"European Bonded Structure Meeting "

EASA – Cologne , 13-14 June 2013

Other Design Configurations GAG cylces (no DP) , Understanding Failure Mode

13 June 2013

Presented by Bruno Moitre

"European Bonded Structure Meeting "

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The material and content of this presentation has been collected and prepared by Amedeo Marzano of the ENAC Product Type Certification Direction.

To him the presenter wish to express recognition for his outstanding dedication and commitment deserved.

Other Design Configurations GAG cylces (no DP) , Understanding Failure Mode

- ***Introduction***
- ***AW 139 Tailboom in service failure***
- ***Tailboom design***
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- ***Conclusion and Lesson Learned***

Introduction

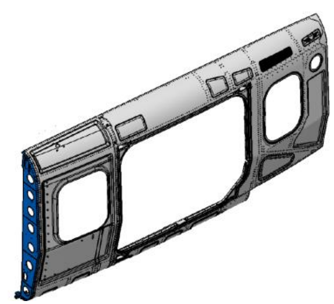
Unlike fixed-wing, helicopter design makes large use of sandwich panels to react loads transmitted by rotors, inertia and aerodynamic.

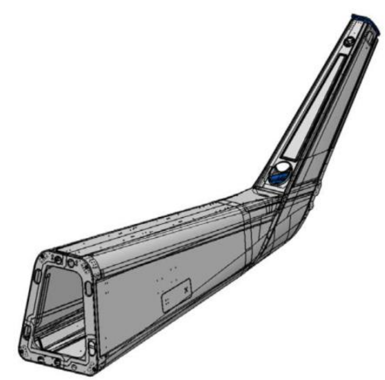
Typical applications of sandwiches panels can be found in the construction of :

•Main rotor blades

•Main cabin fuselage panels

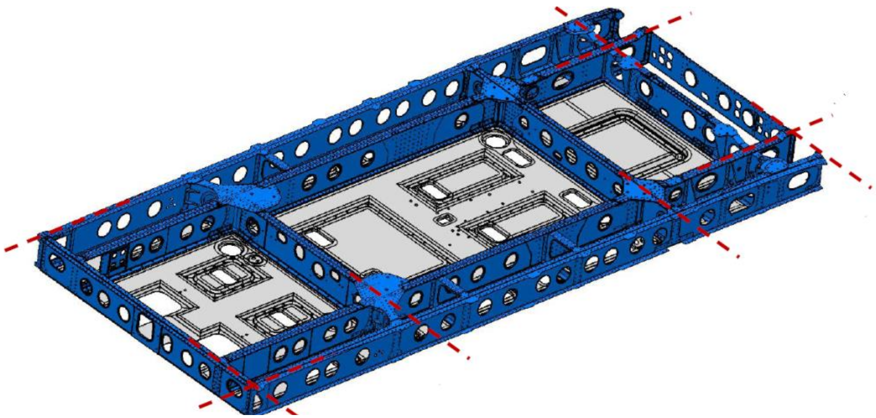
•Tailboom (rear fuselage)

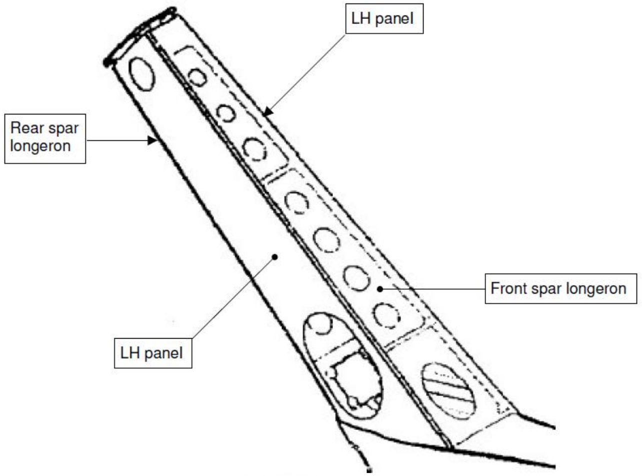


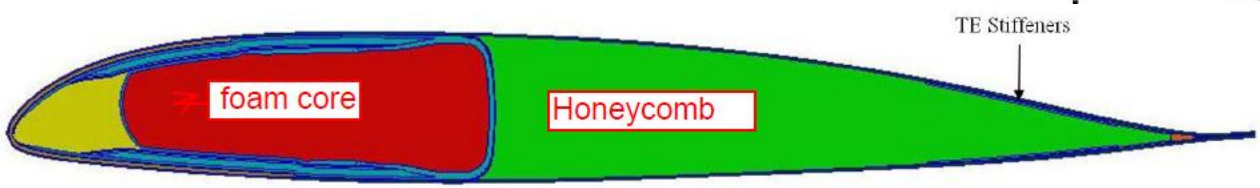


Introduction

Usually for main rotor blades, vertical fins, and fuselage panels, the main carrying load path is represented by metallic or solid laminate spars and longerons.







