C-5 Aging Fleet Integrity& Reliability Management (AFIRM)

Rich DiSalle – LM Aero
Alex Gaskin – WR-ALC
December 1, 2005

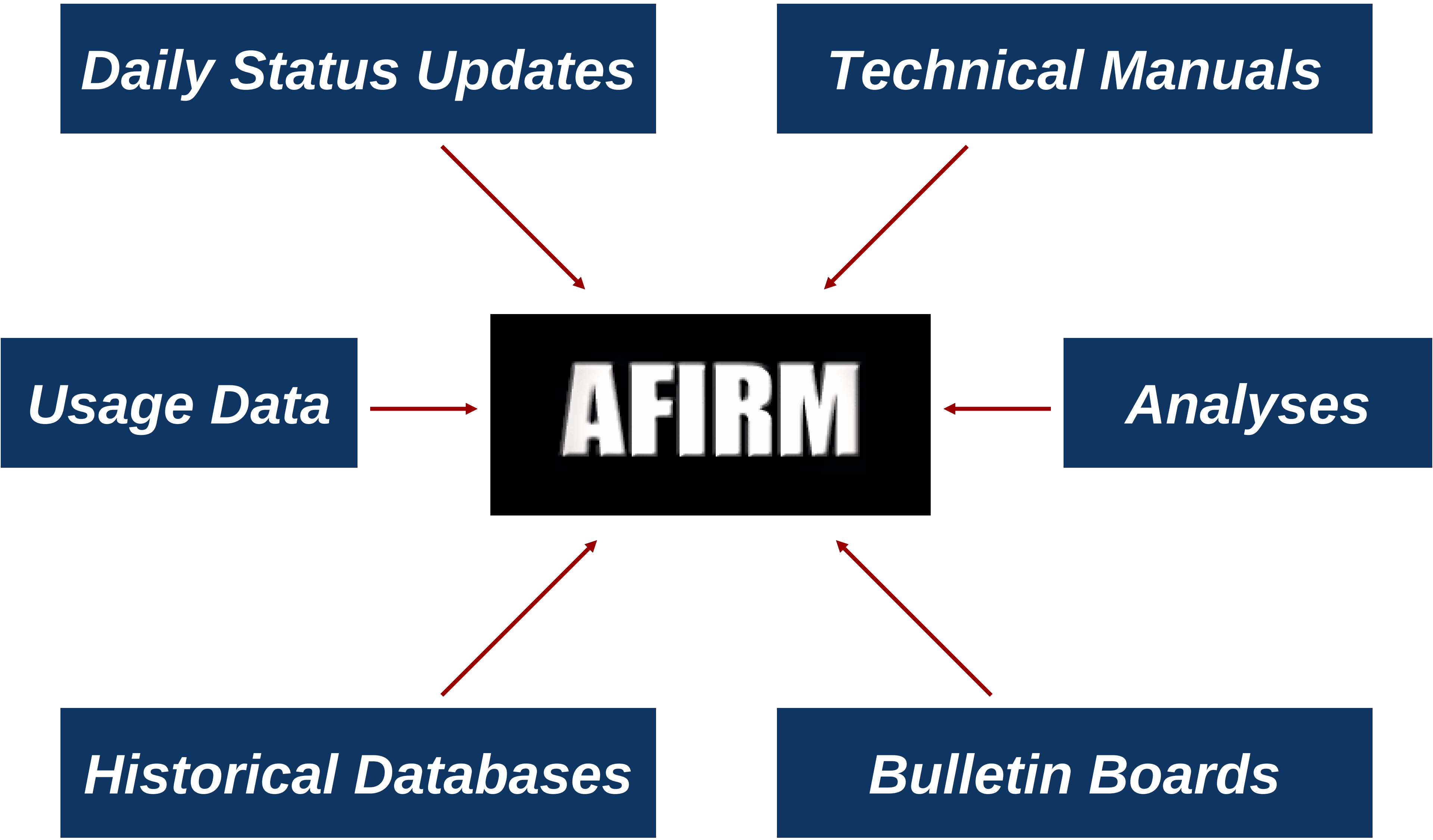
What is AFIRM?

- **AFIRM = ASIP + FSIP**
  - ASIP = Aircraft Structural Integrity Program
  - FSIP = Functional Systems Integrity Program
- **Marriage of Structures and Systems Methodologies ensures the most cost-effective means of Reliability Management.**
  - (A systems component time-changed during PDM is much more cost effective than having an aircraft stranded at a remote base waiting for parts)
- **Effective management of aging aircraft requires an aggressive maintenance plan coupled with comprehensive fleet data.**
  - ASIP and FSIP Managers have access to real-time and archival data
  - Data can be used to manage the entire fleet as well as an individual aircraft

Goals of AFIRM

- Ensure Flight Safety
- Improve Mission Reliability
- Reduce Operation and Maintenance Costs
- Provide a source for an expanding knowledge base
- Consolidate everything needed to manage the fleet into one place

Consolidation of Information



AFIRM Web Site

Updated: Nov-10-2005

AFIRM Aging Fleet Integrity & Reliability Management

ASIP FSIP

Fleet Information Charts | Inspection Dates | Select A/C

C-5 Fleet Summary

Assigned Base	No. A/C	Avg. Flight Hrs.
Altus	8	19,980
Dover	28	15,563
Lackland	16	19,262
Memphis	4	20,483
Stewart	13	19,008
Travis	26	16,309
Westover	15	19,135
Wright-Pat	2	20,102
Total A/C in Service	112	17,715
"A" Models	60	19,357
"B" Models	50	15,813
"C" Models	2	16,002

9 A/C are currently at Robins AFB

5 A/C are currently at LM Aero

64 A/C are currently NMC or PMC

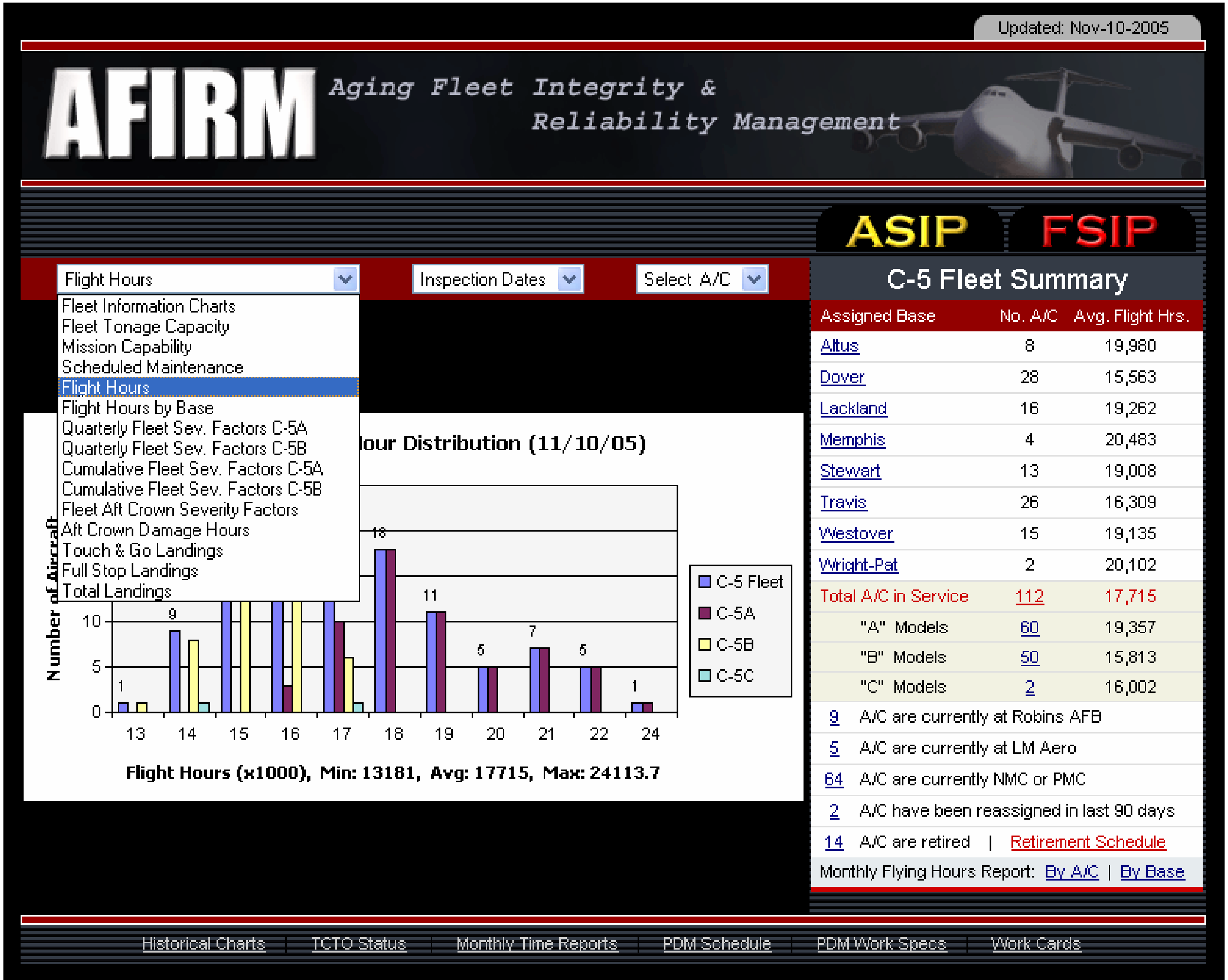
2 A/C have been reassigned in last 90 days

14 A/C are retired | Retirement Schedule

Monthly Flying Hours Report: By A/C | By Base

Historical Charts | TCTO Status | Monthly Time Reports | PDM Schedule | PDM Work Specs | Work Cards

Fleet Information Charts



Fleet Summary / NMC Report

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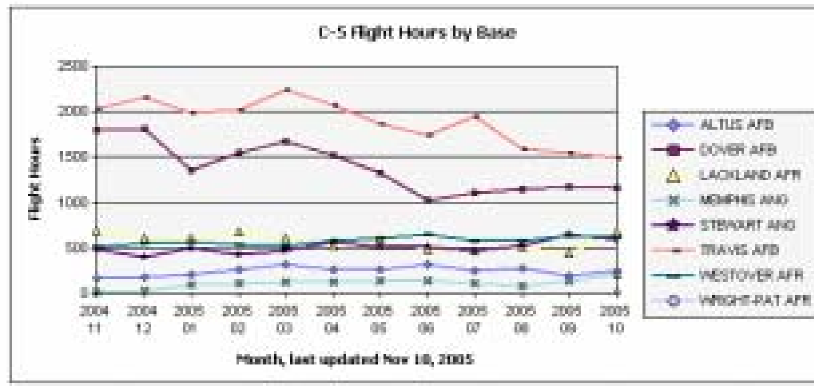
Monthly Flying Hours

AFIRM Aging Fleet Integrity & Reliability Management

C-5 Monthly Flying Hours — View Base Averages by MDS — View Entire Fleet for last 12 months

Date	AMC		AETC	AFR		ANG		Fleet Total
	Dover	Travis	Altus	Lackland	Westover	Stewart	Memphis	
Oct05	1,162	1,409	250	684	627	590	206	5,007
Sep05	1,172	1,547	193	436	629	649	140	4,766
Aug05	1,149	1,593	277	507	577	525	88	4,715
Jul05	1,109	1,943	255	475	576	474	108	4,941
Jun05	1,025	1,746	318	481	653	513	136	4,871
May05	1,327	1,866	267	597	602	513	141	5,316
Apr05	1,518	2,072	263	527	581	563	129	5,652
Mar05	1,674	2,243	323	603	520	463	122	5,948
Feb05	1,542	2,014	260	676	543	434	117	5,584
Jan05	1,247	1,991	209	609	560	492	103	5,210
Dec04	1,804	2,150	180	603	547	400	28	5,712
Nov04	1,794	2,034	199	693	606	482	16	5,690
Totals:	16,622	22,690	2,960	6,868	6,920	6,097	1,334	63,512



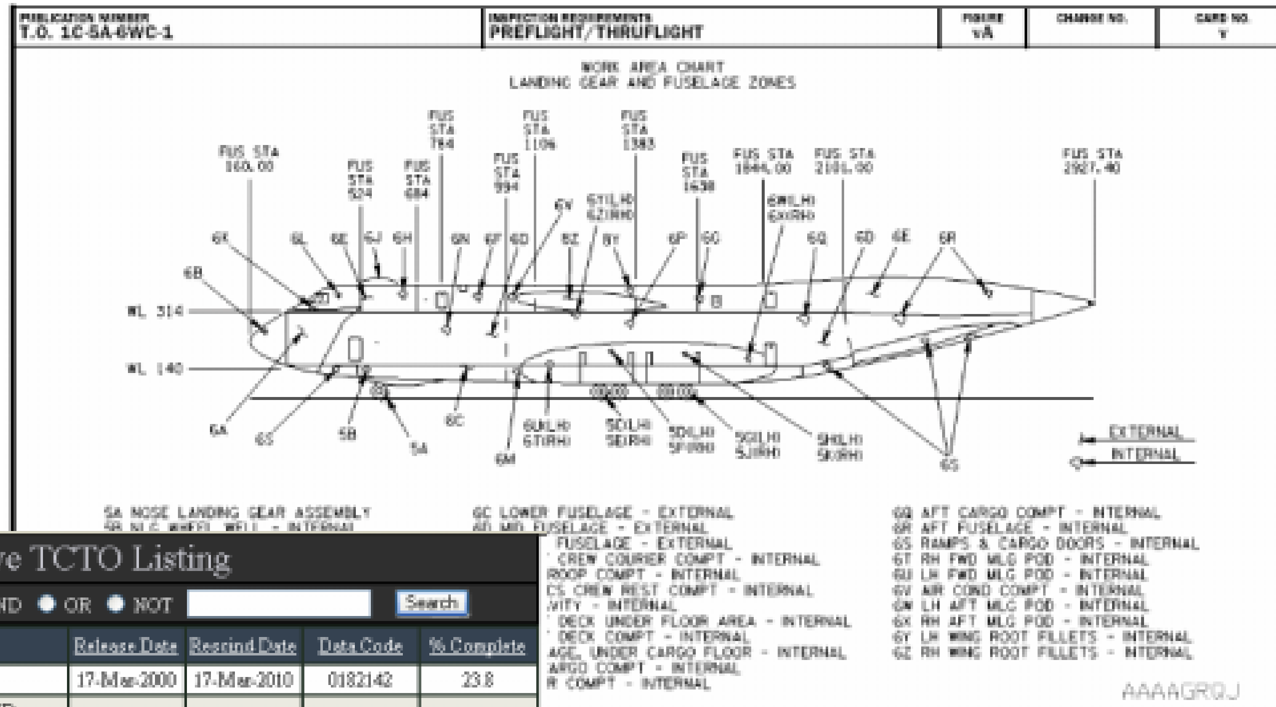
AFIRM Aging Fleet Integrity & Reliability Management

C-5 Monthly Flying Hours — View Monthly Hours by Base

AC	Possessed	Nov05	Oct05	Sep05	Aug05	Jul05	Jun05	May05	Apr05	Mar05	Feb05	Jan05	Dec04	Tot (12 mo)
66080305	LACKLAND AFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.7	28.9	44.6
66080306	TRAVIS AFB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	3.7	0.0	5.6
67080167	WESTOVER AFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	10.5	16.6
67080169	STEWART ANG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	76.6	84.0	182.5
67080169	TRAVIS AFB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	6.3	0.0	0.0	0.0	8.1
67080174	ALTUS AFB	0.0	0.0	0.0	0.0	0.0	3.4	21.0	27.1	0.0	0.0	0.0	0.0	51.5
67080174	STEWART ANG	0.0	0.0	0.0	0.0	0.0	4.9	0.0	1.2	44.4	25.1	7.1	75.7	159.4
68080211	WESTOVER AFR	0.0	52.9	56.9	43.6	22.0	83.8	31.7	0.0	5.1	49.7	29.4	82.1	445.2
68080212	STEWART ANG	6.5	75.0	182.1	77.5	2.3	0.0	0.0	0.0	23.8	43.6	0.0	0.0	300.6
68080213	TRAVIS AFB	0.0	0.0	0.0	0.0	0.0	0.0	28.4	27.2	68.6	29.2	38.4	38.4	231.2
68080214	LACKLAND AFR	0.0	127.2	62.5	41.2	0.0	13.4	78.7	63.2	50.2	10.3	0.0	0.0	439.7
68080215	WESTOVER AFR	0.0	1.9	2.6	24.5	43.6	0.0	12.2	45.0	45.4	46.6	69.7	84.7	356.4
68080215	WRIGHT-PAT AFR	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8
68080216	TRAVIS AFB	7.6	33.6	14.4	37.3	63.6	36.6	22.4	23.7	14.5	39.6	25.6	28.6	337.3
68080217	ALTUS AFB	0.0	0.0	0.0	0.0	27.0	53.7	59.2	35.0	46.3	26.6	0.0	10.0	256.8
68080219	WESTOVER AFR	0.0	0.0	0.0	38.0	9.7	40.6	68.2	57.2	66.5	66.1	44.4	27.2	412.9
68080220	LACKLAND AFR	32.6	51.9	16.8	23.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	125.2
68080221	LACKLAND AFR	11.0	35.1	37.3	17.5	80.0	38.5	78.9	81.8	42.6	79.7	0.0	37.4	517.8
68080222	WESTOVER AFR	21.7	35.6	87.3	7.6	4.6	0.0	0.0	3.8	0.0	4.3	13.2	1.6	159.7
68080223	LACKLAND AFR	3.7	121.6	39.4	2.1	3.0	81.0	49.7	67.0	36.6	0.0	61.0	0.0	453.9
68080224	STEWART ANG	30.0	1.9	76.2	3.9	0.0	0.0	68.2	12.7	73.8	9.0	3.7	2.4	283.6
68080225	WESTOVER AFR	0.0	0.0	35.2	42.6	72.0	78.5	12.7	59.6	52.3	89.6	59.0	80.5	582.0
68080226	STEWART ANG	34.4	84.0	96.0	88.7	109.7	37.0	21.3	69.6	46.5	59.4	86.5	28.8	703.9
69080001	STEWART ANG	30.7	89.4	90.7	16.4	63.6	99.4	13.2	0.0	0.0	0.0	64.9	29.9	432.0
69080002	LACKLAND AFR	7.4	0.0	56.2	81.0	62.5	57.6	18.3	18.5	0.0	61.7	74.2	72.4	501.7
69080003	WESTOVER AFR	0.0	0.0	0.0	3.3	0.5	0.0	34.5	68.3	30.6	41.6	86.2	19.9	305.9
69080005	WESTOVER AFR	0.0	96.4	0.0	30.4	9.7	62.5	101.3	24.4	53.4	43.1	18.2	69.5	497.9
69080006	LACKLAND AFR	0.0	52.4	57.1	37.3	64.2	63.6	68.7	48.3	12.4	0.0	51.9	40.0	500.9
69080007	LACKLAND AFR	0.0	0.0	0.0	6.0	17.7	0.0	41.8	65.1	77.1	89.1	83.5	10.6	390.9
69080008	STEWART ANG	21.8	0.0	0.0	4.0	38.3	74.4	48.8	72.8	72.3	59.3	62.9	48.1	503.6
69080009	STEWART ANG	12.3	65.0	67.7	43.3	27.6	74.0	73.3	73.8	67.9	15.1	60.1	32.9	620.8
69080010	ALTUS AFB	26.1	20.0	43.2	34.8	59.4	87.8	55.9	43.9	71.2	68.5	12.3	0.0	519.1
69080011	WESTOVER AFR	0.0	0.0	9.1	114.9	57.5	55.2	34.4	57.0	49.5	65.7	41.4	3.3	486.0
69080012	MEMPHIS ANG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	33.4	0.0	0.0	35.6

