Aircraft Structural Integrity
Program of Polish Su-22 ‘Fitter’ Aircraft

Maj. Andrzej LESKI Ph.D. Eng., (PAFIT)
Lt.Col. Slawomir KLIMASZEWSKI Ph.D. Eng., (PAFIT)
Capt. Krzysztof DRAGAN MSc. Eng., (PAFIT)
Mr. Marcin KURDELSKI MSc. Eng., (PAFIT)

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OUTLINE OF PRESENTATION

• Introduction
• System for collecting and analyzing operational data
• A/C service loads monitoring
• Fatigue life assessment
• Examples of research works
• NDI methods
• Summary & Conclusions
PECULIARITIES OF POLISH CONDITIONS

- We operate A/C designed and made in Russia or in Poland (mostly in Russia)
- Almost all of currently operated aircraft base on the ‘safe-life’ philosophy
- No formal demand or regulations for ASIP
- Loose connections with the Russian OEMs
- No design-loads spectra and results of FSFT of Russian-made aircraft available
- Increasing demand for maintenance costs reduction
- Role of the Polish Air Force Institute of Technology:
  - formal position of PAFIT (non-profit, subordinated to MoD).
  - systems developed and implemented by our own, e.g.: for collecting & analyzing maintenance & operation-related info, flight parameters decoding,…
  - research efforts financed by MoD and Ministry of Science and Higher Education (grants)
Su-22 ‘Fitter’

Polish Fleet status:
- Su-22M4 ‘Fitter-K’
- Su-22UM3K ‘Fitter-G’

Crew 1 (2 trainer)
Length 62.42 ft (19.02 m)
Wingspan
  *unswept*: 45.25 ft (13.80 m)
  *swept*: 32.83 ft (10.00 m)
Weights
  Empty: 23,455 lb (10,640 kg)
  Max takeoff: 42,990 lb (19,500 kg)
Thrust 1 x 24,800 lb (110.3 kN) with afterburner
max level speed:
  *at altitude*: 1,170 mph (1,880 km/h) at 36,090 ft, Mach 1.77
  *at sea level*: 840 mph (1,350 km/h), Mach 1.1
COLLECTING AND ANALYZING THE MAINTENANCE & OPERATIONAL DATA
CENTRAL DATA BANK

PAFIT
HQ
PLAF

LOCAL DATA BANK

DICTIONARIES

DEPOT

DATA BANKS AB, AC

aircraft/a. components filing
work resources filing
work rates
putting bulletins into practice
changes in what has been filed
operational–phase planning
failures/faults
states within operational phase
maintenance
STATISTICAL DATA

- Report with results of statistical analysis (MTBF, ...)
  - every year & on demand
- Detailed analysis is carried out for particular A/C type – on demand
- Forecasting - on demand

Su-22 Rates for year 2005:

- MTBF (mean time between failure) - 6h
- $\text{MTBF}_F$ (mean time between failure during flight) - 24h
- $\text{MTBF}^{\text{structure}}$ (mean time between failure, structure only) - 65h
- $\text{MTBF}_F^{\text{structure}}$ (mean time between failure during flight, structure only) - 621h
PERCENTAGE SHARES OF INDIVIDUAL SYSTEMS IN TOTAL NUMBER OF FAILURES TO Su-22
Period 1985-2002

- Structure: 25%
- Avionics: 4%
- Engine: 10%
- Radio: 4%
- Armament: 16%
- Total: 45%
FORECASTING

Age of aircraft

MTBF

Short term prediction

Long term prediction

Nalot na uszkodzenie [h]

0 5 10 15 20 25 30 35 40 45

Trend 3-letni

Trend 12-letni

Instytut Techniczny Wojsk Lotniczych

www.itwl.pl
MONITORING OF A/C SERVICE LOADS
SYSTEM FOR COLLECTING $N_z$ SPECTRA

Flight Recorder TESTER U3Ł

$N_z$ Spectra Data Base PAFIT

RD-1 Recorder for Data Transfer

CD-ROM

System THETYS (Analysis, Decoding, Compression and Visualization)
Air Bases
FATIGUE LIFE ESTIMATION OF A/C STRUCTURAL ELEMENTS
FATIGUE LIFE CALCULATIONS