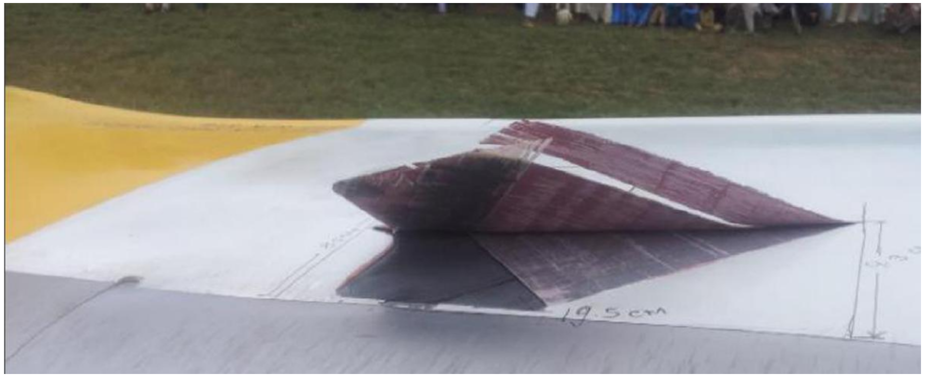
Introduction

The design of these sandwich panels, which normally combines a Nomex Core with either CFRP or aluminum facing provide the following advantages:

- High Stiffness & Strength to weight ratio
- Smooth Surface
- Number of Parts reduction
- No Corrosion Sensitivity
- Good Damage Tolerance Behaviour

Introduction

Notwithstanding these theoretical advantages, ENAC have been in the past deeply involved in service occurrences associated to failure of sandwich panels used on helicopters structures.



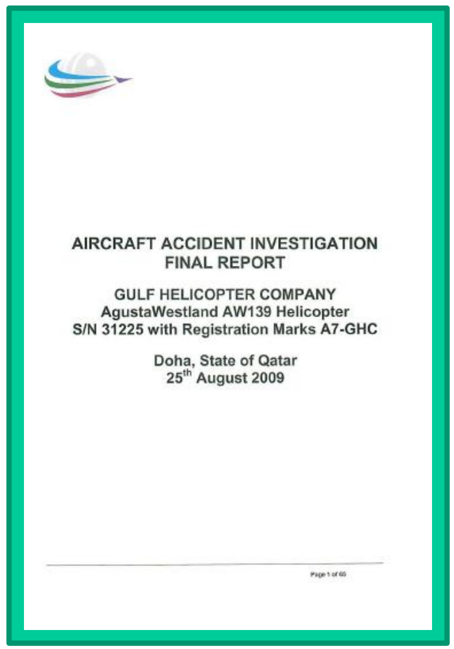
AW 139 Tailboom in service failure

With particular regard to the in-service occurence of the tailboom failure of the AW139 occured in Doha on 25 Auguts 2009

ENAC intend with this presentation to share with the CMH-17 community their opinions and ideas, as prompted by this event, regarding the design, certification and utilisation of composite sandwich panels as primary structures on helicopter.

AW 139 Tailboom in service failure

It is not the intent of this presentation to question the results of the investigation which are public and available in the final report issued by the Italian Accident Investigation Board (ANSV)