Monthly Flying Hours Report: By A/C \| By Base

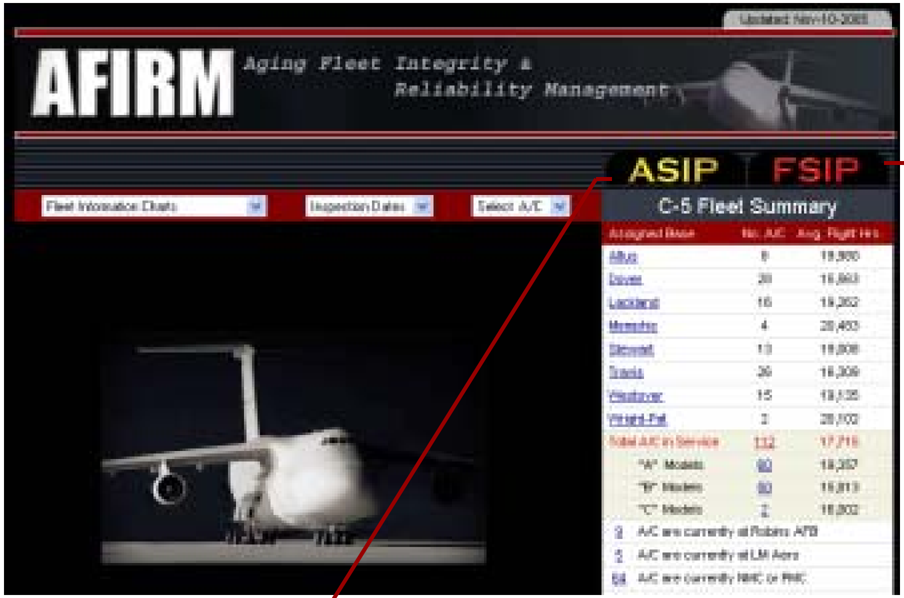
TCTO Status, Work Cards, etc…



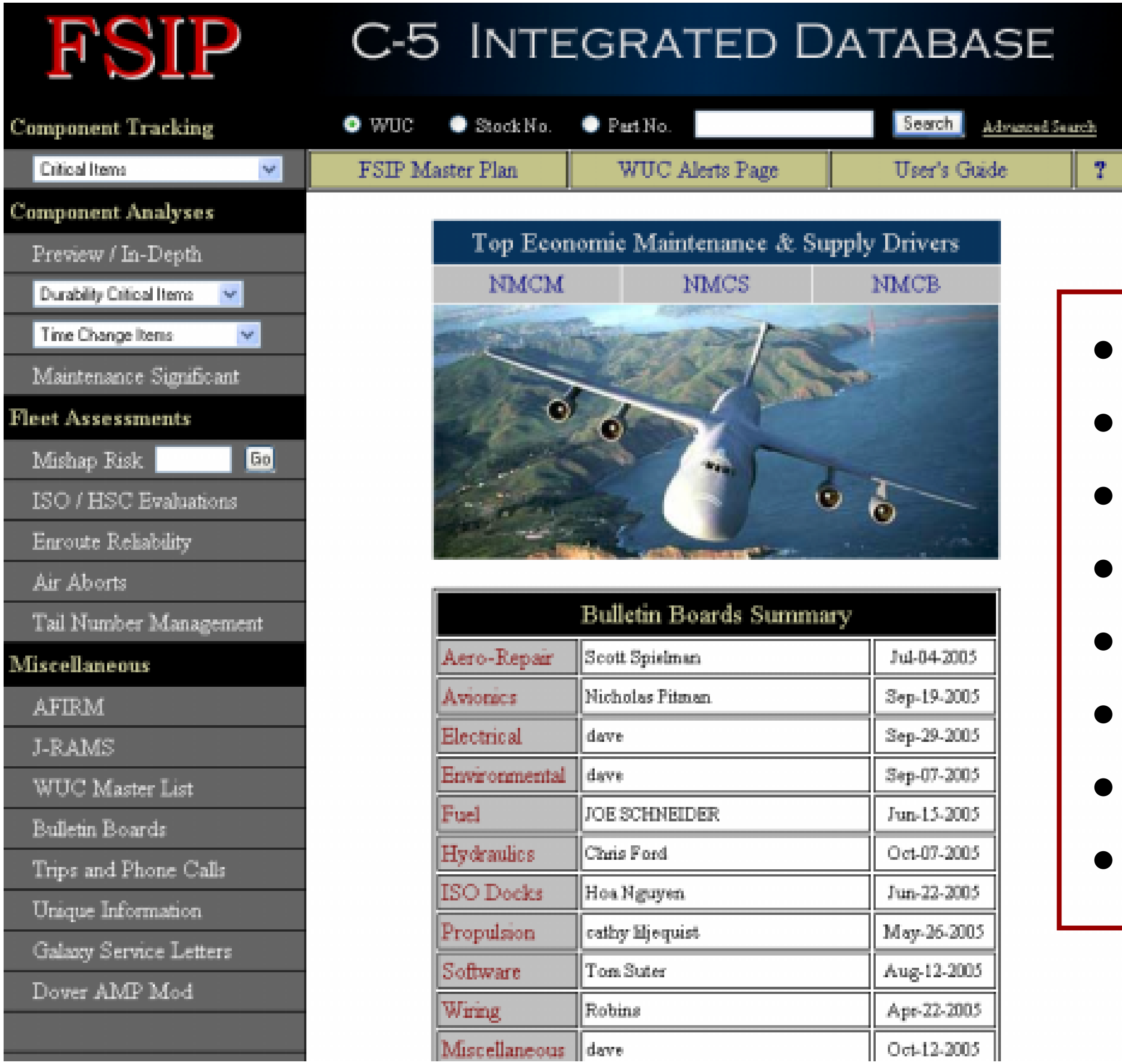
AFIRM Main Menu	Active TCTO Listing				
Enter TCTO (if known)	Enter Key Word(s) (Optional) ◉ AND ○ OR ○ NOT				Search
TCTO	TCTO Title	Release Date	Rescind Date	Data Code	% Complete
1C-5-636	INSP AIL HING FIT ATTACH HARDWARE	17-Mar-2000	17-Mar-2010	0182142	23.8
1C-5-706	REMOVE FUEL FLOW TRANSMITTER P/N 8TJ620BK3 AND REPLACE W/ FFT P/N 9-217-52 ON ALL C-5 AIRCRAFT.	16-Dec-2003	16-Dec-2006	0187951	70.5
1C-5-706D	REMOVE FUEL FLOW TRANSMITTER P/N 9TJ620BK3 AND REPLACE W/ FFT P/N 9-217-52 ON ALL C-5 AIRCRAFT.	14-Jul-2005	17-Dec-2006	0197997	21.4
1C-5-714	INSTALL AMP ON ALL C-5 A/C	04-Jun-2004	01-Jan-2010	0188672	6.2
1C-5-717	REMOVE AND REPLACE MUX PROCESSOR	19-Jan-2005	15-Jan-2007	0189050	100.0
1C-5-736	EMERGENCY POWER SYSTEM UPGRADE (EPSU)	15-Apr-2004	15-Apr-2010	0197644	20.3
1C-5-737	INST OF MADARS III ON C-5 A/C	01-Nov-2002	31-Dec-2005	0197657	100.0
1C-5-755	INSTALL MOUNTING BRACKET TO HOLD 3- 5 GAL WATER CNTR	27-Apr-2004	28-Oct-2005	0197935	100.0
1C-5-756	LOAD OFP SOFTWARE, VER 38, ON AN/ARC-210 R/T-1794(C) RADIO	06-May-2004	07-Nov-2005	0197938	100.0
1C-5-757	REPLACE HEAT EXCHANGER SHELF AND PLENUM	11-Aug-2004	11-Aug-2014	0197939	15.9

Historical Charts | TCTO Status | Monthly Time Reports | PDM Schedule | PDM Work Specs | Work Cards

AFIRM = ASIP + FSIP

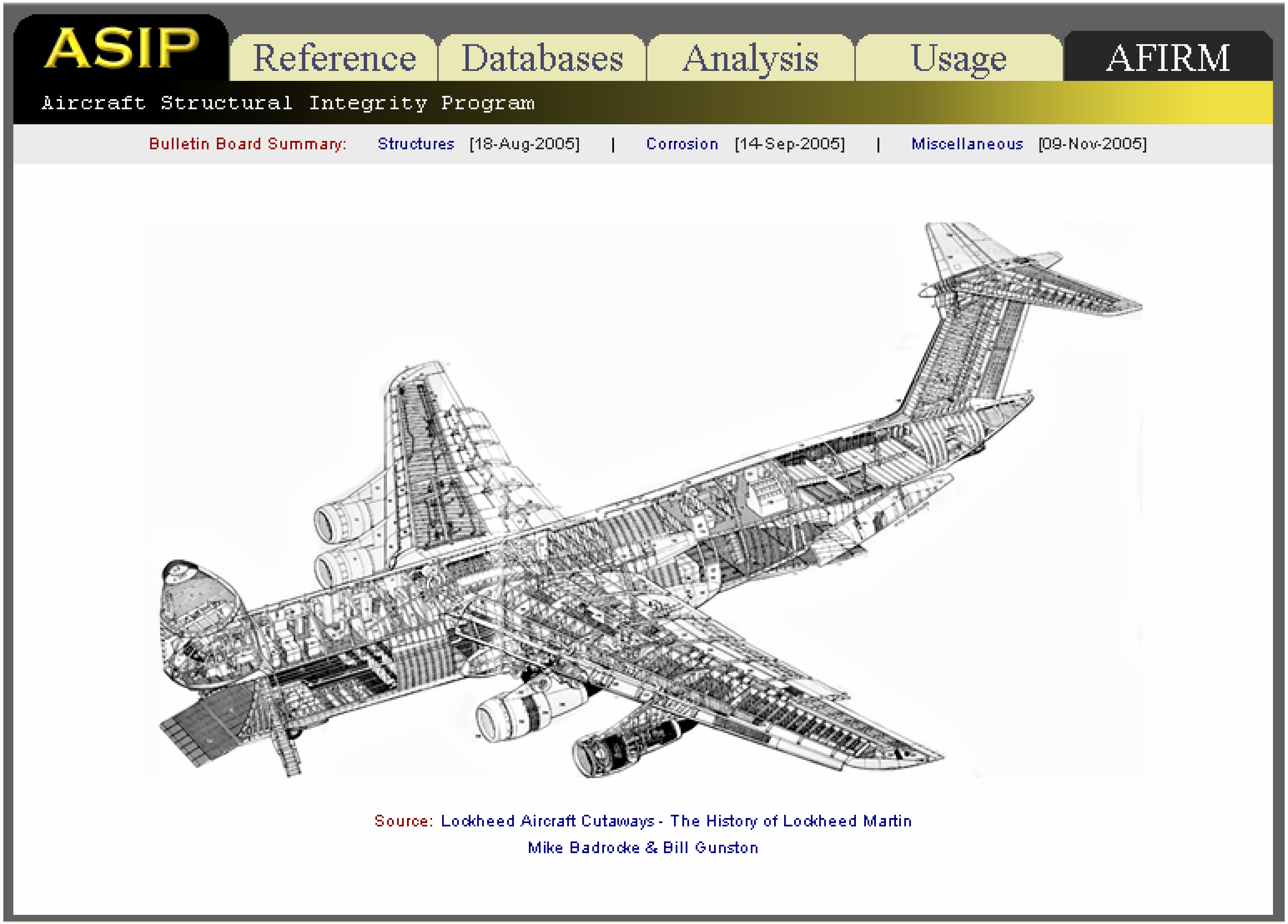


FSIP Integrated Database



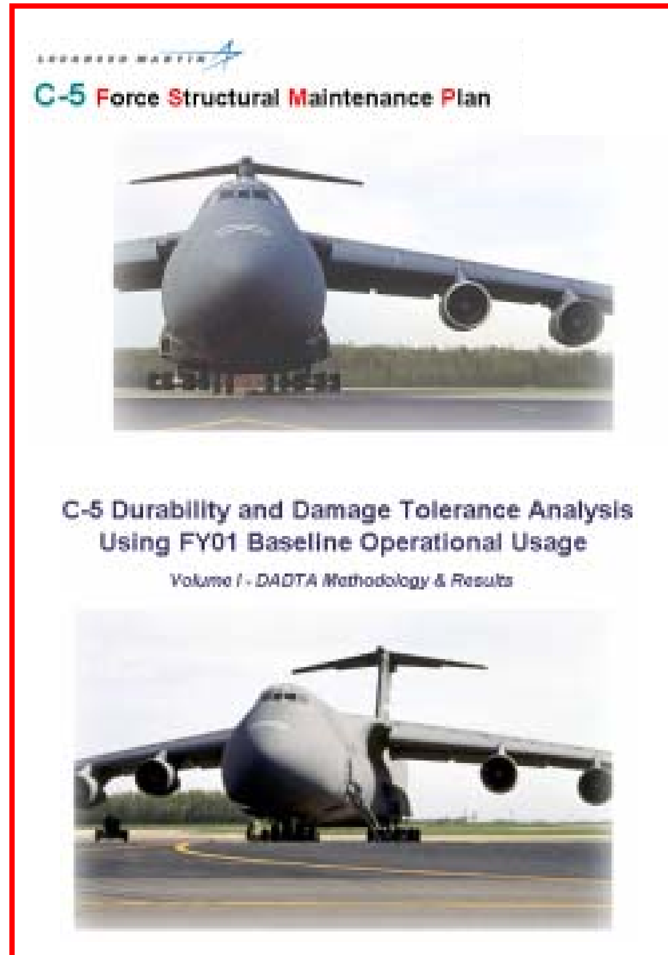
- MTBF
- Serialized Tracking
- ISO / HSC Evaluations
- Top NMC Drivers
- WUC Alerts
- Air Abort Data
- Bulletin Boards
- In-Depth Analyses

ASIP Main Menu



ASIP Menu Options - Reference

- **Reference Items**
  - ***Major Reports***
    - ASIP Master Plan
    - Force Structural Maintenance Plan (FSMP)
    - Durability & Damage Tolerance Analysis (DADTA)
    - Annual LM Aero ASIP Reports
    - All Major Reports can be searched by keywords



ASIP Reference - Search Major Reports

AFIRM ASIP Master Plan FSMP DADTA 2004 ASIP 2003 ASIP 2002 ASIP | pylon | Search

LOCKHEED MARTIN

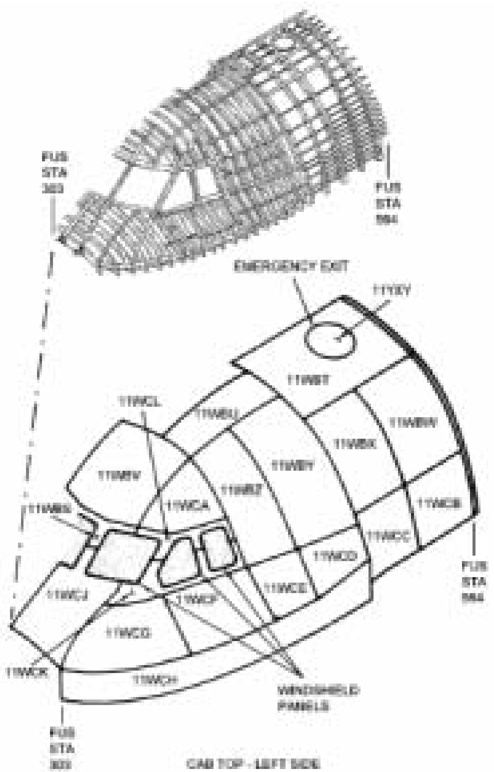
MAJOR C-5 REPORTS

13 Records Found

Report	Section	Page	Description
MasterPlan	3.3.2.9	42	Pylon Tests
MasterPlan	C30	C30-1	Summary of Pylon Fatigue Tests Numbers 6, 7, and 8 (ECP 6411 Configuration)
MasterPlan	C84	C84-1	C-5A Pylon and Wing Interface Structure Damage Tolerance Assessment (DTA) (LG81ER0143)
MasterPlan	C140	C140-1	Summary of Pylon/Wing Fatigue Analyses (LG84ER0138, LG89ER0025 and LG89ER0030)
MasterPlan	C172	C172-1	Summary of C-5 Pylon Internal Loads Analysis (LG02ER0049, LG02ER0050 and LG02ER0051)
FSMP - Vol II	3.6	3.6-1	C-5A PYLON INSPECTION AND MAINTENANCE RECOMMENDATIONS
FSMP - Vol II	4.6	4.6-1	C-5B PYLON INSPECTION AND MAINTENANCE RECOMMENDATIONS
DADTA	5.8	5-837	PYLON ANALYSIS
ASIP 2002	2.1	2-3	ANALYSIS OF THREE PYLON AREAS - 9130FG20/30, 9230FG20/30 & 9133PE10
ASIP 2002	2.1.1	2-3	Pylon Structural Arrangement
ASIP 2002	2.1.2	2-7	Analysis of Upper Longeron Splice Locations at Pylon Wing Fitting - 9130FG20/30 & 9230FG20/30
ASIP 2003	3.5.4	3-87	Pylon Repairs (T.O. 1C-5A-3)
ASIP 2003	Appendix C	C-1	C-5 PYLON MISSILE STRIKE INVESTIGATION

ASIP Menu Options – Reference (cont'd)

- **Reference Items (continued)**
  - TO 1C-5A-6 (Scheduled Inspection and Maintenance Requirements)
  - Work Unit Code (WUC) Diagrams (-06)
  - Work Unit Code (WUC) Master List



ASIP Menu Options - Databases

ASIP | Reference | Databases | Analysis | Usage | AFIRM

AFTO95 Historical Data | -6 Special Insp & Time Change | Structural Audit Program (SAP) | Teardown | Torque Deck Replacement Status

- **Databases**
  - AFTO95 Historical Data
  - -6 Special Inspection & Time Change Items

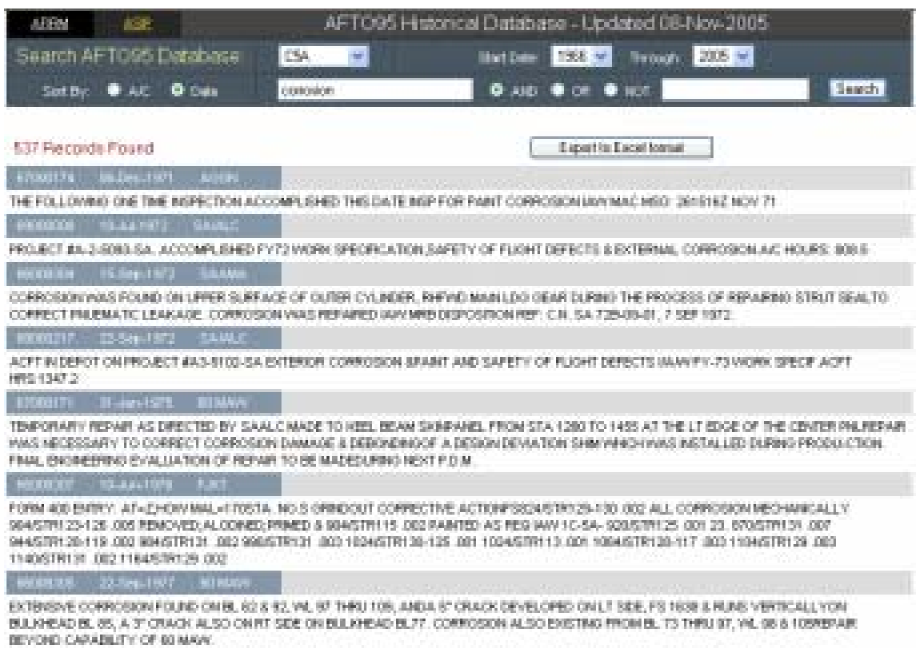
Aircraft	WUC	Type	Sys	SubSys	Par	Due
69000005	11SK0	I	11	24	A	

Noun	Increment
TORQUE SHELF PANEL	

Last Inspection Date	Last Inspection Hours	Last Inspection FS Landings
16-Jun-05	16951	4150

Installation Date	Component Serial No.	Logic Code	Location
15 JUN 05		IS	

Verbage
AT EVERY ISO, INSPECT NINE TORQUE SHELF PANELS. DOCUMENT DAMAGE AND REPAIRS/EXISTING REPAIRS USING THE MAPPING METHOD PER 1C-5A-6.



ASIP Menu Options – Databases (cont'd)

ASIP | Reference | Databases | Analysis | Usage | AFIRM

AFTO95 Historical Data | -6 Special Insp & Time Change | Structural Audit Program (SAP) | Teardown | Torque Deck Replacement Status

- **Databases (continued)**
  - Structural Audit Program
  - Teardown
  - Torque Deck Replacement Status

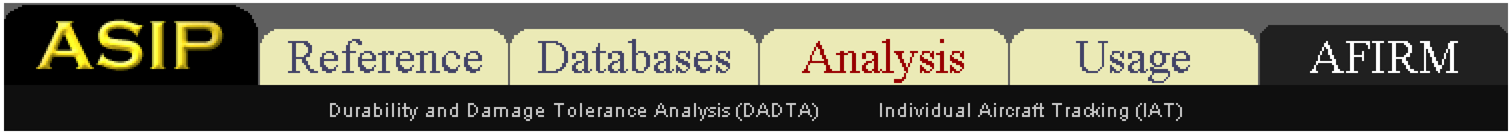
AFIRM | ASIP | Torque Deck | Torque Deck Status

Most recent inspections for each A/C are shown below. Select from any of the following categories to filter data, or click on underlined column headers to sort data.

