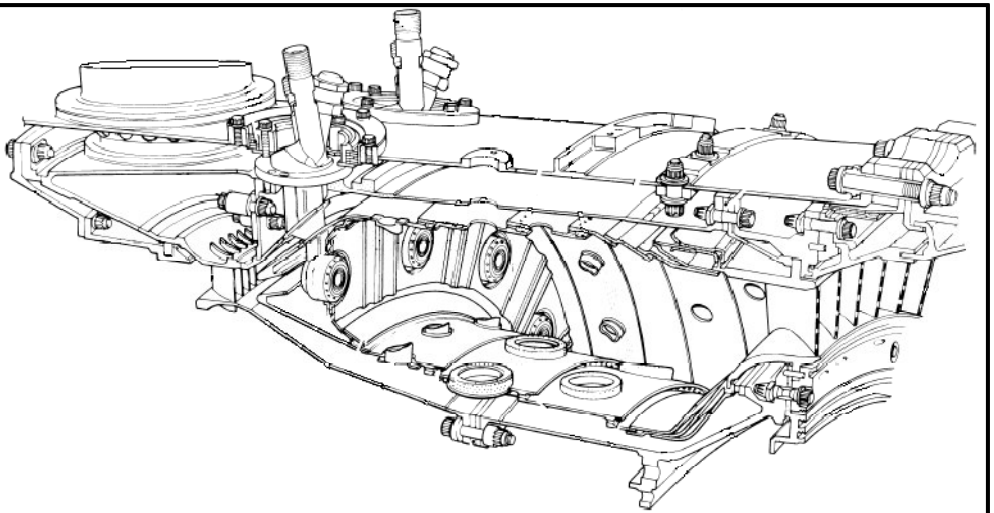
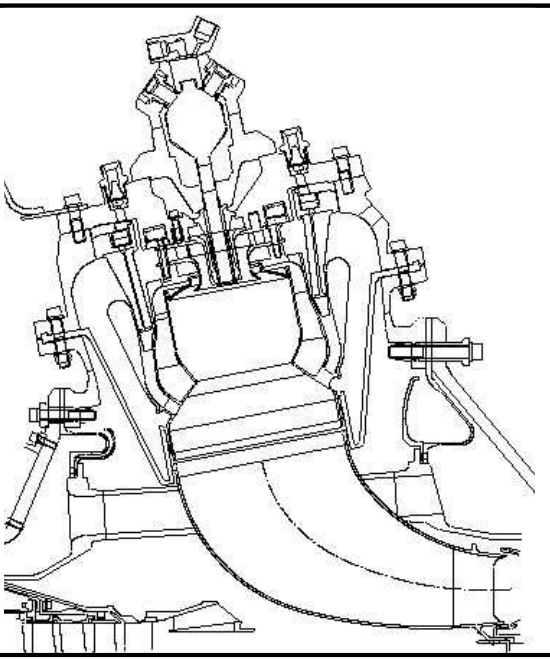
Conventional Combustor

- Single annular combustor
- 18 off fuel injectors
  - Dual fuel capable



DLE Combustor

- Individual combustors
- Serial fuel staging
- Simple control system with only 4 fuel control valves
- Diffusion circuit allows for reliable starting
- Primary and secondary enables individual zone temperature control for optimum emissions control.



