SAND2011-2947 C

SAND2011-2947C

Survey of Transport Airplane Structural Repairs and Alterations: Survey & Teardown Final Results

2011 Aircraft Airworthiness & Sustainment Conference

April 20, 2011

Michel D. Bode[1], Walter M. Sippel[2], Douglas Ostgaard[2], and John G. Bakuckas[3]

[1] Sandia National Laboratories
Airworthiness Assurance NDI Validation Center (AANC)
[2] Transport Standards Staff
Airframe and Cabin Safety Branch, ANM-115
Federal Aviation Administration
[3] William J. Hughes Technical Center
Airworthiness Assurance Branch, AJP-6360
Federal Aviation Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Acknowledgements

***Ciji Nelson*, *Justin Newcomer*, *Todd Sokol, Mark Marrujo, Josh DeReu* – Sandia National Labs**

Airplane operators that gave us access to their airplanes for field surveys.

Airplane salvage operators that provided teardown specimens.

Presentation Outline

- Widespread Fatigue Damage (WFD) Overview
- WFD Rule, Public Comment & Need for Research to Support Rulemaking
- Repair, Alteration and Modification (RAMs) Survey Work Plan Tasking
- Review of Prior AAWG Survey & Existing Data
- Field Survey of Active & Retired Airplanes
- Teardown Inspection of Retired RAMs
  - Review of Individual Teardown Specimens
- FAA Estimates - Number of RAMs in US Domestic Fleet
- Risk Assessment - Based on RAMs Estimates & Teardown Inspection Findings to Support Potential WFD Rulemaking

Technical Overview

•Widespread Fatigue Damage (WFD) = Is the simultaneous presence of cracks at multiple structural locations that are of sufficient size and density that the structure will no longer meet the residual strength requirements of 14 CFR 25.571(b).

•Sources of Widespread Fatigue Damage are:

- •Multiple Site Damage (MSD) - the simultaneous presence of fatigue cracks that grow together in the same structural element (e.g. fatigue cracking in fuselage skin at lap joint multiple adjacent fastener holes).
- •Multiple Element Damage (MED) - the simultaneous presence of fatigue cracks in similar adjacent structural elements (e.g. fatigue cracking in multiple adjacent stringer to frame attach clips).

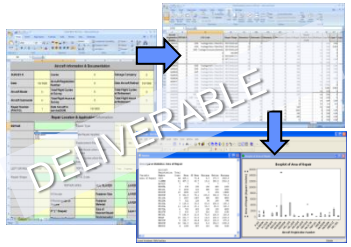
Aloha Flight 243

Southwest 737-300

Overview of WFD Rule & RAMs Survey

- Widespread Fatigue Damage (WFD) notice of proposed rulemaking (NPRM), April 2006.
  - Preclude catastrophic failure of primary airframe structures in transport category airplanes.
  - Requirements included establishing Limits of Validity (essentially life limits) for primary airplane structures and repairs, alterations or modifications (RAMs) to primary airframe structures.
- Dec 2008 public meeting elicited changes to NPRM, including eliminating most RAMs from the WFD final rule. However, FAA wanted data to ensure RAMs would not lead to WFD.
- AANC was tasked with:
  - Gathering and providing field survey data on the occurrence of RAMs in the US domestic transport fleet to support FAA rulemaking determinations.
  - Harvesting RAMs from retired airplanes and performing teardown inspections looking for multi-site, multi-element, and especially widespread fatigue damage.
- FAA preliminary report internally issued in September 2010 and a full data review and final report estimated complete in Dec 2011.
- Aging Airplane Program: WFD; Final Rule was published 15 November 2010, eliminated requirement to establish Limits of Validity for RAMS except when mandated by AD and it still requires OEMs to establish life limits on the baseline airplane structure. Operators must incorporate new limits into maintenance programs.

Sandia/AANC Project Tasking



TASK	STATUS
1. Work Plan and Review Prior AAWG Survey	Complete
2. Survey Aviation Safety Data (1985 to present)	Complete
3. Field Survey of Repairs, Alterations & Modifications (mostly In-Service Airplanes)	Complete
4. Teardown Inspections of Retired Repairs, Alterations & Modifications	Almost Complete (Estimate 2 months more)
5. Documentation and Database Development a. Field Survey b. Teardown	a. Field Survey Database Complete b. Teardown Database Almost Complete

Task 1. Develop Detailed Work Plan

- **With removal of RAMs from WFD Rule NPRM in 2008, the FAA wanted data to support any final determinations and/or supplemental rulemaking regarding the establishment of Limits of Validity pertaining to RAMs.**

- **Purpose of the RAMs survey was to estimate the extent of RAMs currently flying in US domestic transport airplane fleet and estimate the risk of WFD occurring due to the presence of RAMs.**

- **Input from FAA Fatigue & Damage Tolerance Specialists, FSDO Experts on RAMs, Technical Center Structural Integrity Researchers, and Aircraft Certification Office Transport Standards Staff and other FAA experts was sought and incorporated into the work plan.**

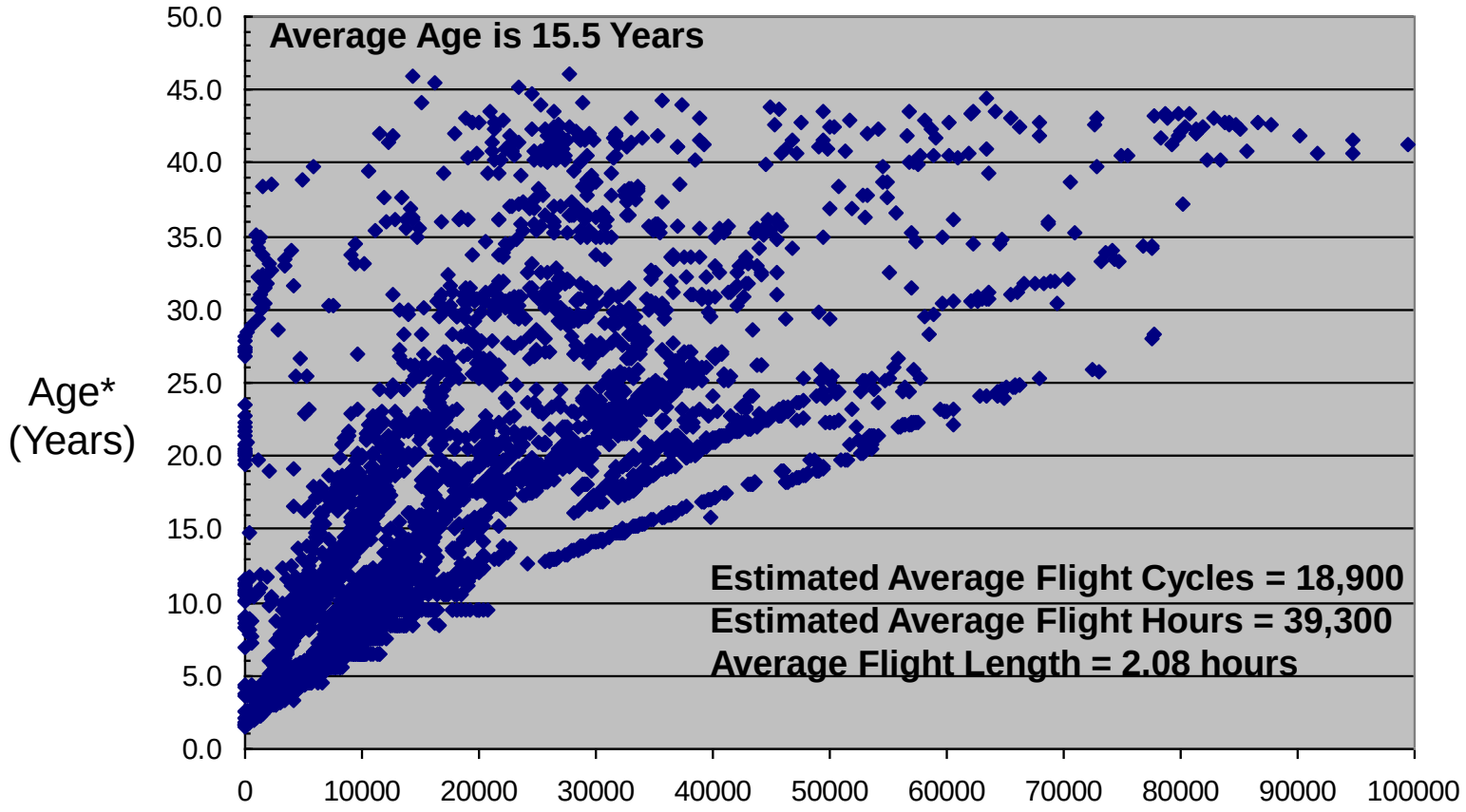
Task 2. Review Existing Safety Data

- Survey Aviation Safety Database Records
- Collected and examined over 440,000 individual SDR records
- Little useful information gained due to incomplete SDR record fields
- SDR's get filed as required, but most mechanics only complete the comments fields.
- Review of Airworthiness Directives and Service Bulletins to guide Field Survey and Teardown Specimen collection activities