MAJCOM | Insp Base | Restriction

Aircraft	MDS	Assigned	MAJCOM	Restriction	No. Insp	Last Insp.	Insp Base	Remarks
67000174	C-5A	AMARC	ANG	None	1	09-Jun-2004	Stewart	Inspection for TCTO with Center Door Removed
68000211	C-5A	Westover	AFR	L1-80%	2	01-Mar-2005	Westover	Panels 2 though 9 identified for replacement
68000212	C-5A	Stewart	ANG	L1-80%	1	22-May-2004	Stewart	Please see note on cover sheet regarding findings on #4 panel. Replace panels 2-9.
68000213	C-5C	Travis	AMC	None	1	31-Mar-2004	Travis	C-model aircraft, there are no panels 1-6 and shortened panels 7-9
68000214	C-5A	Lackland	AMC	None	1	07-Jan-2004	Dover	Panels 2-9 replaced at Lockheed 30Oct03 prior to this inspection
68000215	C-5A	Wright-Pat	AFR	TBD	3	16-Sep-2005	Westover	Two new repair added IAW FSR # 05-660
68000216	C-5C	Travis	AMC	None	1	13-Jul-2004	Travis	C-model aircraft

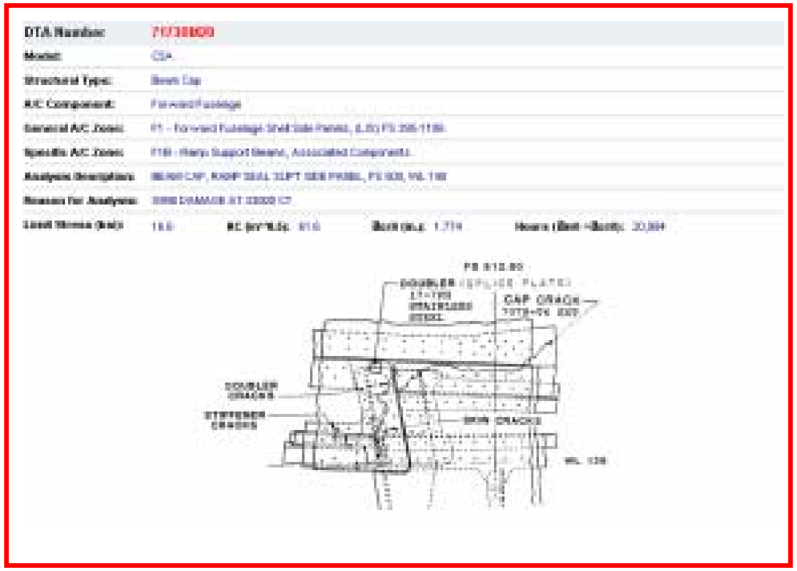
ASIP Menu Options - Analysis



- **Analysis**
  - Durability and Damage Tolerance Analysis

Current Search: DADTA Analyses Where General Zone = F1

DTA No.	Model	Zone	Description	Limit Stress	Kc	Bcrit	Hours [illegible]
7148FR20	C5A	F1D	ALUM STRAP @ CREW ENTRY DOOR FS 484, WL 150, BL 134 LS	13.1	71.8	4.160	35,318
7148FR21	C5A	F1D	TI STRAP @ CREW ENTRY DOOR FS 484, WL 150, BL 134 LS	13.1	123.4	8.035	389,654
7173BM20	C5A	F1B	BEAM CAP, RAMP SEAL SUPT SIDE PANEL, FS 508, WL 140	16.6	61.6	1.774	20,984
7173BM21	C5A	F1B	SPL PLATE, RAMP SEAL SUPPORT SIDE PANEL, FS 508, WL 140	25.5	50.0	0.834	180,524
7241FR18	ALL	F1C	FS 604 FRAME CAP SPLICE AT WL 200, BL 135 LS	10.5	71.1	3.850	265,346
7244FR18	ALL	F1C	FS 944 FRAME WEB SPLICE AT WL 150, BL 130 LS	6.6	71.4	3.992	1,000,000
7245FR26	C5A	F1C	FWD FUSE FAILSAFE ANALYSIS, STR 45 SKIN CRACK, FS 704 FRAME OUTER CAP	44.7	92.4	0.967	6,337
7245FR25	C5A	F1C	FWD FUSE FAILSAFE ANALYSIS, STR 43 SKIN CRACK, FS 704 FRAME WEB CUTOUT @ STR 43	85.0	92.4	1.319	4,437
7246SP22	C5A	F1C	FWD FUSE FAILSAFE ANALYSIS, WL 295 SKIN CRACK, FS 704 UNDERFRAME TITANIUM STRAP	185.6	124.7	0.438	1,088
7248ST24	C5A	F1A	FWD FUSE FAILSAFE ANALYSIS, STR 43 SKIN CRACK, FS 704 STRINGER 43 BASE	34.9	70.8	0.534	6,402

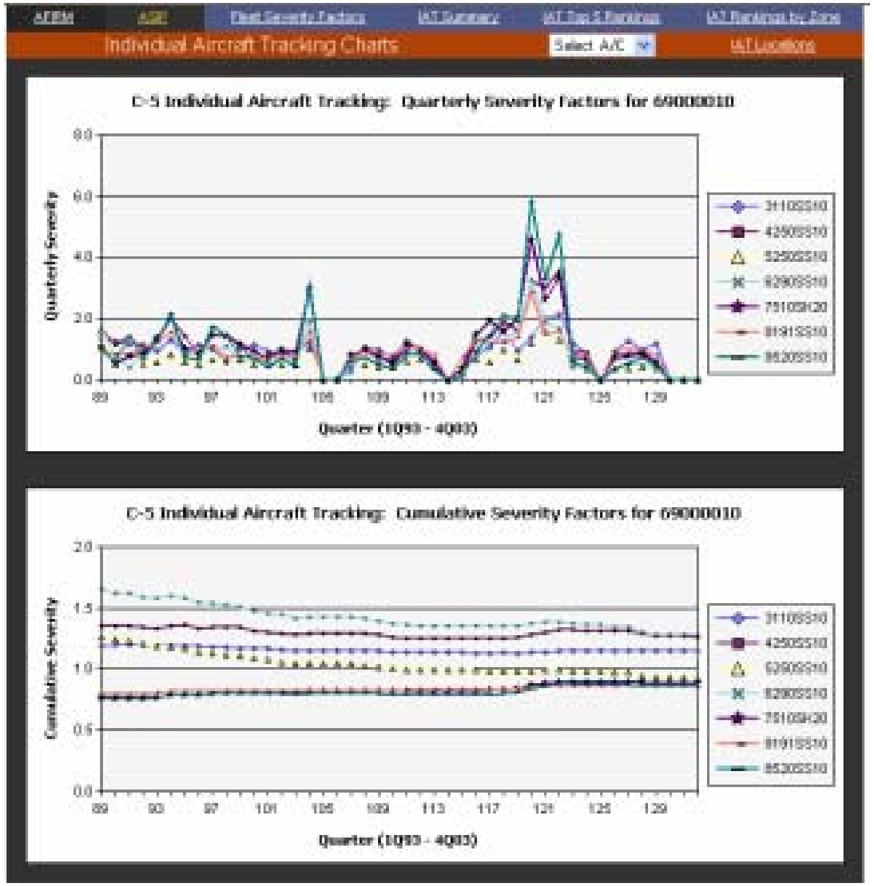


ASIP Menu Options – Analysis (cont'd)

ASIP | Reference | Databases | Analysis | Usage | AFIRM

Durability and Damage Tolerance Analysis (DADTA) | Individual Aircraft Tracking (IAT)

- **Analysis (continued)**
  - Individual Aircraft Tracking (IAT)



AFIRM | ASIP | Individual Aircraft Tracking Rankings by Zone (4Q03)

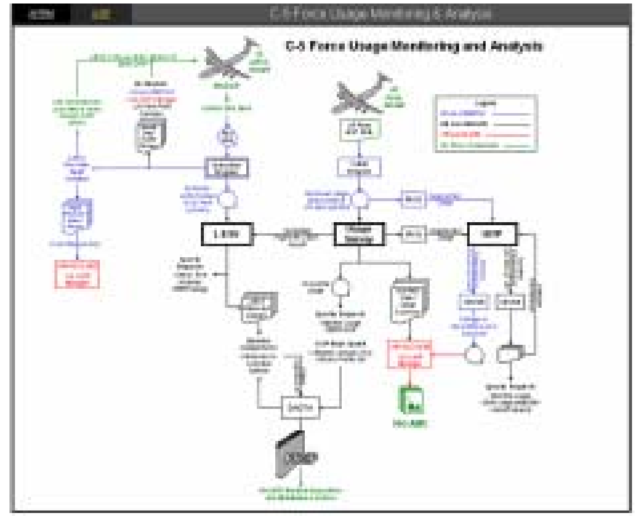
Fleet Severity Factors | IAT Locations | IAT Summary | IAT Top 5 Rankings | IAT Charts

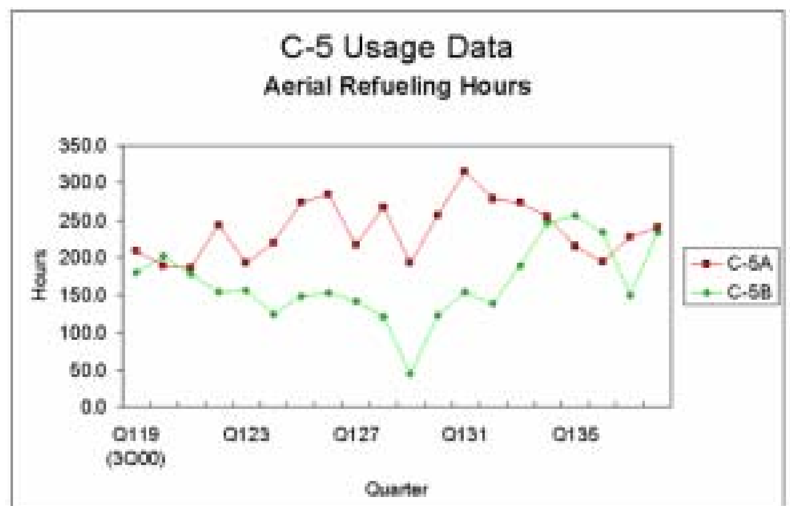
Sorted By Damage Hours — C-5A | C-5B | C-5C — 75106K20 — GO

AC	Base	Flight Hrs	Post Wing Mod	Severity (Qtr)	Severity (Cum)	Damage Hrs
70000454	Memphis	21,406	10,693	4.51	1.19	25,473
69000014	Lackland	18,453	11,110	0.94	1.30	23,989
69000001	Stewart	18,827	11,931	0.73	1.24	23,345
70000462	Altus	18,083	8,025	4.59	1.28	23,146
69000018	Memphis	21,464	12,643	1.51	1.07	22,966
70000455	Stewart	18,826	8,467	2.28	1.21	22,779
70000456	Lackland	22,963	11,935	0.85	0.98	22,504
69000024	Dover	17,829	9,438	0.00	1.21	21,573
70000451	Lackland	21,576	11,561	0.98	0.98	21,144
70000466	Lackland	16,483	9,147	1.10	1.24	20,439
70000452	Altus	19,526	10,393	0.00	1.04	20,307
69000025	Memphis	20,461	11,444	0.00	0.98	20,062
69000214	Lackland	22,167	15,882	1.23	0.90	19,968
70000453	Lackland	19,259	9,807	0.81	1.03	19,837
69000026	Lackland	24,114	14,255	0.73	0.82	19,773
70000457	Wright-Pat	22,813	13,424	0.52	0.86	19,619

ASIP Menu Options - Usage

- **Usage**
  - Force Usage Monitoring Diagram
  - L/ESS Aircraft Summary
    (Loads Environment Spectra Survey)
  - Quarterly Fleet Usage Summary
  - Tinker L/ESS Program





C-5 LESS Aircraft Summary

General Information					Landings		Inspection Dates			
A/C	Status	Assigned	Possessed	Flt. Hrs	Full Stop	Total	Next ISO	Next HSC	Last PDM	Next PDM
69000214	NMCS	Lackland	Lackland	22,187	5,236	15,713		14NOV05	30MAY00	29MAY05
69000012	NMCBU	Stewart	Stewart	18,336	4,413	11,150		11JAN06	24JAN03	23JAN08
69000013	FMC	Westover	Westover	17,984	4,641	14,225		06DEC05	21JUN01	21JUN06
69000014	NMCBU	Lackland	Lackland	18,453	4,791	18,347		10JAN06	16JAN03	16JAN08
69000018	FMC	Memphis	Memphis	21,464	5,363	17,459		05JAN06	07NOV02	20SEP07
69000021	NMCBS	Stewart	Stewart	20,337	4,887	18,972		03NOV05	15NOV01	15NOV06
69000024	Maintenance	Dover	Lockheed	17,029	4,490	15,061		17JUL02	04JAN02	04JAN07
84000062	FMC	Travis	Travis	17,445	3,087	9,046		17SEP05	25APR01	25APR06
85000001	FMC	Dover	Dover	15,258	3,640	8,129		06FEB06	29MAY01	29MAY06
85000002	FMC	Travis	Travis	17,209	3,794	7,982		19JAN06	12OCT01	12OCT06
85000003	FMC	Dover	Dover	15,592	3,785	9,094		16OCT05	30OCT01	30OCT06
85000004	PMCM	Travis	Dover	14,411	3,244	7,887		07DEC05	01OCT01	01OCT06

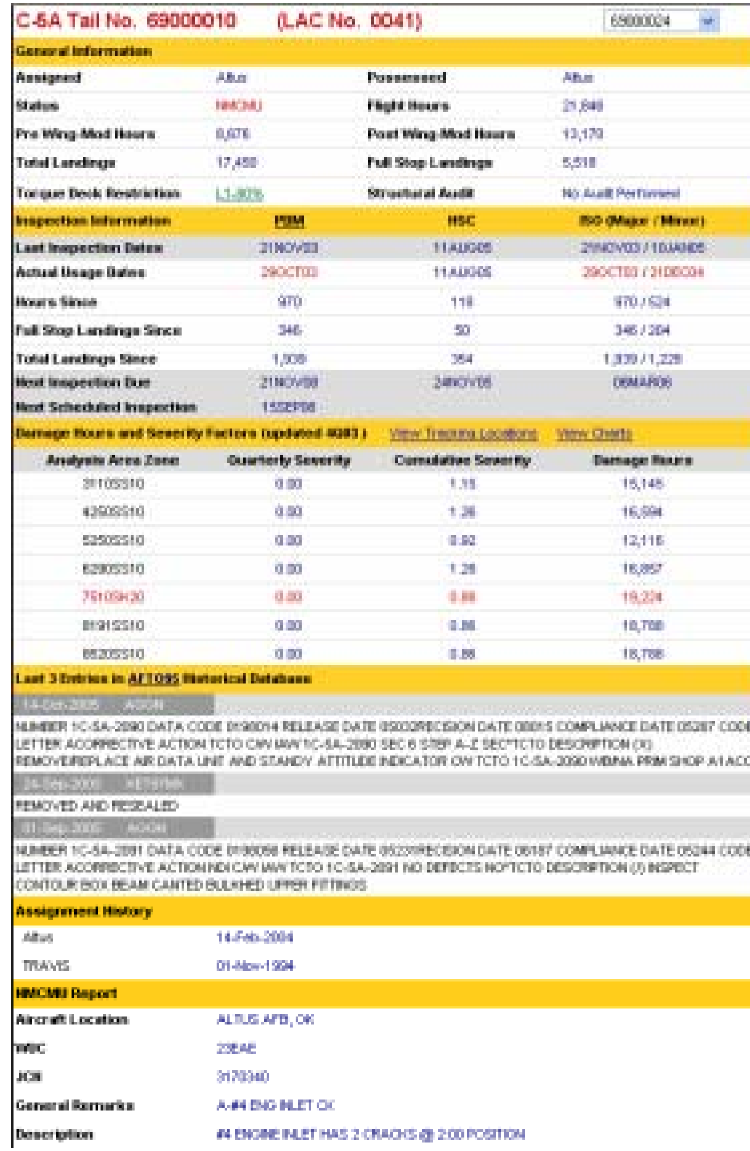
ASIP Bulletin Boards

- ***Bulletin Boards***
  - Structures
  - Corrosion
  - Miscellaneous

Click on * to view original message, and all replies

Name	Base	Subject	Date	Assigned To
Ivey, Robert D.	Westover ARB	* T-TAIL BIRD NESTS	9/14/2005	Buck McRory
Gary Carlson	Altus AFB	* Interior paint scheme	5/5/2005	N/A
Suzanne Sims	Lackland ARB	Re: Interior paint scheme	5/16/2005	
Ivey, Robert D.	Westover ARB	* Corrosion possible cause of bolt failure	4/14/2005	Buck McRory
Buc McRory	Robins AFB	Re: Corrosion possible cause of bolt failure	4/15/2005	
Hector Herrera	Robins AFB	* Aircraft Paint Stencil	4/5/2005	Buck McRory
Buc McRory	Robins AFB	Re: Aircraft Paint Stencil	4/15/2005	
MSgt Snider	Altus AFB	Re: Aircraft Paint Stencil	4/6/2005	
Hutchins	Robins AFB	Re: Aircraft Paint Stencil	4/5/2005	

Aircraft Summary Page



C-5A Tail No. 69000010 (LAC No. 0041) 69000024

General Information			
Assigned	Altus	Possessed	Altus
Status	NMCMU	Flight Hours	21,848
Pre Wing-Mod Hours	8,678	Post Wing-Mod Hours	13,170
Total Landings	17,450	Full Stop Landings	5,518
Torque Deck Restriction	L1-80%	Structural Audit	No Audit Performed

Inspection Information	PDM	HSC	ISO (Major / Minor)
Last Inspection Dates	21NOV03	11AUG05	21NOV03 / 10JAN05
Actual Usage Dates	29OCT03	11AUG05	29OCT03 / 31DEC04
Hours Since	970	118	970 / 524
Full Stop Landings Since	346	50	346 / 204
Total Landings Since	1,008	354	1,339 / 1,228
Next Inspection Due	21NOV08	24NOV05	06MAR06
Next Scheduled Inspection	15SEP08		

Damage Hours and Severity Factors (updated 4Q03) View Tracking Locations View Charts

Analysis Area Zone	Quarterly Severity	Cumulative Severity	Damage Hours
31105310	0.00	1.15	15,145
42505310	0.00	1.26	16,594
52505310	0.00	0.92	12,116
62805310	0.00	1.28	16,857
75105H20	0.00	0.88	19,224
81915310	0.00	0.88	18,708
88205310	0.00	0.88	18,708

Last 3 Entries in AFTO95 Historical Database

14-Oct-2005 ACOM

NUMBER 1C-5A-2090 DATA CODE 0190014 RELEASE DATE 05032RECISION DATE 00015 COMPLIANCE DATE 05287 CODE LETTER ACORRECTIVE ACTION TCTO C/W IAW 1C-5A-2090 SEC 6 STEP A-Z SEC*TCTO DESCRIPTION (X) REMOVE/REPLACE AIR DATA UNIT AND STANDY ATTITUDE INDICATOR C/W TCTO 1C-5A-2090 W/DMA PRM SHOP A1ACC

26-Sep-2005

REMOVED AND RESEALED

01-Sep-2005 ACOM

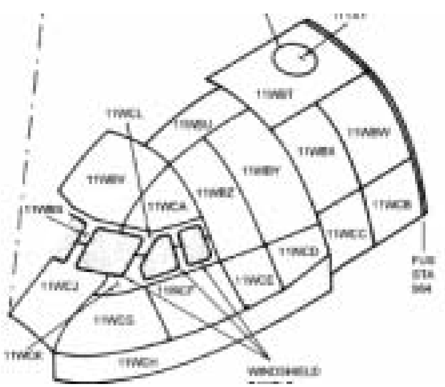
NUMBER 1C-5A-2091 DATA CODE 0190058 RELEASE DATE 05231RECISION DATE 06187 COMPLIANCE DATE 05244 CODE LETTER ACORRECTIVE ACTION INDI C/W IAW TCTO 1C-5A-2091 NO DEFECTS NOTCTO DESCRIPTION (J) INSPECT CONTOUR BOX BEAM CANTED BULKHED UPPER FITTINGS

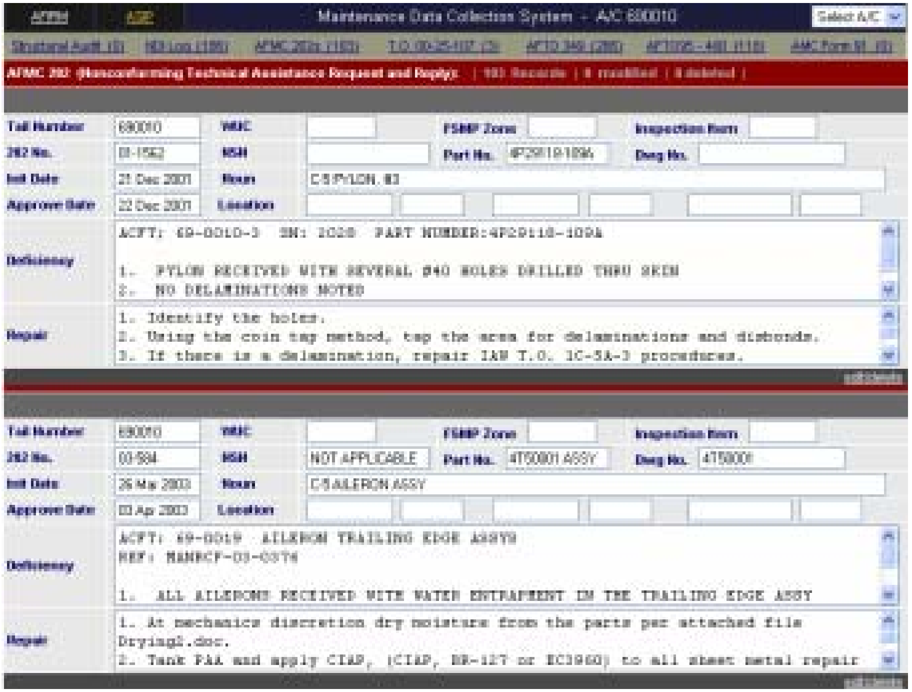
Assignment History	
Altus	14-Feb-2004
TRAVIS	01-Nov-1994

NMCMU Report	
Aircraft Location	ALTUS AFB, OK
WUC	23EAE
JCN	3170040
General Remarks	A-#4 ENG INLET CK
Description	#4 ENGINE INLET HAS 2 CRACKS @ 2:00 POSITION

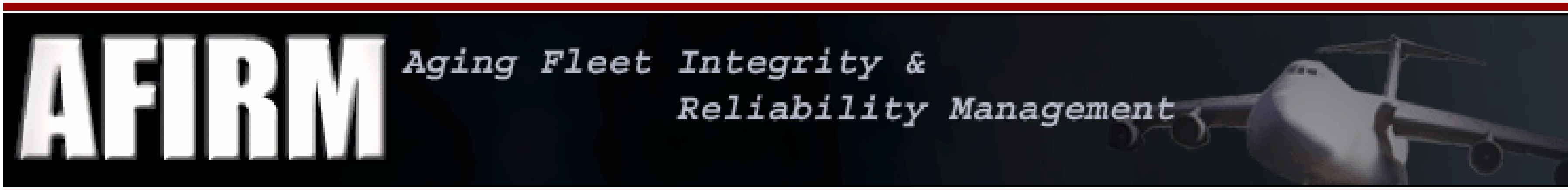
What's Ahead?

