C-130
22/12/1969:
Wing rupture during training flight. Both pilots KIA with no chance for ejecting.
Cause: Crack at the steel wing pivot fitting of F-111
Microphotograph of Crack Area.
Flaw was not revealed during production NDT due to neighboring vertical elements masking the area.

Figure 1.1.1. Origin of the F-111 Wing Defect [Rudd, et al., 1979]
Application of Boron Patches to carry structural loads, “deviating” the flaw area, in order to significantly reduce $K$.

$$\frac{da}{dn} = C(\Delta K)^m,$$
Repair of an ATR-72 aluminium floor beam using a bonded carbon patch, performed in situ by GMI Aero, in cooperation with the ATR company.
Strain a: Next to the crack tip
Strain b: 10mm away from the crack tip
“Life will find a way”
- Michael Crichton, Jurassic Park

“Bonded Composite Repair will find a way”
- Bremen E-LASS 29/1/2020
Bonded Composite Repair Methodologies – Latest Advancements and Developments

George Kanterakis
Sarah Baglione

Services: Engineering solutions at customer’s requests

Research: for internal development & in Collaborative Projects with European Constructors and Universities

Consultancy & Training Worldwide: at GMI’s premises or at customer’s facility

>30 years of experience
GMI Aero: The Company...

- More than **30 years experience**

- Team composed of **20 Engineers and Technicians**

- Departments of **R&I, Production, Design & Engineering** managed by **Researchers and Engineers** of long experience and in depth knowledge of all mechanical, sensors, and other physical aspects of this specialized science.

- **Represented in the world** through agents duly trained (Asia, Central & South America, Middle East, Europe).

- **Several agreements** of equipment through Airbus, ATR, Dassault, Bombardier, Boeing etc.

- **Qualified ISO 9001:2015**
Who are our customers?

Aircraft manufacturers, MRO Centers, OEMs, Airlines, Universities
MoUs and Partnerships

✓ ADAMANT Composites, Greece
✓ Fraunhofer IFAM, Germany
✓ Hellenic Aerospace Industry, Greece
✓ Institute of Aviation, Poland
✓ IPSA, France
✓ Jordan University of Science and Technology, Jordan
✓ Malaysian Institute of Aerospace Technology, Malaysia
✓ Nat.Inst. for Aerospace Research "Elie Carafoli“, Romania
✓ National Technical University of Athens, Greece
✓ SWEREA, SICOMP, Sweden
✓ University of Patras, Greece
✓ University of West Attica, Greece
Typical Composite Repairs

- **Patch repair**
- **Scarf patch repair**
- **Stepped repair**
The vacuum bagging technique can be used to improve the quality of composites produced by the wet lay-up method. A bagging film is placed around the laid-up composite material and is secured to the tool surface with sealant. Air is evacuated from the bag, leaving the composite under an external pressure of up to 1 atmosphere. This forces resin into any remaining voids and helps to ensure an even distribution. Higher viscosity resins can be used in comparison to the wet lay-up technique.
Repair Curing

![Diagram of repair curing process with graphs showing degree of cure vs. time at different temperatures.]
ANITA Family of Bonding Consoles

Anita EZ
Anita EZH
Anita QS
Anita EZ4Z

April (PR)
Anibolt
Anita 6Z
Wide range of heating elements

Heating Technology

[Images of various heating elements]
FGH and SXH High Temperature Composite Curing Blankets

Product Highlights

- Designed for use with the newer high temperature thermoplastic and polymide composite materials
- Highly flexible up to a 1” (25mm) radius
- Compatible with ACR® hot bonders and your current equipment
- CE/RoHS Compliant

Specifications:

- Heating element and a 1” (25mm) layer of high-density fiberglass is covered in an abrasion resistant fiberglass cloth (FGH) or Samox® cloth (SXH series)
- Maximum exposure temperature:
  - FGH series: 800°F (425°C)
  - SXH series: 1100°F (593°C)
- Power density:
  - FGH series: 7 watts/in² (0.011 watts/mm²)
  - SXH series: 13 watts/in² (0.020 watts/mm²)
- Dielectric strength of over 2000 volts
- Power cord 6-foot (1.8m) long with choice of power plug

Temperatures up to 1100°F (593°C)
Surface Preparation – Innovative toolings have been designed to allow technicians to perform easily typical works on carbon surface for patch installation.