Global FE Model

- geometry & boundary conditions

Local FE Model

- Stress distribution

Flight test data

10 hours equivalent load spectrum

Operational profile

Fatigue calculations
- S-N analysis
- da/dN analysis

Material Information
(Engineering Science Data Unit, Metallic Material Properties Development and Standardizations)
THE 3D MODEL OF THE Su-22

Reverse engineering:
- digital photogrammetry
- teardown results
- computer-based model
- FE global model
FE LOCAL MODELS

Manual 3D scanner

Point representation

FE local model
FE ANALYSIS

FE Model

FE Results
REVERSE ENGINEERING - EXAMPLE

Real part → 3D Scan → 3D Model → FE Model → Complex model → FE Results

- Tailplane cantilever
- Spar axis
FLIGHT TESTS

Global FE Model

geometry & boundary conditions

Local FE Model

Stress distribution

10 hours equivalent load spectrum

Fatigue calculations
- S-N analysis
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Material Information
(Engineering Science Data Unit, Metallic Material Properties Development and Standardizations)

Flight test data

Operational profile
MEAN OPERATIONAL-USE PROFILE

- Decoding of all available data from flight recorders (82000h)
- Definition of flight classes
- Analysis of recorded data: assignment of individual records to flight classes
- Generation of mean operational-use profile
MEAN USAGE PROFILE OF POLISH SU-22

- straight flight
- preparation for a turn (30deg)
- nosedive (angle of pitch 0-15deg)
- turn (30 deg)
- acceleration
Examples of strain gage localizations
Recorded 72 parameters:
- flight parameters
- strain-gauges for internal forces investigation
- strain-gauges for measurements at critical localizations
DATA PROCESSING

- Spectra for critical localization and for internal forces
- Cycle matrices and time series
- Rainflow cycles counting method

Matrix of cycles
da/dN CALCULATIONS

- Selected localizations
- Interval between inspections (assumption)
- Compression-dominated loads

Engine bracket
RESEARCH PROGRAMS

EXAMPLES
BEYOND THE LIMITS
- REPAIR OF A CANOPY

- High cost of repairs
- Low level of aircraft availability
- Questionable justification for original limits

Research effort:
To determine where the safety limit for repair of a canopy is
MATERIAL TESTS

specimens

MTS device with a chamber for thermal conditioning
FE CALCULATIONS

Two kinds of analysis:

1. static calculations
   - nonlinear material properties
   - load by pressure
   - load by temperature

2. dynamic calculations
   - bird impact
FINDINGS

- Two different limitations for the canopy thickness:
  - upper limit – caused by a thermal load,
  - lower limit – caused by a pressure load.

- There is no hazard caused by reasonable (<10%) reduction in the canopy thickness

- There is no significant change in a dynamic response when the canopy thickness is reduced

- The only limit for the repair process should be the depth of pits or other surface defects.
Su-22 right strut of the main landing gear with names of main parts
DETAILS OF THE MODEL

Comparison: model and real landing gear
MODEL OF THE SHOCK ABSORBER

a) The Su-22 main landing gear oleo-pneumatic shock absorber.
b) The oleo-pneumatic force model
POSITIONING OF STRAIN GAUGES ON THE MAIN LANDING GEAR

7 channels recorded
- Axial forces - rods and actuators
- Bending – trailer arm
- Strains – selected points

Recorded:
- 11 flights
- Ground maneuvers
- Engine test
COMPARISON OF RESULTS

The axial force of the right lower side brace during taxiing (“eight” maneuver)
COMPARISON OF RESULTS (2)

The axial force of the right lower side brace during landing
WIDESPREAD FATIGUE DAMAGE

Area of interest

- No evidence of WFD
- Theoretical assumption
METHODOLOGY OF WFD CALCULATIONS

Intermediate level model
- Global model
- Intermediate models
- Local models

Crack criterions:
- Crack Tip Opening Angle (CTOA)
- Plastic Zone Linkup (PZL)

