**Introduction & Context**

At the dawn of Industry 4.0, AIRBUS must rethink and renew its processes and way of working to achieve a durable transition. Even something as basic as structural assembly can be upgraded for better agility and manufacturing efficiency. The “Hole to Hole” bolting assembly process introduced by BLOEM [1] is potentially a great opportunity to revolutionize assembly lines. However, it represents a leap for mechanical fastening technology. The aim of the study presented is to evaluate the feasibility and the effect of “Hole to Hole” on the mechanical behaviour and strength of bolted joints under static and fatigue loading.

### Clearance & Misalignments Results:

**Global static behavior:**
- **Phase 2**: Linear friction transfer;
- **Phase 3**: Linear bearing transfer;
- **Phase 4**: Non-linear bearing transfer;
- **Phase 5**: Failure.

**Static Failure Mode:**
- t/Ø < 0.5: simultaneous bolt shearing;

**Fatigue Failure Mode:**
- Initiation location depends on bolt technology, preload & misalignment configuration;
- For high & medium preload initiation location is outside the hole.

**Conclusion:**
- Fatigue: Effect of both clearance and misalignment;
- Static: No impact of clearance, strong impact of misalignment.

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**Specimens & test procedures:**

**Test definition:**
- Single lap shear
- Two titanium bolts
- 1/8x4w specimen material

**Test method:**
- Static: Axial loading until failure, imposed displacement
- Fatigue: Loading Ratio R=0.1, Test frequency: 5Hz

**Test parameters:**
- 5 clearance & misalignments configurations, the misalignment value $m$ is positive for early contact and negative for late contact
- Fastener diameter Ø: [6.35; 12.7] mm
- Thickness ratio t/Ø: [0.25; 0.5; 1]
- Preload level [3.5; 50; 65]% of faster Ultimate Tensile Strength

**Testing data**

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Load (kN)</th>
<th>Displacement (mm)</th>
<th>Fatigue Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>0.5</td>
<td>0.3</td>
<td>Adherent shear</td>
</tr>
<tr>
<td>Phase 2</td>
<td>1.0</td>
<td>0.5</td>
<td>Adherent shear</td>
</tr>
<tr>
<td>Phase 3</td>
<td>1.5</td>
<td>0.7</td>
<td>Adherent shear</td>
</tr>
</tbody>
</table>

**Effect of preload on behavior, strength and fatigue:**

- Low (35%UTS) vs. High (65%UTS)
- Static: Effect of preload on slipping phase;
- No impact on fatigue strength.

**Effect of thickness ratio t/Ø on static strength:**

- 0.25 vs. 0.5
  - For t/Ø = 0.25: strong plate deformations during phase 4 induce large displacement;
  - Failure mode impacted by thickness ratio t/Ø [4];
  - For t/Ø = 0.5: Only 5% decrease of performance in case of clearance & misalignment (A5 & F5).

**Effect of fastener diameter Ø on behavior & static strength:**

- Ø = 12.7mm
- No impact of bolt diameter on behavior of configurations A0 & A5 under loading;
- For F5 configuration: failure of 1st bolt occurs after contact of 2nd bolt;
- However, the failure mode remains non-simultaneous bolt shearing;
- The static strength decrease between F5 & A5 is about 18% so much lower than the 30% decrease for a diameter of 6.35mm.

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**Bibliography:**


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**Conclusions & Perspectives:**

This study has confirmed that “Hole to Hole” assembly leads to lower static and fatigue performances. However, this impact may be controlled by a wise choice of assembly parameters, such as bolt diameter and bolt preload. This experimental campaign has enabled the construction of a large data base. In the framework of industry 4.0, this data base provides a great opportunity to develop a numerical model for the simulation of different assembly designs. To go further, this numerical design tool based on data computing with a probabilistic approach could even take the manufacturing process events into account from material elaboration to fastener tightening.

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**Figure captions:**

1. Specimens & test procedures
2. Test parameters
3. Effect of preload on behavior, strength and fatigue: Low (35%UTS) vs. High (65%UTS)
4. Effect of thickness ratio t/Ø on static strength: 0.25 vs. 0.5
5. Effect of fastener diameter Ø on behavior & static strength: Ø = 12.7mm
6. Conclusions & Perspectives
7. Bibliography