Task 3. Field Survey of RAMs

US Fleet** of 5014 Aircraft

Transport Category, Part 121 & 129, above 75 kip MTOW



* Note: Age is relative to June 2010
**Note: Fleet content from "Snapshot in Time" date of Nov 30, 2008

FAA William J. Hughes Technical Center

Sandia National Laboratories

Field Survey Preliminary Findings

- Data used to estimate the numbers, sizes, locations, ages of RAMs in the US Domestic Transport Fleet and estimate risk of WFD.
- No evidence of WFD on properly designed and installed RAMs
- Some evidence of poor workmanship (less than 1% of RAMs)

Summary Statistics	
Total Number of Airplanes	154
Total Number of RAMS	2584
Average Age at Survey (Months)	301.22
Average Number of Flight Hours	73,198.40
Average Number of Flight Cycles	33,375.00
Average Flight Hours per Cycle	2.99
Average Number RAMS per Airplane	16.78
Average Size RAM (Sqin)	303.46
Number of RAMS with Dates	555
Average Age of RAMS at Survey (Months)	61.78

Nearest Structure Distribution	
Repair	479
Door	819
Window	158
Major Joint or Splice	634
Gear Mounts or Hard Points	70
Cutout in Structure	54
Control Surface Attachment	21
Vertical or Horizontal Tail Attachments	31
Blank	356

Repair Category Distribution	
UNK	671
A	513
B	1367
C	71

Workmanship/Condition Distribution	
No Internal Access	1873
1	419
2	212
3	62
4	10
5	12

Root Cause Distribution	
Unknown	1287
Damage	808
Structural Modification	171
Antenna Modification	112
Corrosion	67
Airworthiness Directive	23
Lightninig Strike	18

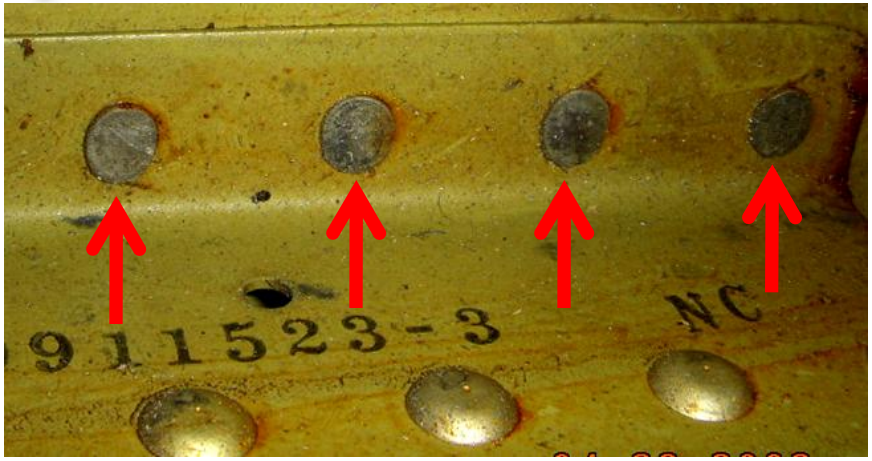
Repair Location Distribution	
FUSELAGE	1569
WING	161
PRESSURIZED DOOR	85
FRAME SUPPORT	398
Press Bulkhead AFT	45
Press Bulkhead FWD	25
H STAB	7
Blank	319

Replacement Repair Distribution	
Yes	106
No	603
UNK	1913

Reason For Replacement	
ADDITIONAL DAMAGE	8
Antenna Modification	9
Category "B" to "A"	5
EA R&R EXISTING REPAIR	7
FURTHER CRACKING	13
INCORRECT INSTALLATION	5
NO DOCUMENTATION	3
Not per FAA approved repair data	7
RAP	2
Replacement of Temp Repair	9
Other	8
UNK	1934
NA	603

Repair Area (Sqin) Distribution	
A (0-100)	1101
B (100-500)	1095
C (500-1,000)	183
D (1,000-2,000)	86
E (2,000-10,000)	55
F (>10,000)	2
Blank	100

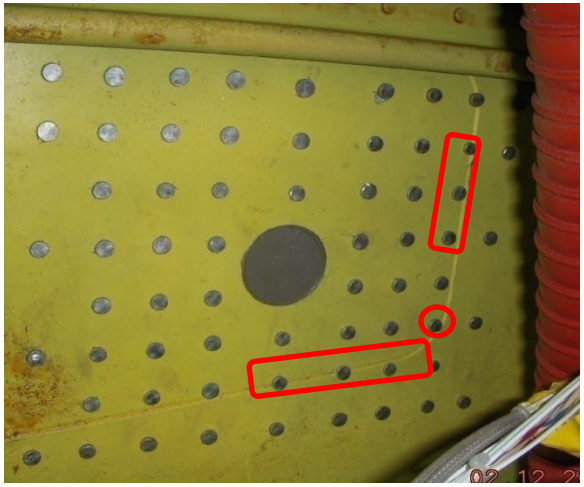
Examples of Poor Workmanship



Overdriven Rivets

(A)Zero Edge distance, (B) Tooling mark

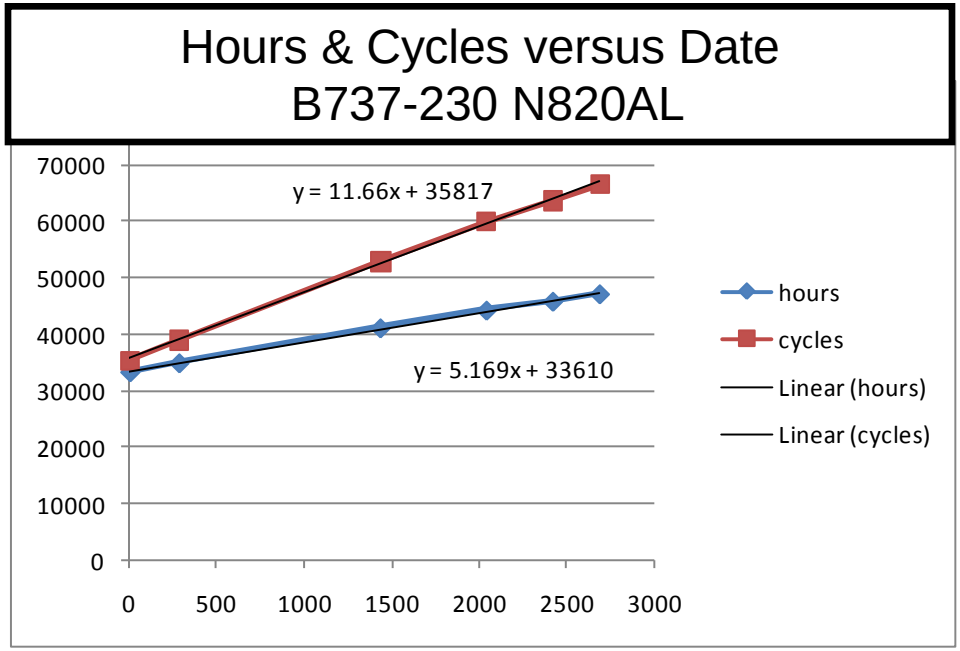
Fasteners installed in Chem-mil skin step



Missing filler and field fasteners required per repair drawing

Task 4. Collect, Teardown & Inspect Retired RAMs

- **25 different specimens identified and acquired along with maintenance records**
- **12 different airplanes across all models and many different operators.**
- **Teardown protocols followed including layer separation, eddy current inspection of all open fastener holes and some wide area scanning.**
- **Extensive photo documentation and collection of all fatigue cracks found.**



