Polish Air Force Institute of Technology (PAFIT)

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

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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

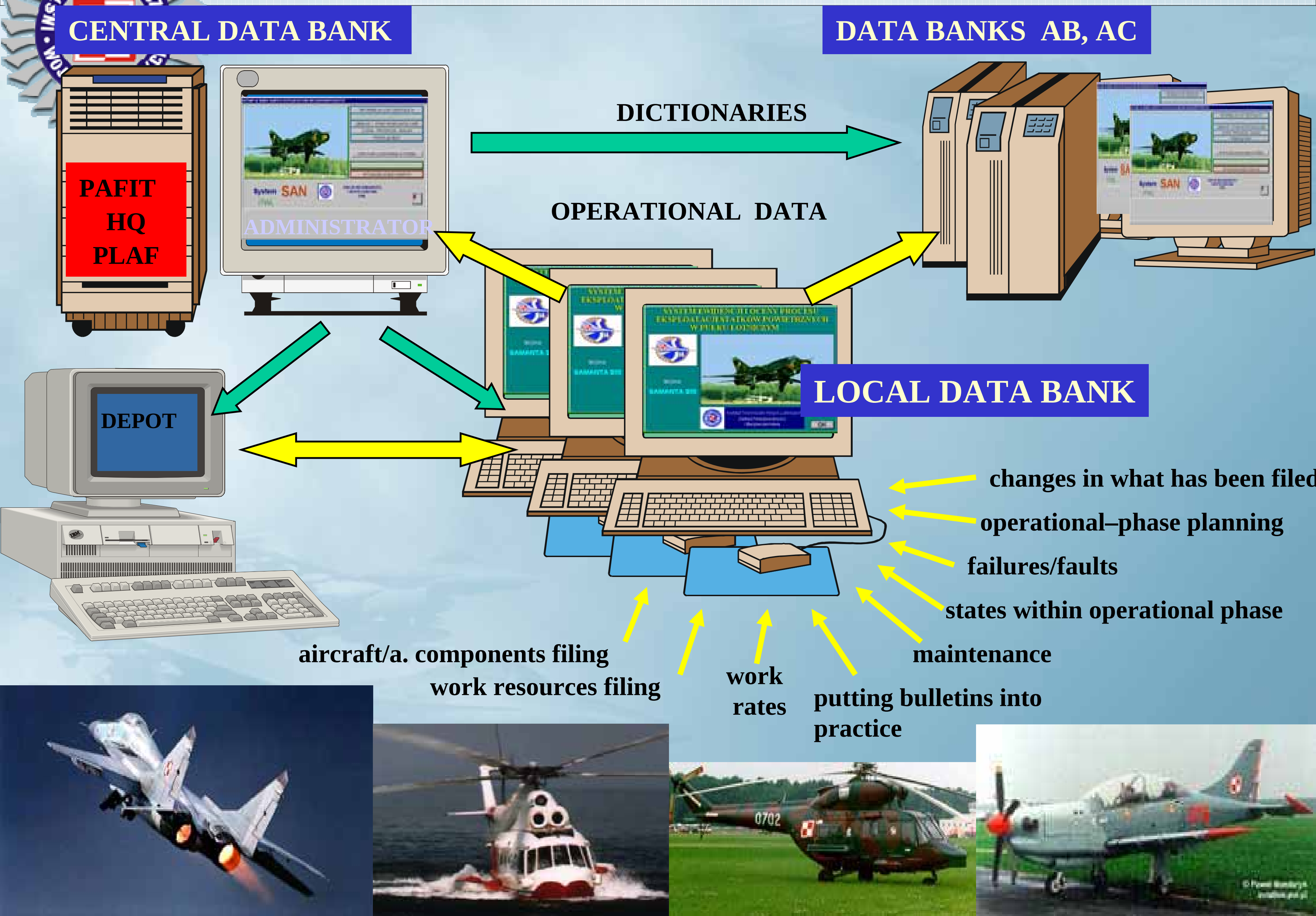
- We operate A/C designed and made in Russia or in Poland (mostly in Russia)
- Almost all of currently operated aircraft base on the ‘safe-life’ philosophy
- No formal demand or regulations for ASIP
- Loose connections with the Russian OEMs
- No design-loads spectra and results of FSFT of Russian-made 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
DATA BANKS AB, AC
PAFIT
HQ
PLAF
ADMINISTRATOR
DICTIONARIES
OPERATIONAL DATA
DEPOT
LOCAL DATA BANK
changes in what has been filed
operational–phase planning
failures/faults
states within operational phase
maintenance
aircraft/a. components filing
work resources filing
work rates
putting bulletins into practice

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:

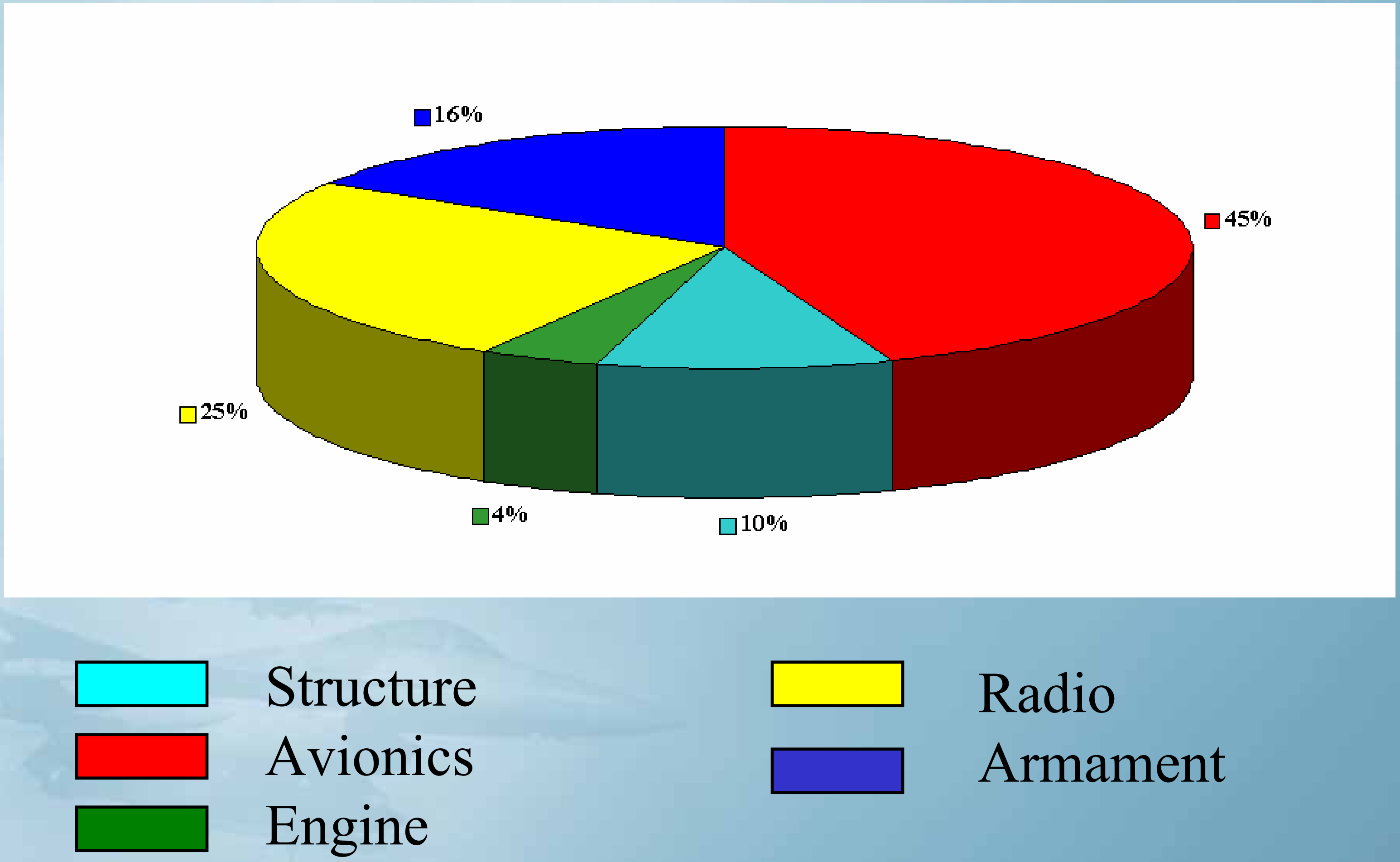
MTBF (mean time between failure) - 6h

$MTBF_F$(mean time between failure during flight) - 24h

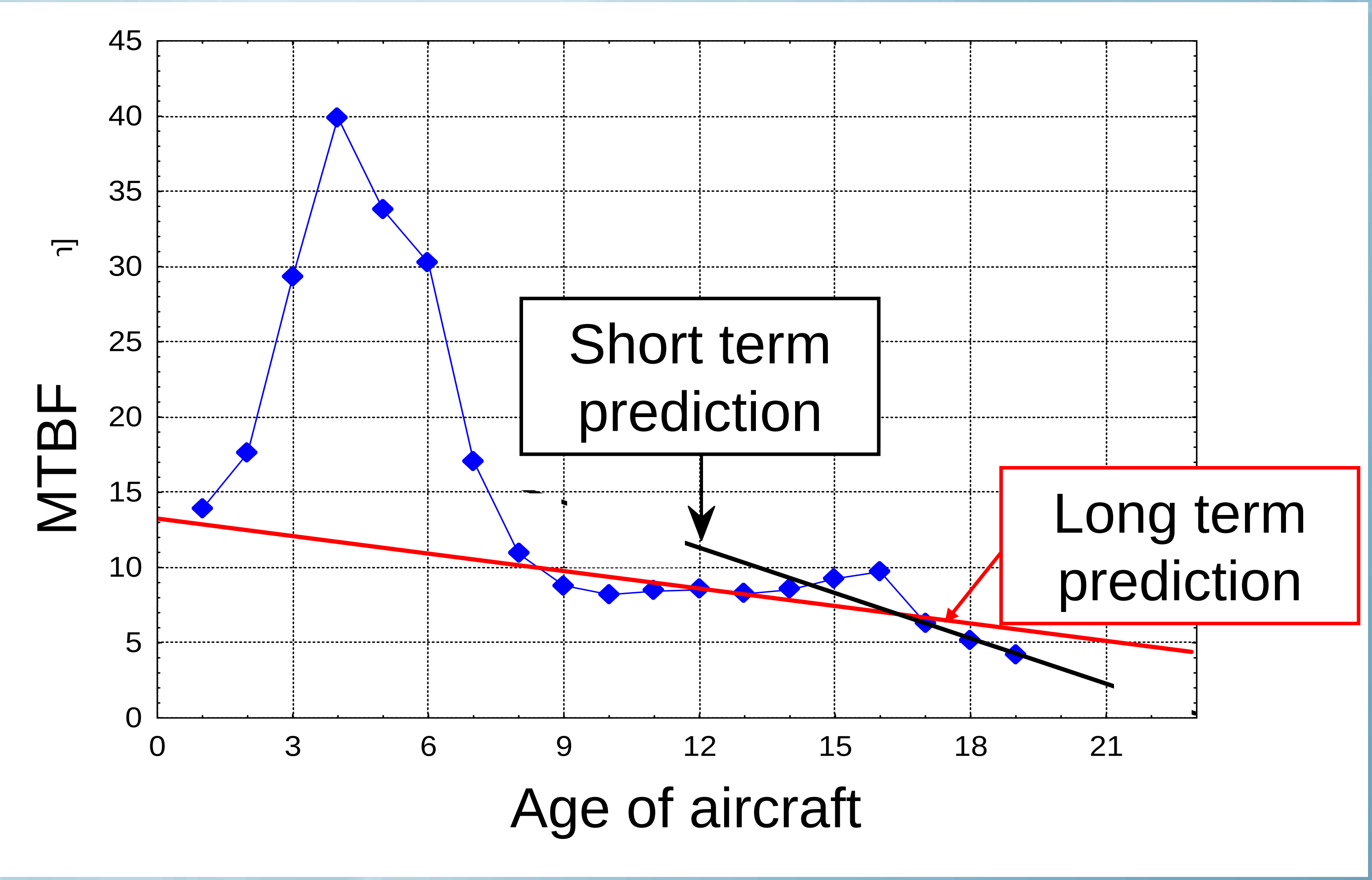
$MTBF^{Structure}$ (mean time between failure, structure only) - 65h

$MTBF_F^{Structure}$(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



FORECASTING

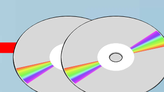


MONITORING OF A/C SERVICE LOADS

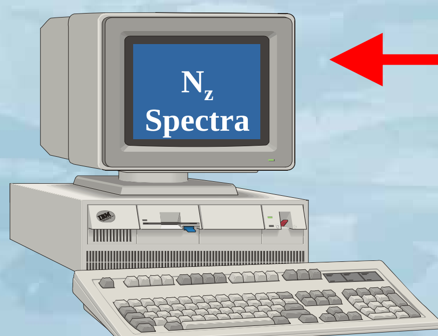
SYSTEM FOR COLLECTING N_Z SPECTRA

RD-1
Recorder for Data Transfer

Flight Recorder TESTER U3Ł



CD-ROM

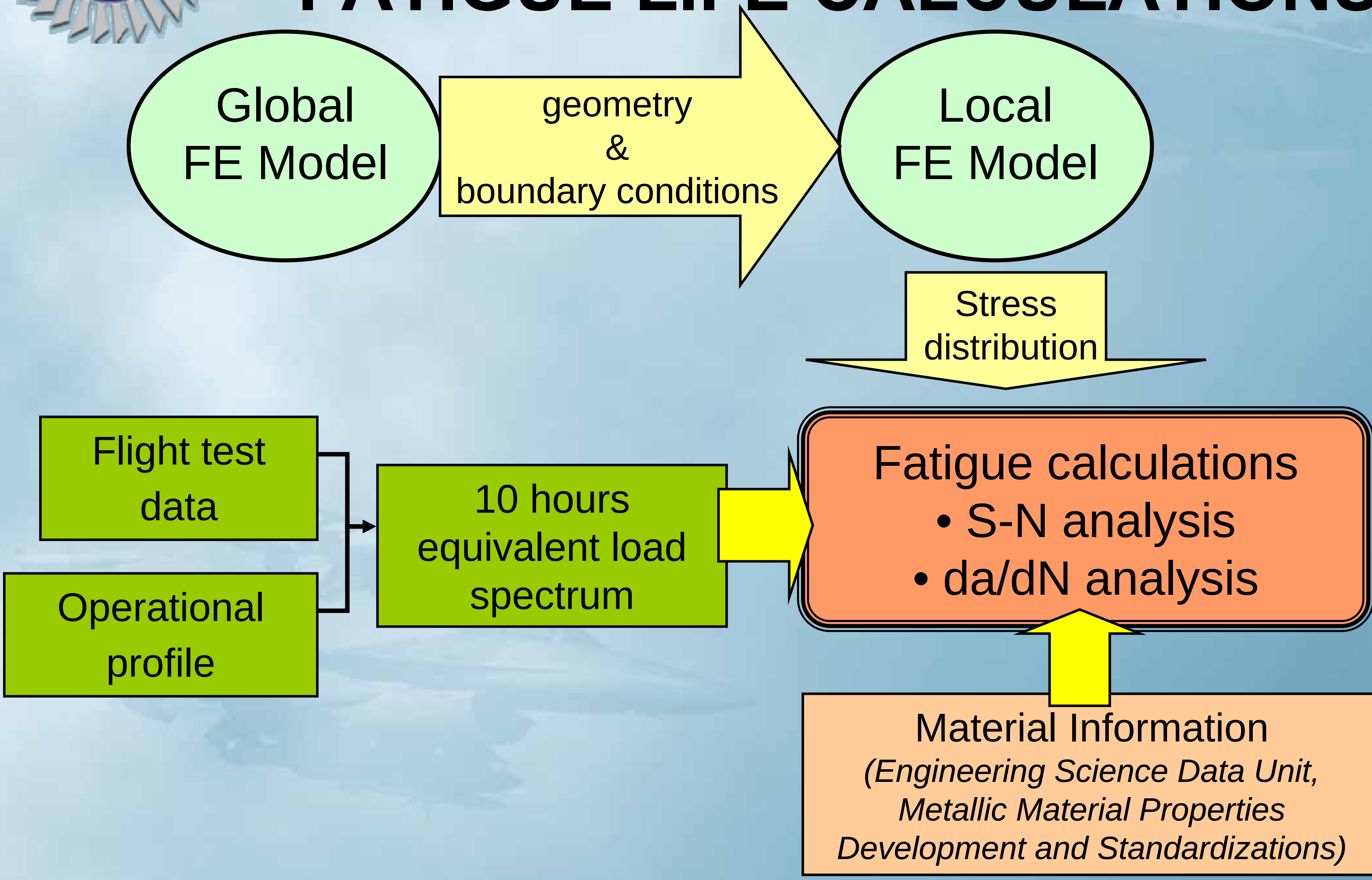


N_z Spectra Data Base
PAFIT

System THETYS (Analysis, Decoding, Compression and Visualization)
Air Bases

FATIGUE LIFE ESTIMATION OF A/C STRUCTURAL ELEMENTS

FATIGUE LIFE CALCULATIONS



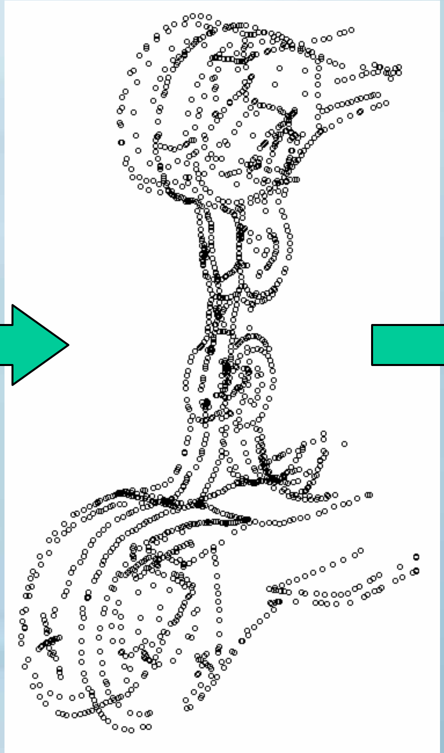
THE 3D MODEL OF THE Su-22

Reverse engineering:

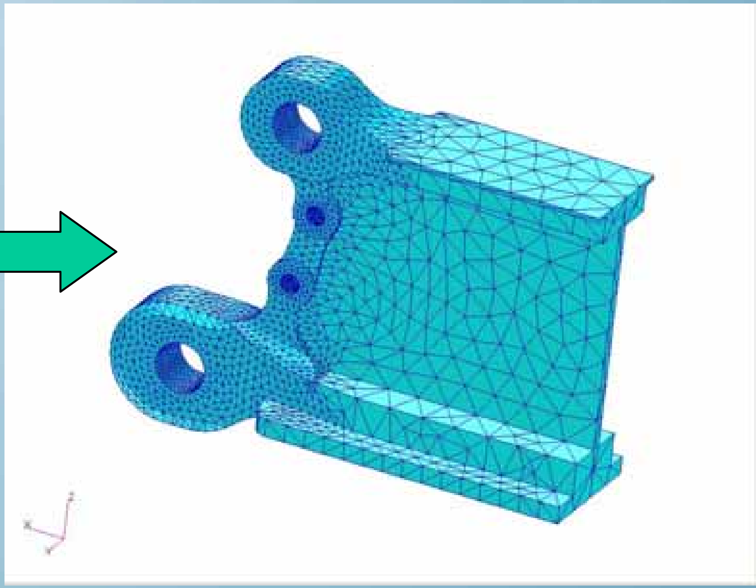
- digital photogrammetry
- teardown results
- computer-based model
- FE global model