- **Maintenance Data Collection System**
  - ***Consolidates the following data***
    - NDI Log
    - AFMC 202's (Technical Assistance Requests)
    - T.O. 00-25-107 (Tech Manual for Requesting Maintenance Assistance)
    - AFTO 349
    - AFTO 95 Corrosion Data
    - AFTO 427 Integral Fuel Cell Repairs
    - Structural Audit Findings
  - ***Repairs will eventually be accessed through graphical user interface***





Summary



- The AFIRM web site has become a valuable tool in C-5 community
- Helps control costs, increase reliability, and improve fleet safety
- Combines everything needed to manage the fleet in one place
- Provides a user-friendly interface to USAF data such as G081.
- The site is constantly expanding and will continue to improve in order to meet the changing needs of the ASIP / FSIP managers.

Updating the C-130 Force Structural Maintenance Plan For Improved Fleet Management

ASIP 2005
01 December 2005

Kenneth L. Taylor, PhD — Mercer Engineering Research Center
Peter Christiansen — USAF, Warner Robins Air Logistics Center

Acknowledgements

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  - Mr. Gary Baker
  - Mr. David Carnes
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  - Mr. Chris Fisher
  - Mr. Robert Frisch
  - Mr. Cliff Hammock
  - Mr. Brian Harper
  - Robert McGinty, PhD
  - Ms. Mary Schleider, PE
  - Mr. Greg Wood

Agenda

- Overview of FSMP
- Rebaselining ASIP critical inspection intervals
- Crack history database
- IATP (AIRCAT)
- Continuing efforts

FSMP = Force Structural Maintenance Plan

ASIP = Aircraft Structural Integrity Program

IATP = Individual Aircraft Tracking Program

AIRCAT = Automated Inspection, Repair, Corrosion, and Aircraft Tracking

- AIRCAT is the USAF's IATP for the C-130 fleet

Agenda

- Overview of FSMP
- Rebaselining ASIP critical inspection intervals
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Overview of FSMP

- Aircraft Structural Integrity Program (ASIP) requires a Force Structural Maintenance Plan (FSMP) ***** to drive:
  – Inspections (when, where, how)
  – Force structure planning
  – Maintenance planning
  – Capture aging/damage data
  – Analytical Condition Inspection program
  – Structural teardown program
  – Repair criteria
- Update as required

* MIL-STD-1530C , Section 5.4.3

MIL-STD-1530 C (01 November 2005) defines the goals, objectives, and tasks of an ASIP program.

Noteworthy sections include:

- •5.1.1 ASIP Master Plan
- •5.4.3 FSMP.
  - •5.4.3.1 Structural Maintenance Database
  - •5.4.3.2 Inspections, intervals, methods
  - •5.4.3.3 Surveillance (ACI and structural tear down)
  - •5.4.4 Loads/Environmental Spectra Survey
  - •5.4.5 IATP
- •5.5 Force Management Execution, including the role of the IATP

Overview of FSMP

- MERC engaged in activities to update elements of the C-130 FSMP in accordance with ASIP requirements
  - Rebaselining ASIP critical inspection intervals
  - Crack history database
  - IATP (AIRCAT)

Agenda

- Overview of FSMP
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Rebaselining ASIP critical inspection intervals

- ASIP tracking points are critical locations that are the focus of:
  - Damage Tolerance Analysis (DTA) crack growth curves
  - Non-Destructive Inspection (NDI) procedures
- Baseline DTA sets NDI intervals in equivalent baseline hours (EBH)
  - Initial inspection occurs at half the baseline safety limit
  - Recurring inspections occur at half the remaining baseline time
- Actual flights are categorized with a spectrum and DTA
  - Each flight has duration (AFH) and a baseline equivalent (EBH)
  - Aircraft tracking point history is plotted as AFH vs EBH (cumulative)
  - Severity Factor (SF) is the slope of the AFH vs EBH curve
- Rebaselining process establishes NDI intervals in AFH
  - Determine a stable, accurate method for determining SF
  - Evaluate SF for all aircraft, all tracking points
  - Set inspection intervals per MDS groups

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01 Dec 2005
Page 8

MIL-STD-1530-C, Section 5.5.1, requires the IATP to determine EBH for each aircraft, and to adjust the inspection, maintenance, and replacement schedules for each component accordingly.

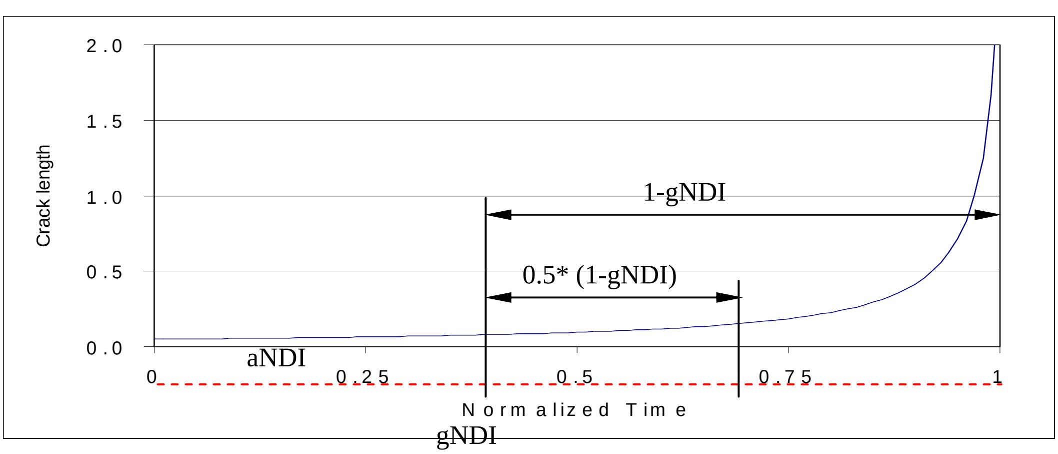
EBH is the standard or baseline measurement of the tracking point status

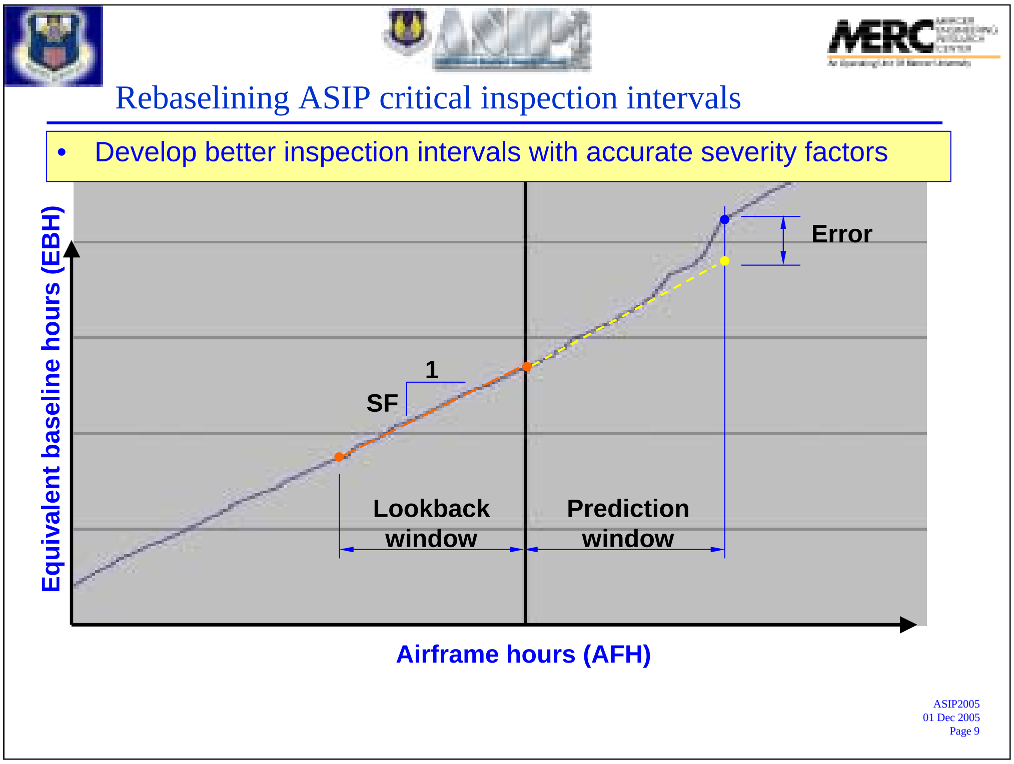
AFH is the actual airframe flight hour accumulation

SF is the conversion between EBH and AFH

Inspection intervals are derived in theoretical time (EBH) and scheduled in directly measurable time (AFH).

The rebaselining process for a given inspection translates the EBH interval into customized AFH intervals based on considerations of the specific mission history severity for each aircraft within the MDS.



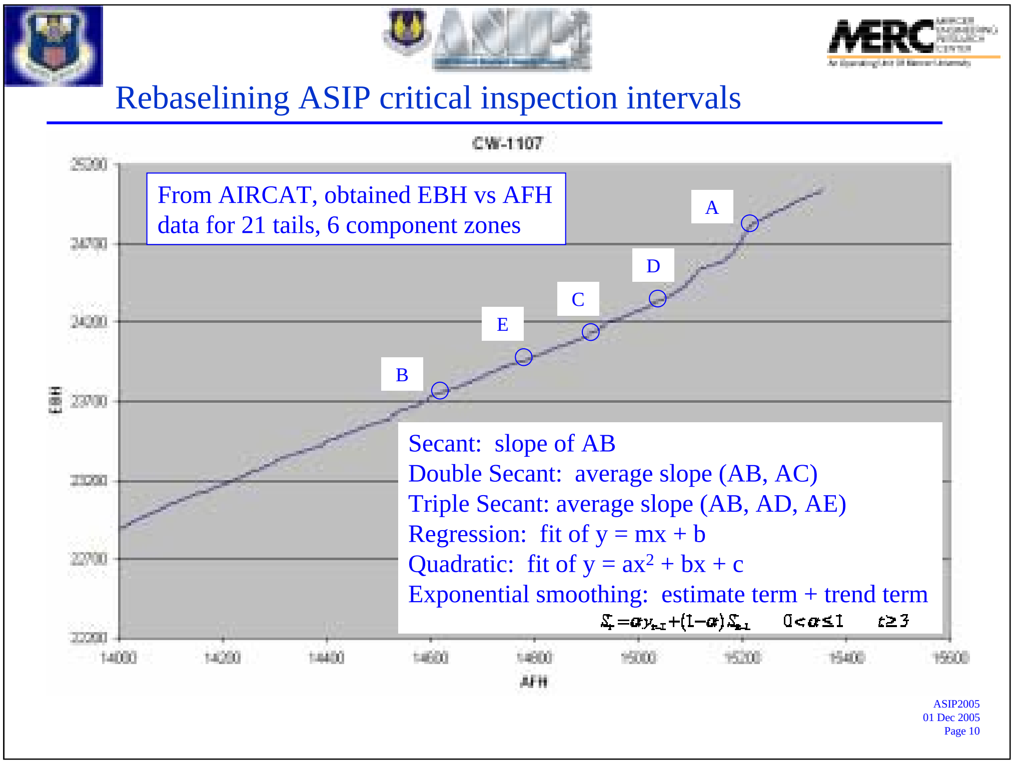


Each flight possesses a known AFH increment and a derived EBH increment for each ASIP tracking point, based on the mission parameters of that flight.

- The history may be summarized by the cumulative EBH vs AFH plot
- The SF is the slope of this plot
- The plot is not a straight line for all time, due to variation in mission types

Rebaselining requires a reliable, robust method of calculating severity factor from the EBH vs AFH plot.

- The efficacy of a SF calculation method can be tested by going back to a given point in time and evaluating the error when forecasting forward from that point
- Lookback window defines how much of the total historical data to use in the SF calculation.
- Prediction window defines how far forward in time the forecast is to be made.



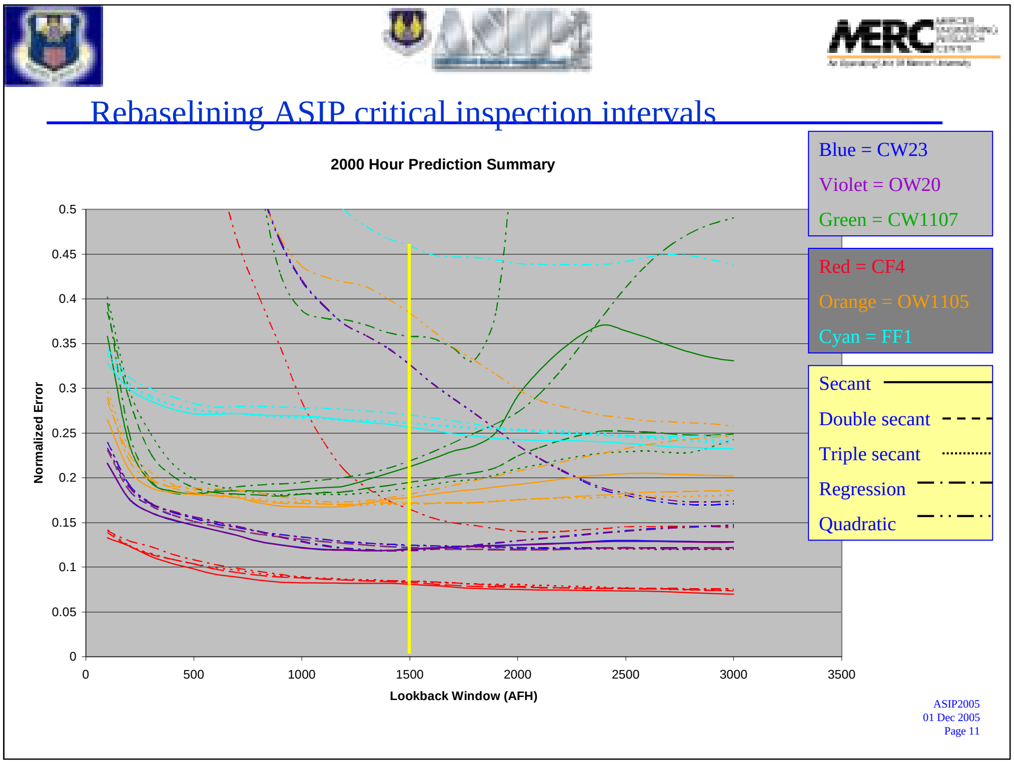
Multiple methods were considered candidates for SF calculation.

Multiple look-back window sizes were considered for each calculation method.

- •Shorter windows respond to trends faster, but also over react to transients
- •Longer windows are slow to detect trend changes, but tend to attenuate the effects of spurious transients

To ensure the method was not customized for an outlier:

- •Data from multiple tails were considered (representative of various MDS in the fleet)
- •Data from multiple tracking points were considered
- •Multiple projection points were considered (i.e. the point defining the end of the lookback window and the beginning of the forecast window)



To compare results, the forecasting error was normalized for each choice of tail, component, method, lookback window, forecast window, and choice of projection point.

- A root mean square value of the normalized error was determined for the range of projection points and tails
- The result is an error metric encompassing the effects of different tails and points in history
- Plotting this metric as a function of the lookback window enables comparison of the different methods

- Secant method using 1500 AFH lookback window chosen as prediction method for individual aircraft SF
  - Most robust predictor based on minimal normalized error and stability

Method	Error
Double Secant	1.0126
Secant	1.0140
Triple Secant	1.0192
Regression	1.1310
Exponential Smoothing	1.2827
Quadratic	1.3914

The error metric results were renormalized and averaged across the tracking points at a given lookback window value.

The result was a single metric value that encompasses not only the different tails but the different components as well.

Rebaselining ASIP critical inspection intervals

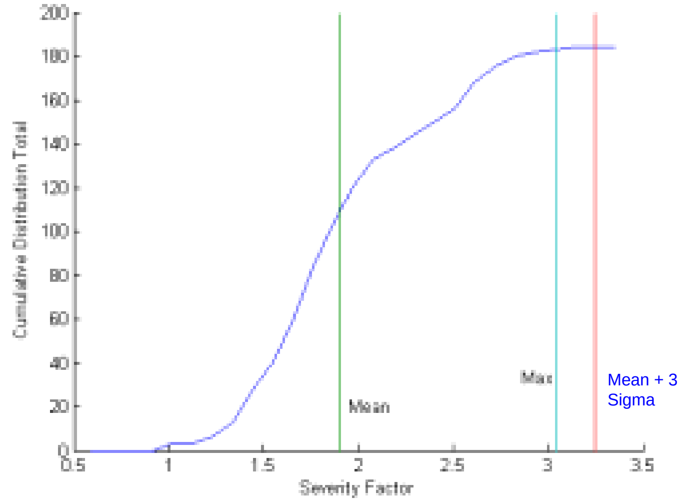
- Rebaselining ASIP critical inspection intervals
  - SF's calculated with 1500hr secant method for all component zones, all active aircraft
  - Representative component zone SF chosen for each MDS group
  - Inspection interval ranges established for each NDI procedure

The SF values for a component zone and all the tails within an MDS group was examined. The max value was noted, as well as the mean plus three sigma value. The representative value was selected to be the smaller of the two.

The representative value was then used to convert the inspection interval from EBH to AFH.