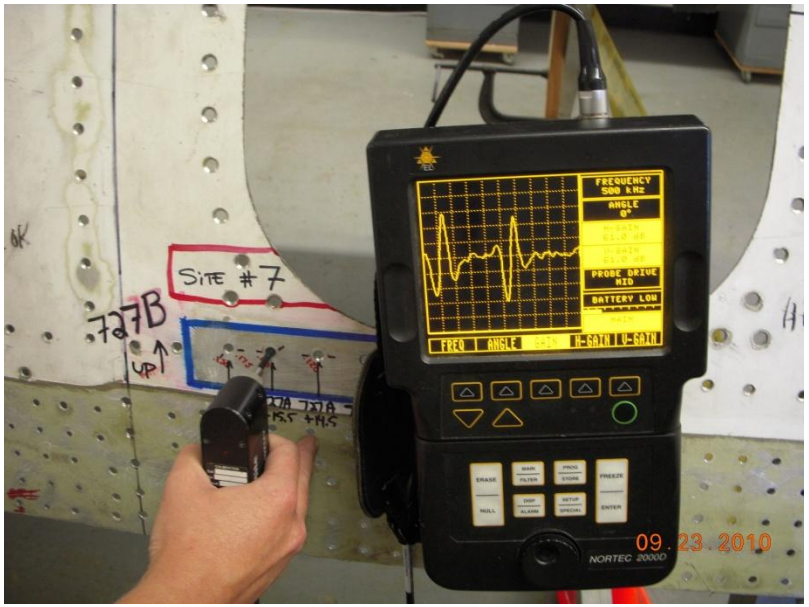
Full maintenance records with hours and cycles not always available.

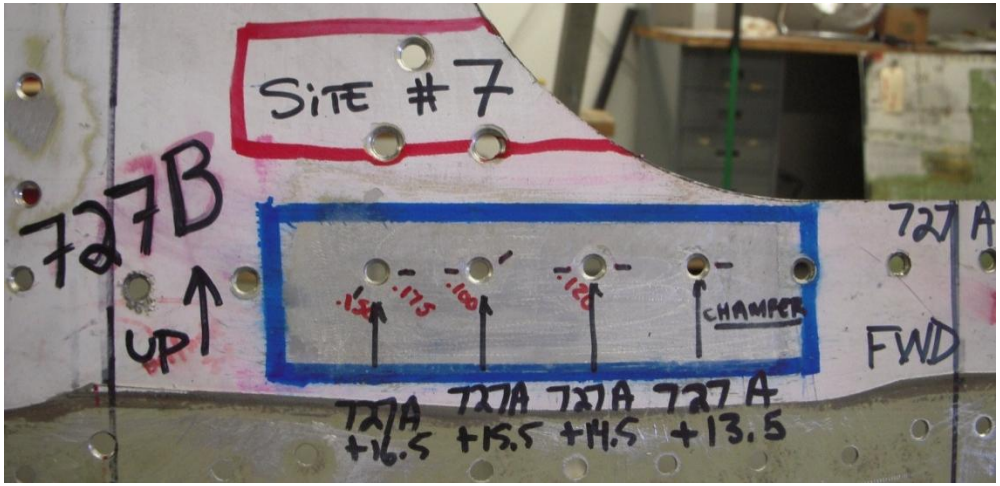
date	hours	cycles
4/30/1997	33459	35509
2/5/1998	35051	39058
4/1/2001	41258	53009
11/29/2002	44400	60171
12/14/2003	45980	63764
9/7/2004	47304	66701
retired		86436

Teardown Specimens

Item #	Airplane	Airplane Model	Component Description	Approx. Location	Flight Hours/Cycles	Teardown Status	NDI Results Baseline Structure	NDI Results Repair Structure
1	N820AL	B737-200	Lap Joint Window Belt Replacement Doubler RIGHT	BS 727-907, Str 9L-15R	35,255 FC	Complete	11 sites w/ 16 cracks	2 clips w/ 3 cracks
2	N820AL	B737-200	Lap Joint Window Belt Replacement Doubler LEFT	BS 727-907, Str 9L-15L	35,255 FC	Complete	No Indications	No indications
3	N820AL	B737-200	Lap Joint Replacement Doubler	BS 540-907, Str 4L	35,255 FC	Complete	No Indications	No indications
4	N820AL	B737-200	Lap Joint Replacement Doubler	BS 540-907, Str 4R	35,255 FC	Complete	No Indications	No indications
5	N600GC	DC-10-30F	STC Conversion Cargo Door Pax to Freighter	BS 575-840, Str 5L-31L	29,557 FH /7180 FC	Complete	No Indications	No indications
6	N810EA	B727-200	STC Conversion Cargo Door Pax to Freighter	BS 450-700, Str 1-20L	Date 6 Dec 1993	In Process	TBD	TBD
LR1	N642NW	B747-200	Fuselage LH Aft Lower Lap Repair	BS 1700-1840, Str 38L-42L	25181/3777	Complete	No Indications	No Indications
LR2	N634US	B747-200	Fuselage Skin, APB Web + T-chord	BS 2360, Str 1-22R	Approx Date Mar 2000	Complete	No Indications	No Indications
LR3	N920UW	B757-200	Fuselage Fwd Skin	BS 560-680, Str 12L-17L	3 RAMs FH/FC Known	Complete	No Indications	No Indications
LR4	N226KW	A300-B4-203	Wing to Fuselage SB53-265 Repair, hole "I" FR47	FR 47 LH, Lower Aft Wing S	15821/10031	In Process	3 Known Cracks	TBD
LR5	N226KW	A300-B4-203	Lap Joint Repair Doubler below window belt RH	FR 34-41, Str 18R	Searching Records	In Process	TBD	TBD
LR6	N226KW	A300-B4-203	Lap Joint Repair Doubler at floor line RH	FR 36-44, Str 28R	Searching Records	Complete	No Indications	No Indications
LR7	N226KW	A300-B4-203	Skin Doubler Gross Wt Increase Mods LH & RH	Aft of MLG bay, Below aft w	Searching Records	TBD	TBD	TBD
LR8	N820AL	B737-200	Fuselage Skin combines 4 RAMs	BS 727-727B, Str 15L-19L	16327FC	Complete	1 site w/ 7cracks in 4 holes	No Indications
LR9	N820AL	B737-201	Fuselage Skin comines 2 RAMs at Potable Water Pc	BS 927-987, Str 20L-27L	33427FC	Complete	No Indications	No Indications
LR10	N820AL	B737-202	Lower Aft Fuselage Skin Repair Doubler	BS 834-899 , Str 25L-25R	32989FC	Complete	No Indications	1 cracked stringer clip
LR11	N920UW	B757-200	Cab Skin Repair, 4 way splice	around BS 310. LH side	Searching Records	Complete	No Indications	No Indications
LR12	N918UW	B757-200	Fwd Fuselage Skin Repair below window belt lap j	BS 570-630, Str 14L-19L	Approx 11,500 FC	Complete	No Indications	No Indications
LR13	N942F	DC-9-30	Fuselage Skin Repair Fwd LH Wing under fairing	BS 760-813, Str 14L-22L	approx 2000 FH/FC?	Complete	No Indications	No Indications
LR14	VT-EYI	A320	Fuselage LH Aft of L3 Cabin Door 4 RAMs in one		have records	In Process	TBD	TBD
LR15	N327NW	A320-200	Fuselage skin at FWD RH Avionics Access Door &	FR18 & FR24, STR33RH & S	12350/5997	Complete	No Indications	No Indications
LR16	N601DL	B757-200	Fuselage Fwd Lwr VHF Antenna Skin	BS 715-740, Str 28L-28R	16984/6929	Complete	No Indications	No Indications

Teardown Inspection Process





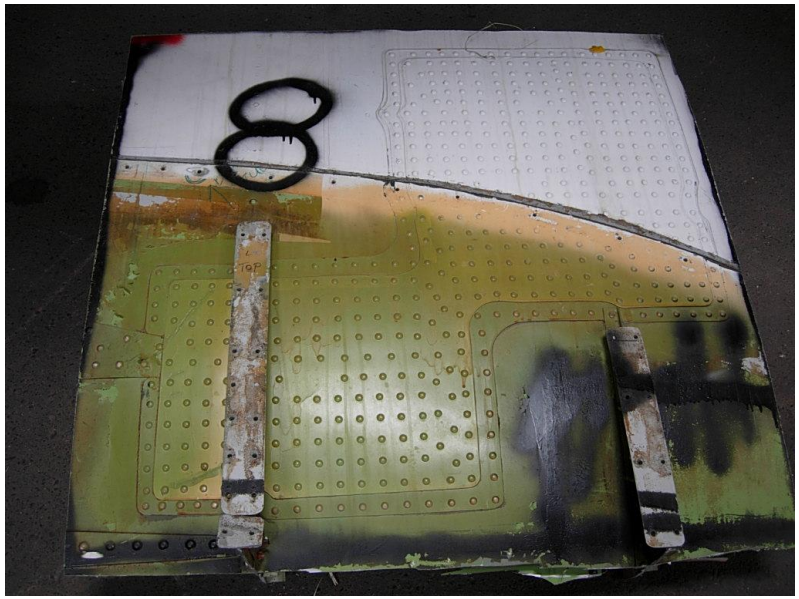
B737-200 Fuselage Sections (2) Window Belt Replacement Lap Joint Modification Specimen 1&2

