• LM Product Lines
• Combustor Comparison – SAC vs DLE
• Fuel Flexibility
• Summary
LM Product Lines
Marine & Industrial aeroderivative gas turbine power

LMS100

LM6000

LM2500+

LM2500

LM1600

LM500

Southern Electric

Asgard FPSO

TransAlta Southdown

Fort Lupton

Queen Mary 2

Aeolos Kenteris

Coral Princess

Sleipner A Platform

Aghada Site TM2500s

U.S. Navy DDG 51

Oseberg 2 Platform

U.S. Navy FFG 7

Mols Linien

Dusty Lake Station

Stena

Foret LaZaida
Where do LMs come from?

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Engine Type</th>
<th>Power Output (MW/SHP)</th>
<th>Thermal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>B747, B767, MD-11, A310/330</td>
<td>CF6-80C2</td>
<td>23.3/31,200</td>
<td>38%</td>
</tr>
<tr>
<td>C-5, DC-10</td>
<td>TF39/CF6-6</td>
<td>14.3/19,200</td>
<td>37%</td>
</tr>
<tr>
<td>F/A-18, F-117</td>
<td>F404</td>
<td>34.0/46,000</td>
<td>39-41%</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

coming soon to a project near you...
Combustor Comparison
Challenging Requirements

Trying to Balance the Forces of Nature with Business and Regulatory Realities

Better!

Lower CO\textsubscript{2} Emissions Requires Higher Efficiency
Therefore Higher Firing Temperature and Pressure Ratio
Helps Lower CO Emissions

Same Reliability/Availability
Same Operability
Same Component Lives

Generating Higher NO\textsubscript{x}
### Flexible emissions reduction

<table>
<thead>
<tr>
<th>Control Technology</th>
<th>Water Injection</th>
<th>Steam Injection</th>
<th>Dry Low Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25ppm NOx (gas fuel)</td>
<td>25ppm NOx (gas fuel)</td>
<td>15ppm NOx (gas fuel)</td>
</tr>
<tr>
<td></td>
<td>42ppm NOx (liquid fuel)</td>
<td>+15ppm NOx (gas fuel)</td>
<td>25ppm NOx (gas fuel)</td>
</tr>
<tr>
<td></td>
<td>Single Annular Combustor</td>
<td>Triple Annular Combustor</td>
<td>Dual Fuel DLE</td>
</tr>
</tbody>
</table>
DLE vs. Standard Combustor

With dry low emissions combustor

- 30 PREMIXERS COMPRISING 75 STAGED INJECTORS
- 4 PASSAGE COMPRESSOR DIFFUSER

With standard combustor

- SINGLE COMPRESSOR DIFFUSER PASSAGE
- SINGLE ROW OF 30 FUEL NOZZLES
DLE Combustor Design

Premixers
Heat Shields
Combustor details

Alternating 2 cup and 3 cup premixers
Premixer design

- Axial counter rotating swirlers for efficiency mixing and low NOx
- High axial velocities
- Flashback resistance
- Prevents Auto-ignition
## LM DLE Experience – 330 Engines

<table>
<thead>
<tr>
<th>Model</th>
<th>Type</th>
<th>Cumulative Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM6000PD</td>
<td>Gas Fuel</td>
<td>~2,400,000</td>
</tr>
<tr>
<td>LM2500+</td>
<td>Gas Fuel</td>
<td>~2,000,000</td>
</tr>
<tr>
<td>LM2500</td>
<td>Gas Fuel</td>
<td>~2,500,000</td>
</tr>
<tr>
<td>LM1600</td>
<td>Gas Fuel</td>
<td>~170,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>&gt;7,000,000</td>
</tr>
</tbody>
</table>
LM DLE Applications:

- Independent Power Producer
- Utility
- Floating Production Vessels
- Platform
- District Heating
- Pipeline

• Experience in extreme temperature environments
  ✓ North Slopes Alaska...-50 F
  ✓ Sahara Desert... > 100 F
Fuel Flexibility
Fuel Properties – SAC Combustors

- Can accommodate wide band of Wobbe numbers
- No special instrumentation required
- Extreme Wobbe number ranges will need to be evaluated for proper fuel system sizing
- Current capability exceeds proposed interim guidelines
Fuel Properties – DLE Combustors

> Multiple LM DLE applications have gas properties vary:
  
  - O&G upstream applications...changing gas wells
  
  - O&G midstream applications...blending gas supplies
  
  - Power Generations applications...gas supply varies due to market pricing
Fuel Properties – DLE Combustors

- Typical Wobbe Number range is 40 to 60

- On-site gas analysis equipment is supplied for most installations where gas properties are expected to vary

- Gas calorimeter or chromatographs are typically used

- Calorimeters – faster, not as accurate, and sensitive to disturbances.

- Gas chromatographs – Slower, more accurate, updates are in the range of once every 90 to 180 seconds –
  - New technology is being developed to greatly reduce the response speed
Fuel Property Accommodation

- Annular combustion System...one set of instrumentation
- Adaptive flame temperature control designed to accommodate transient shifts in operation

Example: Rapid change in actual fuel properties where the sensed lower heating value (LHV) lags the true LHV

- Step change in LHV
- Ramp change in LHV
Summary
Summary of LM Fuel Flexibility

Annular combustor allows for single integrated instrumentation and control system

LM DLE system has demonstrated the ability to handle significant variation in fuel properties
  > Over 12% Wobbe number change
  > Using gas analysis as control inputs
  > Maintains low emissions with fuel property changes
  > Adaptive logic increases capability for fuel variations

LM products currently operate with proposed interim guidelines:
  > 4% Wobbe variation
  > 1.5% max Butane +, 4% max inert