A complete set of tools for all tasks – Easy to handle and use – Presented in a complete Mobile Workshop.
Elisa U/S NDT Console

Advanced Software Tailored to Composite Repairs

Range of Calibration Specimens
OLGA Positive Pressure Application

Repairs using OLGA patch preparation (to overcome porosity issues) and secondary bonding on aircraft
GILDA Phosphoric Anodizing

Automatic adjustment of flow and amperes.

- Vacuum pump
- Aluminium external sealing bag
- POACH
- Mesh
- Voltage (V)
- Ampere (A)
- H3PO4 (fresh)
- H2O

Flow from bottles to the poach.

Power system.
Autoclaves & Ovens

Various dimensions and specifications
Full controlled by our computers
GMI ANIFIB

Model standard of internal dimensions
2,5 x 2,5 x 4 m
Fully equipped.
With vacuum system
With GMI ANIFIB Computer control
GMI autoclaves are controlled by our system **ANIFIB™** that offers several unique solutions:
The **ANIFIB™** system is composed of two sub-systems:

a) An Industrial Computer called itself **ANIFIB** and which is mounted near the oven/autoclave.

b) A PC linked to the **ANIFIB™** computer as a supervisory station with cycle programming and supervisory software.
With Anifib, GMI has developed an activity of autoclave control.

Helping companies ease their production process and qualify it.

We are now turning to a development of Industry 4.0
Participation in more than 30 EU Research Programs focusing on bonded composite repairs

FP5, FP6, FP7, H2020, Cleansky, Cleansky 2, Research for the Benefit of SMEs, Eurostars, EUROGIA+, Ten (10) Cleansky & Cleansky 2 R&D Projects

In cooperation with: Co-funded by:

GMI R&D Activities 1997 – 2020

58 Research Papers
“Revolutionizing Aircraft Materials and Processes”, Edited by Sp.Pantelakis and K.Tserpes
Chapter: “Bonded Repair of Composite Structures”
G. Kanterakis, R. Chemama, K. Kitsianos
H2020: MG.1.1+2014.-RIA 636494-2
Quality assurance concepts for adhesive bonding of aircraft composite structures by advanced NDT – ComBoNDT
Consortium: Fraunhofer IFAM, EADS, CNRS, UoP, ASTRIUM, EASN

**State of the art**

- **ENDT techniques can detect:**
  - *Single surface contaminations* (pre-bond) on **simple** sample geometries
  - *Weak bonds* due to single contaminations/poorly cured adhesive (post-bond) on **simple** geometries

**1st step**

- **Maturation of ENDT techniques to detect:**
  - Different **multiple surface contaminations** down to a certain threshold value (pre-bond) on **test coupons**
  - *Weak bonds* due to **multiple contaminations/poorly cured adhesive** (post-bond) on **test coupons**

**2nd step**

- **Adaptation and improvement of ENDT in terms of:**
  - *Pre-bond/post-bond* inspection on pilot samples with **realistic geometries**
  - **Automation and industrialization** of ENDT techniques, including its use on a demonstrator and automated data evaluation
  - **Validation** of measuring results/round robin test

**Final results/innovations of ComBoNDT**

- Validated **ENDT techniques** for:
  - Surface quality assurance (pre-bond)
  - Adhesive bondline quality assurance (post-bond)
  - ...for integration into future adhesive bonding processes
Cleansky 2: AIR-02-05-686701
Novel Processes & Equipment in Composite Repair Technology – NEWCORT
Topic Manager: Airbus

Support of mid-term needs for innovative faster repair process of monolithic composite airframe and long-term repair processes for future epoxy and thermoplastic materials

NEWCORT Background knowledge in Bonded Composite Repair Processes

- GMI commercially available Composite Repair Equipment and Solutions (110-page equipment catalogue)
- NEWCORT Partners’ R&D projects in Bonded Composite Repairs (~20 R&D projects)
Research & Innovation / Main Projects

Cleansky 2: AIR-03-02-831882
Non-destructive testing (NDT) of bonded assemblies - SealedWithoutAKiss
Topic Manager: Dassault Aviation