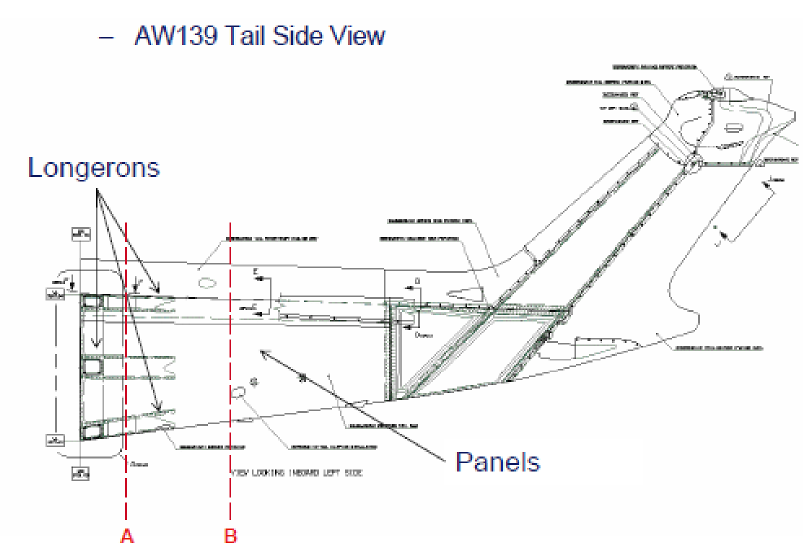
AIRCRAFT ACCIDENT INVESTIGATION
FINAL REPORT

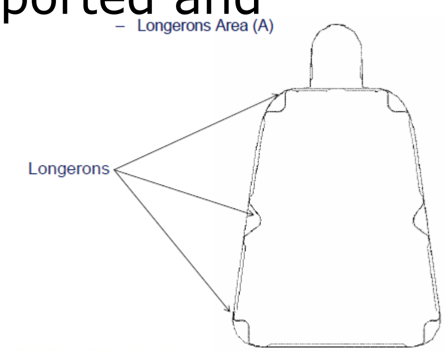
GULF HELICOPTER COMPANY
AgustaWestland AW139 Helicopter
S/N 31225 with Registration Marks A7-GHC

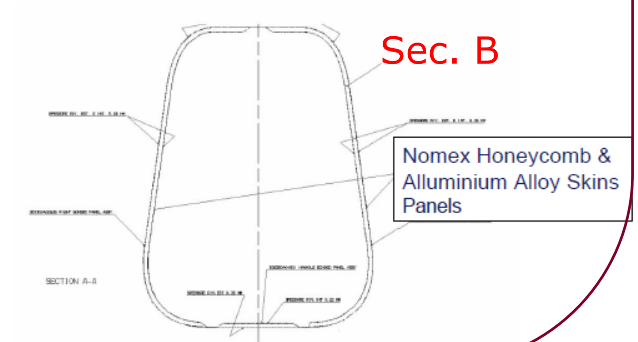
Doha, State of Qatar
25th August 2009

TAILBOOM DESIGN

The tail boom assembly of the AW139 is made-up by two sandwich pales made by Nomex honeycomb and two skin metallic panels .The honeycomb is bonded on the inner and outer skins using a film adhesive (supported and unsupported)

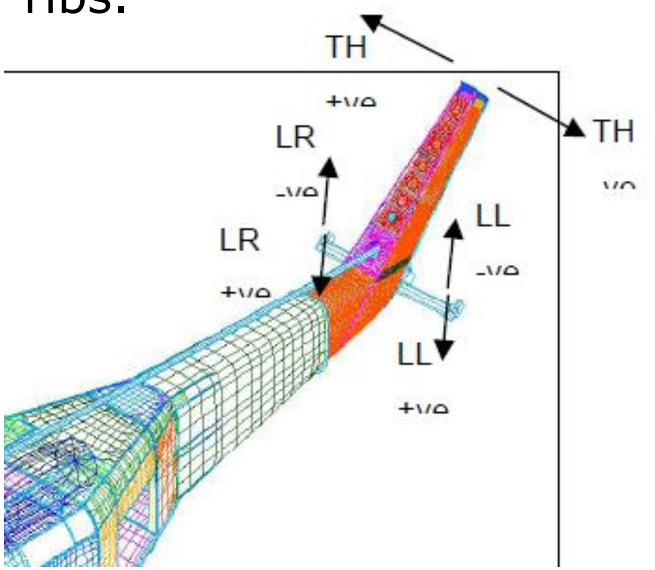






TAILBOOM LOADING CONDITIONS

The two side sanwich panels are the main load paths to transfer the load from the tail area to the main cabin. The sandwiches panel must react the combination of bending (compression on RH and tension LH) and torque loads without any supports from stringers, longerons or ribs.



The main loads for the tailboom **are large GAG cycles** associated to the application at each flight of tail rotor thrust and vertical and horizontal stabilizer loads.

For this type of helicopter the FSFT applied GAG stresses on the RH side panel **are about 80% L.L**

Accident Synopsis

At 6:45 am local time,as soon as the helicopter started to make a LH U-turn to get into the taxiway, the pilot felt a pedal shaking, the ground staff advised the crew to shut down the aircraft having realised the tail boom failure.

FDR data showed that the pilot during the LH U-turn applied 90% of left pedal.