FE LOCAL MODELS

Manual 3D scanner

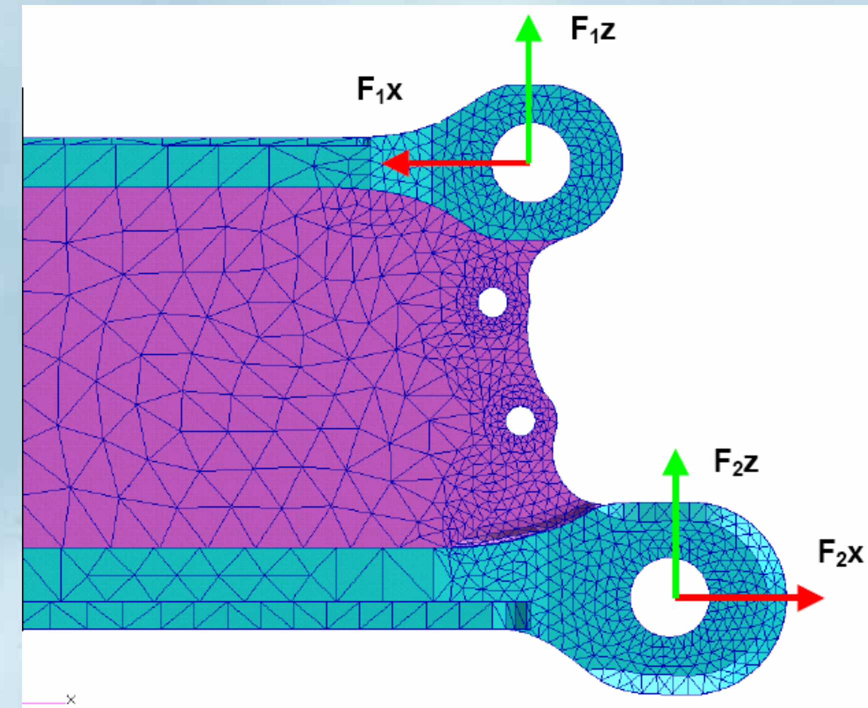


Point representation

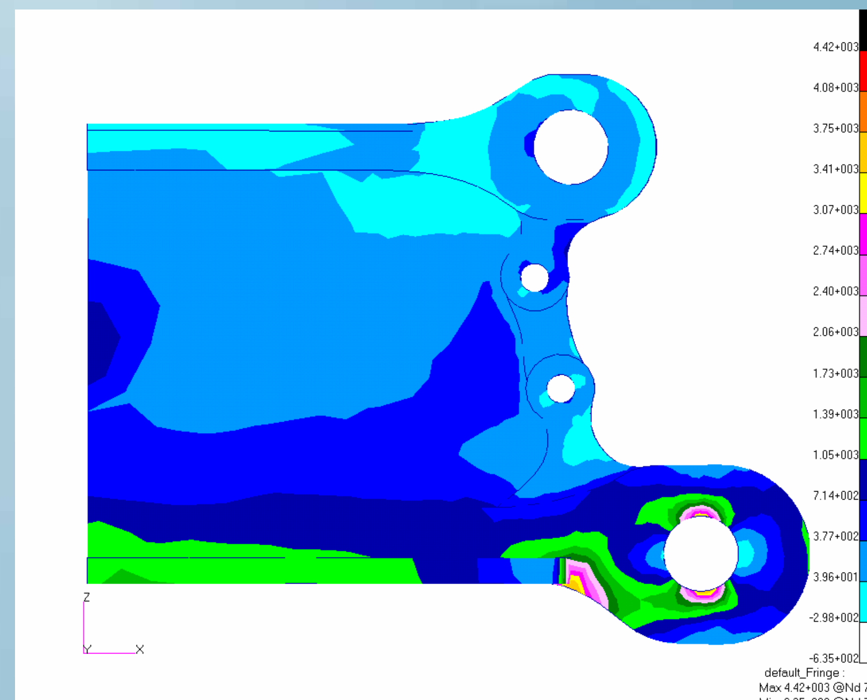


FE local model

FE ANALYSIS

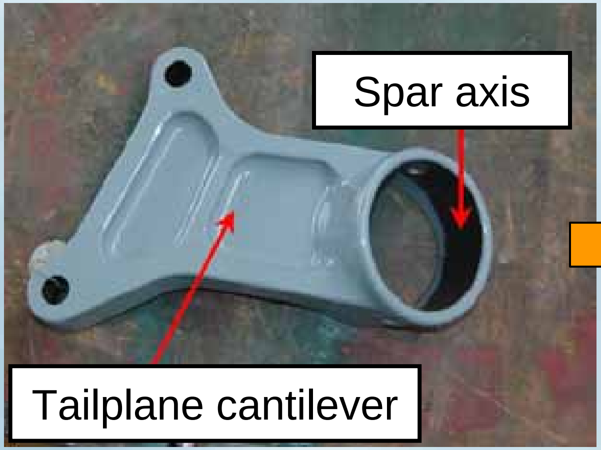


FE Model



FE Results

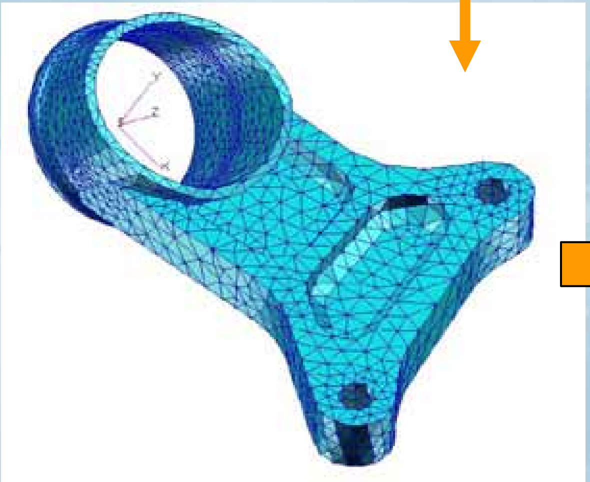
REVERSE ENGINEERING - EXAMPLE

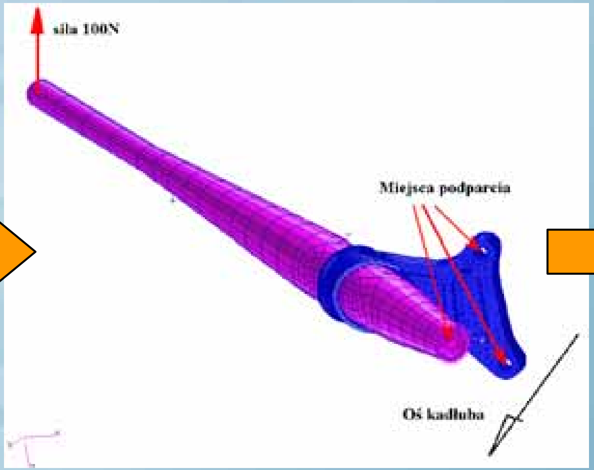


Real part

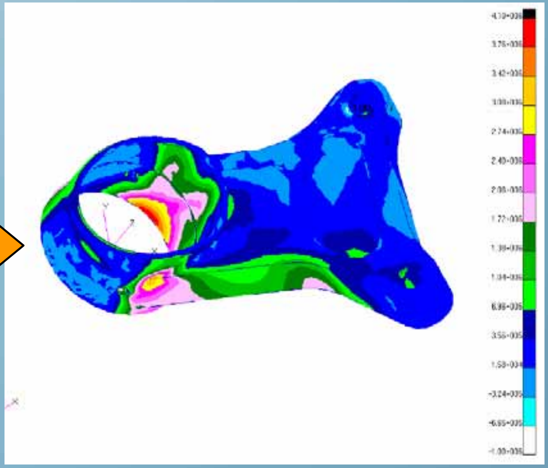

3D Scan


3D Model

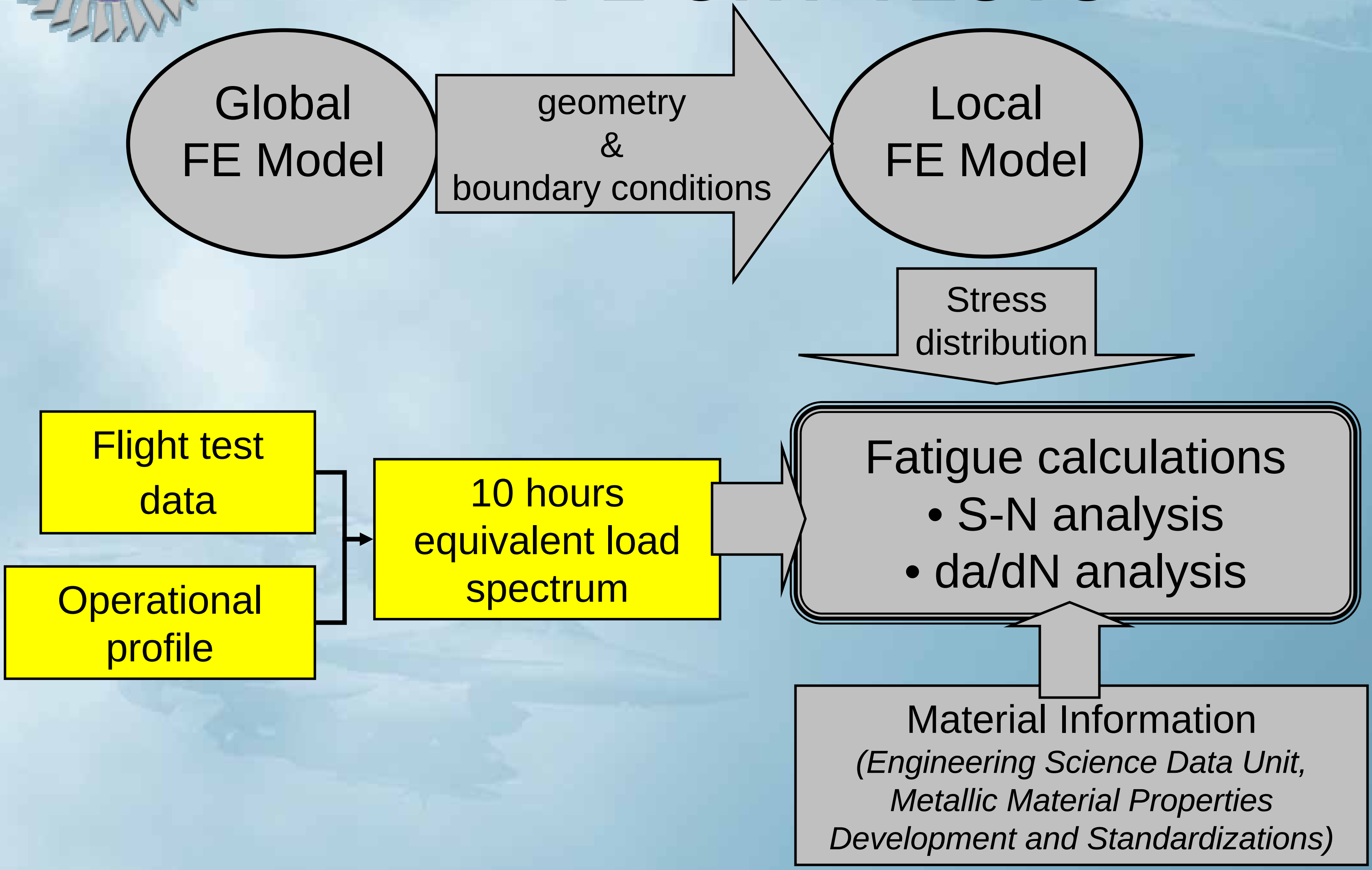

FE Model



Complex model


FE Results

FLIGHT TESTS



MEAN OPERATIONAL-USE PROFILE

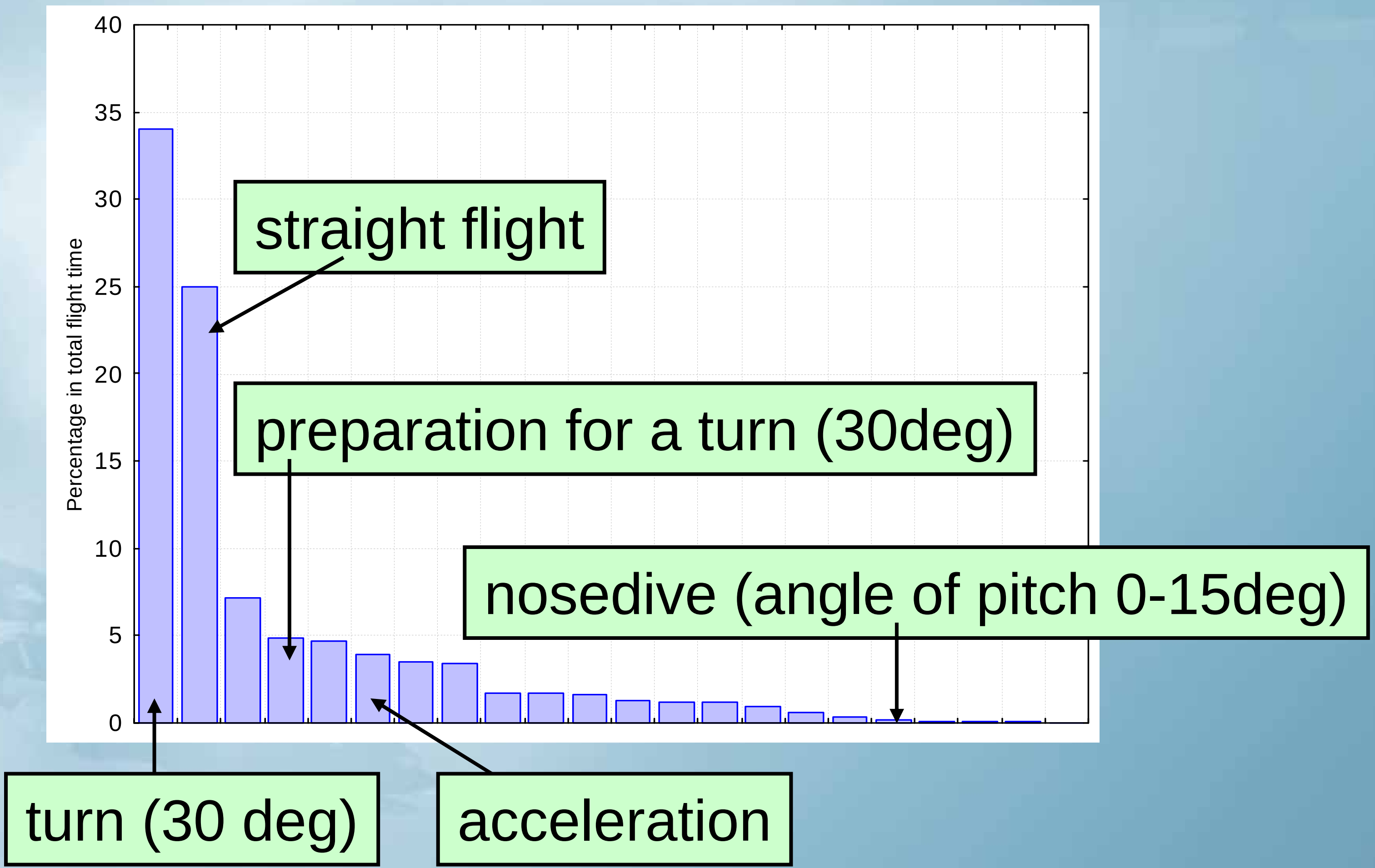
Definition of flight classes

Decoding of all available data from flight recorders (82000h)