Rebaselining ASIP critical inspection intervals

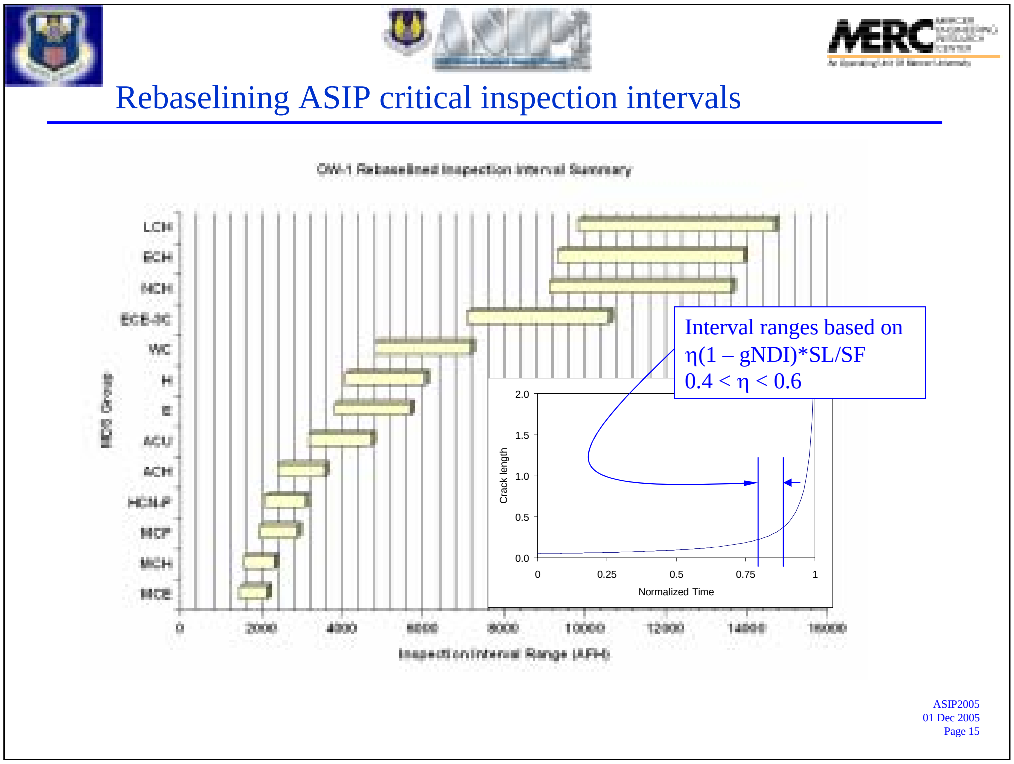
Severity factor distribution for all C-130E, Component Zone OW-1



The choice of a representative value facilitates scheduling inspection by MDS group.

It is customized for that MDS group because it only considers those tails within the group.

It is conservative in that it forces early inspections for the majority of the tails in the MDS group.



The inspection method and area being inspected establishes the crack probability of detection (POD), and a maximum crack size that can go undiscovered (aNDI)

The baseline DTA defines a time tNDI (in EBH) that corresponds to aNDI.

The recurring interval (in EBH) is defined as half of time between tNDI and the safety limit. This is accordance with MIL-STD-1530-C 5.4.3.2.1.

This recurring interval is converted to AFH using the representative SF.

For scheduling purposes, this time will need to be rounded. To provide a measure of the sensitivity of the interval to rounding, lower and upper bounds may be calculated using 40% and 60% of the time between tNDI and the safety limit

Agenda

- Overview of FSMP
- Rebaselining ASIP critical inspection intervals
- Crack history database
- IATP (AIRCAT)
- Continuing efforts

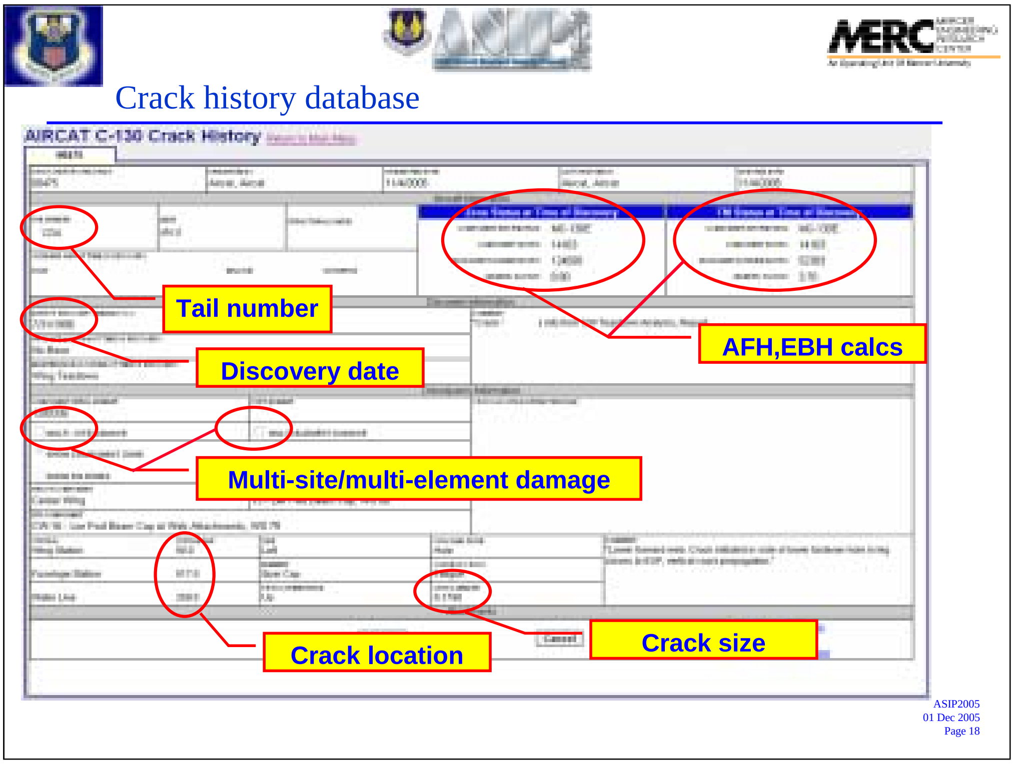
Crack history database

- Database for logging crack findings
- Embedded within AIRCAT
- Crack findings mined from multiple sources:
  - Engineering assistance requests (107s, 202s)
  - Failure analysis reports
  - Wing durability reports
  - CW teardown reports
- Specific information sought:
  - Tail number/serial number
  - Date of discovery
  - Crack size/location/orientation
  - Multi-element-damage/multi-site-damage assessment
  - Documentation, images, photos, etc.
- AIRCAT determines AFH, EBH, SF at time of discovery

MIL-STD-1530-C 5.4.3.1 prescribes a database for capturing aging process information.

Advantages of embedding the crack history database within AIRCAT:

- Web-based, accessible worldwide by authorized users for analysis and for entry of new crack events
- Linked to flight history data for updated assessment of AFH, EBH, SF



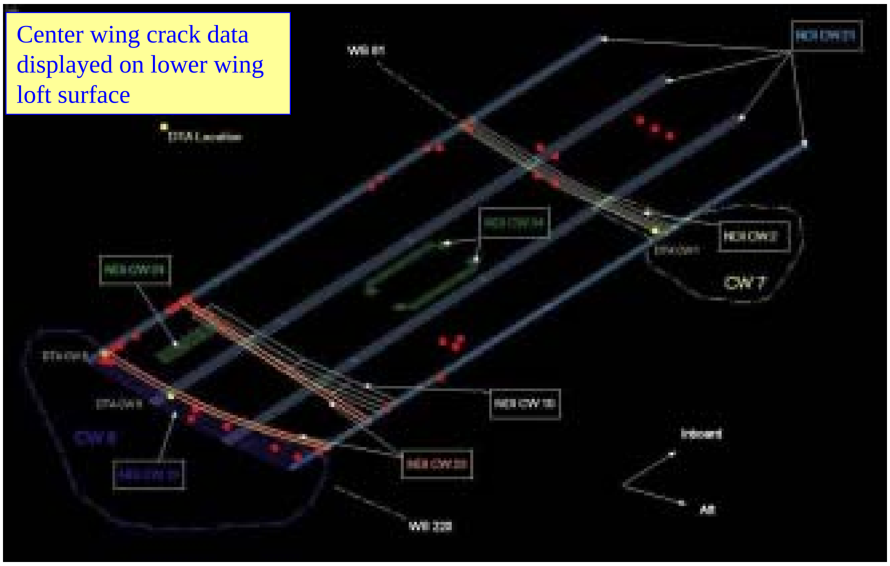
Web-based form guides user through data entry for complete information capture.

Information recorded includes crack size, location, orientation details.

The crack record may be linked to other records if it is a part of a multi-site damage (MSD) or multi-element damage (MED) event.

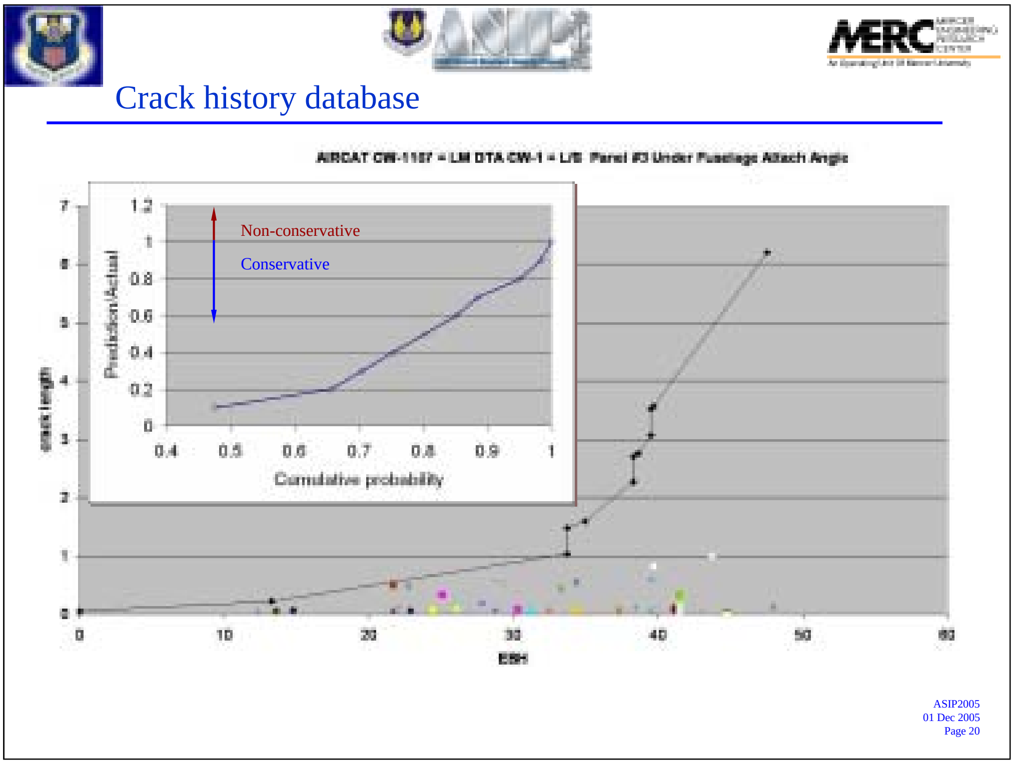
Other documentation, photos, etc. may be electronically attached to the form.

Crack history database



The crack data is available for analysis via numerical and graphical methods.

Shown here is a 3-D plot of the center wing lower surface crack discovery locations, the locations of the DTA points, and the areas covered by the NDI procedures. This permits evaluation of the inspections and DTA locations with respect to where the cracks are actually occurring.



In this plot, information for cracks for a specific component zone have been extracted from the crack history database. Each crack may be plotted using its length and EBH at time of discovery as coordinates. The DTA crack growth curve used to track the component zone is then superimposed on the data.

For a given crack length, the ratio of the DTA curve EBH to the EBH at the time of discovery is a measure of the effectiveness of the analysis. Here, the ratios are less than unity. The DTA is conservative, because the crack sizes at the time of discovery are smaller than the DTA predicts.

A cumulative distribution function plot of the error ratio shows the probability of the analysis being conservative.

Agenda

- Overview of FSMP
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- Continuing efforts

IATP (AIRCAT)

- AIRCAT (Automated Inspection, Repair, Corrosion and Aircraft Tracking)
  - USAF C-130 IATP (Individual Aircraft Tracking Program)
- Oracle database tracking all active, inactive, retired tails
  - 1.7 million flight records
  - Series-Command-Base-Wing assignment (SCBW)
  - Mission Design Series (MDS), configuration/component history
  - Retirement status
  - Inspection history
  - ASIP critical point fracture growth tracking data

MIL-STD-1530C sections 5.4.5 and 5.5.1 prescribe the functionality of the IATP. Specific aspects include providing flight data for the purposes of adjusting maintenance intervals and component replacement intervals.

Every USAF C-130 flight is logged into AIRCAT. Flight data includes the date, take-off and landing time, tail number. Additionally, parameters describing the various flight segments is also entered (airspeed, altitude, etc.). AIRCAT evaluates these parameters and categorizes the flight with one of several hundred predetermined mission codes. For each mission code, every tracking point has an incremental damage associated with it. The tracking point EBH is determined by summing the increments over the entire flight history and multiplying by the baseline safety limit. In this manner, AIRCAT computes both the airframe hours and equivalent baseline hours for each aircraft, according to the unique flight history of each aircraft.

IATP (AIRCAT)

- AIRCAT is comprehensive database enabling robust analysis for implementing ASIP, FSMP concepts
- Current reporting processes data in AIRCAT to evaluate
  - Airframe hours, equivalent baseline hours
  - FGT (Fracture Growth Tracking), i.e. normalized time accumulation
  - Rates (severity factors, usage rates) for forecasting future events (inspection due, component end of service life)
  - Inspections due, accomplished
  - Grounding, restriction decisions
  - Daily flying rates
  - Squad-based performance

AIRCAT algorithms process the flight data to provide comprehensive, up-to-date usage parameters (flying rates, SF, EBH) for individual tails and ASIP tracking points.

The parameters can be used to forecast when the next inspection is due, or when a component is expected to reach a targeted EBH value that signals the end of its economic service life.

The trends of current flight data can also be used to re-evaluate the inspection intervals. For example, if current flights have shifted towards more severe missions, then the inspections intervals may shorten.

IATP (AIRCAT)

Input: Aircraft Tail Number

- Series of reports by component
- Each report broken into zones
- Batch Report

Aft Fuselage

Component SN	AAA	Component Hours	6396.9
Component	Aft Fuselage	Annual Flying Rate	504.89
Comp Model Cafg	C-130H	Last Flight Date	Apr 20, 2005

Zone	Stru Cafg	Stru Date	Stru Hours	Insp Date	Insp Meth	Insp Hours	Stru Grth	Insp Grth	Delta Grth	Hours to Next Insp	Date of Next Insp
1	FY 74 Redesign - 7549-T73	7/1/1984	6396.9								
2	FY 57 Redesign	7/1/1984	6396.9								
3	FY 57 Redesign	7/1/1984	6396.9								
4	FY 57 Redesign	7/1/1984	6396.9	2001/12	SEC	1969.6	0.1942342	0.0896326	0.3067668	7366.27	202307
5	FY 57 Redesign	7/1/1984	6396.9								
6	FY 57 Redesign	7/1/1984	6396.9								

Back to Top

Component-zone info | Last inspection | Next inspection

This is an example of an inspection forecasting report. This is run for a specific tail, and can show the status for multiple zones of a given component (in this case, the aft fuselage).

The AIRCAT database can retrieve aircraft fracture growth tracking information at the time the last inspection was accomplished, and based on the inspection interval, usage, and severity factor, make a forecast regarding the next inspection.

IATP (AIRCAT)

- AIRCAT improvements:
  - All flight record chronology from 1987 forward was verified with Air Force Knowledge System (AFKS) data
    - Repaired keying, rounding errors that created extraneous makeup flights
    - Affirmed high confidence levels in AIRCAT usage rates
  - Reviewed base and command history with AFKS records
    - Anomalies identified
  - Verification of inspection and end-of-service life forecasting algorithms
  - Update of inspection accomplishments via TCTO
  - Added capability/framework for embedding ASIP Master Plan and FSMP documents within AIRCAT

AFKS flight data consists of dates and flight hours. These inputs are independent of the AIRCAT flight data inputs and are generally believed to enjoy a higher reporting rate. The AFKS hours are accepted as the defacto correct flight hour records. Synchronizing the AIRCAT history with the AFKS hours brings maximum accuracy and minimal flight rejection to the AIRCAT data. (Note: The other flight parameters required by AIRCAT to categorize each flight are not recorded in AFKS, and are found only in AIRCAT.)

TCTO records (applicability and accomplishment status) are also logged in AFKS. Those TCTOs enacting an ASIP critical inspection were identified, and their accomplishment status extracted from AFKS. The data was reformatted for updating the AIRCAT records of inspection accomplishment.

Agenda

- Overview of FSMP
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Continuing efforts

- Increased automation of fleet management tools, task updates
  - ASIP Master Plan and FSMP document content finalization with automated update capability via links to AIRCAT data
  - 3D graphical depiction of crack, fleet management data
  - Modularity for future data analysis tools
  - Report customization
  - Maintenance data collection

C-130
Inspection Developments

ASIP 2005
01 December 2005

W. Darin Lockwood, PhD — Mercer Engineering Research Center
Peter Christiansen — USAF, Warner Robins Air Logistics Center
Darren Fritz — USAF, Warner Robins Air Logistics Center

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- Special thanks to the following colleagues for their contributions to this presentation:
  - Mr. Bob Bailey
  - Mr. Daniel Edwards

Agenda

- C-130 Inspection Program
  - Identify critical structure
  - Track damage growth
  - Inspect for damage
- Fatigue Cracking Issues
  - Current service cracking
  - Historical findings
- Inspection Developments
  - Updated Inspection Manual
  - Implementation of new procedures
- Summary

The purpose of the talk is to provide a look at the current state of the C-130 inspection program and highlight ongoing developments that are being incorporated as a result of current service findings as well as examination of historical data.

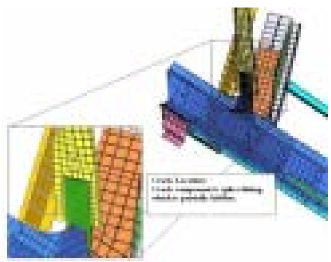
Characterize the C-130 inspection program through its components.

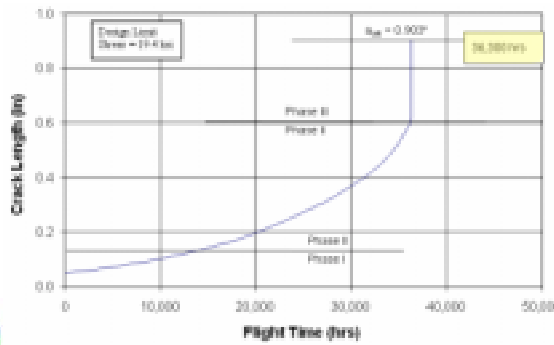
Identify current and historical fatigue cracking issues.

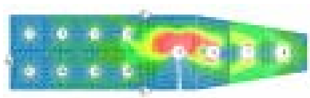
Highlight developments being incorporated into an updated inspection manual.

C-130 Inspection Program

- Identification and analysis of critical structure:
  - Durability and Damage Tolerance Assessment (DADTA)
  - Determine baseline Safety Limit
  - Define initial inspection interval (0.5*Safety Limit)







First component of the inspection program is identification of critical structure. Historically, this is done through durability and damage tolerance assessments.

The critical structural element is identified and crack growth analysis is performed.

Results of the crack growth analysis used to define:

Safety Limit- time for the crack to grow to critical length

Initial inspection interval- computed as half of the safety limit

C-130 Inspection Program

- Tracking damage growth in critical structure
  - **AIRCAT** is the C-130 IATP
    - Tracks individual flights and categorizes each by FTP code
    - Primary structure organized into component zones (ASIP Tracking points)
    - Each component zone is driven by a DTA which characterizes damage accumulation
      - DTA provides baseline growth rate
      - FTP code assigns growth coefficient for each flight
      - Accumulated growth expressed as EBH
        - EBH = growth / baseline rate
  - **AIRCAT** uses this information to determine inspection intervals

Second component of the inspection program is tracking damage growth in the critical structure. The aircraft contains numerous components that are considered critical from a structural integrity standpoint and these components are tracked on a fleet wide basis via the USAF C-130 Individual Aircraft Tracking Program (IATP) known as AIRCAT (Automated Inspection Repair Corrosion and Aircraft Tracking).

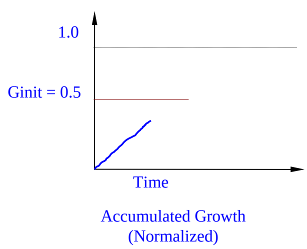
AIRCAT is a web based database system used to track and monitor the fleet on a flight by flight basis. Individual flights are recorded and categorized by a FTP (Fracture Tracking Program) code that essentially describes the type of mission the flight represents.

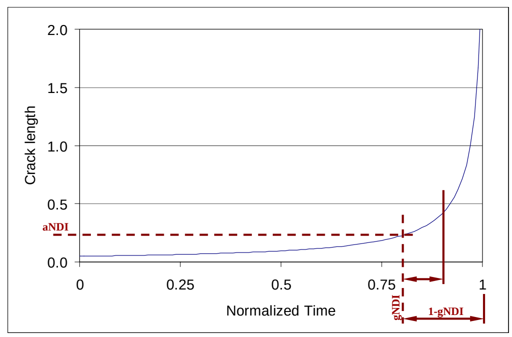
Critical structure is organized into component zones, where the component defines the major structure (i.e. center wing) and the zones represent further subdivisions of the component (i.e. lower surface spanwise splices). The collection of component zones represents the ASIP tracking points.

Each component zone is driven by a corresponding DTA which characterizes the damage accumulation. DTA provides the baseline growth rate. The FTP code assigns a growth coefficient for flight and the accumulated growth is expressed as Equivalent Baseline Hours (EBH), where EBH is effectively the actual growth divided by the baseline rate.