The tailboom structure collapsed and bent on the RH side

At the time of the accident A7-GHC have accumulated 691 FH.

Mantainance information

At the time of the accident there was no malfunction reported.

The H/C suffered a tail strike on March 2009 at about 326FH.
This event caused damages to the rear part of the tail structure.
The H/C was repaired and inspected.
No tail boom panel hammer tapping check was requested.

HUMS data analysis was carried out without any remarks.

The mandatory 600FH inspection, including hammer tapping check of the RH and LH side panels has been carried out at H/C 586FH with no reported debonding about 100FH before the accident.

AW139 Tailboom Disbond Service Experience

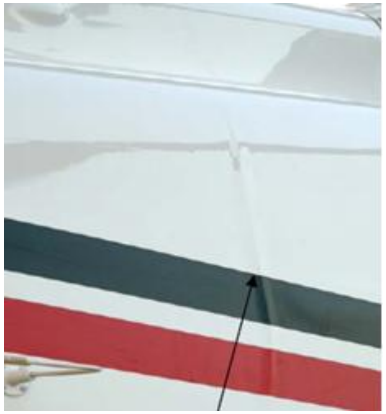
At the date of the accident of A7-GHC, a relevant number of RH/LH panels disbonds of the AW139 Tailboom RH and LH were already reported by Operators to AW.

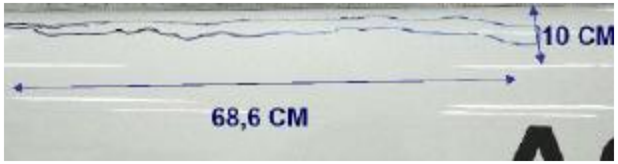
EASA issued AD 2008-0157 to address these in-service findings by mandating a 300 FH inspections (hammer-tapping) on the RH and LH panels.

In most cases these disbonds affected the upper curved area of the panels although some examples on the lateral flat area of the panels were also reported.

82 % of the reported events were from Operators using the AW139 in Tropical and Subtropical regions.

AW139 Tailboom Disbond Service Experience





FAILURE ANALYIS

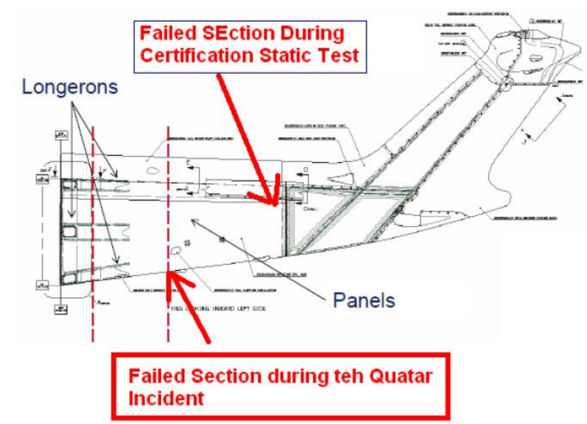
Tail Boom Failure consistent with the T/R applied loads with failure at STA 10100

FDR data indicated that compressive stresses at failed section were 65% of L.L

Panel failure in compression was due to local buckling

RH side panel failure in tension

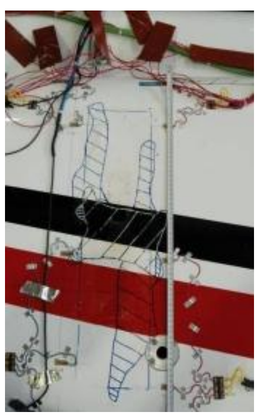
Extensive disbond between Nomex and outer skin about 40% of the examined area
This disbond area was not comparable in size and location to the previous disbonds occurred to the AW139 fleet