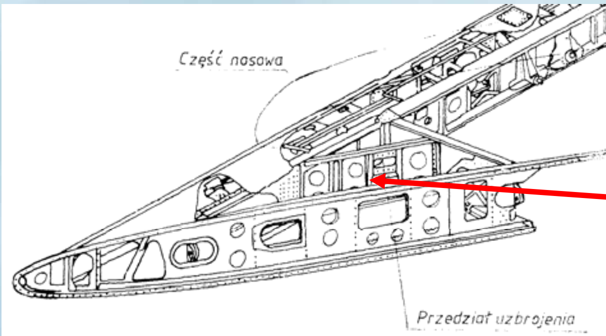
Analysis of recorded data:
assignment of individual records to flight classes

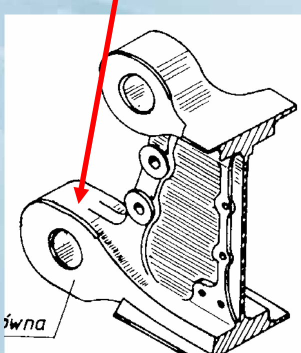
Generation of mean operational-use profile

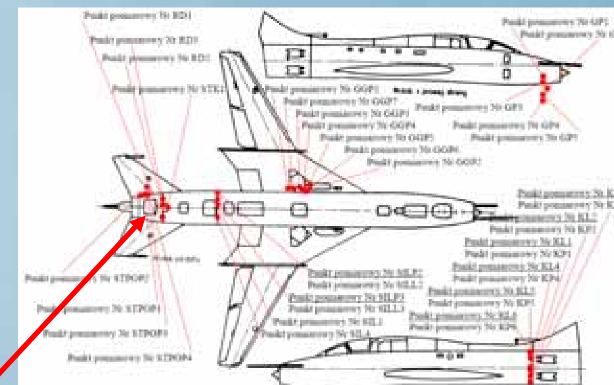
MEAN USAGE PROFILE OF POLISH SU-22

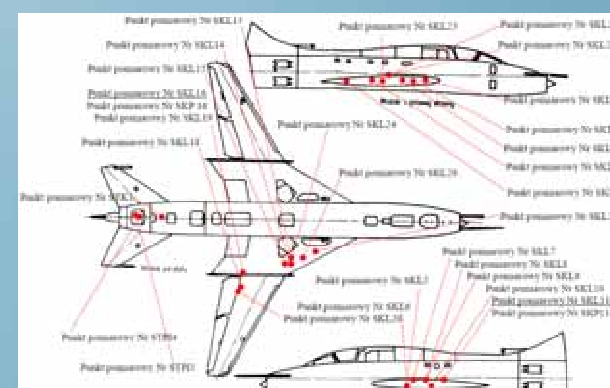


FLIGHT TEST - INSTRUMENTATION



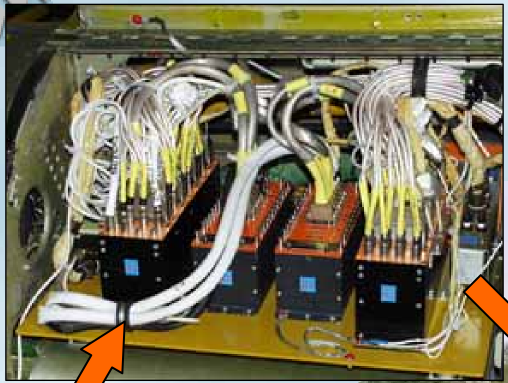






Examples of strain gage localizations

FLIGHT TEST

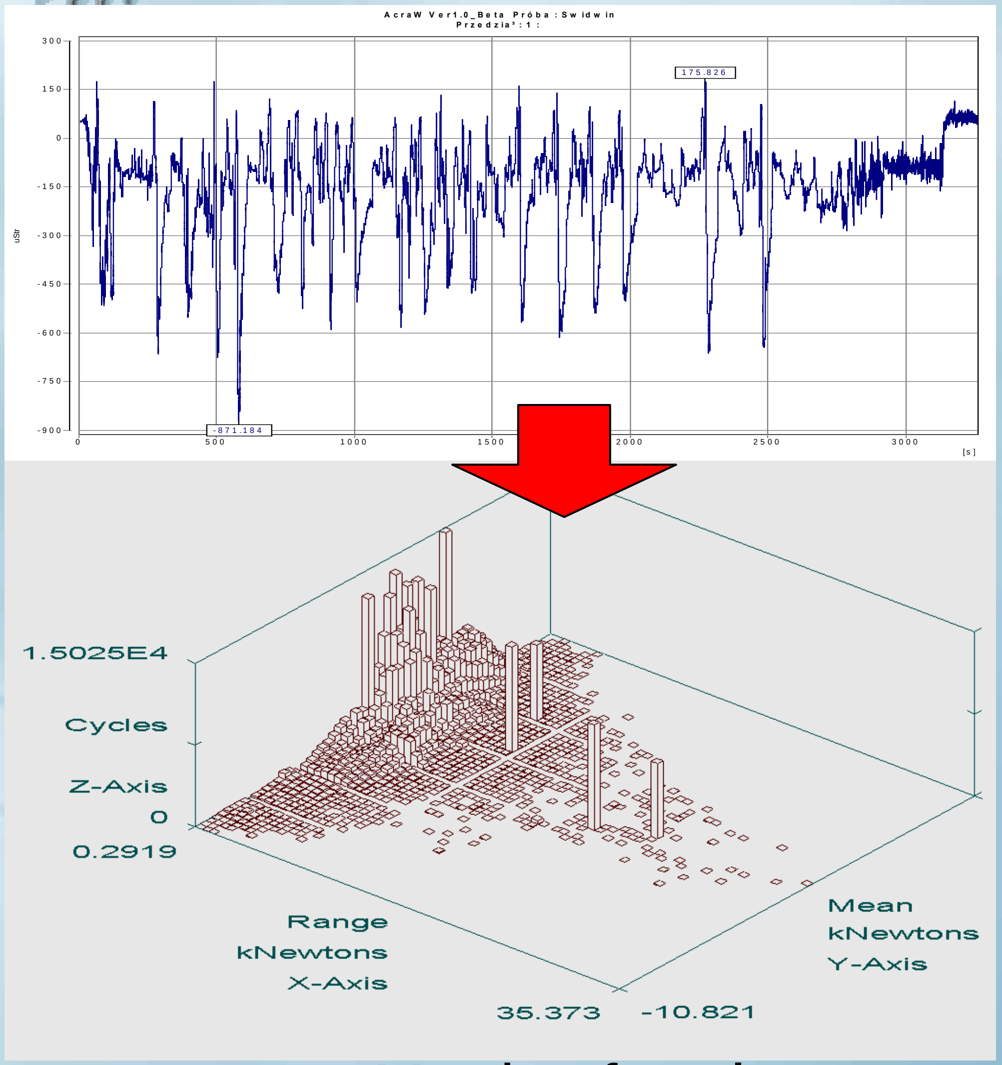


Other equipment

Data recorders KAM-500
& interface blocks

Recorded 72 parameters:
- flight parameters
- strain-gauges for internal forces investigation
- strain-gauges for measurements at critical localizations

