Joints - Rolls-Royce Perspective

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Joints in Gas Turbine

Compressor
- Rotor dovetails
- Stator shrouds

Engine Structure
- Flanges / spigots
- Splines
- V-blade

Fan
- dovetail
- snubbers

Turbine Blades
- Dampers / seals
- Firtree
- Shroud
- Lockplate / cover plates

Key
Damping
Stiffness / frequency
Stress
Whole Engine Issues

- Whole engine uses a simplified model.
  - Need simplified representation of joints.
- Static loads (thrust / external loads / manoeuvres)
  - Are stiffness effects adequate for tip clearances and load distribution etc?
- Dynamic Loads
  - Engine/Wing Dynamics (0-10 Hz)
    - Frequency, damping, loads
  - Engine Rotordynamics (30-500 Hz)
    - Frequency, damping, loads
  - Extreme events (eg Fan Blade Off)

Example Joint (and simplification)
Damping

- Drive towards prediction of vibration amplitude for design and certification.

Structure (known)

Force (usually known)

Damping (aero & mechanical) (non-linear) (measured ?)

Response

Wear / deterioration / contamination

HCF capability
Effect of Non-linear Contact on Frequency

- Dampers can have a significant influence on resonant frequency.
  - Affect on resonant speed
  - Change in force amplitude

Campbell Diagram of HP Turbine

- With Damper
- Without Damper

Upstream vanes
Downstream vanes
No. of Burners
Low engine order

Gas Turbine
High Pressure Turbine Stage

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Effect of Joint on Modeshape => Stress

Contours of WP Stress
At 2F resonance

Typical position of strain gauges in engine tests.

<table>
<thead>
<tr>
<th>Gauge Position</th>
<th>Gauge Sensitivity [Mpa/mm]</th>
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<tr>
<td></td>
<td>1T Mode</td>
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<tr>
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Effect of Shroud Contact on Stator Response

- Uncertainty about inner shroud restraint => variability in effective stiffness
- Change of stiffness leads to change in amplitude and frequency.
- Difficulty interpreting measured results
Effect of Shroud Contact on Stator Modes

- It gets more complicated ...
Structural Integrity Assessment of Fan Dovetail Joints

• Assessment capabilities enhanced significantly in recent years
  ➢ Steady and vibration stress predictions
    ➢ Based on load extraction from ‘coarse’ FE model and analytical half-space model.
    ➢ Converged stresses using detailed FE sub-sub modelling.
  ➢ Robustness determined using short crack modelling techniques.
  ➢ Integrity of root managed via use of surface coatings and treatments.
  ➢ More careful design possible.
Outstanding Issues?

- Varying (patchy) friction, local wear, effect of local fillet, half-space assumptions.
- Longer lasting surface coatings have clear cost benefits.
- EoB and near edge of bedding locations can be life limiting features.
- Prediction of stresses near edge of bedding in vibration is problematic.

➤ Use of locked contact can be misleading

ABAQUS friction analysis shows separation of fillet and EoB stress. Region close to EoB is now showing a much reduced stress.
Summary of Needs

- **Damping**
  - Stability & Amplitude prediction (including non-linear effects)
  - Friction Properties
  - Validation of System Behaviour
  - Interpretation of measured results (in engine)
  - Rotor dynamics for stability

- **Frequency**
  - Effect of blade dampers is already under control
  - Snubbers / Interlocks (mainly for fleet support)
  - Whole engine at high frequencies – accessories

- **Stress**
  - Edge of bedding stress including steady stress and vibration.
  - Surface treatments, coatings
  - Wear