Manufacture of adherent samples (plates) → NDT inspection
Performed by: Dassault

NDT inspection → Bonding
Reference samples → Contaminated samples

Inspection with ultrasonic NDT (A-scan)
Performed by: GMI

Defect detection → YES
Discard

Mechanical testing
Performed by: TWI, BUL

Fail at less than 20% compared to reference samples

Approved method

Not approved method

Sealed without U Ta Kiss
### Latest innovations related to bonded composite repair application

**Participation to EU Research Programs** Brite Euram (FP5), FP6, FP7, H2020, Cleansky JTI, Research for the Benefit of SMEs, Eurostars & EUROGIA+

<table>
<thead>
<tr>
<th><strong>Innovation Description</strong></th>
<th><strong>Challenges answered</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Repairs using OLGA (positive pressure application equipment) for patch preparation and secondary bonding on aircraft.</td>
<td>Enhancement of bonding quality, and overcoming patch porosity issues</td>
</tr>
<tr>
<td>2 <strong>Adaptive</strong> (multi-sectorial) heating blankets using existing 2-zone ANITA bonders combined with variable insulation.</td>
<td>Improve temperature homogeneity on geometrically complex structures.</td>
</tr>
<tr>
<td>3 “Plug-and-play” 24-Thermocouple scanner, together with appropriately prepared sensing mats.</td>
<td>Increased quality control requirements during repair on complex structures.</td>
</tr>
<tr>
<td>4 Real-time transmission of repair data, for curing duplication using dielectric sensors to enable curing degree monitoring.</td>
<td>Increased quality control requirements during repair on complex structures.</td>
</tr>
<tr>
<td>5 Heating solutions for quick repairs of small number of plies and limited dimensions tailored to aircraft needs.</td>
<td>Fast aircraft turnaround when limited repairs need to be applied.</td>
</tr>
<tr>
<td>6 CONDUCTOR consumable heating blankets that could be cut in different shapes to adapt to geometrical requirements.</td>
<td>Improvement of T homogeneity and suppression of blankets’ lead time.</td>
</tr>
<tr>
<td>7 MAGNASENSE magnetostrictive sensors, for fast and accurate strain mapping of new or repaired composite structures.</td>
<td>Ensuring bonding adequacy both for SHM and certification requirements.</td>
</tr>
<tr>
<td>8 Autonomous mobile composite repair workshop to be used by airlines that need to perform repairs outside of their hangars.</td>
<td>Flexibility in repair application. Reduction of aircraft turnaround time.</td>
</tr>
<tr>
<td>9 Advanced heating system &amp; control mode for homogeneous Out-Of-Autoclave curing of large composite repairs - ADVANCED</td>
<td>Reduction of energy consumption and CO₂ footprint for repair / production.</td>
</tr>
<tr>
<td>10 Heating Bolts provide localized heating to repair damages associated with drilling &amp; reaming operations in carbon laminate.</td>
<td>Curing of resin inside drilled holes, achieving required T homogeneity.</td>
</tr>
</tbody>
</table>

Co-funded by: [Logos of various organizations]
A350 : Composite Materials overview
(Source Airbus)

Most of the External structure of the Airframe are with Composite materials
A350 : Involving Large & Complex Structural Panels
(Source Airbus)
Increase of **volume** of Composites per aircraft

Together with increase of **complexity** of Composite parts
Answer to Challenges:

a. Adaptive Heating Solutions
b. Integration in 4.0 concept
c. Training & Continuous Professional Development
Adaptive heating solutions for aeronautical applications

If the only tool you have is a hammer, everything looks like a nail.

To change your perspective (and find new solutions.)

Pick up new tools.

Please consider...

Expertise and Innovation for Composite Repair
Carbon Structures Hot Bonding Issues

• The main challenge: to match in temperature the resin manufacturer specs: respect of a set-point of temp. at +/-5 °C max. on the whole surface.

• Heat transfer on structures heated by conduction through mats leads to gradients up to 40 °C and more, due to:
  – Large dimensions
  – Orientation of structures
  – Variation of skin thicknesses
  – Variability of materials covered by the patch
Question: Why do we have temperature differences?