Fuel Flexibility Challenge

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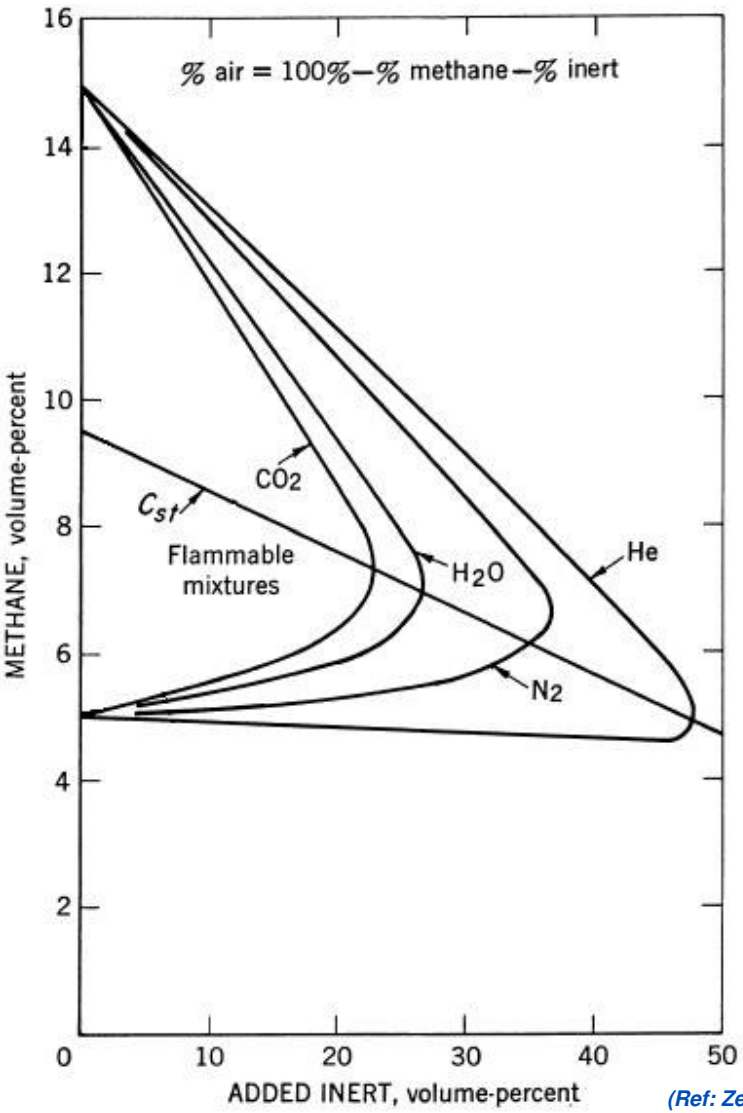
- The industrial GT the requirement is to burn anything available but at the same time not compromise on operational characteristics .

- How do non-standard fuels affect gas turbine operation?
  - Combustion
    - Operability
      - Reliable ignition and starting
      - General operability
      - Flashback and auto-ignition limits
      - Static and dynamic stability (spatial and temporal flame anchoring)
      - Multiple fuels
    - Emissions
  - Component durability
  - Fuel supply conditions
  - Turbo-machinery performance

Fuel Flexibility - ignition and starting

- Reliable ignition and starting requires the right fuel flow.
  - Dependant on gas fuel properties (LHV, density, flammability limits).
- Fuels having high C2+ and H_2 content will have bigger flammability ratios (UFL/LFL) – easier to ignite
- Fuels having high inert gas content will have narrower flammability ratios – more difficult to ignite and to keep lit.
- Control system adjustments will be required. Hardware changes may be required.



(Ref: Zebetakis 1965)

Flammability limits of Various CH4-inert gas-Air mixtures 25 C and atm. pressure

Fuel Flexibility - General Operability

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- Reliable operation requires that
  - proper margin to lower extinction limits be maintained.
  - proper margin to turbo-machinery operability limits be maintained.
  - This implies that right fuel flow for a given condition (dependant on LHV, density, flammability limits, …)
- C2+ and H_2 content will drop lower extinction limit – more margin to extinction.
- High inert gas content will raise lower extinction limits – less margin to extinction
- Control system changes will be required.
  - To maintain transient operability.
  - In DLE combustion system - to maintain emissions compliance and avoid combustion stability issues.
  - Special hardware / controls methodology will be required to handle variations in fuel LHV.

Fuel Flexibility - Flashback

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- Multiple flashback mechanisms:
  - Dependant on the aerodynamic flow structure and turbulence in the combustor.
  - Dependant on the combustion process.

- Strong dependence of laminar and turbulent flame speeds on fuel composition.

- H2 content will increase flame speed.