DATA PROCESSING

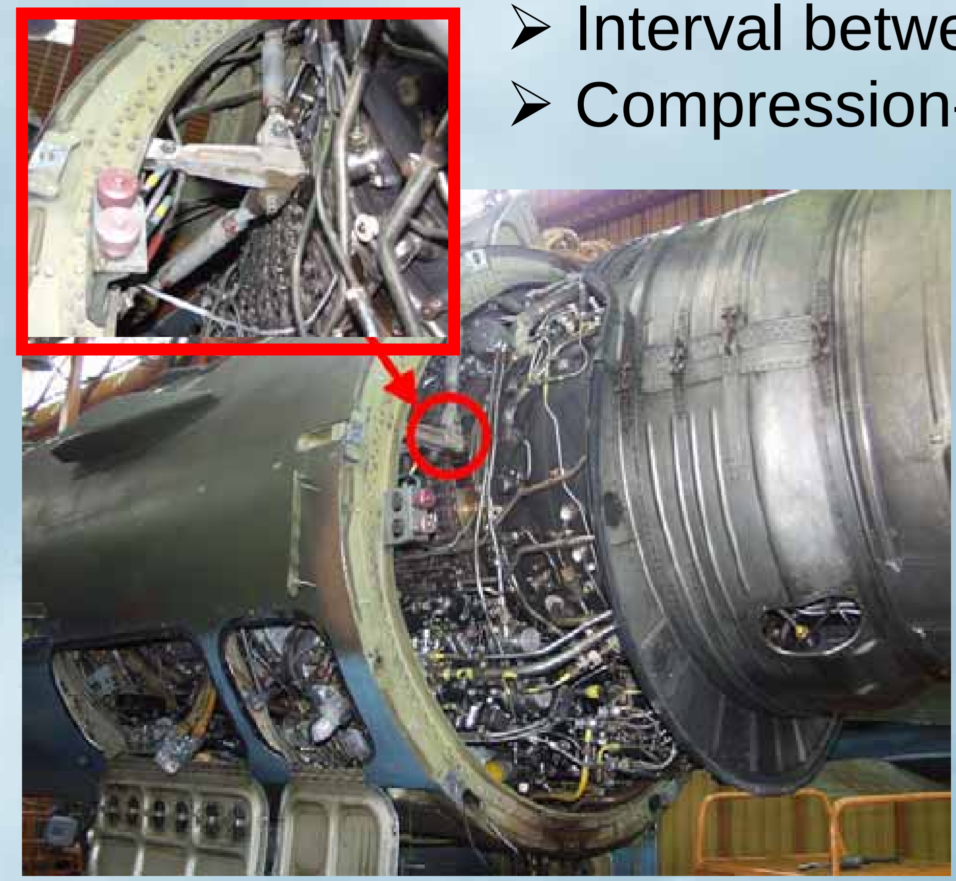


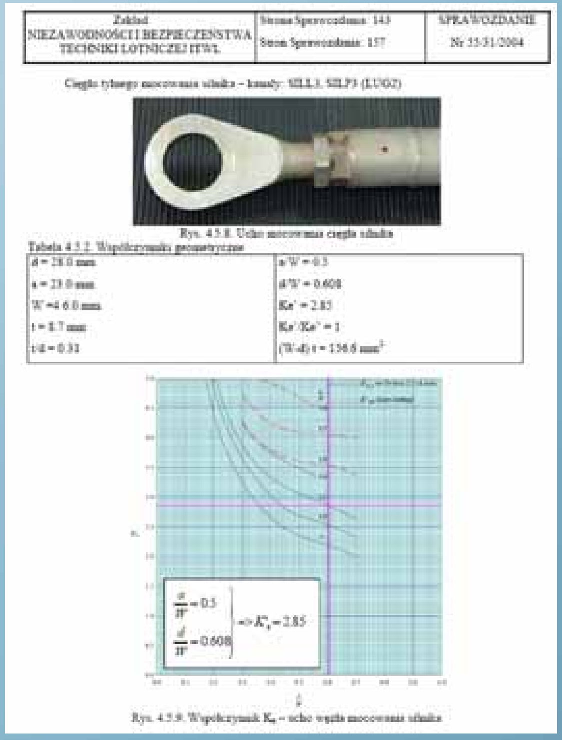
Matrix of cycles

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

da/dN CALCULATIONS

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





Zakład NIEZAWODNOŚCI I BEZPIECZEŃSTWA TECHNIKI LOTNICZEJ ITWL	Strona Sprawozdania: 143 Stron Sprawozdania: 157	SPRAWOZDANIE Nr 33/31/2004

Cięgło tylnego mocowania silnika – kanały: SILL3, SILP3 (LUGZ)

Rys. 4.5.8. Ucho mocowania cięgła silnika

Tabela 4.5.2. Współczynniki geometryczne

$d = 28.0$ mm	$a/W = 0.5$
$a = 23.0$ mm	$d/W = 0.608$
$W = 46.0$ mm	$K_t' = 2.85$
$t = 8.7$ mm	$K_t'/K_t'' = 1$
$t/d = 0.31$	$(W-d)\cdot t = 156.6\ mm^2$

$\frac{a}{W} = 0.5$, $\frac{d}{W} = 0.608$ $\Rightarrow K_t' = 2.85$

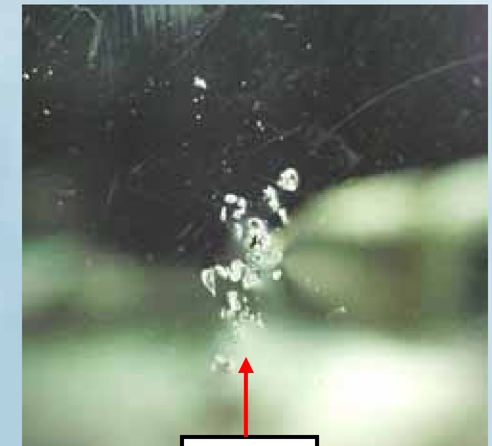
Rys. 4.5.9. Współczynnik K_t – ucho węzła mocowania silnika

Engine bracket

RESEARCH PROGRAMS

EXAMPLES

BEYOND THE LIMITS - REPAIR OF A CANOPY

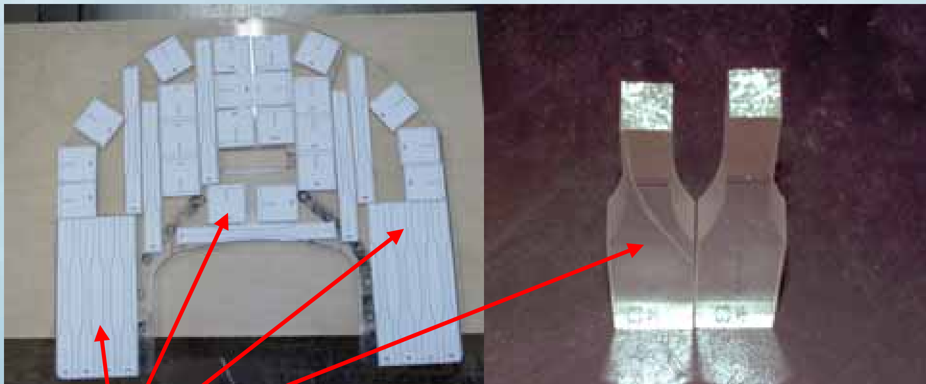


pits

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

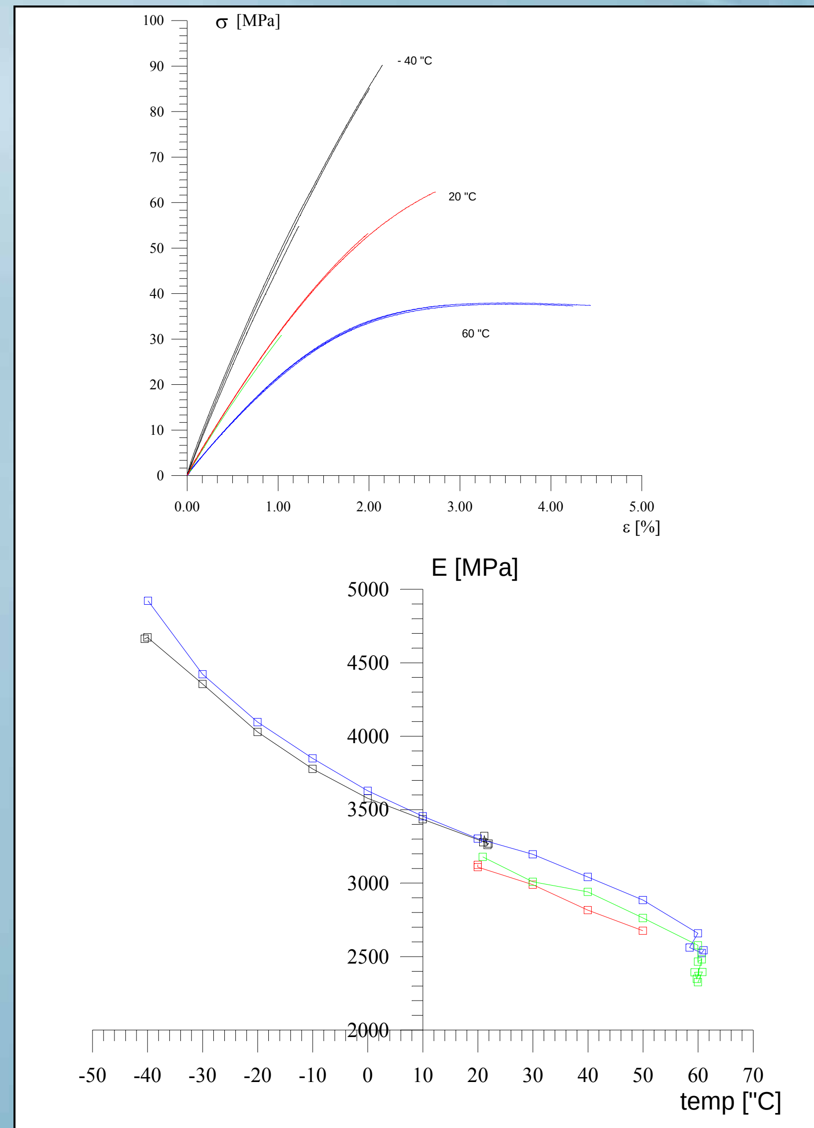
Research effort:
To determine where the safety limit for repair of a canopy is