Answer: The problem starts due to the continues interaction of the thermal transfer modes, as follows:

- Heat is **directed to the repair area** (composite patch & peripheral structure) **through the heating** blanket by conduction, at a uniform rate across the blanket surface (increase of temperature).

- Heat is **propagating through conduction to the whole structure** which is surrounding the repair according to its geometry (i.e. in a non-uniform way) and, at the same time,

- Heat is **lost by the whole repair area through convection to the environment** according to the geometry of free surfaces of the surrounding structure (i.e. in a non-uniform way)

**As is it well understood the result of uniform thermal heating, minus non uniform heat losses due to conduction and convection is a non-uniform temperature distribution**
Tip: Impose additional heat to areas affected by “heat sinks”

Structure below or near the repair may act as “heat sink”, by transferring heat to the environment. These areas are better identified during the “heating survey”, which should be performed BEFORE the actual repair. To compensate for these losses, additional heat should be offered to these areas, either by increasing the overlap length or by an additional blanket (see GMI’s blanket inventory). A multi-zone heating strategy should be considered, as well.
Example of multi-zone configuration, used for other demanding repair heating applications and corresponding heating blanket manufactured according to the definition calculated for this structure.
Multi-zone / Shaped Blankets
A350/B787 Increased complexity

Thermal issues associated with A350 / B787 Panels repair

- Significant temperature fluctuation due to “Omega stringers” effect: trapped air acts as insulator
- Single heating zone approach is no longer valid.

Zonal Approach is required...
Adaptive Heating

| Section 1 – Zone 1 | Section 2 – Zone 2 | Section 3 – Zone 1 | Section 4 – Zone 2 | Section 5 – Zone 1 | Section 6 – Zone 2 | Section 7 – Zone 1 |

AdaptHEAT solution designed for A350 Omega stringers

Heat Equilibrium = Algebraic Sum of Thermal Routes No 1+2+3+4
Adaptive Heating

AdaptHEAT: Overall A350 panel application example

- Specially designed to ADVANCED / ANITA legacy equipment (no need for upgrade)
- Heating elements’ geometry adapted to A350/B787 composite structures (fuselage / wings)
- Heating performance optimized for Ω/T/I stiffened composite structures
- Compatible with 2- zone controllers of all bonding console manufacturers (adaptors required)
- Standard procedure followed for preparation and vacuum bagging operations
- No need for additional training of operators
- Flexible dimensions, according to requirements
- Further customization possible, according to repair area configuration
“Cuttable” Blankets

Blankets
Heating Blanket “Cut-to-Measure” CONDUCTOR

Developed and tested under the guidance of AIRBUS GROUP INNOVATIONS

Conductor Blanket cut to measures under verification test
Blankets

Heating Blanket “Cut-to-Measure” CONDUCTOR

Combined with AdaptHEAT for A350 repairs...
Special Heating Elements

Heating Pins - Heating Bolts for repair inside drilled holes of 3-20mm diameter
Install the control thermocouple very close to the repair

To succeed good control you need to put the control thermocouple “C” at an area of “representative” temperature. As such, a point very close to the edge of the repair is usually proposed. Take care to put the monitoring thermocouples “M” around the repair and definitely at areas with potential heat sinks.

Ideally, use the GMI’s “sensing mat”, in order to be able to get temperature measurements from the center of your repair, without marking your part.
GMI has developed a solution to attach the complete metallic stringer set to reinforce the rear cone skin on Bombardier C-Series. These blankets are plugged on an Anita 6 zones.
Repair Enhanced Autoclaves

Using flexible blankets as the main source of heating!

• Addressing repair requirements of complex aeronautical parts, such as the A380 engine reverses, the B777/B787 engine nacelles etc.

• Globally heating the parts in “conventional” autoclaves would immediately distort them while causing severe and unrecoverable damage, due to variation of thermal expansion coefficients of involved materials.

• Even though an autoclave is still used to provide required pressure and slightly elevated ambient temperature (i.e. 50-80°C), heating at 120-180°C is ensured using specially designed adapted heating blankets, at the repair area ONLY!
Repair Enhanced Autoclaves

Using flexible blankets as the main source of heating!