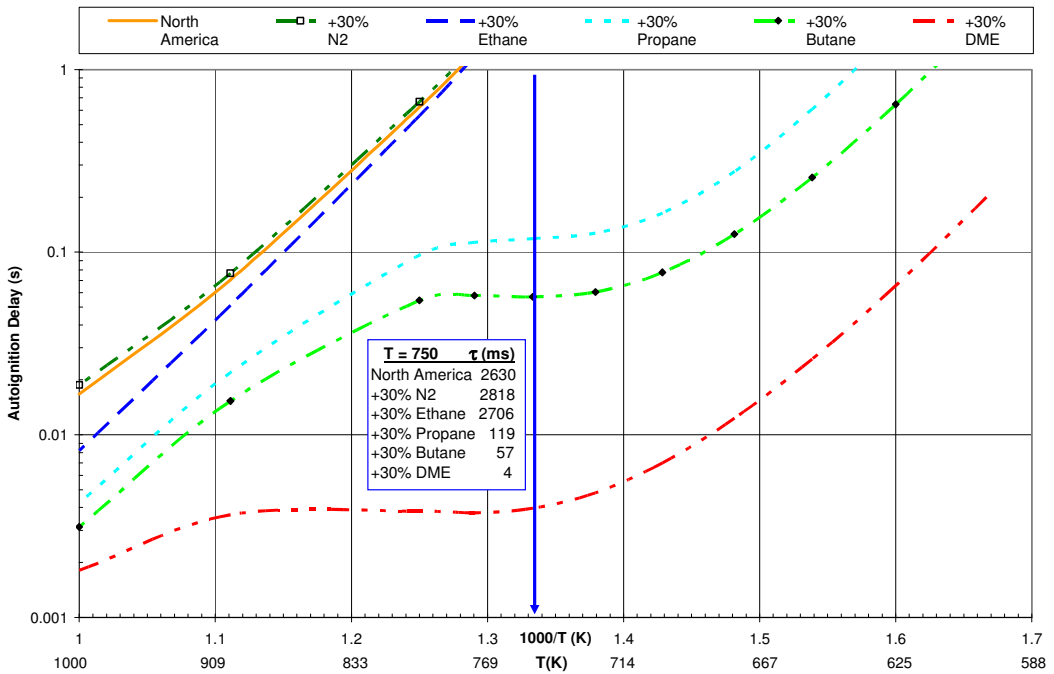
- Inert gas content will have little or no effect.

	LHV (MJ/m^3)	LHV (MJ/kg)	Flammability Limits (Vol. %)		Laminar Flame Speed (cm/s)
			Lean	U/L Ratio	
CH_4	36.447	50.048	5.00	3.00	44.8
C_2H_6	64.862	47.511	3.00	4.13	47.6
C_3H_8	92.836	46.330	2.10	4.52	46.4
C_4H_{10}	120.651	45.725	1.80	4.67	44.9
C_5H_{12}	148.586	45.343	1.40	5.57	43
C_6H_{14}	176.441	44.925	1.20	6.17	
CO	12.828	10.113	12.50	5.92	52
H_2	10.990	120.071	4.00	18.75	325

- Combustor design must be inherently robust.

Fuel flexibility – Auto-ignition

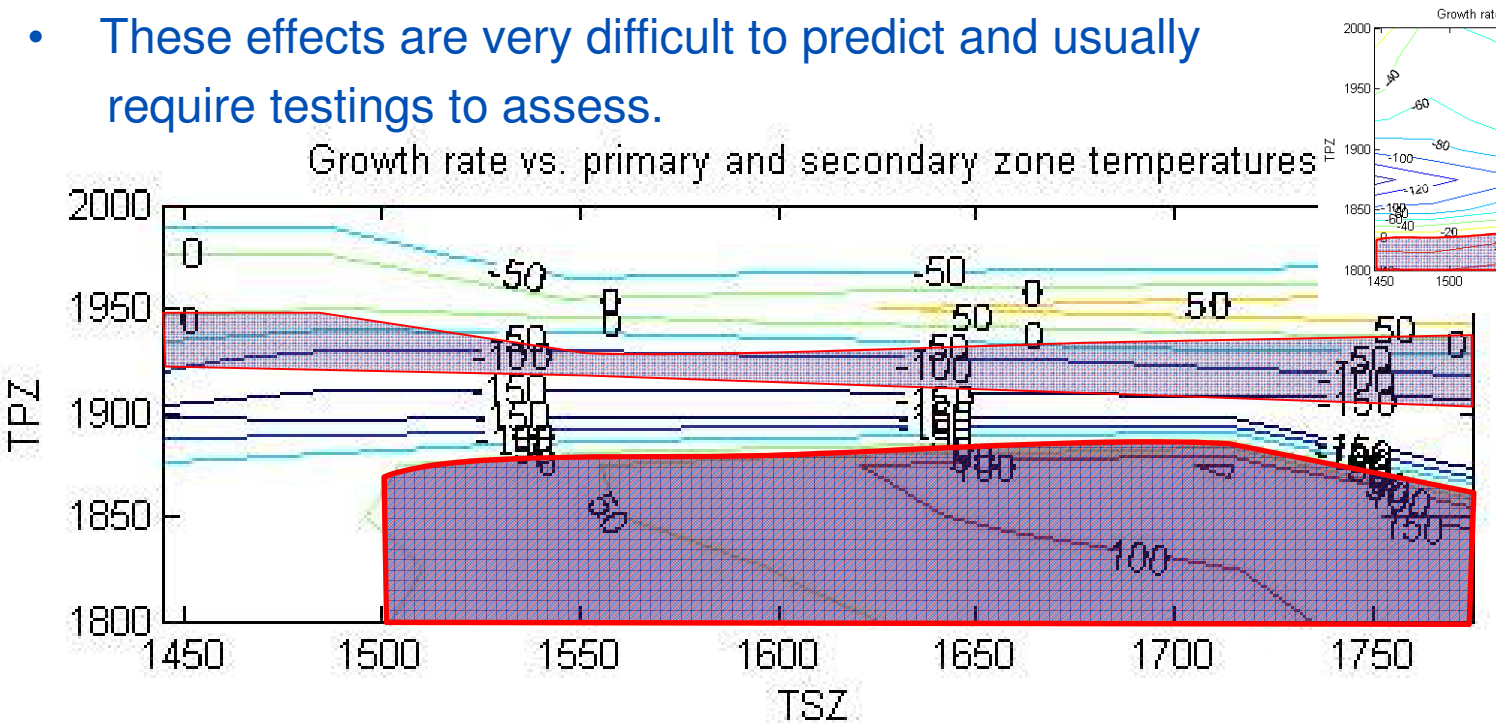
- Conditions at which auto-ignition will occur are dependant on fuel composition, temperature, pressure, AFR and residence time at temperature.

