ALENIA EXPERIENCE
IN METAL BONDING

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ATR 72 METAL BONDED STRUCTURES
The ATR Family: Unmatched Versatility

- Passenger version
- Rough field version
- Corporate version
- Large Cargo Door
- Maritime Patrol version
ATR Family

ATR 42
46-50 seats

The only true family in the 40-70 seats turboprop market segment

ATR 72
64-74 seats
Metal-to-Metal Bonding vs Mechanical Fastening in ATR A/C’s

• More durable structure
  • No fastener hole acting as cracking sources
  • Better behaviour in case of accidentally damaged skins
• More efficient manufacturing sequence
• Aerodynamic improvement
• Appearance improvement
Design Concepts

• Application limited to
  • Section 13 Upper side panels
  • Section 13/15 Crown panels

• Metal bonding to skins of
  • Stringers, doublers, straps

• Reduced numbers of skin-stringer configurations

• No joggle provided for stringers to be bonded
  • Extra layers of adhesive films at stepover

• No bonding under the floor

• Installation of fasteners through the bondline quite limited
  • Wet installation where necessary to
M-M Bonding in ATR 72 vs ATR 42
CROWN PANEL SECT. 13

CROWN PANELS AFT & FWD SECT 15
View of Clip, Bonded Stringer & Frame - Typical
Materials

Adherends

• Skin, Straps and Doublers - Clad 2024-T3 Aluminium Alloy per QQ-A-250/5
• Stringers - Bare 7075-T62 Aluminium Alloy per QQ-A-250/12

Adhesive film

• AF163-3M Grade5/Grade10 per NTA 65252
  • Grade 5 used for doubler, strap bonding
  • Grade 10 used for stringer bonding
• Superior properties to other systems
  • Resistance to ageing
  • Mechanical strength
  • Good behaviour during processing

Primer

• Corrosion Inhibiting Adhesive Primer
  • BR127 or EC3960 per NTA 65253
The Alenia Experience

Processes

• Adherends surface preparation
  • Phosphoric Anodization per NTA 72267

• Primer Application
  • Spray coating
  • Air Dry
  • Oven Cure at 121°C per 90 minutes
  • Baked film thickness: 3 – 10 µm

• Bond Assy
  • Vacuum Bagging and Autoclave curing
    • Cure Temperature: 121°C per 90 minutes
    • Cure pressure: 3.2 daN/cm²
## Manufacturing Flow sequence

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<td>Adhesive cut for straps &amp; doublers</td>
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<td>Phosphoric Anodization</td>
<td>Omega tool positioning</td>
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<td>Stringer positioning</td>
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<tr>
<td>Primer application and curing</td>
<td>Adhesive laying</td>
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<td></td>
<td>Extra adhesive laying in joggled areas</td>
<td></td>
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<tr>
<td></td>
<td>Vacuum bag preparation</td>
<td></td>
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<tr>
<td></td>
<td>Autoclave curing</td>
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</table>
PHASE A-

• All metallic components are checked to ensure a satisfactory fit up during bonding assembly.

• The tolerances are defined in terms of max lateral and longitudinal deflections

• Max web-to-flange angle and twist angle are controlled for stringers
STRINGER QUALITY REQUIREMENTS

The in house rolled stringers must have the following acceptance limits when measured tapered to a flat surface:

- **Lateral Inflexion**
  \[ \frac{\epsilon}{t} \leq \frac{1}{250} \]
  \[ \delta_{ax} \leq 0.8 \]

- **Longitudinal Inflexion**
  \[ \frac{y}{z} \leq \frac{1}{500} \]
  \[ \delta_{ax} \leq 0.8 \]

- **Flange Angles**
  \[ \beta = 90^\circ \pm \delta \]

- **Flange Flatness**
  \[ X \]
  \[ Y \]
  \[ \neq \text{Acceptable} \]

All wrinkles or joggling of the flange is allowed if greater than .005 in depth.
PHASE B-

- Omega shaped tools used as stringer positioners
  - Improved dimensional quality due to their acting as pressure distributor

- Joggles (Stringers/Straps & Stringer/Doubler)
  - 2 extra adhesive film layers applied over .35 mm
  - 3 extra adhesive film layers applied between .35 and .60 mm
PHASE C

• The bonded panel is visually inspected

• The presence of properly adhesive squeeze out all along the bonded edges is of primary significance for the bonding goodness and acceptance.