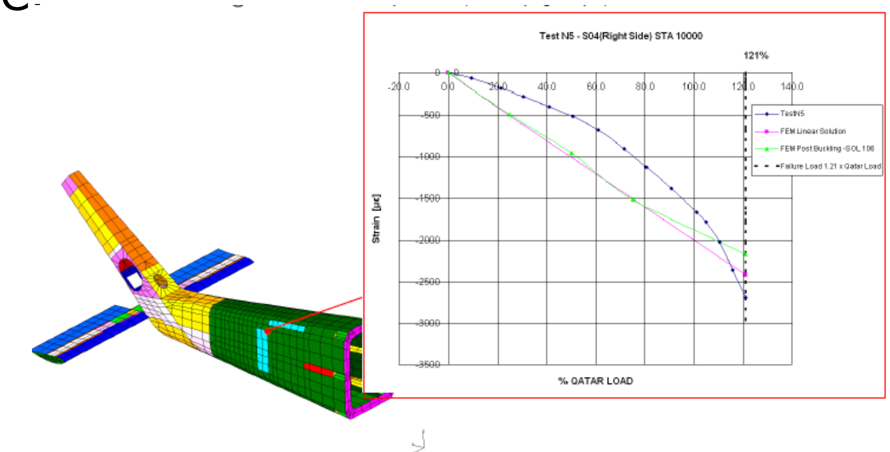


FAILURE ANALYSIS

A failure of the RH Panel in compression at only **65 % of LL** could have been explained only by the presence of a large disbonded area on the flat side of the panel as the one identified during the post accident inspection.

Non-linear FEM simulation as well as dedicated full scale static tests, showed that in case of a large disbond of the RH panel, the AW139 tailboom would have collapsed in buckling at a load equal to **120%** of the one experienced by A7-GHC.

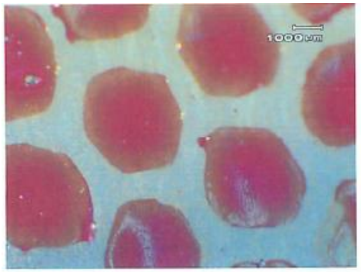


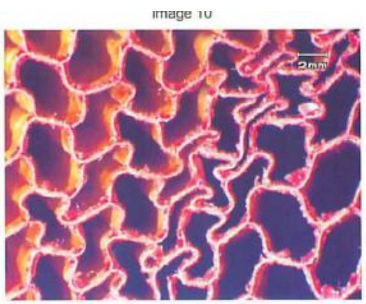


The disbonded area of the RH panel showed different patterns of disbond failures between the honeycomb core and the alluminium skins depending on the locations along the panel profile

In the curved regions 1 and 4 of the panel, where supported adhesive was used, generally a cohesive failure was observed.

However in the flat areas 3 and 2, in particular in proximity of the curved section, adhesive failure was observed, featuring very thin adhesive meniscus and Nomex cells distortion, paper failure within the Nomex core was also observed.





POST Accident Continued Airworthiness Review.

The discussions with AW in the context of the Cont. Airw. highlighted some points which are worth of being mentioned:

1) Adhesive Suction

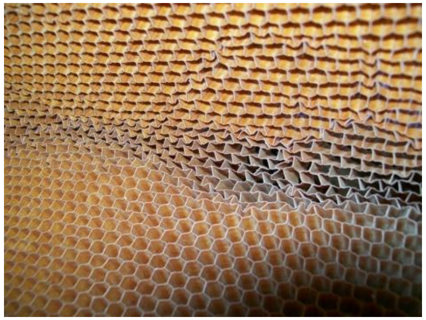
Review of the manufacturing process showed that the unsupported adhesive used to bond the NOMEX core to the skins was subject to suction during the application of the vacuum used for compaction of the skin to the core before pressure application in autoclave.

A7-GHC

POST Accident Continued Airworthiness Review.

2) NOMEX Core formability issues

It was found out that NOMEX core was very difficult to be shaped around panel profile charachetised by high curvature, it is believed that this issue led to the carachteristic core cell distortion as found in several occasion on the curved section of the AW139 Panels.
The presence of this highly distorted cells may explain the reason for the thin not fully developed meniscus as found on the RH tailboom panels of A7-GHC.



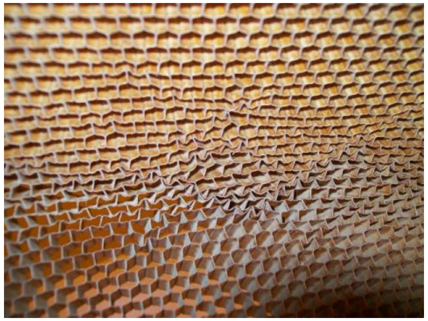
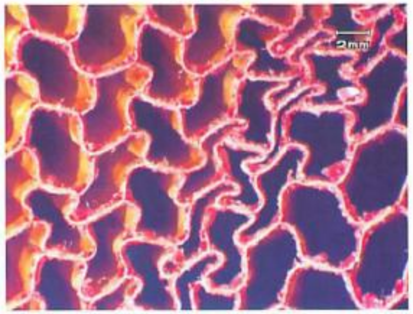


Image 10



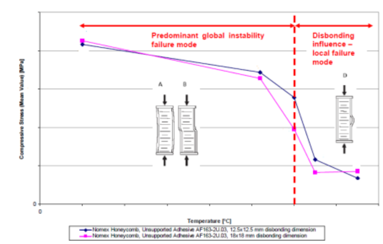
A7-GHC

POST Accident Continued Airworthiness Review

3) Adhesive Glass Transition Temperature.