- **Teardown and Inspection complete**
- **BS-727-907, S-10L-14L & S-10R-14R**
- **Modified structure has 35255 cycles since installation and 86436 total cycles at retirement**

B737-200 Fuselage Sections (4) Crown Skin Lap Joint Modification Specimens 3 & 4

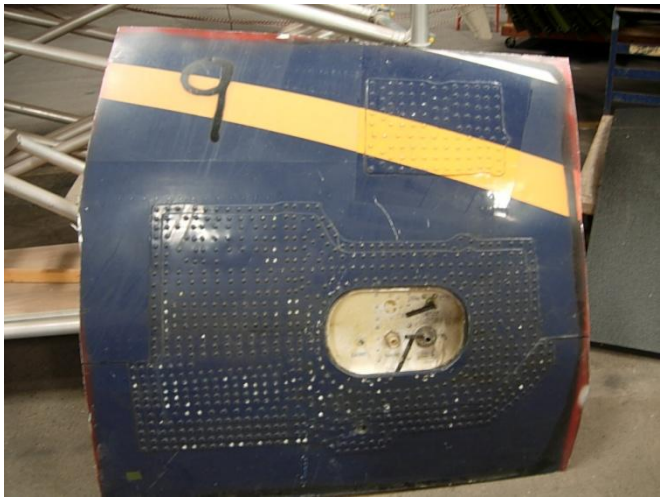
- **Teardown and Inspection complete**
- **Modified structure has 35255 cycles since installation and 86436 total cycles at retirement**
- **BS-540-907 S-4L & S-4R**

B737-230 fuselage sections – Skin Repair Patch LR8



- **Fuselage skin repairs at BS-747, S-14L-19L**
- **Repaired at 70109 cycles (est.)**
- **Airplane retired at 86436 total cycles**
- **16327 Cycles (est.) on repaired structure**
- **Repair of skin crack at BS-727A+14 above S-17L.**
- **Repair incorporates 2 existing repairs which were removed.**

B737-230 fuselage sections – Skin Repair Patch LR9



- **Large fuselage skin repair at BS-967, S-25L forward side of water panel cutout**
- **Repaired at 53009 cycles (4/18/01)**
- **Airplane retired at 86436 total cycles**
- **33427 Cycles on repaired structure**
- **Two adjacent repairs**
- **Older, small repair nearby at B- 942 S-24L (5/30/00) (estimated 48946 cycles at repair)**

B737-230 fuselage sections – Skin Repair Patch LR10

- **Fuselage skin repairs at BS-807-867, S-26L-26R**
- **Repaired at 53447 cycles (est.)**
- **Airplane retired at 86436 total cycles**
- **32989 Cycles on repaired structure (est.)**
- **Multiple co-located repairs**
- **Larger Repair possibly encompasses older small repair**

B727 Passenger to Freight STC Conversion Cargo Door

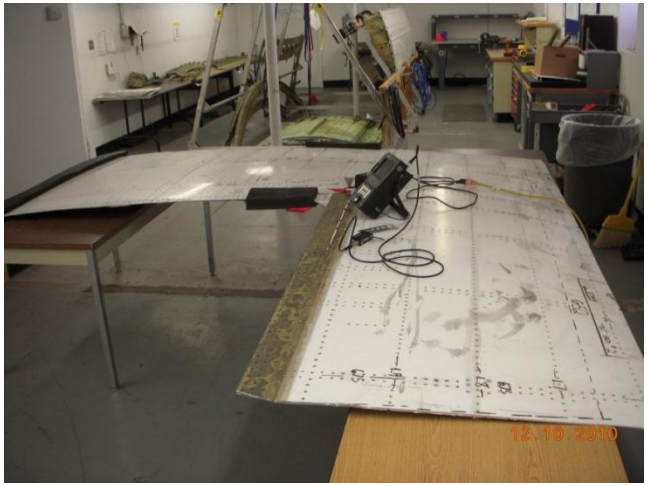
- Passenger to Freight STC conversion Cargo Door
- Pemco STC and install – Full data package on hand
- Airplane registered as both N810EA and N936PG
- Specimen 5

FAA William J. Hughes Technical Center

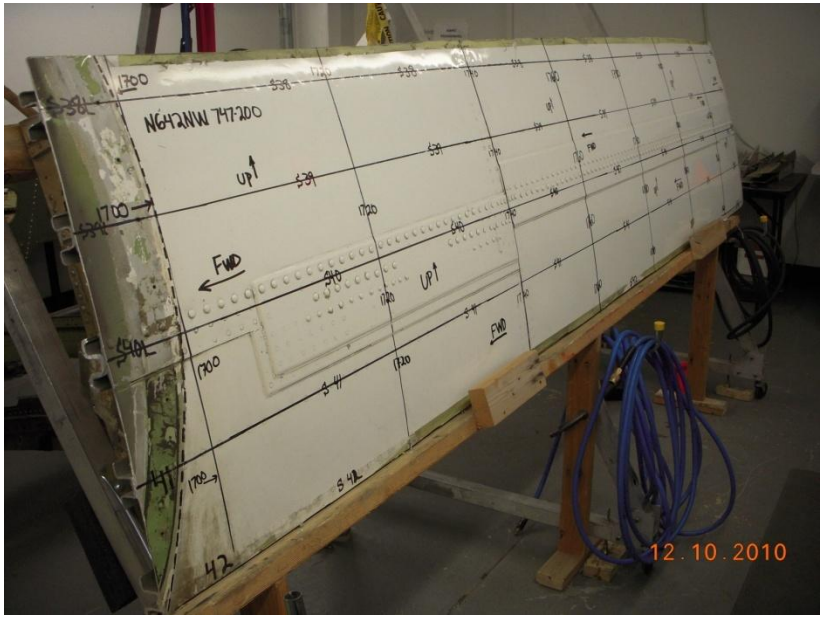
Sandia National Laboratories

DC-10-30F Passenger to Freight STC Conversion Cargo Door

- Passenger to Freight STC conversion Cargo Door
- 35522 FC
- N600GC
- Specimen 6



B747-200 Fuselage LH Aft Lower Lap Repair
N642NW BS 1700-1840, Str 38L-42L
25181 FH 3777 FC, LR1



B747-200, N634US, Fuselage Skin & APB Web & T-Chord, BS 2360, Str 1-22R Installed Approx. Mar 2000, LR2

FAA William J. Hughes Technical Center

Sandia National Laboratories

B757-200, N920UW, Fuselage Fwd Skin
BS 560-680, Str 12L-17L,
3 RAMs with Known FH/FC, LR3