• The adhesive fillet ensures edge sealing. Only excess fillet is removed

• After visual checks, all bondlines are inspected by a Fokker bondtester-ultrasonic resonance technique.
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Bond Assy and BAJ (Curing Tool)

View of Bonded stringers
Structural Analysis Approach

• Post-buckling design of bonded stringer reinforced skins

• Design provisions to improve the assy strength
  – Stringer stopped on doublers, at highest thickness
  – Adequate run out shape at stringer end

• Adhesive must have the capability to:
  – Transfer shear loads from skin to stringer, avoiding peeling stress
  – Withstand the pulling load originated by diagonal tension field at buckling
Durability

• All the fatigue critical details in ATR 72 have been verified
  • Hardpoints
  • Stringer–to-frame attachments
  • Stringer runouts
Hardpoints

• Fatigue tests have been carried on hardpoint specimen.
• Typical “hardpoint” (bonded flange for hoop stress) have 0.8 – 1.27 mm strap.
• The strap thickness seems almost not influencing the fatigue strength up to 100000 cycle life.
• The failure origin occurred regularly at the strap edge that act as stress concentration points.
• A comparison with tests on similar riveted details evidenced comparable results, despite the presence of a secondary bending in bonded details.
Stringer runouts

• Different geometries have been considered for the stringer end bevel.

• Fatigue tests have been carried out at constant mean stress $S_m = 50$ MPa, this one referred to the total stiffened panel area (stringer + skin).

• A secondary bending factor has been evaluated, but increasing stiffness of skin/end stringer ratio results in stress concentration as well as in secondary bending decrease.
Stringer-to-frame attachments

• “Pull Up” detail – Test performed with a 50 daN load corresponding to the pressure induced load on shear clip at 5 PSI for the larger stringer spacing.

• All the tests have been continued until to 300000 cycles, without any failure in the adhesive.

• A fatigue test performed on a bonded fuselage barrel proven the capability of this bonded detail to sustain pressure loads by not less than 200000 cycles.
Corrosion

• Corrosion behaviour evaluated through exposure of metal bonded parts in salt solution
• Mechanical properties decay verified on standards “Lap Joints“ specimens
• The same materials and processes of ATR 72 used for specimens manufacturing.
• Each specimen exposed in salt solution per ASTM B-117 for 1000 Hours.
• “Cohesive” type of failure found on bonded surfaces. Absence of degradation and corrosion of bonded surfaces.
• Fatigue tests performed aft environmental conditioning. The tests performed at “pull up” after exposure at 100% R.U. and 55°C for 42 days, under cyclic “pressure equivalent load“ (50 daN)
• No evidence of problems in bondlines. after 242.000 cycles when testing was stopped
Service Experience

• Near 11,900,000 Flight Hours cumulated by the whole fleet
• 1,370,000 F Number of Flights cumulated by the whole fleet
• No major inconvenience reported for bonded structures
• No corrosion problem ever reported
• No repair embodied during the whole service
DEVELOPMENTAL ACTIVITIES
ON METAL BONDED STRUCTURES
TANGO Metallic Fuselage ALA deliverables

Technology Application to the Near-Term Business Goals and Objectives:

- 2 Fault Technology Panels
- 2 Bonded Panels

- 1 Keel Sx Welded Panel
- 1 Keel Dx Welded Panel

TANGO BARREL
Length Mt 8.5 Dia Mt 6

DASA Panel
SAAB Panel
Alenia Panel
Series Panel
Multi-layer Concept

• Structural configuration based on a basic thickness with additional doublers added where needed

• Substitute chem-milling operation for thickness variation in the skin

• Improvement of damage tolerance behaviour

• Accomplishment of significant weight saving
Multi-layer Metal bonding Technology

- Materials and processes selection
- Multi-layer adhesive bonded flat Panel
- Flat panels with co-bonded window frames
- Metal to Metal Bonding Full scale TANGO panels
Testing objectives

• To acquire more knowledge about static, fatigue and damage tolerance behaviour of fuselage panels manufactured using Alenia Metal Bonding technologies

• To verify methods used for the analysis

• To substantiate the capability of Alenia full-scale panels to sustain static and fatigue loads according to Tango Barrel F.E. model results
Activities performed

A representative multi-layer adhesive bonded flat panel, with circumferential splices of 0.3 mm Al lamina, was designed and manufactured.