• **Installation** of power supply plugs, connectors, extension cables.

• **Thermal simulation** and **analysis** of the repair area to ensure Temperature homogeneity.

• **Design and manufacturing of adapted heating blankets**, tailored to the specific repair requirements.
Overview of the GE90 area to be repaired, showing variations in construction materials and methodology (sandwich – monolithic)

The 8-element / 5-zone adapted heating blanket, designed to cover the upper surface of the right / left cowlings.
“ADVANCED” Out-Of-Autoclave (OOA) Heating Solution for Production and Repair of A380 Thrust Reversers using 18 zones

- Heating configuration defined (15 heating blankets on cocured side + 3 on opposite side)
- Up to 72 T/C available for regulation and monitoring
- Some of them could be localized specifically for correlation with Thermal Simulation
“ADVANCED” Out-Of-Autoclave (OOA) Heating Solution for Production and Repair of A380 Thrust Reversers
Answer to Challenges:

a. Adaptive Heating Solutions
b. Integration in 4.0 concept
c. Training & Continuous Professional Development
ANITA 4.0 is the application of the Industry 4.0 concept in the field of bonded composite repairs.
ANITA 4.0 concept Main Steps

- Last steps of repair preparation on an A350 fuselage
- ANITA EZ with AdaptHEAT ® controlling the curing process
- ANITA EZ connections to the company’s intranet
- On-line inspecting and evaluating the overall process
Remote Control Tablet

Surveillance and control of up to four (4) bonding consoles

Technicians could be engaged with other activities in their offices or around! → 80% reduction of MH associated with repair...
Proximity WiFi Solution
Remote Monitoring and Control Tablet

WiFi Range and Extension Possibilities
General Network Architecture

Web server:
- Collect Anita’s data
- Accessible from web browser through network

CUSTOMER NETWORK

Gateway to customer network

Wifi access point

Supervision computer with large screen
Up to 8 Anita and more
Distant Parallel Monitoring

- Up to **eight (8) ANITAs** connected to end-user’s central IT system through WiFi.

- **Web application**, accessible from main web browser.

- Collects ANITAs information & stores in a **database**.

- **Visualizes** summary of all connected ANITAs current status (Zones on cycle, Setpoint, T/C, Vacuum, etc).

- **Data presented** on PC screen or Smart TV.

- Format and variety of presented data **tailorable** to end-user's requirements.
- When a **safety critical** structural repair is performed all repair data (temperatures, vacuum level etc.) are **recorded** and **real-time transmitted** to the aircraft manufacturer.
- At the aircraft manufacturer’s facilities a **setup using same materials** is prepared and is **simultaneously** to the actual repair **cured**, using **appropriately selected portion of transmitted real time data** (e.g. lagging thermocouple), so as to enable **imminent destructive or non-destructive testing** of produced material.
- Within the set-up prepared at the aircraft manufacturer’s facilities, **dielectric sensors for curing degree monitoring** are included, thus providing **real time degree of cure data**, equally valid for the remotely performed structural repair on the aircraft.
Answer to Challenges:

a. Adaptive Heating Solutions
b. Integration in 4.0 concept
c. Training & Continuous Professional Development
BUTCHER OR BAKER?

There are some significant challenges for technicians due to the nature of composites - which are very process driven and rely heavily on the composite technician building quality into the finished product. To illustrate this, the Aug/Sep 2012 edition of Aviation Maintenance (AVM-mag) published an article discussing the difference between repairing a metal vs a composite aircraft being akin to the difference between highly skilled butchers and talented bakers. Here’s why:

Butchers don’t have to create the meat they work with. The raw meat comes into the shop fully formed. The butcher’s job is to carve it up into the required cuts. This is similar to mechanics working on a metal aircraft. Whether they are installing a new part, re-shaping and repairing an old one or - in extreme cases - custom measuring, cutting, shaping and custom fitting a new metal part from scratch, mechanics don’t have to smell and cast the metal they are working with. Instead, the metal comes into the shop in workable shapes, sheets and thicknesses, no fundamental manufacturing is required. It’s not quite as convenient as working with meat, but it is close.

