AFMMAA History

Development of Statistical Based Non-Destructive Inspection Methods

AFML/MLLS

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The F-111aircraft was developed as a front line fighter-bomber for the U S Air Force and was also being sold under Military Sales to the Australian Air Force. When some USAF questions came up about the steel material used in the wing box and the wing pivot fittings it got a lot of interest in the AF Flight Dynamics Lab and the AF Materials Lab. These are huge parts of the aircraft and are the heart of the swing-wing supersonic Fighter Bombers combat capability. AFFDL had some larger tests they wanted to accomplish and the AFML signed up to do the tensile, fracture toughness tests, and some new fatigue crack growth rate tests.

On the day before Christmas vacation, December 22, 1969 an F-111 crashed in rural Missouri and both the pilots perished. This was a stunning shock to the AF as the F-111 was just settling in for a long duration in its chosen role. The cause of the crash was determined to be from a forging lap in one of the wing pivot fittings fabricated from D6ac steel and the flaw at fracture had grown only about 0.1 inches from its original length. The final surface length was about 1.2 in. and in a thumbnail shape.

All of the D6ac Steel used in the wing carry-through structure was heat-treated to a strength level of 220-240 KSI which was a normal heat treat for that steel.

A Scientific Advisory Board (SAB) was convened to pursue the investigation. Initial data showed a high degree of variability in the mechanical properties in the material. This was traced to the variability of the heat treatment quench rates: the quench media was 200 degree oil with agitation. The weight of the carry-thru box as machined was near 1000 pounds and this was surrounded by another 2000 pounds of steel framework to keep the box from warping during the quench cycle. Much more attention was paid to the quench and heat treat cycles during the recovery program. The SAB was trying to lay out an assessment of where the F-111 design was at the present time and a definition of what was the future safety of flight for the fleet. They needed expert personnel to help them. AFML had a running start in an ongoing contract with Mr. Charles Tiffany of the Boeing Company. His reputaltion for fracture knowledge was well known through the aero industry and he was subsequently assigned to the SAB Team as a Technical Expert.

After many iterations of ideas for how the Recovery Program should pursue the concept of the Cold Proof Test was selected as the way forward to get the safety included in the recovery tests.

A synopsis of the method is presented below:

a. Remove all fairing and extraneous equipment from the structural airframe
b. Run full NDI to the highest level possible
c. Load structure to limit load using standard aircraft loading methods at room temperature (whole aircraft)
d. Load tests to limit load at -40 degrees F using standard cold test procedures
e. Put a/c back together again

The Secretary of the Air Force decreed all new a/c would include the design for damage tolerant structures using the methodologies developed during the F-111 Recovery Program integral with all current design methods. These were then merged into MIL-STD 1530 as the Aircraft Structural Integrity Program.

The Aeronautical Systems DIvivision got hiring authority to carry out the Technical Direction of the Secretary of the AF. Col George Haviland, ASD/EN, was charged with creating a Senior Group for the three new PL313s he would now have on his staff:

1 Mr Charles Tiffany, Boeing Company

2 Dr John Lincoln, Vought Company

3 Dr Walter Crichlow, Douglas Corporation

After a fast introduction and shakedown of who is going to be where, the result was: a) Chuck Tiffany would handle ASD/NORTH (B-1 Primary), b) Dr Jack Lincoln would handle ASD/SOUTH as the prime support to the C-5 Cargo Aircraft development, c) Dr Crichlow was assigned to current flying a/c support at ASD/EAST at Patterson Field.

The B-1 Program was just gaining in speed when the Decree came down that the B-1 System Program Office structure had to provide a design document that the North American Rockwell (NAR) Contractor could use to meet the requirement.

NAR's initial response was that they did not need the design add—they would build us a good airplane. This push-back was one of the reasons for the creation of the Tiffany Fracture Group. This drew on structures personnel from around Wright Field and included the Laboratory personnel.