Panel was inspected with ultrasonic control.

A destructive inspection was performed in order to characterize natural defect and establish a correspondence with ultrasonic map.

Specimens were manufactured with coupons cut from the flat panel.
Testing on specimens

- Tensile
- Compression
- Bearing (e/D=1.5 and e/D=2.0)
- Impact
- Fatigue
- Crack Growth
Achievements

• Material selection (aluminium alloy, adhesive, primer)

• Configurations definition (minimum/maximum thickness)

• Bonding requirements definition within an ALA internal specification

• Process parameters optimisation (surface treating, autoclave pressure, temperature profile, etc.)

• Testing of specimens and details for material basic properties data base implementation
### Metal Bonded Subcomponents

<table>
<thead>
<tr>
<th>ID</th>
<th>Test Type</th>
<th>Loading</th>
<th>T.A. Configuration</th>
<th>T.A. Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB #1</td>
<td>Static</td>
<td>Shear</td>
<td>Flat skin panel with a machined window frame</td>
<td>600mm x 800mm</td>
</tr>
<tr>
<td>MB #2</td>
<td>Fatigue</td>
<td>Shear</td>
<td>Flat skin panel with a machined window frame</td>
<td>600mm x 800mm</td>
</tr>
<tr>
<td>MB #3</td>
<td>Static</td>
<td>Hoop Tension</td>
<td>Flat skin panel with a machined window frame</td>
<td>600mm x 800mm</td>
</tr>
<tr>
<td>MB #4</td>
<td>Fatigue</td>
<td>Hoop Tension</td>
<td>Flat skin panel with a machined window frame</td>
<td>600mm x 800mm</td>
</tr>
</tbody>
</table>
MB #1
test article
instrumentation

Outside view

Inside view
MB #1
Set-Up
Metal Bonded Subcomponents Test Results

- Very good static (loading failure higher than 180% of Limit Loads) and fatigue behaviour (no failure up to 100,000 cycles) of the bonded panel (window frame bonded to a metal to metal bonded multi-layers skin) under hoop tension and shear loading (separately)
METAL BONDED
FULL SCALE PANELS
TANGO TX 9 / TX 10 PANELS

- **Technology:** Metal to Metal Bonding (one shot bonding)

- **Skin**
  - Basic: 2524-T3 Al Alloy t=1.8mm
  - Reinforcement: 2024-T3 Al Alloy t=0.3/0.4mm

- **Max Skin Thk:** 2.8mm

- **Stringers:** 2024-T3 Al Alloy (Series)

- **Window Frame:** 7050-T7451 Al Alloy Prec. Forg. (Series)

- **Stringers, Doublers and Window Frames bonded to Skin in one shot.**
TX 9 PANEL

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TX 9 / TX 10 PANELS DESIGN DETAIL

Multi-layers skin and bonded window frame
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METAL TO METAL MFG FLOW

ALUMINIUM SHEET PREPARATION

LAYERS LAY-UP (METAL SHEET &

ASSY SKIN/STRINGER/WINDOW FRAME

BAGGING

ONE SHOT AUTOCLAVE CYCLE FOR SKIN CURING AND STRINGER / WINDOW FRAME BONDING
1. FLAT PANEL METAL TO METAL BONDING DEMONSTRATOR
(1200 X 3000 mm)

= 2024 -T3 /THICKNESS 0,3 mm

= 1 ADHESIVE /THICKNESS 0.1 mm

= 2024 -T3 /THICKNESS 1,6 mm
2. SINGLE STEP BONDED STRINGER & SHEAR TIES FLAT PANEL
DEMONSTRATOR
1700 X 1000 mm
Multilayer Adhesive Bonded Skin and Window Frame - One Step-cure cycle

Micrographic cross section of bonded window frame
METAL TO METAL BONDING
MULTILAYER TECHNOLOGY

FULL-SCALE PANELS
TX 9 PANEL
TX 10 PANEL

Skin: Multilayer Adhesive Bonded (2524 & 2024 Al sheets)
Co-Bonded Window Frame
Bonded Stringer (extruded 2024)
TANGO Metallic Fuselage - Barrel assy