In contrast, bakers must start with the raw ingredients, condition them to room temperature, and combine them into specific mixtures first. Then they have to transform these mixtures into cakes, pies, breads, etc. and use the right levels of heat for the correct amounts of time. In the same vein, composite repair technicians must follow strict processes to combine and cure ingredients to achieve an optimum result.
GMI Training Activities

- **Level 1:** BASIC BONDED COMPOSITE REPAIR STANDARD TRAINING COURSE – 5 DAYS

- **Level 2:** ADVANCED BONDED COMPOSITE REPAIR INTENSIVE TRAINING COURSE – 5 DAYS

- **Level 2:** ADVANCED BONDED COMPOSITE REPAIR STANDARD TRAINING COURSE – 10 DAYS
Example of 5 days Basic Training Course

Level I – Basic Bonded Composite Repair

Scope: This curriculum is intended to meet the formal training requirement for individuals who intend to become certified as aircraft composite repair technicians. Persons who successfully complete this aircraft structural repair training program are considered to be able to perform basic composite bonded repairs to aircraft structures in compliance with the manufacturers’ repair documentation or other acceptable or approved repair data.

Applicable documents: GMI Aero proposed Training Courses align with the latest SAE Commercial Aircraft Composite Repair Committee (CACRC) and regulatory authorities documents, as follows:

- AIR4938C Composite and Bonded Structure Technician/Specialist Training Document
- AIR4844D Composites and Metal Bonding Glossary
- AIR5719B Teaching Points for an Awareness Class on "Critical Issues in Composite Maintenance and Repair"
- FAA AC 65-33 Development of Training/Qualification Programs for Composite Maintenance Technicians

Trainee’s prerequisites:
- Experience as aircraft maintenance technician or engineer
- Good knowledge of the English language (minimum B2)
- Basic mathematics, physics and chemistry considerations (minimum High School - level or equivalent)

Course Outline: This training course is divided into four (4) main training units, namely:
- Basic Theoretical Considerations
- Bonded Composite Repair Equipment and Toolings for Curing and Machining
- Implementation of actual Bonded Composite Repairs
- Theoretical & Practical Examinations
Continuous Professional Development

**Programme Content**

The recent venue of all-composite fuselage aircraft (A350 – B787), together with the expansion of older aircraft fleets, introduces new requirements in bonded composite repair. These contemporary repair challenges and the latest innovations in equipment and methodologies to address them, will be the subject of a 2-Day CPD Seminar, organized by EASN Association in cooperation with GMI Aero, the lead European composite repair equipment manufacturer.

**Key Benefits**

Experienced industrial personnel, together with academic experts, will provide an insight of recent R&D developments and critical issues in the field of bonded composite repair, ensuring that seminar participants acquire a full "process understanding", including a demonstration workshop, to support reliable application of bonded repairs, even on Class I (safety-critical) structures.

**Key Note Speakers**

Two keynote speeches will be presented by experienced engineers from major aircraft manufacturers and MROs.

The participants will receive a Certificate of Attendance highlighted by the added value of the EASN Association quality label.

**Practical Information**

Technical Visit
Participants will have the opportunity to join an optional visit to Le Bourget Air Show on a date reserved for professionals (25th).

**Fees**

- EASN members €500.00
- Non-EASN members €400.00
- Students €350.00

Contact & Registration Details
For further information on CPD seminars please visit our website:
www.easn-tic.com/cpd

EASN Association: www.easn.net • GMI Aero: www.gmi-aero.com
GMI Aero YouTube channel: https://www.youtube.com/channel/UCCLwJ3V6lyZ31lc7k85gM-HUjbadANvideos

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Continuous Professional Development

“New Aircraft, New Materials, New Repairs”
**Guillaume FERRER**  
Embodiment Industrialisation Manager  
Composite Repair Process Development  
**Airbus Customer Services**

“Technical challenges and innovations in bonded aircraft composite repair”
**Philippe SERVANT**  
Responsible for Engineering, Research and Development of Aerostructures,  
**AFI KLM E&M**
Continuous Professional Development

Composite Technology Seminar & Experts Forum
Singapore, 10/2/2020

Composite Repair Seminar & Experts Forum
Berlin, 11-13/5/2020
Questions?