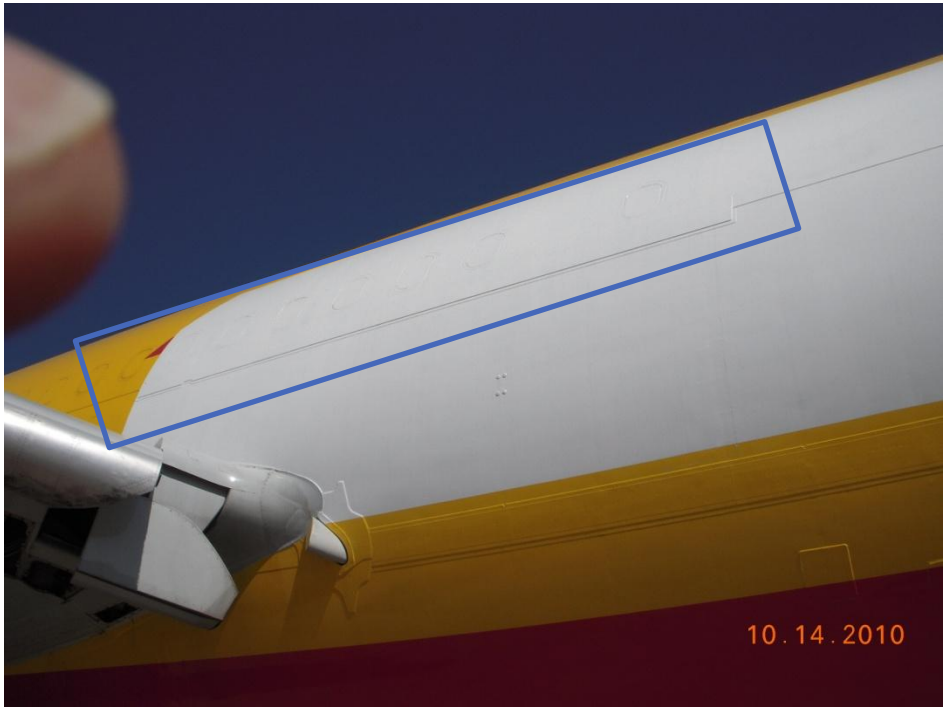
A300-B4-200 MSN095 N226KW, LR4
Wing To Fuselage & Lower Rear Spar Repair

- **15821 FH & 10031 FC on Repair**
- **Airbus Engineered Repair installed in France**






A300-B4-203, N226KW, Lap Joint Repair
Doubler below window belt RH,
FR 34-41, Str 18R, LR5



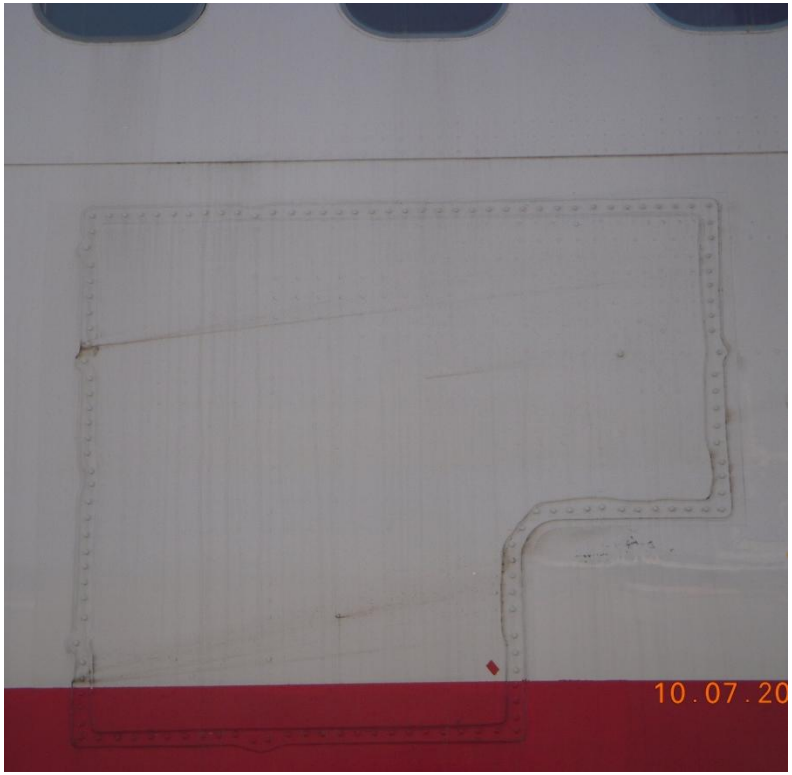
A300-B4-203, N226KW, Lap Joint Repair
Doubler at floor line RH, FR 36-44, Str 28R, LR6

A300-B4-203, N226KW, Skin Doubler Gross Wt Increase Mods LH & RH, Aft of MLG bay, Below aft wing fairings, LR7

2 Panels – Left & Right

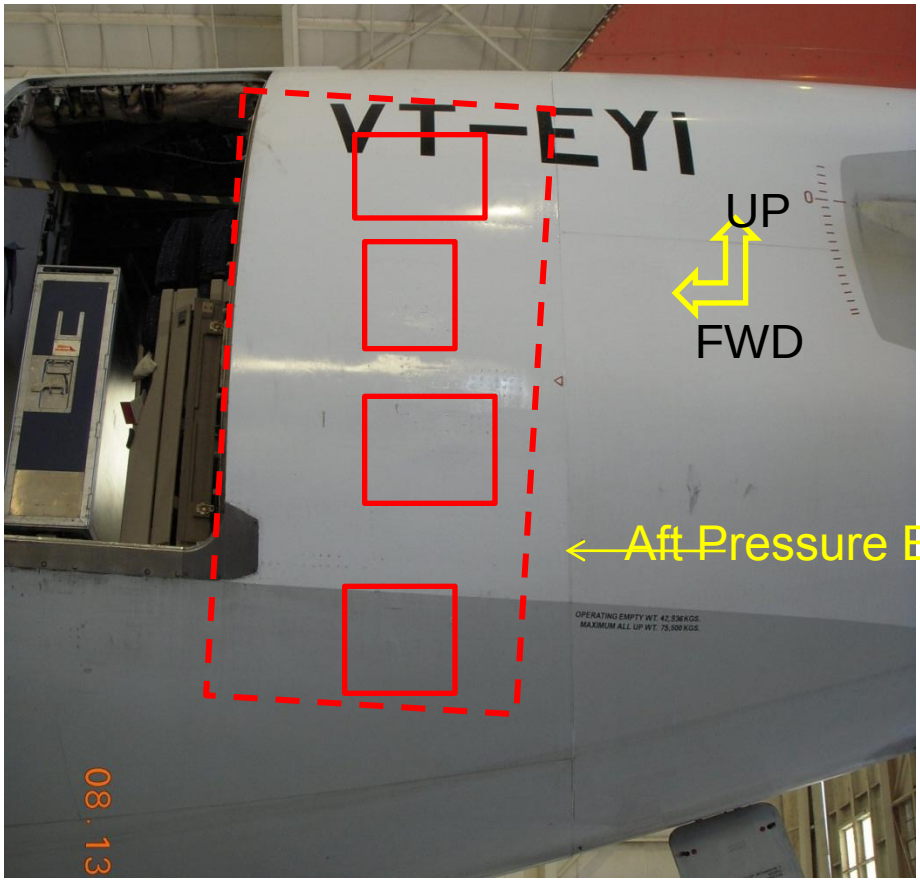
B757-200, N920UW, Cab Skin Repair, 4 way splice, around BS 310. LH side, LR11

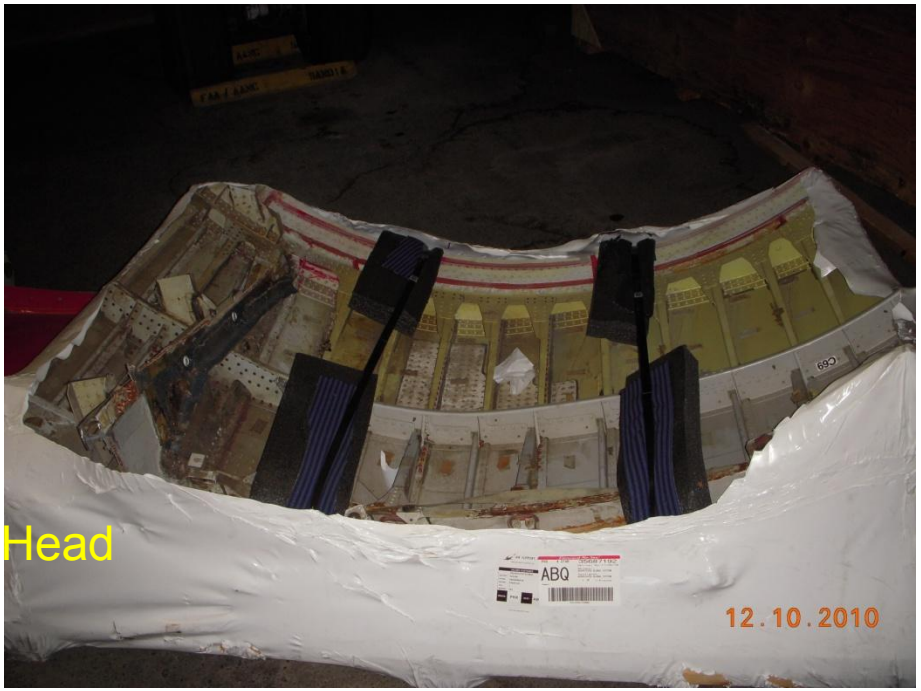
B757-200, N918UW, Fwd Fuselage Skin Repair below window belt lap joint, BS 570-630, Str 14L-19L, Approx 11,500 FC, LR12