The adhesive used by AW to bond the NOMEX core to the skins had a TG value in the range of the maximum temperature experienced during some flight phases on the RH and LH panels of the AW139 tailboom.

The reasons for this high temperature due to the combination of proximity of the engines, exposure to sunlight and extreme OAT conditions.



AW dedicated compression tests on coupons of the AW139 sandwich panels showed that buckling loads could be sensibly reduced for panels operating at temperatures close or beyond the adhesive TG.

AW139 Review of the Manufacturing Process

No significant departures or anomaly in the main parameters governing the manufacturing of the panels were found (e.g curing temperature, autoclave pressure or clean room environmental conditions)

All the results of the quality control process on specimen travellers were within the limit of the specification.

US check (flat area) and hammer tapping (curved area) records showed no departure from the maximum acceptable limit size for disbonds.

AW139 Review of the Manufacturing Process

However the manufacturing process of the AW139 Tailboom Panels was not subjected to a First Article Inspection.

The reason for this decision, was because these panels were not considered as a critical part.

Furthermore quality checks in production were limited to travelers specimen and the process specification did not envisage periodic destructive inspection of the panels.

It is noted that a dedicated post accident test on specimens taken directly from the panel showed a relatively high variability (11%) in adhesive shear strenght.

AW139 Review of the Manufacturing Process

Process Quality Control in production :

- **EACH autoclave load has its own specimens batch,** used as process verification indicator, manufactured and cured together with the parts, with the same adhesives:
  - One drum peel specimen (method 400 STA110A0025)
  - Four shear specimens (method 301 STA110A0025)
  - Four 90 degrees peel specimens (method 300 STA110A0025)

Certification issue of the AW139 Tailboom

During certification, the AW139 tailboom sustained :

- 160% of limit load during the full scale static test.
- 38000 equivalent Flight Cycles during full scale fatigue test (FSFT)

However both the static and fatigue tests were performed
without manufacturing defects, impact damages and at RTD conditions.

No considerations regarding effects of process and material variability for the determination of any LEF to be applied to the static and fatigue loads test.

ENAC
ENTE NAZIONALE PER L'AVIAZIONE CIVILE

Certification issue of the AW139 Tailboom

Process specifications were not reviewed in detail to check as requested by CS 29.605 that the methods of fabrication were able to produce consistently sound structure.
Autoclave pressure could be varied between 1.4 and 2.2 bar

No request for a substantiation by a test programme (e.g FAI) of the sandwich panel fabrication method.
Possibly a test programme before starting of production could have highlighted in advance the issues with NOMEX formability or adhesive suction under vacuum conditions.

Poor communication at Authority level between Certification and Production .
At some point during production the maximum curing temperature was increased to 180 °C, whereas the maximum Supplier recommended value for the adhesive was 120 °C

ENTE NAZIONALE PER L'AVIAZIONE CIVILE

Residual Static Strengh of the AW139 Tailboom

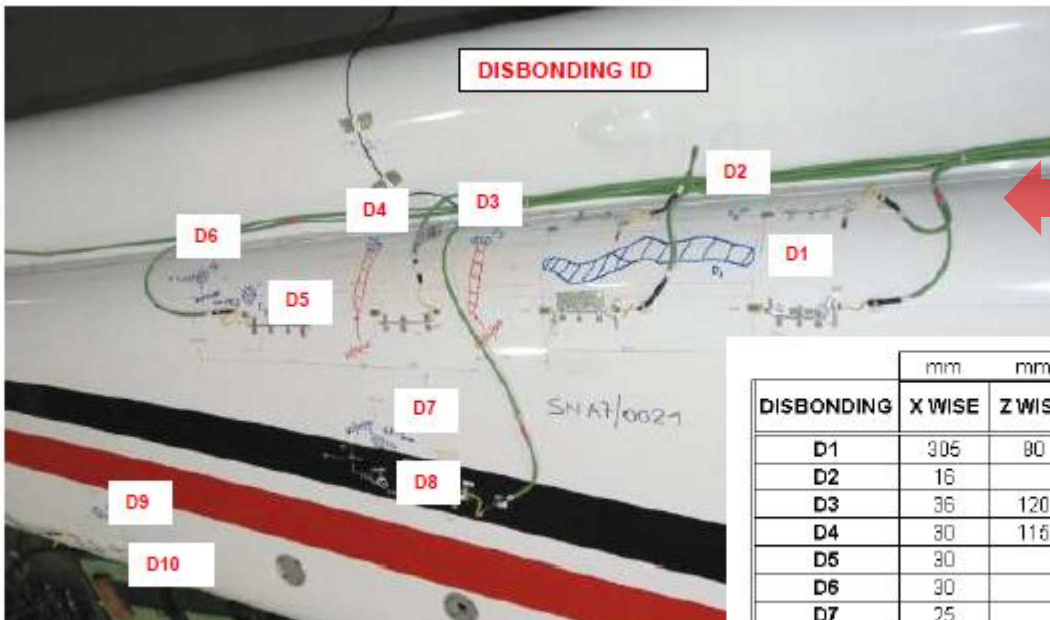
After the accident to A7-GHC, upon request from EASA AW performed fatigue and static test to show the residual strength of the tailboom RH panels considering the effects of enviroment