Solver:
- MSC.Marc
- Own procedures

Findings:
Critical crack lengths for different crack scenarios (with and without MSD)
CAUSED BY MSD?
HIDDEN CORROSION INSPECTION (1)

DAIS® (D-Sight™ Aircraft Inspection System)

- Based on Double Pass Retroreflection
- DSight™ effect converts local surface curvature to gray scale changes
- Detection of hidden corrosion (visible by pillowing) in horizontal and vertical lap splices: DAIS-250C (250 Cx)
- Detection of disbonds and low energy impact damages in honeycomb: DAIS-500
- At present, it is used by AFIT and in MiG-29, Jak-40, Mi-8, Mi-17 and Mi-14 inspections

DAIS inspection of Su-22
HIDDEN CORROSION INSPECTION (2)

D-Sight Index Description Possibility

\[ D - \text{Sight index} = \left( \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} \right) \times 100 \]

\[ I_{\text{max}} \Rightarrow \frac{\partial I_n}{\partial x} = 0 \& \frac{\partial I_{n-1}}{\partial x} > 0 \land \frac{\partial I_{n+1}}{\partial x} < 0; \]

\[ I_{\text{min}} \Rightarrow \frac{\partial I_n}{\partial x} = 0 \& \frac{\partial I_{n-1}}{\partial x} < 0 \land \frac{\partial I_{n+1}}{\partial x} > 0 \]

D–Sight Index Corrosion Ranges:

- 0 – 49 – Light
- 50 – 80 – Moderate
- 81 – 100 – Heavy

D-Sight Index:
- Quantitative assessment of hidden corrosion (pillowing) grow
- Fast comparison of received data
- ‘A posteriori” analysis possibility
HIDDEN CORROSION INSPECTION (3)

- Average service life: 17 years
- Not uniform corrosion distribution;
- Higher for vertical stabilizer;
- Detailed corrosion distribution and rate of growth were made;
- Hazardous areas were described
- Corrosion-resistant structure

27 A/C population data results

<table>
<thead>
<tr>
<th>Function</th>
<th>Number of Measurements/A/C</th>
<th>Number of Indications/A/C</th>
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<tr>
<td>AVERAGE</td>
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<td>15</td>
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<td>Std. Deviation</td>
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<td>22</td>
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<tr>
<td>SUM</td>
<td>14731</td>
<td>343</td>
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</table>
ATMOSPHERIC CORROSION

- Service bulletin: Dec 03
- 21 different localizations
- Conformity: PN-EN + ISO standards (8565, 9226, ...)
- Corrosion rates of 29 materials (Al, Zn, steel)
- Exposition: 1, 3 and 4 yrs
- Exposure beginning: 2004 at 3 different localizations

Atmospheric Exposure Site in Kraków-Balice
PAFIT is originator of Service Bulletins and NDI Instructions

Number of NDI instructions related to the Su-22 structure (check points):
- fuselage – 18
- fin – 5
- tail plane – 4
- wings – 17
- landing gear – 7
- other - 4

Total: 55
CRACK INSPECTION

Fatigue Crack Inspection:
• Landing Gear;
• Wing skin;
• Structural components (wing attachment)

Nose landing gear

Hydraulic actuator bracket
- tail part of fuselage

Strip on the edge of landing-gear door
CRACK INSPECTION

Used Techniques:
• Mainly Visual (Video-endoscopy aided);
• Penetrant;
• Magnetic Particle;
• Eddy Current (MOI aided as well);
• Ultrasonic.

Magneto-Optic Crack Indication

Ultrasonic crack indication

Visual Crack Indication
SUMMARY

&

CONCLUSIONS
SUMMARY

• Quasi ASIP was implemented to ‘safe life’ operated Su-22

• Major parts of Polish ASIP for Su-22:
  - Collection of operational data
  - Service loads monitoring
  - Applications of advanced NDI
  - Durability and damage tolerance analysis

• Similar programs will be launched for other A/C and helicopters operated in Poland
PLANS FOR FUTURE

1. Teardown of one aircraft

2. Individual Aircraft Tracking
   - historical data have been collected
   - lack of good references (FSFT results, design load spectrum)

3. Ongoing discussion about future of the Polish Su-22