C-130 Inspection Program

- Inspection Intervals
  - Initial inspection occurs when Ginit = 0.5
    - aNDI = max undetectable crack length
    - For inspection purposes, growth is reset to gNDI
  - Recurring inspection interval = 0.5*(1-gNDI)





Previously, the initial inspection interval was determined from the crack growth curve as one half the safety limit. On a normalized scale, this translates to when the accumulated growth equals 0.5.

The technique used to perform the inspection has a corresponding aNDI, associated with a given POD, which describes the largest undetectable crack length. This aNDI value is then used to determine the remaining life from which the recurring interval is computed. For inspection purposes, accumulated growth is reset to gNDI (determined from aNDI) and the recurring inspection interval is set to one half the remaining life (1-gNDI) to allow for two inspections prior to the crack going critical.

C-130 Inspection Program

- Inspection of critical structure
  - **AIRCAT** tracks 91 component zones
    - ASIP Tracking Points
  - Component zones typically cover large areas and include DTA point
    - Zones representative of associated structure analyzed in DTA
  - Inspection procedures assigned to cover each component zone
    - Inspection techniques/procedures tailored to finding expected service cracking

The third component of the inspection program is the inspection of the critical structure.

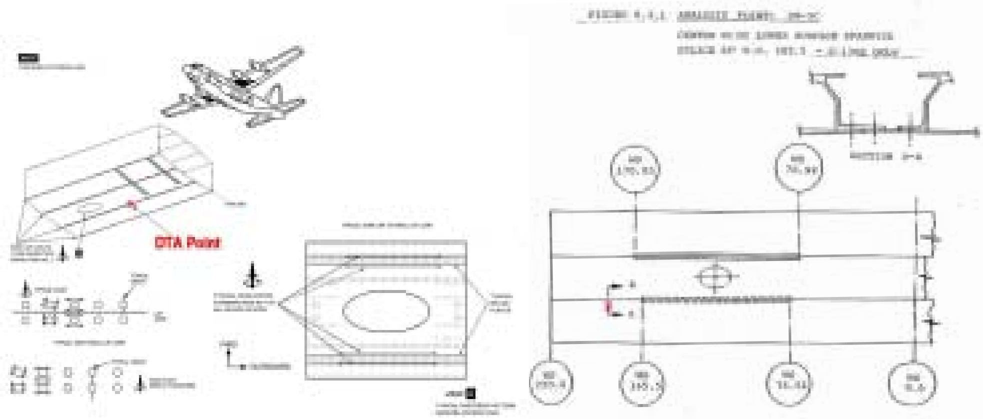
AIRCAT currently tracks 91 component zones, which comprise the ASIP tracking points.

The tracking zones are typically representative of the structure associated with the DTA driver and generally cover large areas including the DTA location.

Inspection procedures are assigned to cover the component zones and are tailored to finding expected service cracking.

AIRCAT - NDI - DTA Relationship

AIRCAT Tracking Zone	Inspection	DTA Point
CW-1	CW-21	CW-5C
“Lower Surface Panel Spanwise Splices”	“Lower Skin Panel Lap Joints, CW 220 L/R”	“Lower Surface Spanwise Splice, WS 185.5”



The relationship between identification of critical structure (DTA), monitoring (AIRCAT), and inspection (NDI) is shown here visually for reference.

AIRCAT tracking zones are defined to monitor damage growth in critical structure.

Ideally:

AIRCAT utilizes a DTA, from representative structure, as the driver for damage growth in the component zone.

An inspection procedure is employed that completely covers the intent of the tracking zone and includes the DTA driver.

C-130 Inspection Program

- Review of AIRCAT-NDI-DTA relationship
  - Identification of cases where following criteria not met:
    - Inspection procedure assigned to tracking zone?
    - Inspection covers tracking zone and DTA driver?
  - MERC providing update of existing procedures and development of new procedures as required
- Inspection Schedules and Procedures
  - TO 1C-130A-6 (Scheduled Inspection and Maintenance Instructions)
    - Lists the scheduled inspection intervals for tracking points
  - TO 1C-130A-36 (Nondestructive Inspection Procedures)
    - Schedule not included
    - Instructions and artwork

MERC conducted a thorough review of the relationships between the three components of the inspection program for all of the ASIP tracking points.

The goal of the review was to identifying cases where the following criteria were not met:

-Is there an inspection procedure assigned to the tracking zone?

-Does the inspection procedure adequately cover the tracking zone and include the location for the DTA driver.

As a result of the review, MERC is providing an update of existing procedures and development of new procedures as required.

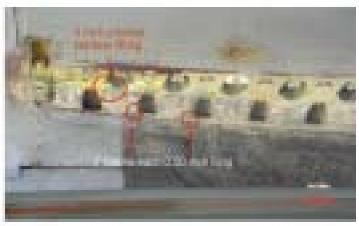
The inspection schedules and procedures are contained in the following tech orders:

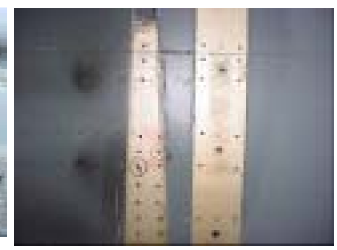
1C-130A-6 contains inspection schedules and maintenance instructions

1C-130A-36 contains the NDI procedures

Fatigue Cracking Issues

- Recent service cracking
  - Increased number and severity of cracks found in lower wing panels, rainbow fittings, spar caps, corner fittings
  - Center wing crack findings led to the grounding of ~30 A/C and the restriction of 60 A/C in early 2005





Recent findings of in-service cracking have identified both an increased number and severity of cracks found in several areas of the center wing box. These areas include flight critical structure such as the lower wing panels, rainbow fittings, spar caps and corner fittings.

The figures at the bottom of the chart represent (from left to right) crack findings in the lower wing panels and the rainbow fitting at the wing joint; corner fitting cracks; and cracks in the lower wing panels under the engine drag fitting and nacelle attach angle.

As a result of these findings, the AF grounded roughly 30 aircraft and placed approximately 60 additional aircraft on restricted flight status.

Fatigue Cracking Issues

- Review of historical data
  - MERC developed Crack History database feature for **AIRCAT**
    - Utilize **AIRCAT**'s existing field/depot maintenance and inspection records
    - Include all historical maintenance / test data sources
      - Requests for engineering assistance (107's, 202's)
      - Wing Durability Test
      - Wing Teardown Reports
  - Provide ASIP manager with fleet management tool
    - Identify trends
    - Highlight deficiencies

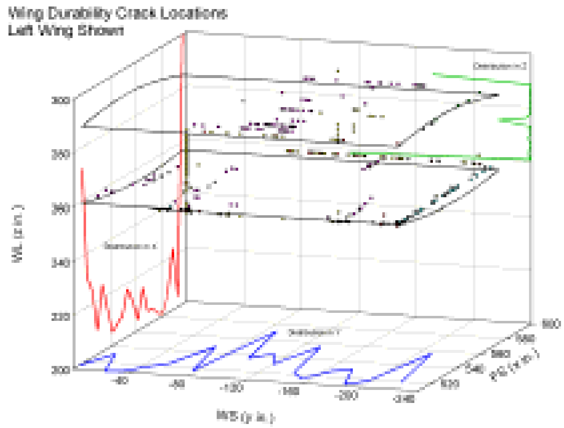
In addition to the current service cracking issues, MERC examined historical data made available through the Crack History database feature in AIRCAT.

The Crack History database is a feature developed by MERC that has been added to AIRCAT as part of the task to update the Force Structural Maintenance Plan (FSMP). It utilizes the existing field and depot maintenance and inspection records that reside within AIRCAT in addition to crack related data mined from historical maintenance and test data sources. The historical data sources used to mine crack data included all available requests for engineering assistance (AF Forms 107's and 202's), wing durability test reports and wing teardown reports.

The Crack History database provides the ASIP manager with a valuable tool, which can be used to both identify trends and highlight deficiencies pertinent to the C-130 fleet management in general and the inspection program in particular.

Fatigue Cracking Issues

- Data sample generated from Crack History database
  - Location and distribution of cracks
  - Used to identify potential problem locations and components



The plot shown on this chart provides a sample of the type of information now readily available from the crack history database.

Shown here are crack findings from the C-130 wing durability test plotted over a contour of the center wing boundary. The plot provides a graphical view of the individual crack locations, as well as, the distribution of cracks (colored solid lines) along the aircraft coordinate axes.

This data may be used to identify locations and components of interest.

Fatigue Cracking Issues

- Implications
  - ASIP manager relies on inspection program for comprehensive and thorough coverage of C-130 primary structure
  - Service cracking and extended analysis of historical data have identified need for updating the current inspection program
  - Inspection program update to include:
    - Review of all ASIP critical inspection procedures
    - Procedure modification to improve coverage and confidence in the inspection
    - Development of new procedures to cover problem locations that currently have no inspection

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In light of the current inspection program and current trends within the fleet, it is evident that:

(1) The ASIP manager relies on the inspection program to provide comprehensive and thorough coverage of the aircraft primary structure.

(2) Examination of current service cracking and historical data have identified a need for updating the C-130 inspection program.

The inspection program update is to include a review of all ASIP critical inspection procedures with the goal of updating existing procedures to improve coverage and confidence in the inspection, and developing new procedures to cover problem locations that currently have no inspection.

Inspection Developments

- Update of TO 1C-130A-36
  - Review all ASIP critical inspection procedures
    - Updating equipment callouts to match current USAF equipment
    - Tailoring (expanding/limiting) inspection scope
    - Improving instructions and artwork detail
    - This is a work in progress
  - Center Wing inspection procedures:
    - Lower surface panels
    - Rainbow fittings, splice angles and attachments
    - Spar caps

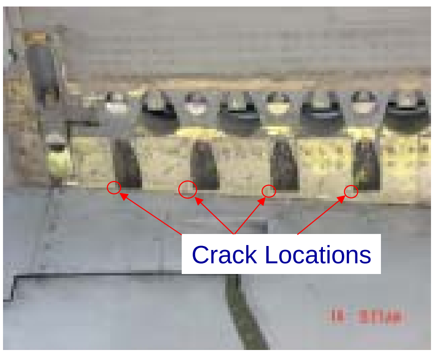
The focus of the inspection program update and the subsequent inspection developments is on providing a revision to the -36 Inspection manual for all ASIP critical inspections.

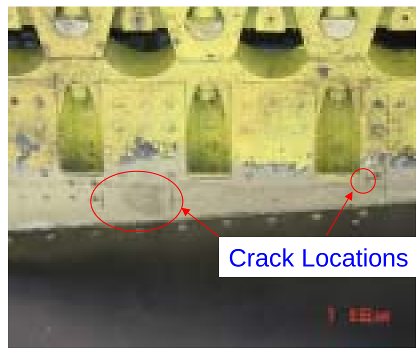
Revisions will include updating all equipment callouts to reflect equipment currently used by the USAF, tailoring of the inspection scope, and improving the instructions and detail in the artwork. Priority is given to center wing inspections, however, this is a work in progress and will eventually include all ASIP critical inspections.

The following slides highlight a few of the developments made in the center wing inspection procedures for the lower surface panels, rainbow fittings, and spar caps.

Inspection Developments

- Lower Surface Panels
  - Service cracking at multiple locations
  - Extensive inspection area
  - Existing inspections required updates
  - MOI (Magneto-Optic-Imaging) procedure developed for enhanced inspection coverage





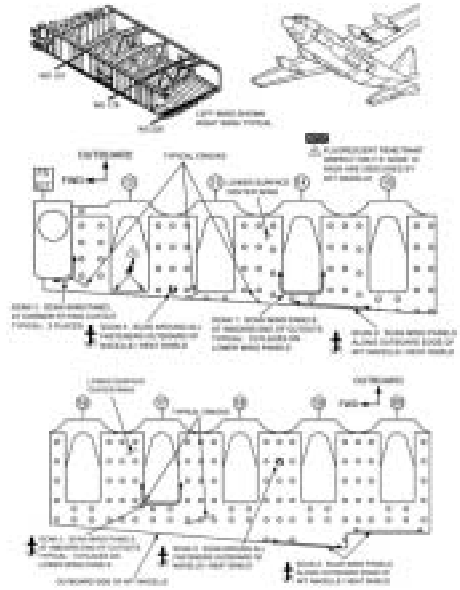
The center wing contains 3 panels on the lower surface that extend the entire length of the wing box and present an extensive inspection area.

Service cracking has been identified at multiple locations including the panel cutout radii at the wing joint (shown in the figure on the left), panel to rainbow fitting attachments (shown in the figure on the right), and under the engine drag fittings and nacelle attach angles. The existing procedures employed to inspect these areas required updates to address the current findings.

As a result of the crack findings, suspicions arose about the remaining portions of the lower wing panel which were not being inspected. This represents a large inspection area (in terms of number of fasteners) and the AF required a relatively quick response, so MERC developed an inspection procedure utilizing MOI technology to satisfy these requirements.

Inspection Developments

- Lower Surface Panels at Rainbow Fittings
  - Scan all panel fasteners outboard of nacelle attach angle
  - Scan all panel finger radii
  - Scan panel cutouts at corner fittings
- Improved coverage to capture service cracking



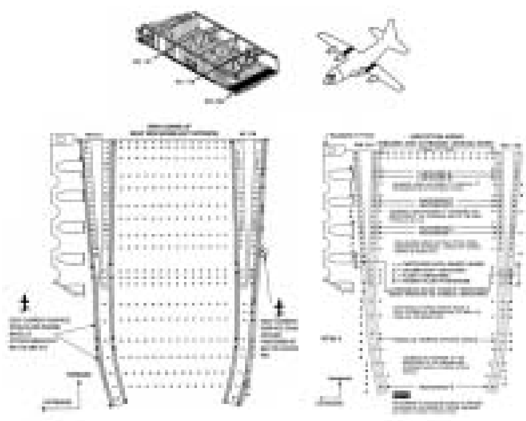
The procedure for inspecting the lower wing panels at the wing joint fitting is demonstrated in the figure. Detailed drawings of the structure including fastener and cutout locations landmark references, and actual service cracking locations were incorporated as enhancements.

Eddy current scan paths were added to cover the all fastener holes outboard of the nacelle attach angle, all panel cutout radii, and panel cutouts at the corner fittings.

Resulting procedure provides improved coverage to capture actual service cracking.

Inspection Developments

- Lower Surface Panels under Engine Drag Fittings
  - SEC scan along inboard and outboard edges of drag fittings and nacelle attach angles
  - UT scan all fasteners common to drag fittings and nacelle attach angles
- Improved inspection coverage and capability for detecting hidden cracks



The lower surface panels in the area under the engine nacelles presents challenges in the inspection due to obstructions of the engine drag fittings and nacelle attach angles.

Service crack locations have been added to the drawings as well as detailed fastener locations to provide specific guidance for the inspection.

The procedure has been enhanced with the addition of SEC scans along the inboard and outboard edges of the drag fittings and nacelle attach angles and the addition of ultrasonic scans on all fasteners common to the drag fittings and nacelle attach angles resulting in improved inspection coverage and capability for detecting hidden cracks.

Inspection Developments

- MOI Inspection of Lower Surface Panels
  - Magneto-Optic-Imaging (MOI) system
    - HUD with signal output for image/video capture
  - Fast and effective inspection of major portion of lower surface
  - Allowed USAF to make quick assessment regarding restricted aircraft

The lower panel service cracking caused concern about the remaining portions of the lower wing panels and the AF requested the development of a procedure for examining a large section of the lower wing skin.

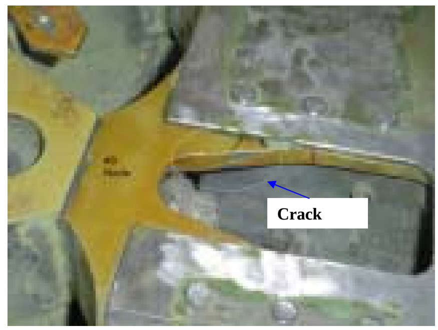
A procedure was developed utilizing the MOI system for inspecting a major section of the wing skin from the armpit fairing to the engine nacelle. The MOI system is an eddy current system that allows for visualization of cracks around fastener holes. The unit comes with a heads up display (HUD) as well as signal output for image and video capture capability.

The figures on the right represent the type of crack and no crack images produced using the MOI.

This procedure offers fast and efficient inspection of large portions of the lower surface and allowed the AF to make quick assessment regarding restricted aircraft.

Inspection Developments

- Rainbow fittings, splice angles and attachments
  - Service cracking at multiple locations in wing joint area
  - Rainbow fittings and attachments transfer panel and stringer loads from OW to CW
  - Existing procedures updated

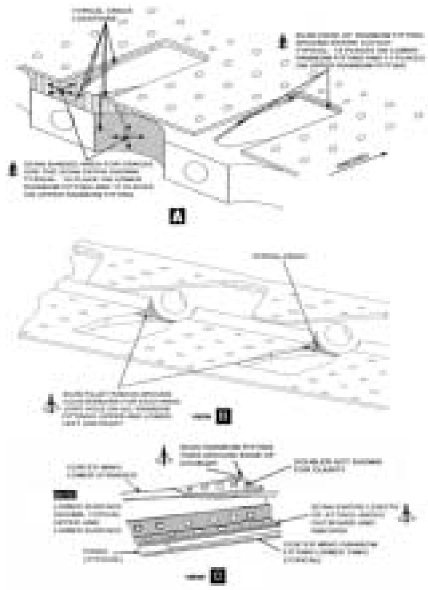


The next location deals with the rainbow fittings, splice angles and stringer attachments in the area of the wing joint.

This structure transfers panel and stringer loads from the outer wing to the center wing and has exhibited service cracking at multiple locations including the scalloped portion of the fitting (shown in the figure on the right) and in radii of the external tangs of the fitting (shown in the figure on the left).

Inspection Developments

- Rainbow fittings, splice angles and attachments
  - Added edge scan along cutouts
  - Expanded inspection to include entire length of attach angles
  - Enhanced images clarify inspection areas
- Improved inspection coverage and capability in detecting service cracks



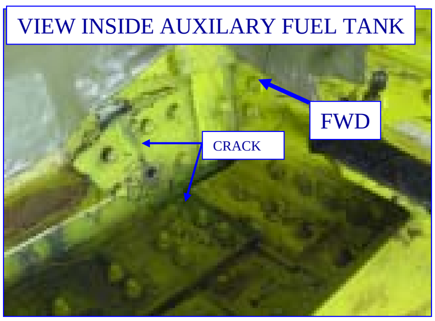
The inspection procedure for the rainbow fittings, splice angles and attachments is shown in the figures on the right.

The rainbow fitting is a complex component and the inspection procedure required enhancements to the images in order to identify specific inspection locations such as the spotface region shown in the middle figure.

EC scans along the edges of the cutouts were added and the scan of the attach angles was expanded to include the entire length of the angle. Detailed scan paths were added to the inspection as well as the locations of service crack findings resulting in improved inspection coverage and capability.

Inspection Developments

- Spar Caps
  - Service cracking at multiple locations on lower forward and aft caps
  - Extensive inspection area covered by several procedures
  - Existing inspections updated



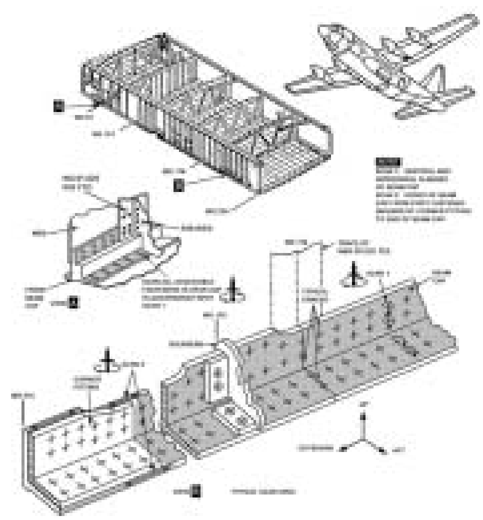
The final location deals with the wing spar caps. The spar caps run the entire span of the wing box and provide connections for the upper and lower surfaces the front and rear beams of the center wing.

The figure on the left, viewed from inside the wing box, shows cracking in the horizontal and vertical flanges of the spar cap and the figure on the right shows an external view of a crack in the exposed bulb of the spar cap.

Service cracks have been found at multiple locations along the lower forward and aft spar caps and necessitated updates for several procedures.