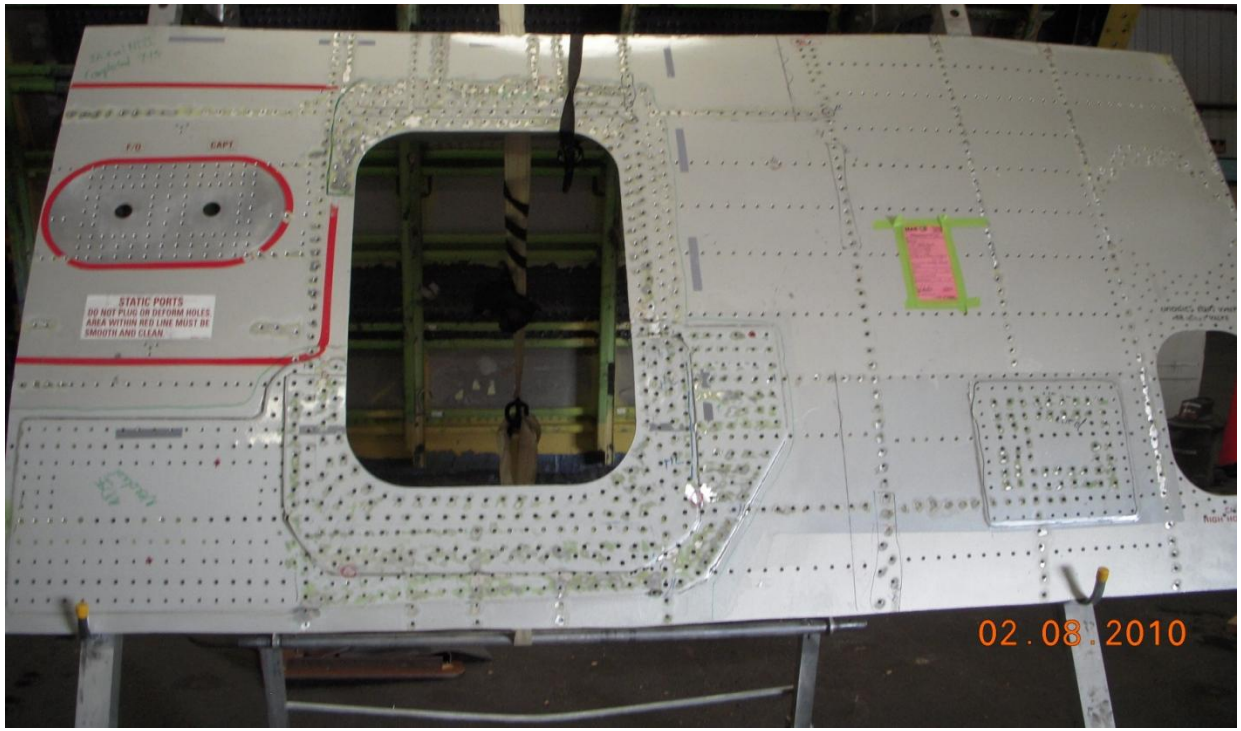
DC-9-30, N942F, Fuselage Skin Repair Fwd LH Wing under fairing, BS 760-813, Str 14L-22L, approx 2000 FH/FC? LR13

A320, VT-EYI, Fuselage LH Aft of L3 Cabin Door 4 RAMs in one, LR14



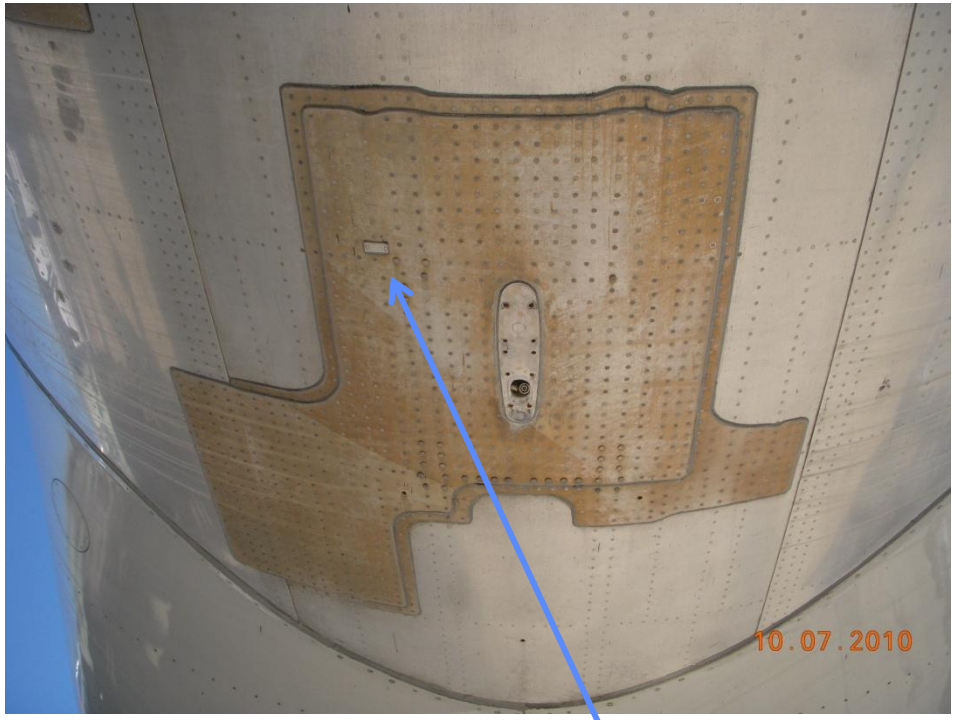


A320-200, N327NW, Fuselage skin at Lower RH Avionics Access Door & Static Ports, 5997 FC, LR15



- Specimen of opportunity from N327NW
- Total Airplane Cycles 23909
- Teardown & Inspection Complete

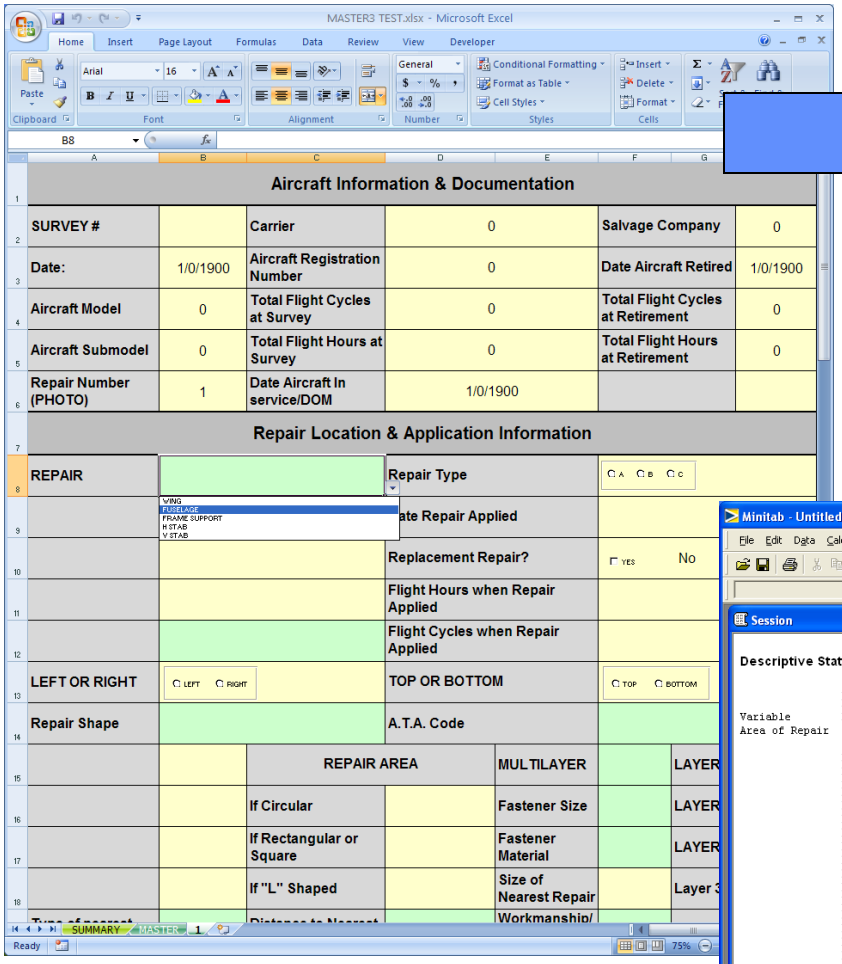
B757-200, N601DL, Fuselage Fwd Lwr VHF Antenna Skin, BS 715-740, Str 28L-28R, 16984 FH 6929 FC, LR16