MATERIAL TESTS

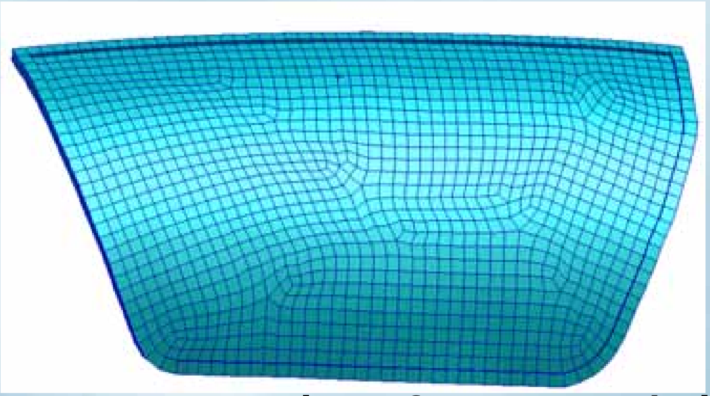


specimens

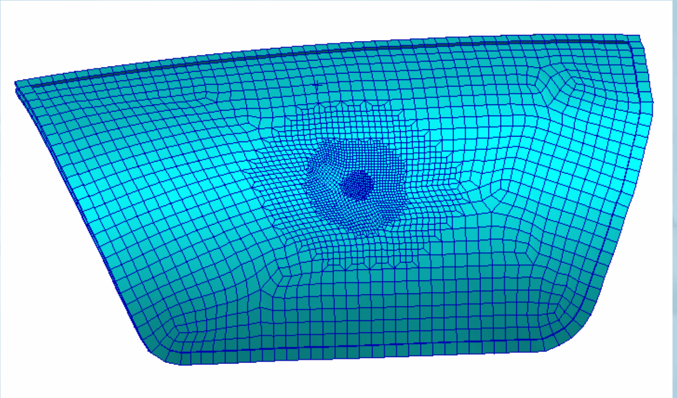
MTS device
with a chamber for
thermal conditioning



FE CALCULATIONS



Example of FE model
for static calculations

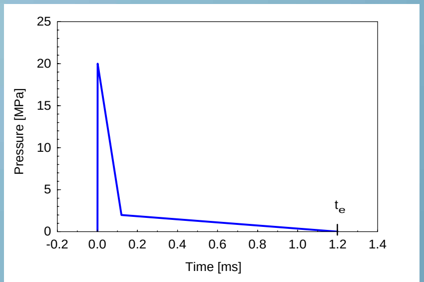


Example of FE model
for dynamic calculations

Two kinds of analysis:

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

2. dynamic calculations
   - bird impact



FINDINGS

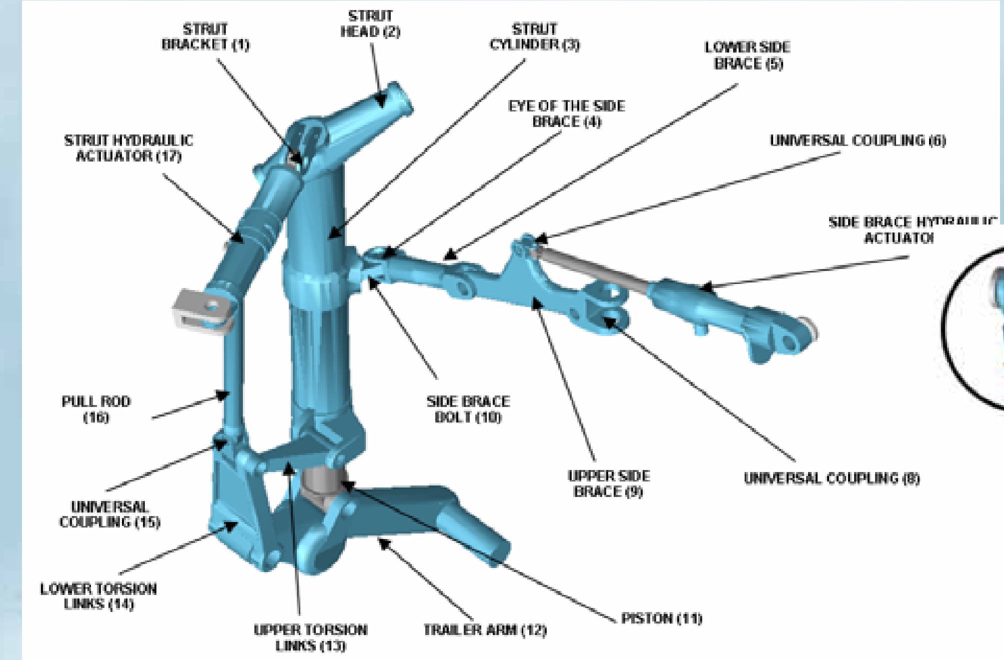
- Two different limitations for the canopy thickness:
  - upper limit – caused by a thermal load,
  - lower limit – caused by a pressure load.

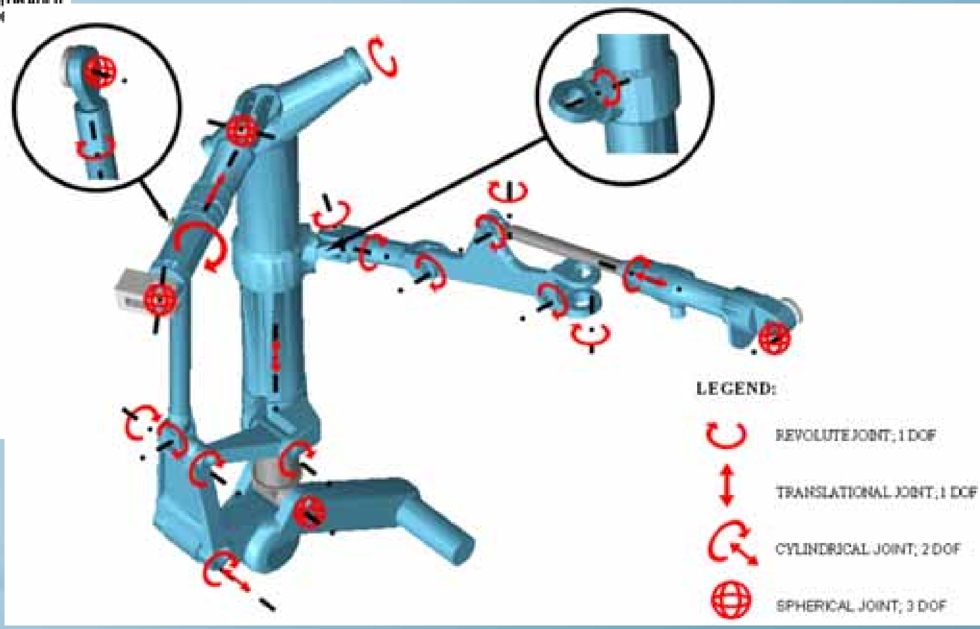
- There is no hazard caused by reasonable (<10%) reduction in the canopy thickness

- 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.