Inspection Developments

- Lower Forward Spar Caps
  WS 178 - 214
  - Added edge scan at cap termination
  - Expanded coverage to capture service cracking
  - Enhanced images indicate obstructions and provide landmarks for inspectors
- Improved inspection coverage and detail

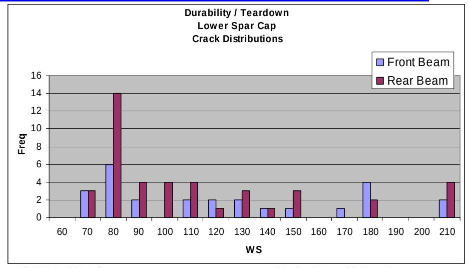


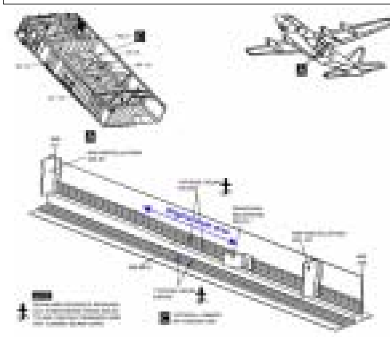
The procedure for inspecting the lower forward spar caps in the engine dry bays (from wing station 178 to 214) is shown on this slide. It is an internal scan performed inside the wing box.

The inspection procedure was modified to show service crack locations, provide enhanced images for identifying landmarks, and provide better guidance for inspecting around obstructions. EC scans were added to the include edge scans at the termination of the spar cap which is obstructed by the corner fitting resulting in expanded and improved inspection coverage.

Inspection Developments

- Lower Spar Caps at WS 80.5
  - Original inspection scanned 6 inboard/outboard of WS 80.5
  - Expanded coverage due to service cracking and historical data analysis
  - Enhanced images reflect accurate geometry and provide landmarks for inspectors
- Improved inspection coverage and detail





A separate procedure for inspecting the lower forward and aft spar caps in the vicinity of wing station 80.5 also required modification.

The original procedure called for EC scans approximately 6 inches inboard and outboard of WS 80.5 However, indicated service cracking and examination of historical findings in this area indicated a need for expanding the inspection area. Analysis of wing durability and teardown reports identified a large portion of the crack findings fell within the range from WS 61 to WS 108.

In addition to expanding the coverage area, new drawings were created to accurately reflect the geometry changes in the structure and provide additional landmarks for the inspectors resulting in improved inspection coverage and detail.

Summary

- Review of C-130 Inspection Program in progress and focusing on ASIP critical tracking points
- Examination of historical and recent findings indicate need for updated inspection program
- MERC teaming with WR-ALC to provide updated NDI manual
- New and improved inspection procedures have enhanced the capabilities of inspectors and reliability of inspections
- Updated inspection program provides the ASIP manager with increased confidence in ability to manage the fleet

Ogden Air Logistics Center

Converting A-10A DTA to AFGROW

December 1, 2005

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- **Hill AFB A-10 SPO and Engineering & Analysis Branch**

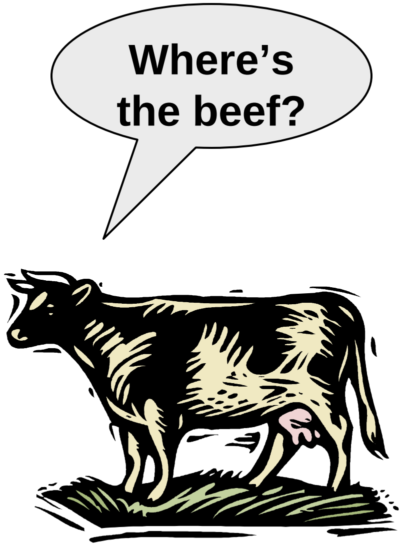
Overview

- Objectives
- AFGROW Specifics
- Challenges & Successes
- Precautions and Pitfalls
- Summary

Objectives

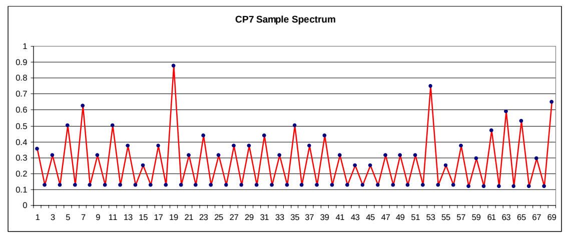
- **Why?**
  - **Extended service life requirement**
    - **16,000 hours (Current design = 8000 hours)**
- **<u>Where's the beef?</u>**

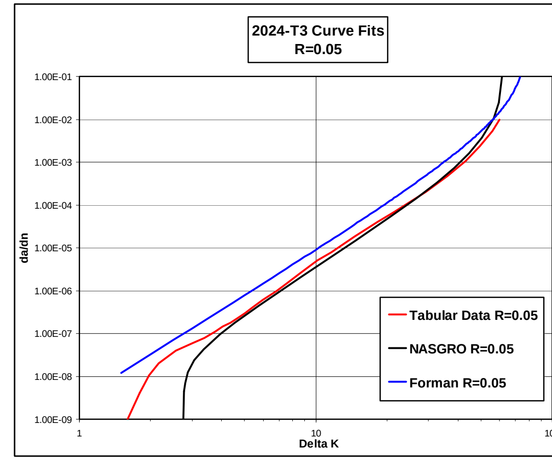
  (What does USAF get out of this effort?)
  - **Organic capability with A-10 validated crack growth tool (AFGROW)**
  - **Eliminate reliance on OEM legacy tools**
- **Damage Tolerant Analysis (DTA) & Force Structural Maintenance Plan (FSMP)**
  - **Updated usage *(last update 1993…)***
  - **Required by MIL-STD-1530 & OSS&E**

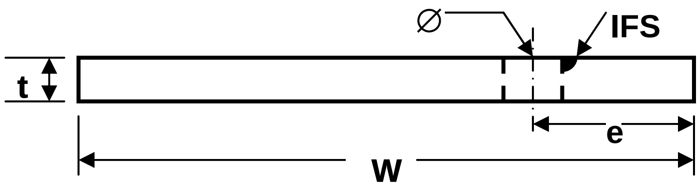


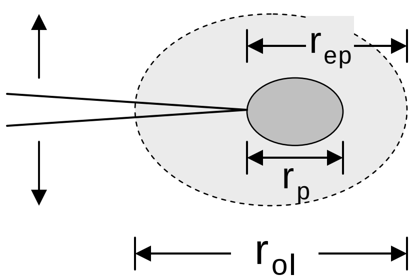
AFGROW Input

- Material model (da/dN vs. ΔK)
- Spectrum
- Model geometry
- Retardation model
- Others…



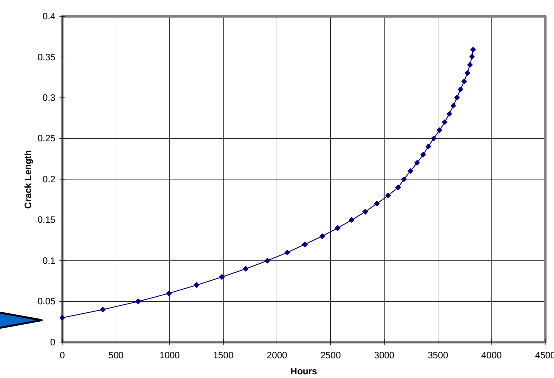






Retardation when $r_{ep} > r_p$

AFGROW



Material Model

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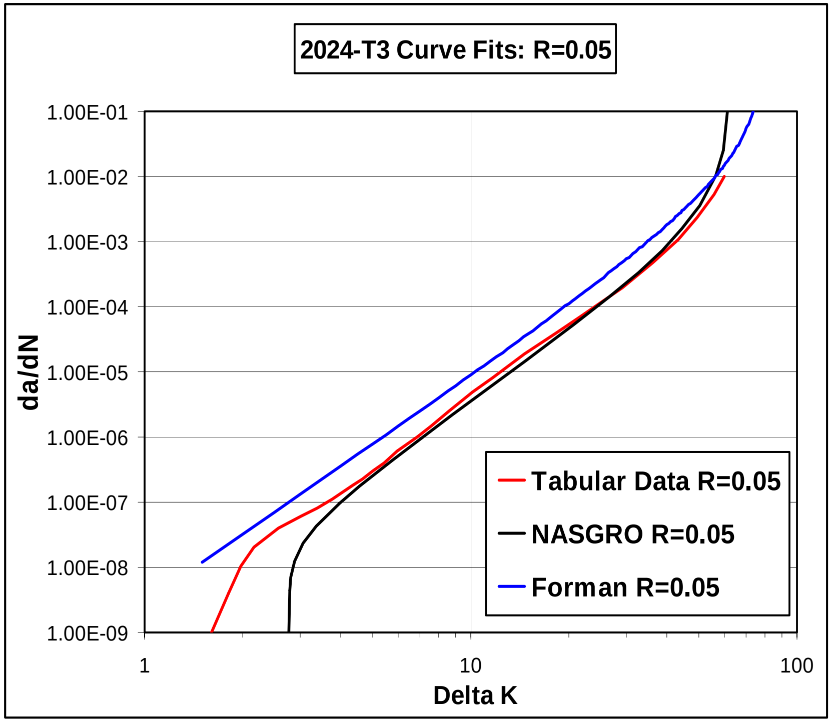
- WHICH MATERIAL MODEL???
  - Forman equation
    - Used historically for A-10
  - NASGRO equation
    - Built into AFGROW
    - Newer NASGRO updated
  - Tabular lookup files
    - Tailored to tested data
      - A-10 materials tested
    - Other available data
      - DTDH
      - MMPDS-HNDBK *(MIL-HNDBK-5)*
      - USAF data
        - T-37
        - T-38



Material Model

Challenges

- **Forman & NASGRO Equations**
  - **Does not account for specific behaviors (i.e., double knee)**
  - **Curve shifts when K_c changed**
- **Tabular Input Files**
  - **Pulling da/dN vs. ΔK data together**
    - **Large amount of data**
      - **Variety of sources [M(T), C(T), NaCl, Lab Air, Hz, etc.]**
      - **Increase in confidence**
    - **Too little data**
      - **Did not increase confidence**
    - **Vary K_c with model thickness without curve shift**

$$da/dN = C\Delta K^n / ((1-R)Kc - \Delta K)$$

Forman Equation

Material Model

Successes

- Tabular Input Files
  - 76% of control points (CPs)
    - a.k.a: FCLs
  - Increase in confidence
  - Specific A-10 data
  - Stable material models

- Forman Equation
  - Used as default

Material Models Utilized

7 Tabular Input Files

2024-T3, 2024-T351, 2024-T3511, 4340 Steel, 7075-T6, 7075-T7351, and 7175-T74 (7175-T736) (76% of CPs)

8 Forman Equations

2024-T42, AMS 6526, 17-7PH, 7075-T6511, 7075-T73, 7075-T76, 7075-T7651, 7075-T76511 (24% of CPs)

Material Model Example

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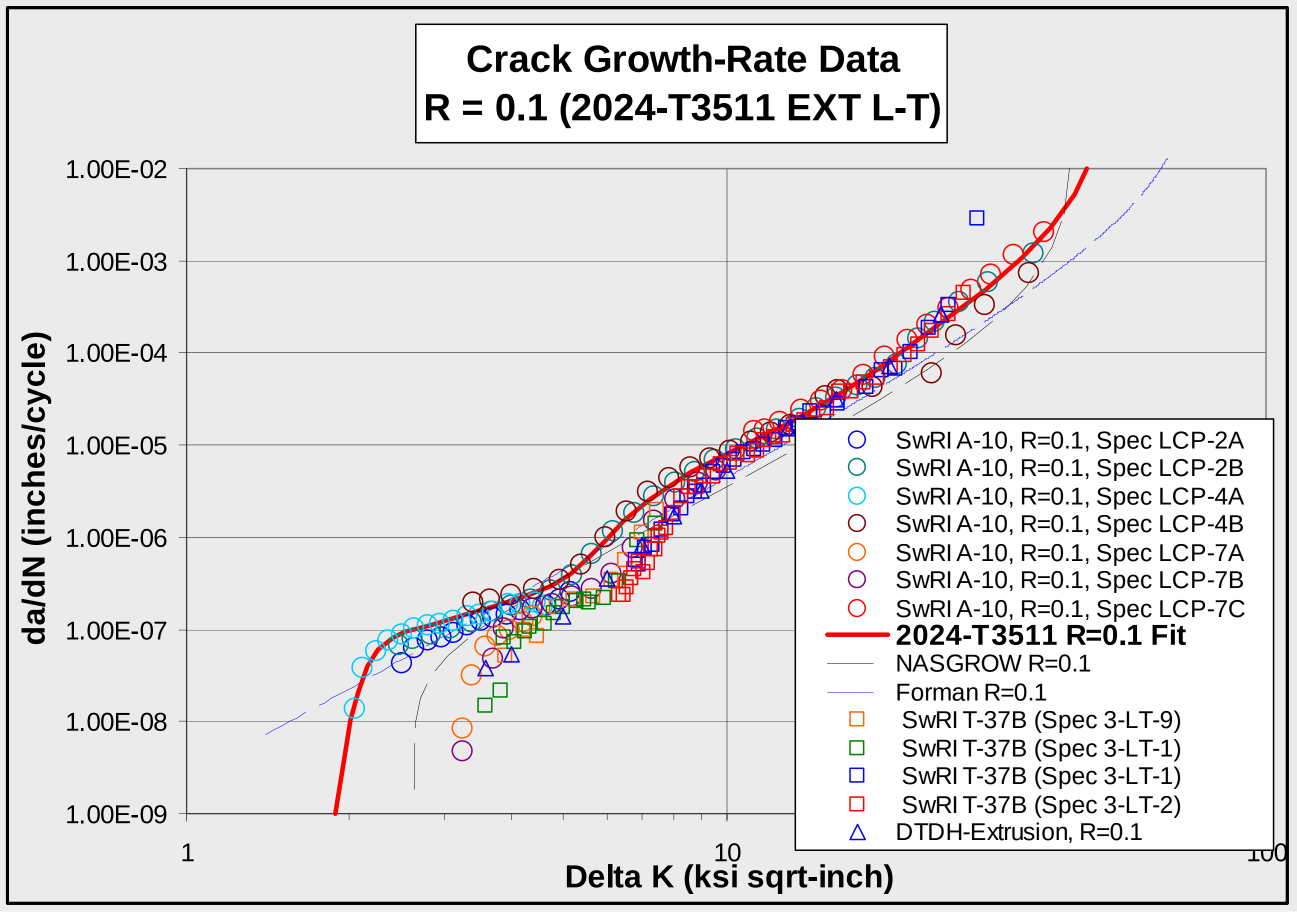

Model Geometry

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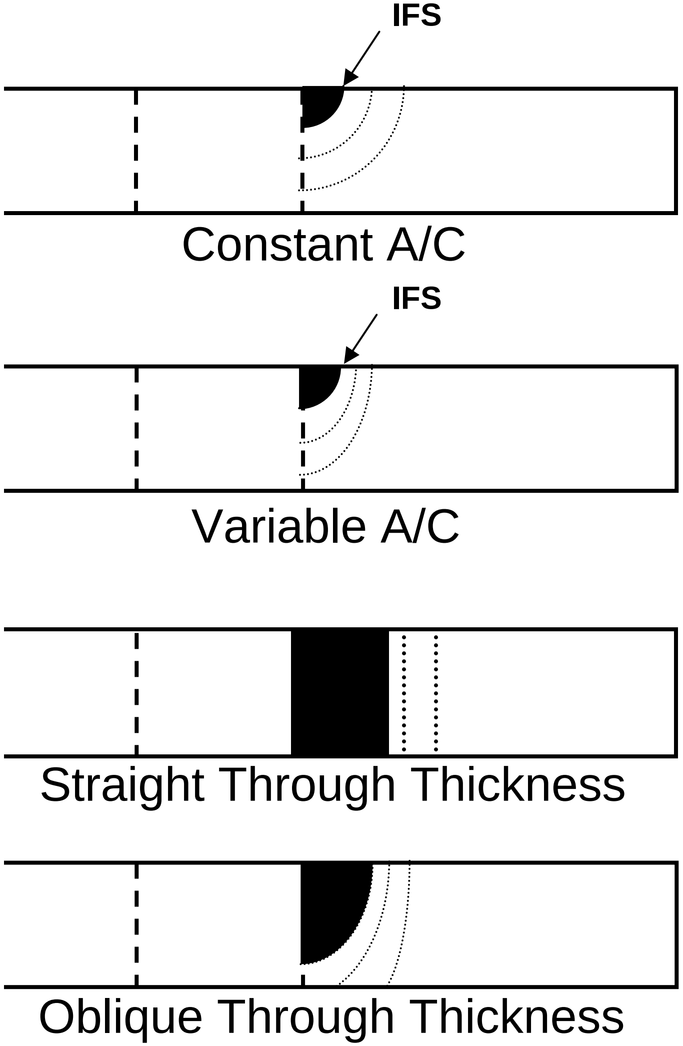
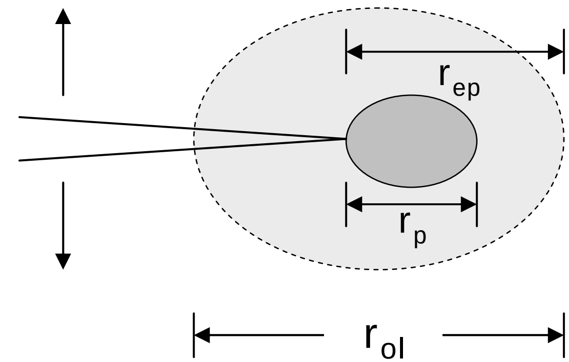
- AFGROW standard solutions
  - Covered most analyses (97%)
- AFGROW user defined
  - Requires *Beta* solutions (3%)
- Attention to:
  - Aspect ratio for corner crack
    - Constant A/C for analysis
      - A-10 DTA history
  - Oblique through thickness cracks
    - Not used for analysis
    - When used with A/C constant
      - Caused AFGROW to hiccup

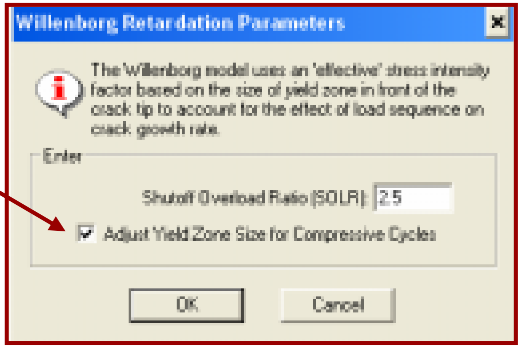


Retardation Model

- AFGROW offers:
  - Generalized Willenborg
    - Shutoff Over Load Ratio (SOLR)
    - Default accounts for compression effects.
  - Wheeler
  - Closure
  - Fastran
  - Hsu



Retardation when $r_{ep} > r_p$



Generalized Willenborg selected due to previous study by NGC showing it to be the most suitable retardation model within AFGROW to compare with legacy (OEM) crack growth results.

Retardation Model

- **General Approach for SOLR Correlation:**
  - **Coupon tests**
    - **Select materials and spectra (CP specific)**
    - **Varied material thickness and peak stress level**
  - **Not all CPs were tested**
  - **SOLRs were assigned for non-tested CPs based upon engineering judgment and similar testing**
  - **For SOLRs where no like-testing was performed, the SOLR values were back-calculated using the previous DTA results *[This was done to correlate SOLR with legacy results.]***

Retardation Model

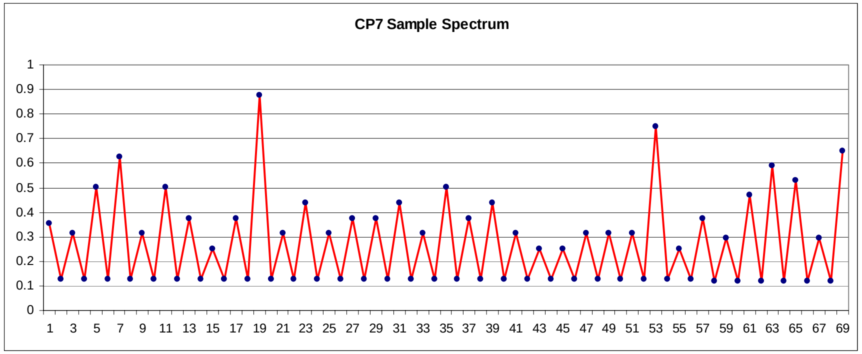
- SOLR Correlation Challenges
  - Fracture Mechanics Models:
    - Testing was performed using a single corner crack at a hole.
      - After a period of growth, a second crack formed at the opposite side of the hole.
    - Since AFGROW does not have an applicable model for this geometry, the SOLR correlations were performed using only the single crack data.
  - Aspect Ratio Variance:
    - The aspect ratio of the part through crack varied significantly.
    - Because AFGROW does not allow user-specified aspect ratio variance, beta values were determined in NASGRO and StressCheck. These beta values were then entered into AFGROW (user-defined beta option).