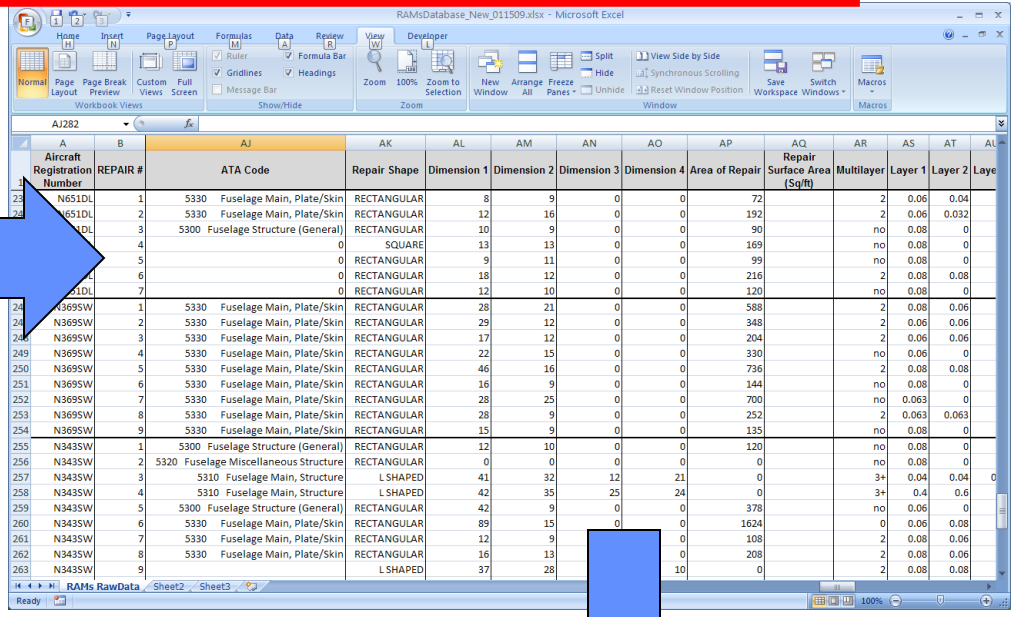


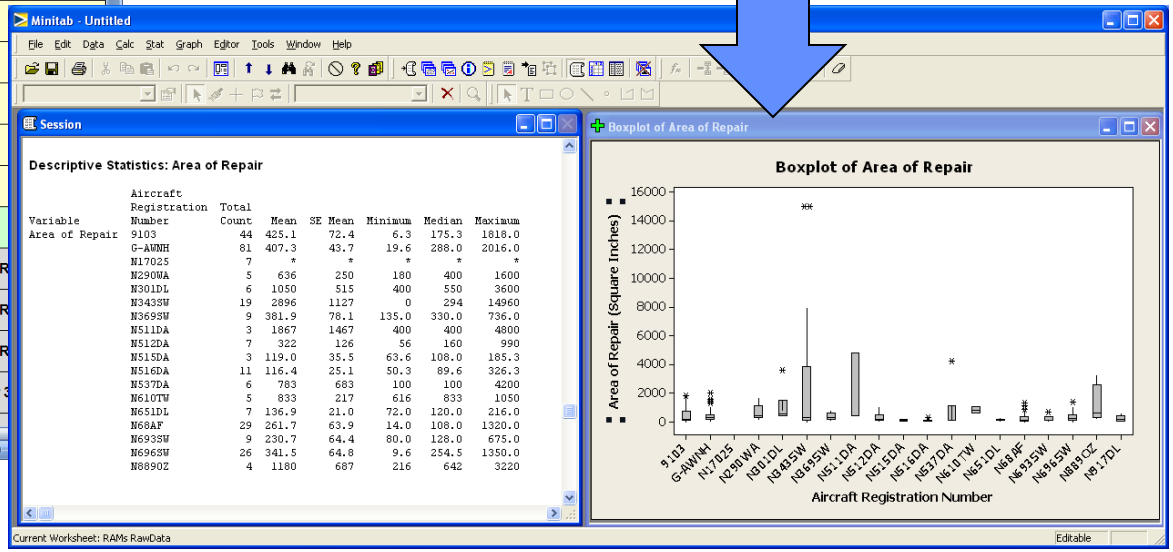
FAA William J. Hughes Technical Center

Sandia National Laboratories

Task 5. Field Survey Database Delivered May 2010



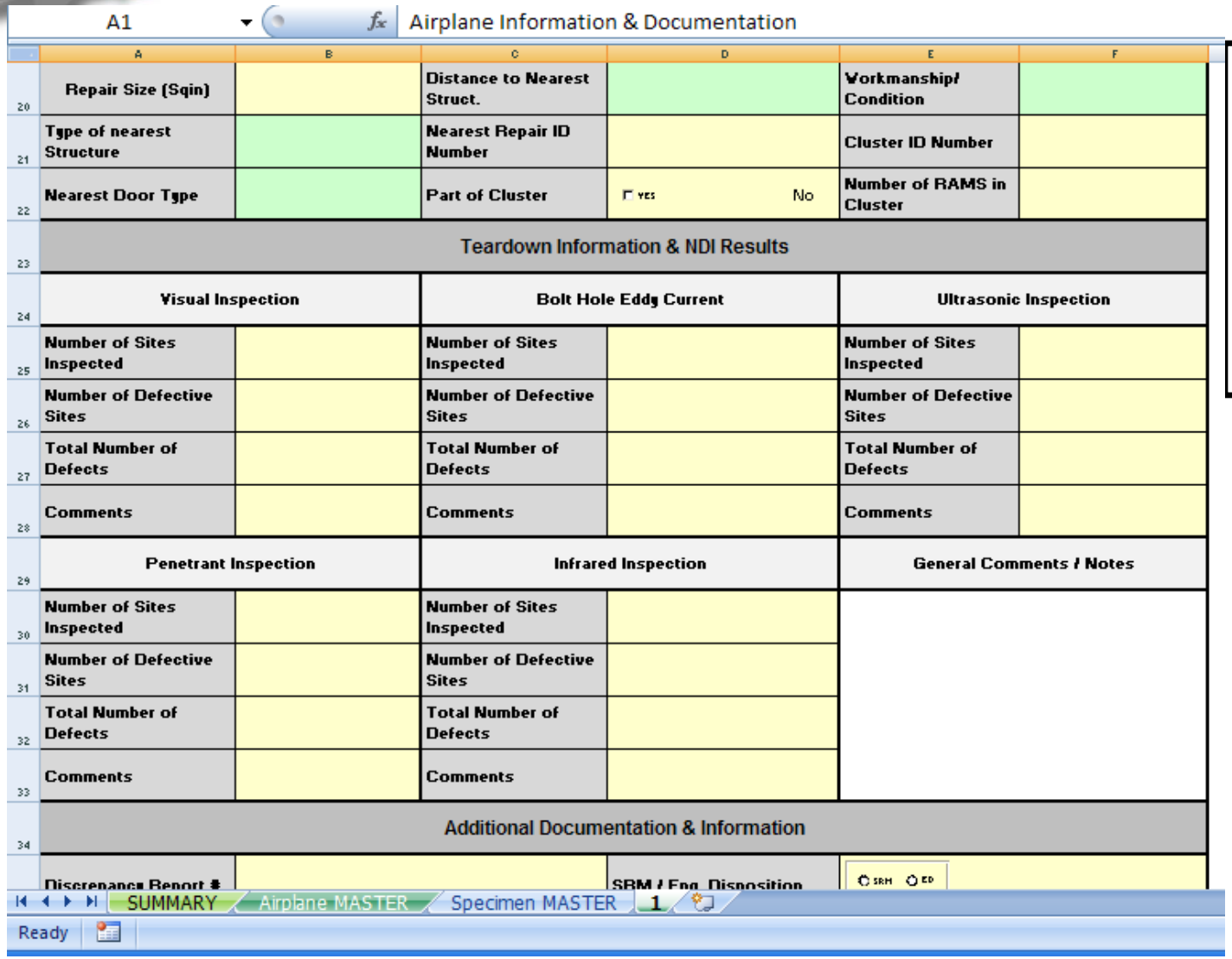




FAA William J. Hughes Technical Center

Sandia National Laboratories

Task 5. Teardown Database Scheduled May 2011



A1 — Airplane Information & Documentation

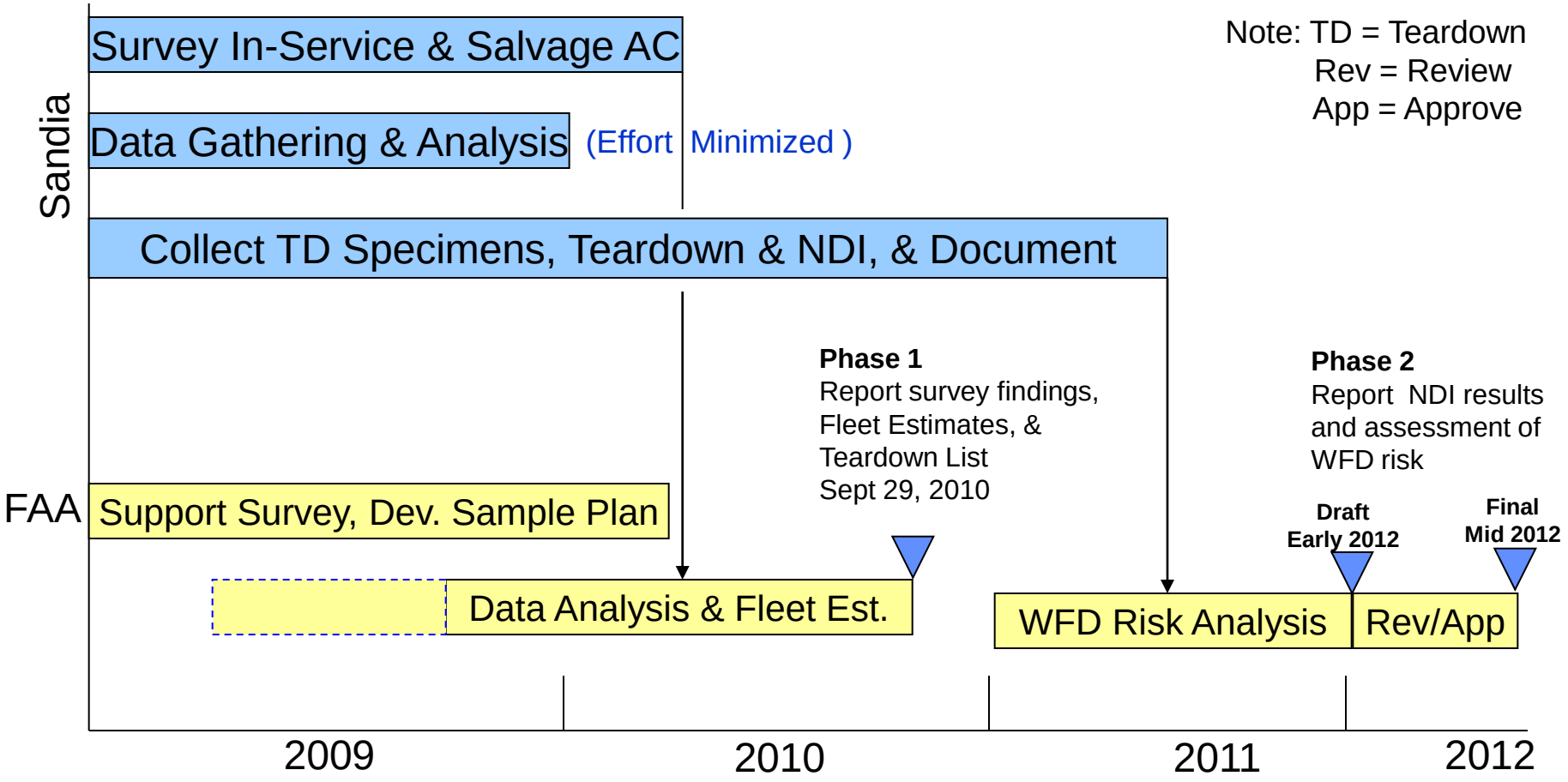
	A	B	C	D	E	F
20	Repair Size (Sqin)		Distance to Nearest Struct.		Workmanship/ Condition	
21	Type of nearest Structure		Nearest Repair ID Number		Cluster ID Number	
22	Nearest Door Type		Part of Cluster	☐ Yes No	Number of RAMS in Cluster	
23	Teardown Information & NDI Results					
24	Visual Inspection		Bolt Hole Eddy Current		Ultrasonic Inspection	
25	Number of Sites Inspected		Number of Sites Inspected		Number of Sites Inspected	
26	Number of Defective Sites		Number of Defective Sites		Number of Defective Sites	
27	Total Number of Defects		Total Number of Defects		Total Number of Defects	
28	Comments		Comments		Comments	
29	Penetrant Inspection		Infrared Inspection		General Comments / Notes	
30	Number of Sites Inspected		Number of Sites Inspected			
31	Number of Defective Sites		Number of Defective Sites			
32	Total Number of Defects		Total Number of Defects			
33	Comments		Comments			
34	Additional Documentation & Information					
	Discrepancy Report #		SBM / Eng. Disposition		○ SBM ○ ED	

SUMMARY | Airplane MASTER | Specimen MASTER | 1

Ready