Two full scale fatigue and static tests of two AW139 tailboom were performed with damages representative of the maximum disbonds found in service (965 mm extension).

Thermal blankets were applied to the test article to simulate a local temperature of 90 degree at the location of disbonds.

The test showed that even under the above conditions the AW139 tailboom had a residual static strength up to ultimate and it could be able to sustain a minimum of 3200 GAG cycles

Residual Static Strength of the AW139 Tailboom

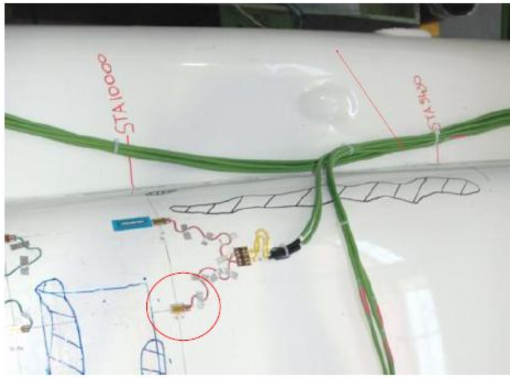


160 % LL after
3200 GAG
Limited disbond
Propagation.

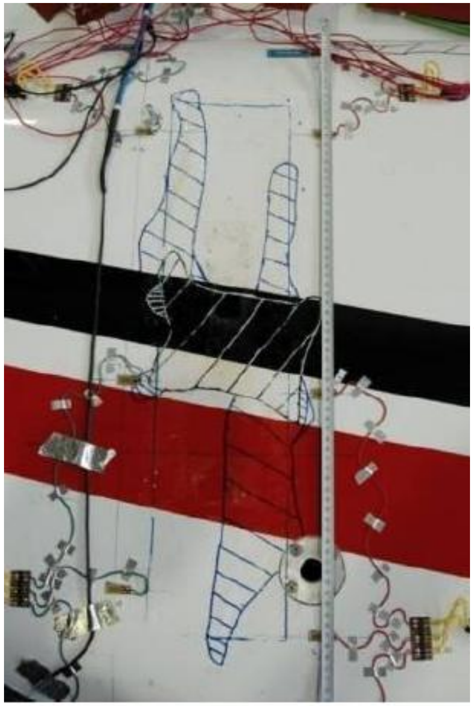
	mm	mm		mm
DISBONDING	X WISE	Z WISE	SHAPE	MINIMUM DISBONDING SPACING
D1	305	80	■	40
D2	16		●	
D3	36	120	■	207
D4	30	115	■	
D5	30		●	85
D6	30		●	
D7	25		●	58
D8	22		●	
D9	25		●	75
D10	28		●	
D1	305	80	■	115
D3	36	120	■	

Maximum Allowable Manufacturing
Disbonds 18 mm ●

Residual Static Strength of the AW139 Tailboom



RH Upper corner debonded
(530mm x 50 mm)



RH Panel debonded
(500 mm x 150 mm)