Tiffany Fracture Group:

Mr Charles Tiffany	ASD/EN	Leader
Mr Buck Meadows	ASD/B-1	Structures
Sgt Roger Bullock	ASD/B-1	Structures
Mr Nate Tupper	AFML/B-1	Materials
Mr Howard Wood	AFFDL	Structures
Mr Allan Gunderson	AFML	Materials

The concepts of using damage tolerance in design has three major data inputs;

1) Initial flaw size – this is set by the inspection capability of the contractor, in some cases it is set by negotiation. We allow the contractors to select their own size if they can prove statistically that they can reliably find cracks of a very small size by the Non-Destructive Equipment(NDE) they will use on the

assembly line. (Otherwise the default crack size they must use is 0.050 inch depth on a surface crack).

2) Fatigue crack growth rate-- information for various loadings and environments in the most critical areas of the structure.
3) End Point—this is the point where the structure can no longer function as a flight structure. This calculation also has to take into account any safety margins required by accumulated flight hours or other critical to flight conditions.

This is where the AFML really made a giant step forward! The Systems Support Division developed the lab techniques to make specimens for testing aluminum, titanium, and steel materials which cover the basic aircraft airframe metals.

Our method of fabrication evolved somewhat as we improved our process but below is the basic format:

1) Decide on the number of specimens and flaw size range for each alloy. The process is tedious and takes a lot of continual measurements to keep the integrity of the finished product.
2) Initiate a starter defect. This was initially small machined notches, but we learned to use laser strikes and thin foil electric discharge machining to our advantage.
3) We would load the specimen in a three point bending fixture to apply a tensile fatigue loading on the surface of the starter notch. Both our high speed Amsler fatigue machine and the MTS servohydraulic machines were used to produce the growth of the cracks into the depth of the specimen. The flaws would grow very predictably into thumb-nail shaped flaws and we could predict the flaw depth necessary to be removed to get the desired surface length on the machined surface. The flaw shape went into the depth in a nominal 2:1 length to depth ratio.
4) When we got to the calculated precrack size we would take the specimens to our very talented and conscientious machine shop. We would furnish them with the calculated machine cut depth that we

would have to take off to a) remove all starter notch indications and b) finish to the flaw size we needed for each of the specimens.

5) The initial ten specimens were given to North American Aircraft (NAA) of Los Angeles. They ran them through their standard inspection, then through another super inspection by the best in the company. Two of their NDE Reps came back to our AFML lab and declared there were no flaws in any of the specimens.
6) We had produced five of the specimens with flaws and five with no flaws in them. We had the reps select a specimen from the five with the flaws. We then had our inhouse people make saw cuts to close to the flaw location. We then put the specimen in a vise and loaded it in bending until FAILURE with a BEAUTIFUL SEMI-CIRCLE FLAW of 0.100 inch surface length!
7) The NAA people wanted more proof , so we had them select another specimen with the exact same outcome. This surface length was 0.125 inch and just as BEAUTIFUL! With this second proof specimen staring back at them they decided to call NAA/LA and let them know they had some improvements to make in their inspection process.
8) The NAA leaders took the downfall of their inspection system seriously! They went through a complete cleanup and overhaul of their system, that included retraining and qualifications for the new methods they had to the subscribe to. After about two years of progress the NAA inspection team was judged to be one of the best in the country.
9) Overall the inspection improvement program the AFML produced over 1000 flawed specimens for use by all active aircraft systems. The Damage Tolerance Assessment (DADTA) was being applied to all active aircraft programs. Included were C-5, F-15, and A-10.

In order to use the statistical approach in design we had to have a good handle on what a miss in the inspection would mean to the safety of flight. For this approach to be developed we called on Dr Paul Packman from Vanderbilt University. Dr Packman was enlisted for a years sabbatical as a Visiting Scientist by Dr Ted Nicholas.

The aircraft structures got the most attention coming off the design changes in aircraft due to the Damage Tolerant Approach. However the Turbine Engine Design was following right behind. Dr Walter Reiman, MLLN, was working with Aeronautical Flight Propulsion Lab to convert the ASIP document to the Engine Structural Integrity Program version to take advantage of the the damage tolerant assets which could aid in new turbine engine design.

And once again the System Support Division was in the business of making inspection specimens of now superalloys and high temperature alloys. And the loads now go round and round!   Life goes on!