Teardown Inspection Form Individual Defect Page

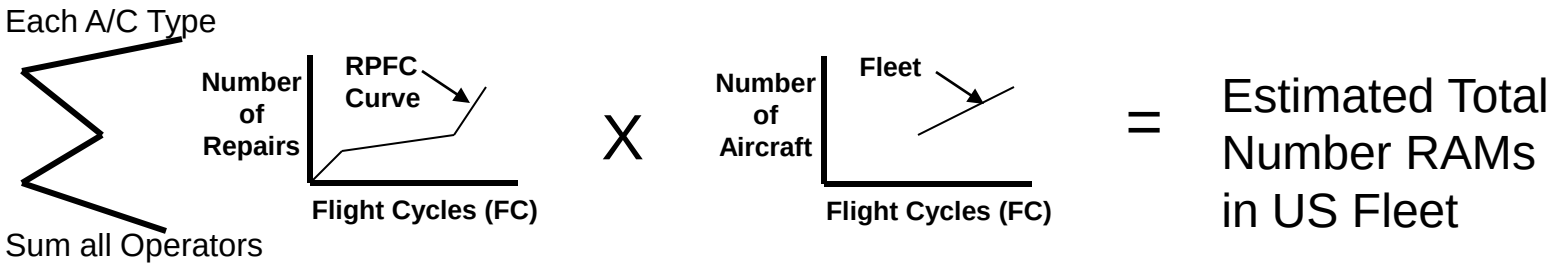
RAMS Research Project Plan



Overall RAMs Analysis Highlight

a) Define an aircraft sampling list for each aircraft type and operator
    1) Show number of airplanes per operator, and targeted age group
b) Perform analysis using sampled survey data. Develop a fleet level:
    1) Magnitude of repairs to baseline and alteration structure
    2) Magnitude of alteration structures
    3) Fatigue Performance data of the repairs and alteration structure

Determine quantity of RAMs in the fleet using the following approach:
Develop a RAMs per Flight Cycle (RPFC) curve and multiply by the number of airplanes in the fleet;
Summing all operators for each airplane type, then sum all airplane types:



Approximately 50,000 RAMs in US Domestic Fleet

Summary of RAMs Survey

- **Currently, LOV requirements for RAMs have been eliminated from the WFD Final Rule (published Nov 15, 2010, finalized Jan 2011).**
- **Acquisition of survey data to support potential future FAA rulemaking determinations on RAMs has been completed.**
  - **Field Survey of about 2584 RAMs on 154 airplanes**
  - **Teardown Inspection of 25 RAMs from 12 airplanes**
  - **WFD associated with RAMs have NOT been observed**
  - **Most RAMs observed appear to be properly installed**
  - **Repair Assessment Program required under AASR**
  - **Existing deficiencies (<1% of RAMs) appear to be workmanship issues**
- **FAA data review and Final Report estimated completion mid 2012**