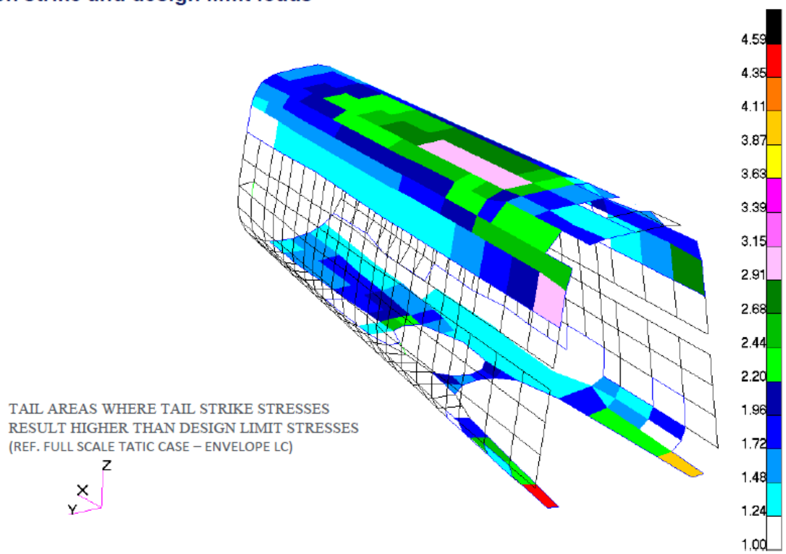
120 % QUATAR
800 GAG
Limited disbond propagation.

★ Area of disbond comparable
to the one found on A7-GHC !

Development of the investigation and most likely cause of disbond

Review of the HUMS and FDR data of the the tail strike occurred to A7-GHC before the accident showed that during this event The tailboom LH side panel experienced in the region of STA 10100 compression loads in excess of 1.7 the design limit loads

Stress ratio between strike and design limit loads



Development of the investigation and most likely cause of disbond

The compressive stresses developed during the tail strike event were clearly in excess of the maximum buckling allowable of the panel

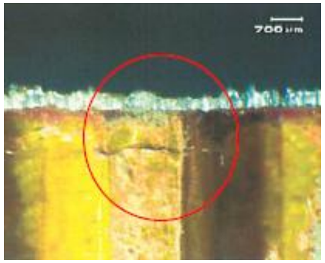
Therefore as result of this event a large disbond might have occurred At STA 10100 of the RH panel

But why this large disbond was not detected ??
(hammer tapping inspection every 300 FH)

Development of the investigation and most likely cause of disbond

AW presented to the Investigation Board some results of 3-pt bending test performed on specimen representative of the AW139 panels

The results of these test showed an internal shear failure of the honeycomb cells, the panel after the initial collapse returned to their original shape upon removal of load application



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Development of the investigation and most likely cause of disbond

On the basis of the shear test performed by AW, the Investigation Board came to the following conclusions :

The most probable root cause of the accident was determined in a tail boom strength degradation caused by hidden Nomex internal damages of the RH panel corners areas induced by the previous tail strike event suffered on March 2009 about 350FH before the accident. At that time the damage assessment did not identify the internal Nomex failure mode.

The limited failed areas identified by the failure analysis as adhesive failure mode can be considered only a marginal contributing element to the event considering also the adhesive properties reduction due to the temperature effects.

The additional tail boom full scale tests confirmed the structure damage tolerance capability for damaging extension extremely higher than the actual allowable for which dedicated repair activities are required. The absence of detectable propagation of extensive damages under GAG loads provides additional confidence of the conservative periodic inspection for debonding introduced by the in place current Technical Bulletin 139-195 and related AD.

The full scale static test in presence of a debonding extension on the flat right panel area comparable with the one found on the tail boom failed section after the accident in addition with the upper right corner debonding, pointed out a structure failure in buckling at load condition higher but comparable with the ground taxing accident one.

Conclusion and Lesson Learned

- A7-GHC accident investigation experience highlight the **extreme criticality** of the sandwich panels installations when used as a sole primary load path..
- Residual strength demonstration even with large damage could not suffice in absence of an effective fail-safe design based on alternative load paths.
- Notwithstanding the precautions which could be taken at level of certification testings, there is a need to fully qualify the manufacturing process of sandwich panels used as primary structural load path.
- This process qualification needs to be supported by a test programme aimed at identifying any deficiency in the process before this being frozen for production.

Conclusion and Lesson Learned

- ❑ There is a need to establish more clear communication and exchange of information between DOA and POA organisations in the definition of the process specification, particularly when defining and updating allowable manufacturing discrepancies.

- ❑ Dedicated certification guidelines for sandwich panels are needed because of their peculiarities in terms of failure modes , type of loading and defects.

- ❑ Sandwich Panels must be regarded under all aspects as secondary bonded structures and all the relevant considerations associated to this type of structures need to be applied

(…….however ……how to deal with residual strength ??)

Thanks for the attention !