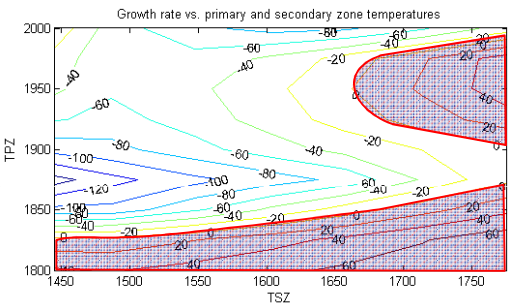


- C2+ and H2 content will increase the propensity of the gas fuel to auto-ignite.
- Auto-ignition delay is a consideration in High PR Gas Turbines, especially with DLE combustion systems, and where the auto-ignition delays become very short.
- Combustor design must be inherently robust.

Fuel flexibility - Combustion Stability

- Fuel composition influences
  - Flame shape
  - Flame standoff location
  - Pressure ratio across fuel injectors
- Alteration in flame shape and location can worsen or improve combustor dynamic stability.
- These effects are very difficult to predict and usually require testings to assess.





- Effect of Butane on combustion noise (80% NG + 20% Butane)

(Ref: Lieuwen 2008)

Fuel Flexibility - Exhaust Emissions

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- In conventional combustion system emissions are strongly dependant on composition.

- Fuels having high H_2 or C_2+ content
  - Increased NOx formation due to higher firing temperatures.
  - Reduced CO formation at part load
- Fuels having high inert content
  - Reduced NOx formation due to lower firing temperatures.
  - Increased concentration of CO and UHC in the exhaust gas.

- In DLE combustion systems the effect of fuel composition on NOx emissions is controlled via the fuel staging.

- Fuels having high H_2 or C_2+ content
  - Combustion temperature control via fuel staging.
  - Leaner combustion potentials that comes with increase in H2 or C2+ content can help reduce CO emissions at low power.

Fuel Flexibility - Hardware Durability

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- Increased fuel reactivity can causes thermal distress to premixer (DLE) and hot gas-path components due to:
  - Higher flame temperature.
  - Flame shape and flame stand-off position.
  - Flashback.
  - Auto-ignition.
  - Combustion dynamics.

- Reduced fuel reactivity cause thermal distress to hot gas-path components due to:
  - Flame shape and flame stand-off position.
  - Combustion dynamics.