Retardation Model

- SOLR Correlation Challenges
  - AFGROW Newman-Raju equation limitations:
    - Part through crack aspect ratio cannot be greater than 2:1
    - Thickness cannot be greater than the hole diameter.
    - Both of these limitations were exceeded by the some specimen coupon tests.
      - These limitations were discovered post test.
  - To investigate the effect of exceeding the N-R limitations, the “a” and “c” crack tip betas were compared using AFGROW and StressCheck
    - Ideally, the betas should be the same in both directions
  - Stress-Check betas matched, AFGROW did not.
    - This indicated that the N-R limitations may have affected the SOLR correlation.

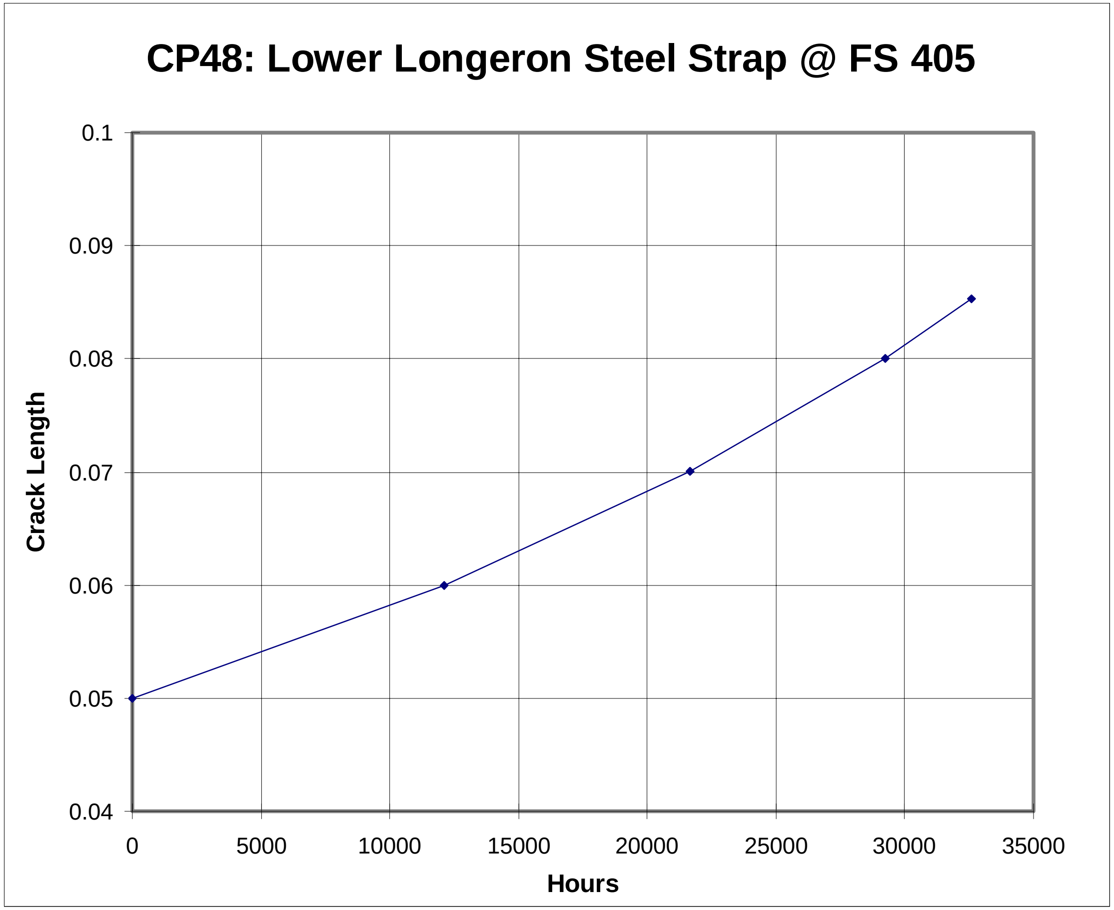
Spectrum

- **Things were progressing well…**
  - **Reconfigured Post Desert Storm (RPDS) spectrum…up to mid 90s**
  - **Results in the same ballpark as previous spectrum on WCP and OWP**
- **Lower longeron tossed up a RED FLAG!!!**



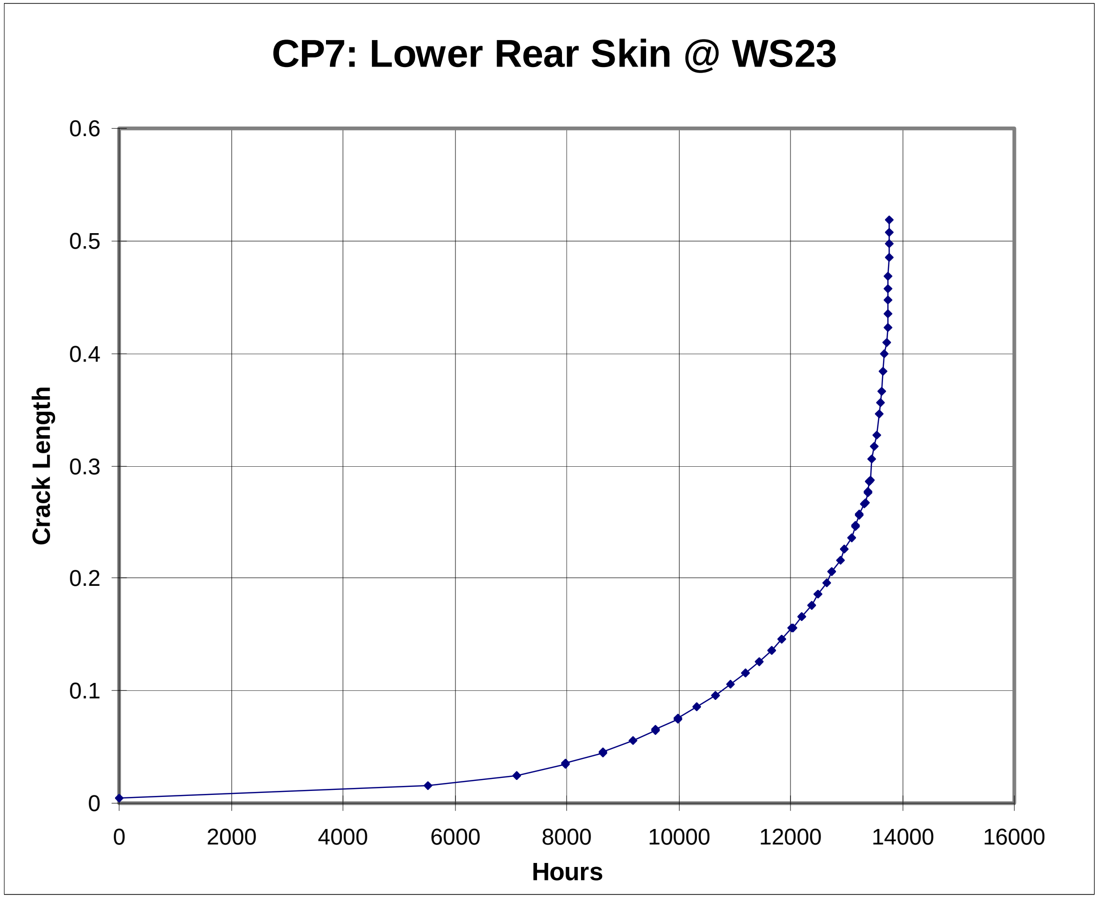
Spectrum

- **For Lower Longeron Steel Strap @ FS 405 (CP48)**
  - **New spectrum was more severe than previous**
  - **Previous analysis predicted ~12,000 hours of crack growth life**
  - **RPDS was predicting greater than 32,000 hours**
  - **Off by more than 250%**



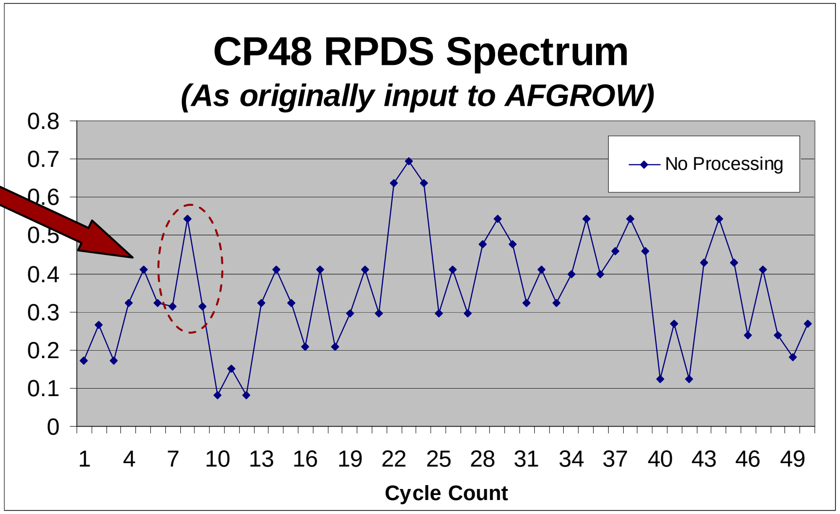
Spectrum

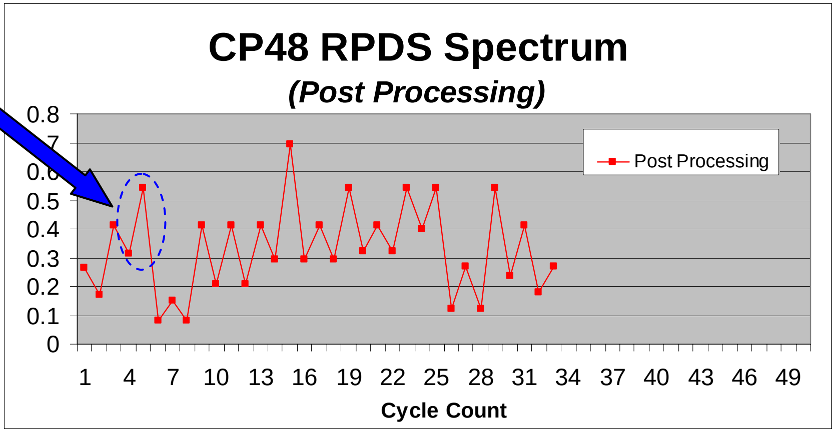
- **Was not observed on wing analyses…**
  - **RPDS wing spectrum was slightly less severe than previous spectra**
  - **Previous analysis predicted ~10,000 hours**
  - **New analysis predicted 13,700 hours**
    - **(within expectation)**



Spectrum

- Typical A-10 Spectrum
  - Base-Peak-Base format
    - *Three points define a cycle*
      - *Established because of stress sensitivity to aircraft speed.*
    - *Extra Midpoints*
      - *AFGROW see more cycles with lower ΔK=slower da/dN*
- AFGROW Requirement
  - Peak-Base format
    - *Two points define a cycle*
- SwRI developed processing software
  - Eliminates mid points and redundant bases
  - Generates AFGROW specific files





Spectrum

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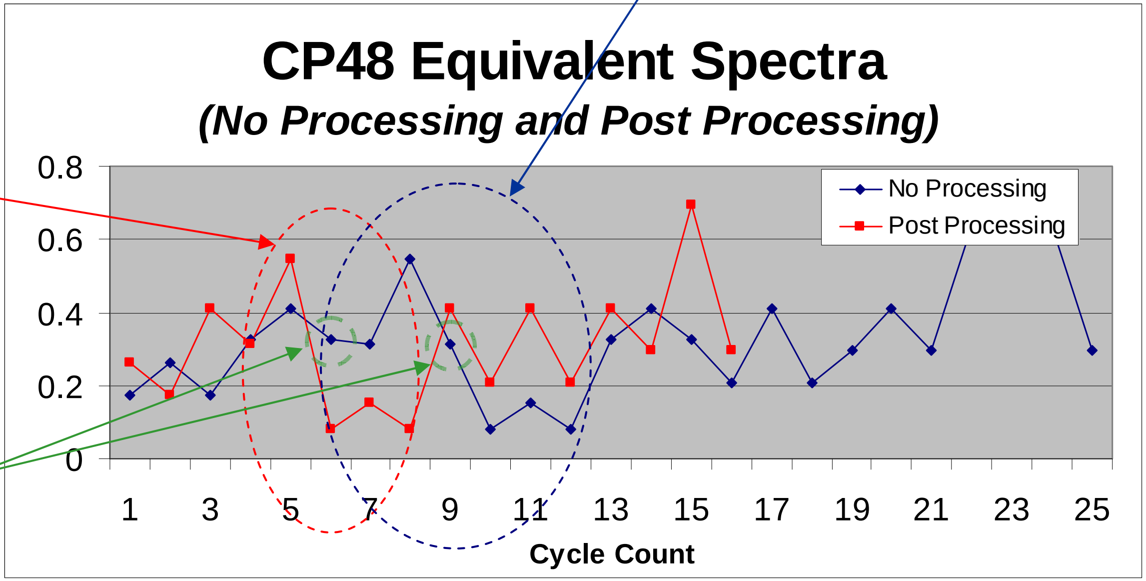
- **Lower Auxiliary Longeron Steel Strap @ FS 405 (CP48)**
  - **Base stress varied significantly**
    - **Due to changes in speed**

- **No Processing**
  - **Midpoints remain**
  - **Lower ΔK calculated**

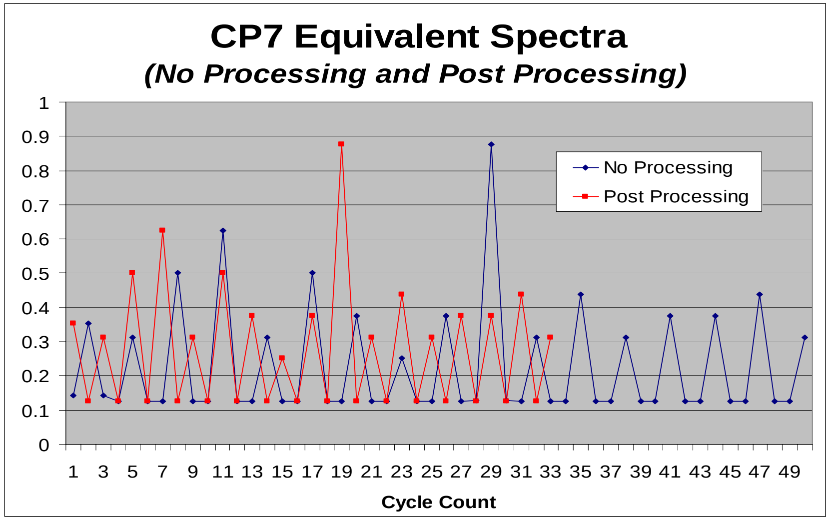
- **Post Processing**
  - **Midpoints removed**
  - **Higher ΔK calculated**

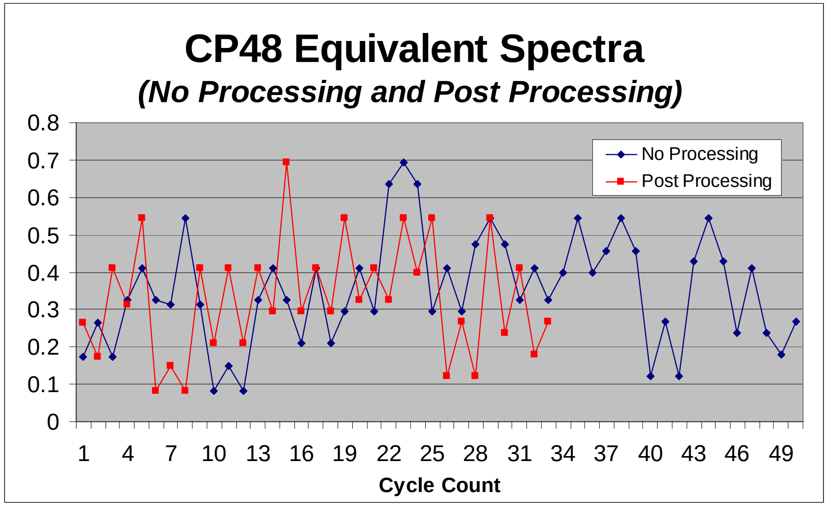
- **Midpoints removed**



Spectrum

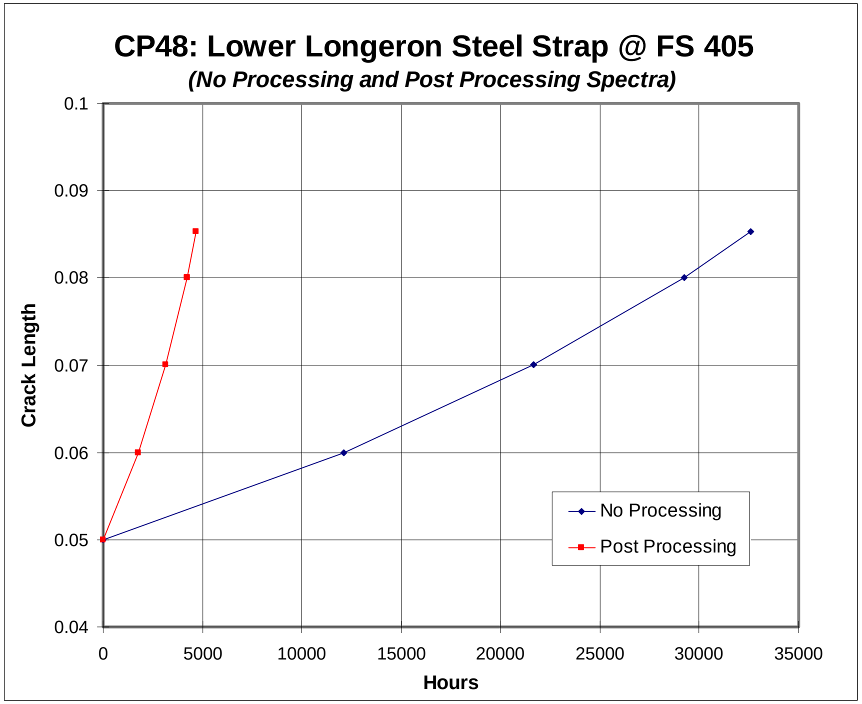
- Lower Wing Skin @ WS23 (CP7)
  - Tension dominated
    - Base stress around 0.12
  - 240 hour block
- Lower Auxiliary Longeron Steel Strap @ FS 405 (CP48)
  - Base stress varied significantly
    - Due to changes in speed
  - 240 hour block





Spectrum Issues Solved

- Non Compatible Format Processed and Converted
- Software Developed to Process Spectra Files and Create AFGROW Specific Files
- Results Now within Expectations

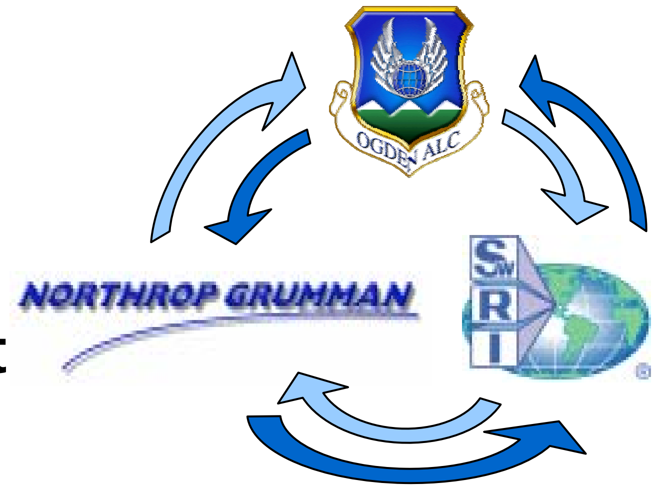


Precautions & Pitfalls

- Understand Input Files
  - Spectra
    - Formatting a critical requirement
  - da/dN vs. ΔK
    - More or less
  - Retardation
    - SOLR correlation time intensive
      - Note AFGROW (Willenborg) default: accounts for compressive cycles
- Establish Ground Rules
  - Common practices
  - Guides new analysts

Successes

- **Successes**
  - **Strong Technical Team**
    - **USAF / NGC / SwRI**
  - **Resolved Spectrum Mystery**
  - **Compiled many sources of da/dN vs. ΔK data**
  - **Updated DTA and FSMP to reflect more modern usage**
    - **Framework exists digitally…**
  - **Increased Organic Capability**
    - **Digital database of current CPs**
    - **Improved warfighter support**
      - **Depot and field support (quick response)**
      - **Assess usage variations**



The A-10 Team

Planning for the Future

- Testing & Experimentation
  - Attention to model constraints
  - Supplement existing data
    - Aircraft specific
    - Lack of previously available data
- Extending Analysis…
  - Repairs
    - Fleet wide
    - Individual aircraft
- Regular Updates
  - Reflecting Updated Usage

Summary

- Objectives Accomplished
  - Organic Capability
  - Updated DTA & FSMP
- AFGROW Requirements Defined
  - Material Model
  - Geometry Model
  - Retardation
  - Spectrum
- Precautions & Pitfalls
- Challenges & Successes

QUESTIONS?