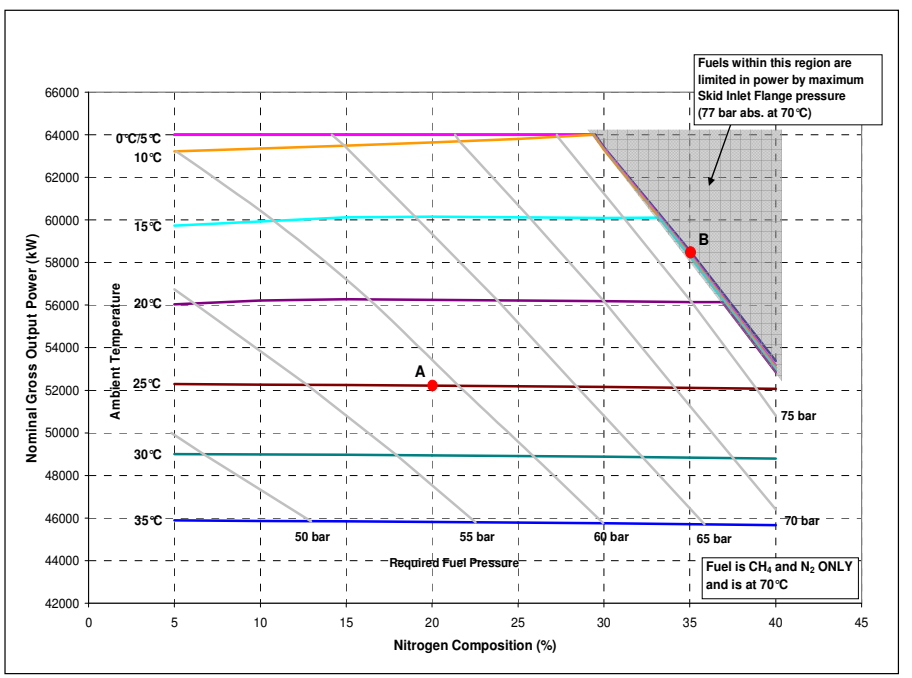
Fuel Flexibility – Fuel supply conditions

- Fuel composition has an impact on fuel supply temperature and pressure

- High C2+ content fuel will increase fuel supply temperature required to avoid condensation of heavier fractions in the fuel system and carry-over into the combustor.
  - Maximum allowable supply temperature is set by fuel skid hardware.

- High inert content fuel will increase required fuel supply pressure.
  - Maximum allowable supply pressure is set by fuel skid pressure rating.
  - Required supply pressure is determine mainly by flow capacity of FMVs and fuel injectors.

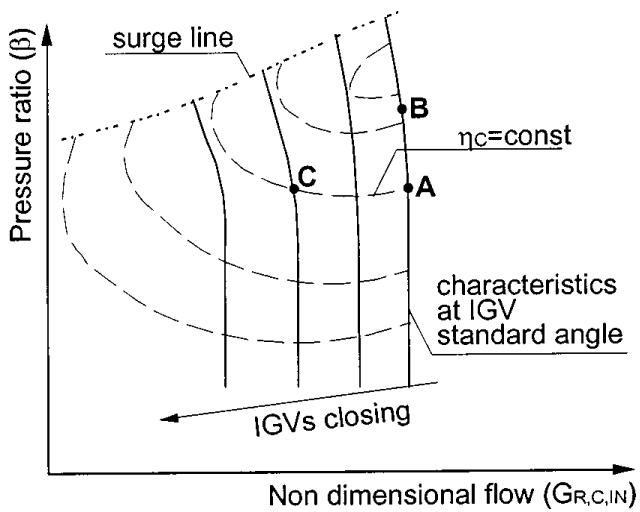
- Hardware changes may be required.
- Engine power may be limited by fuel supply pressure and hardware flow capacity.

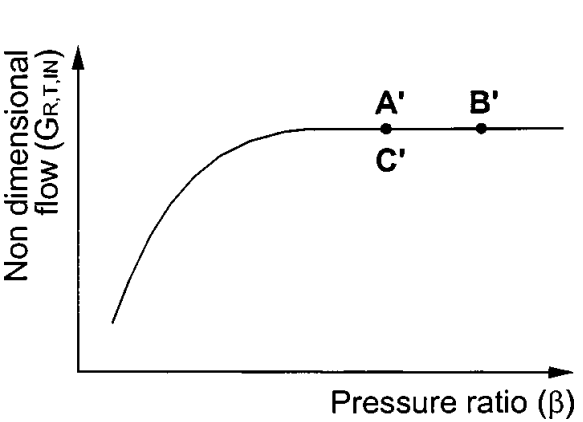


Fuel flexibility - Turbomachinery Performance

- Fuel composition will affect
  - Flow rate at turbine inlet.
  - Cp of the combustion products.

- High inert content gas will increase the power output at a reference condition
  - Increased mass flow through the turbine.
  - Increased pressure ratio through the compressor.
  - Compressors operate closer to the surge line





What are the impacts of “getting it wrong”?

- Gas turbines are tolerant to fuel composition changes

- Gas turbines are intolerant to poor “fuel quality”

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