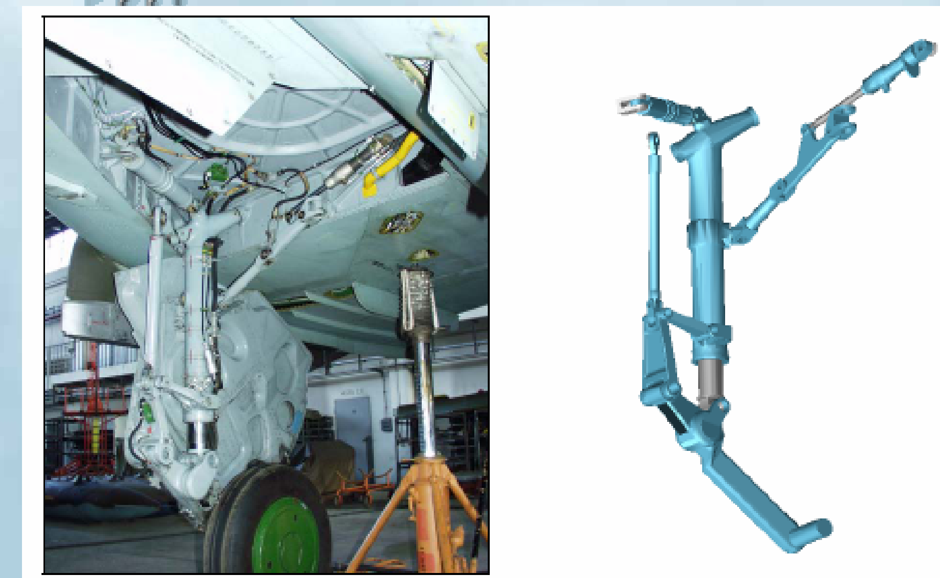
3D MODEL OF THE LANDING GEAR

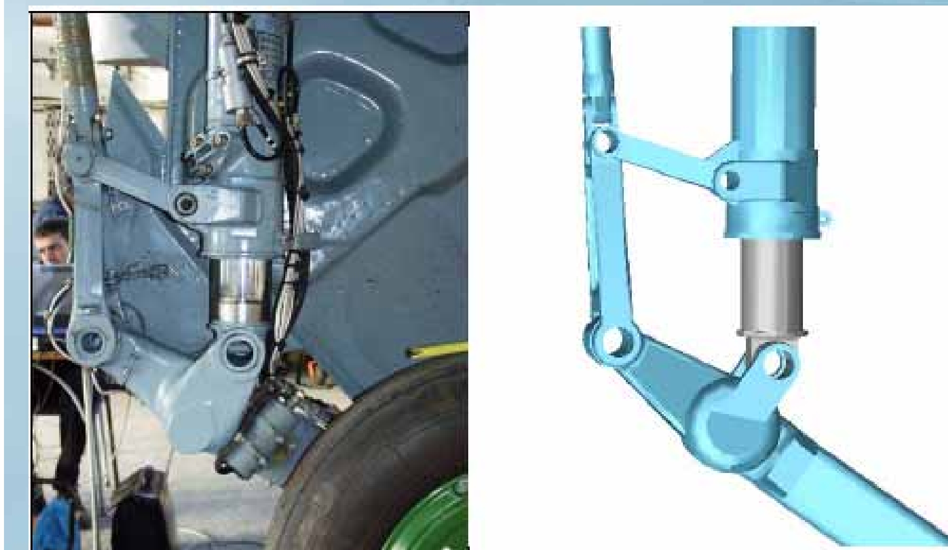




Su-22 right strut of the main landing gear with names of main parts

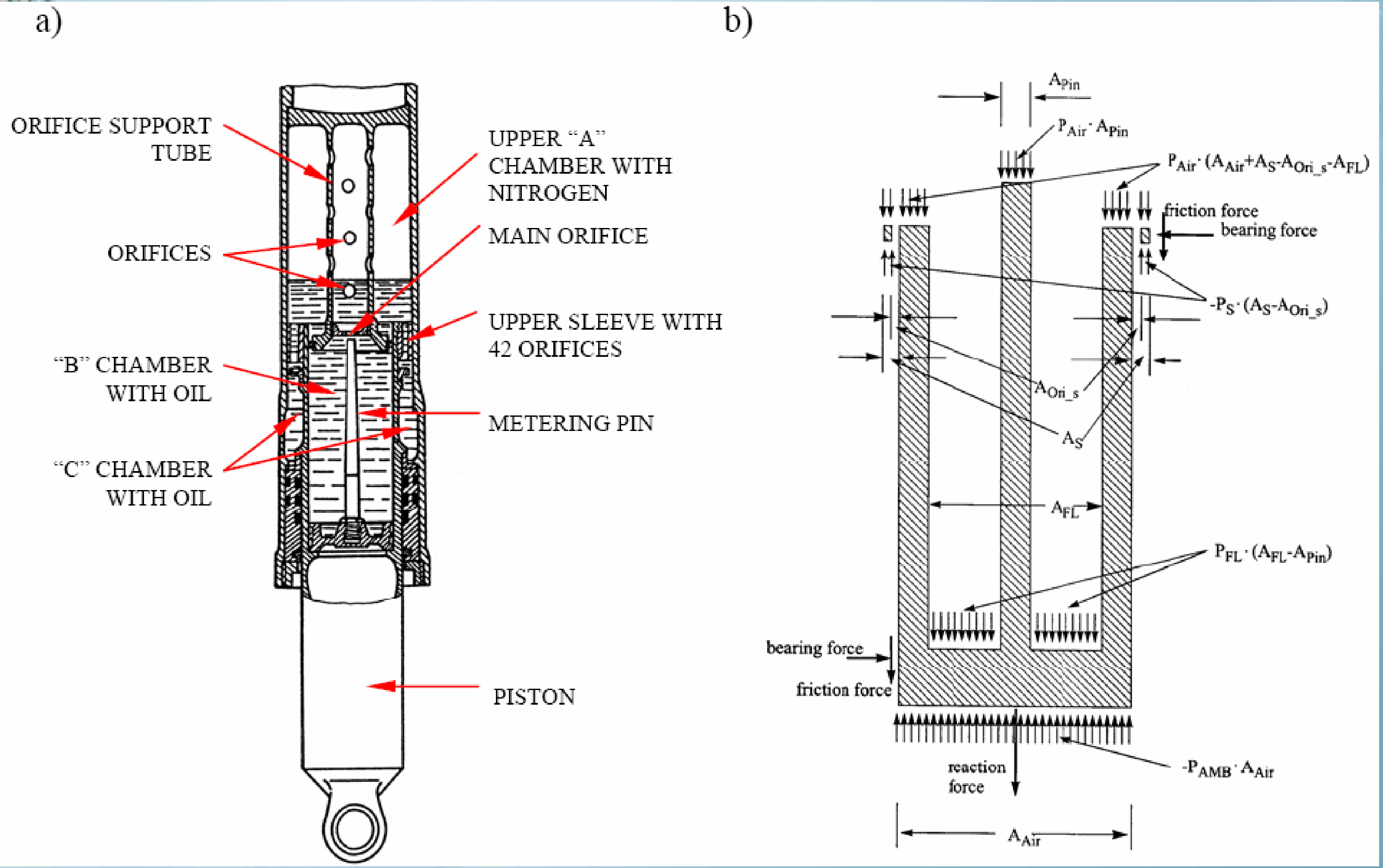
DETAILS OF THE MODEL





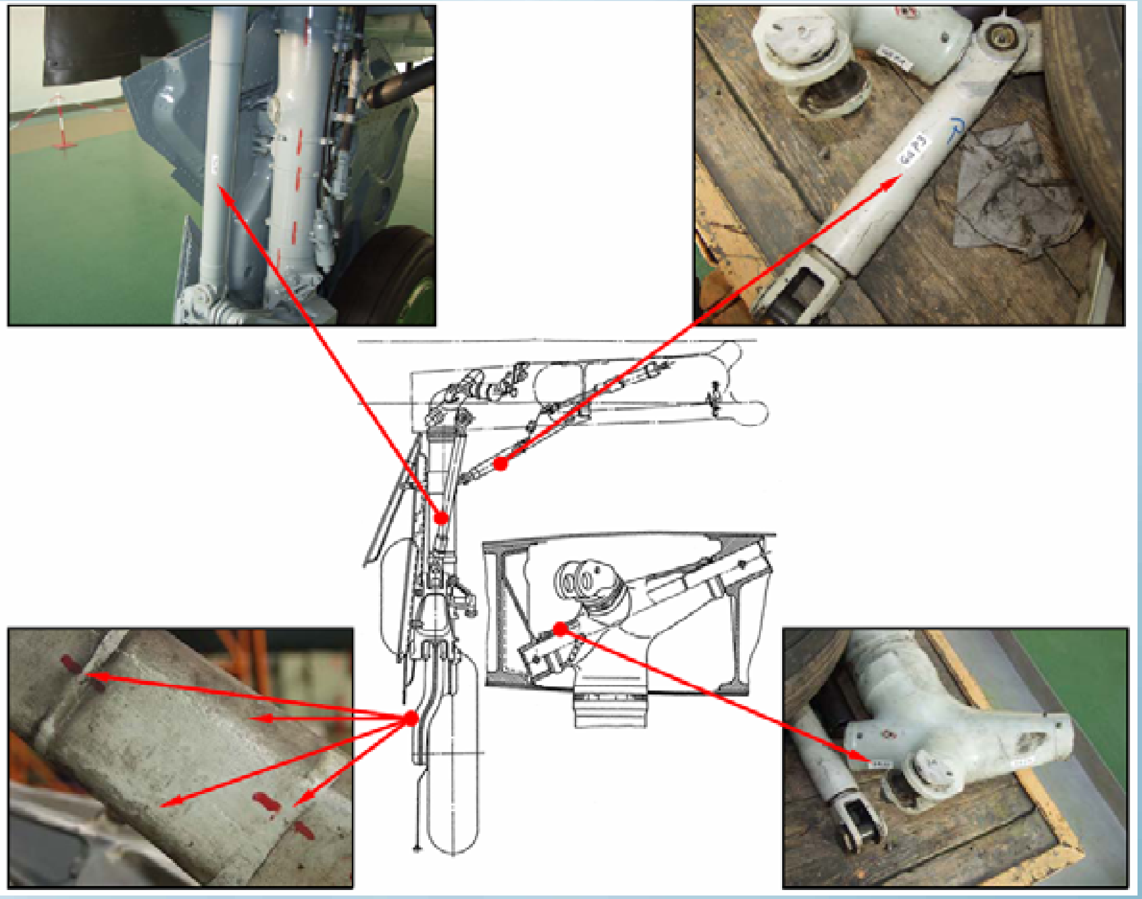
Comparison: model and real landing gear

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



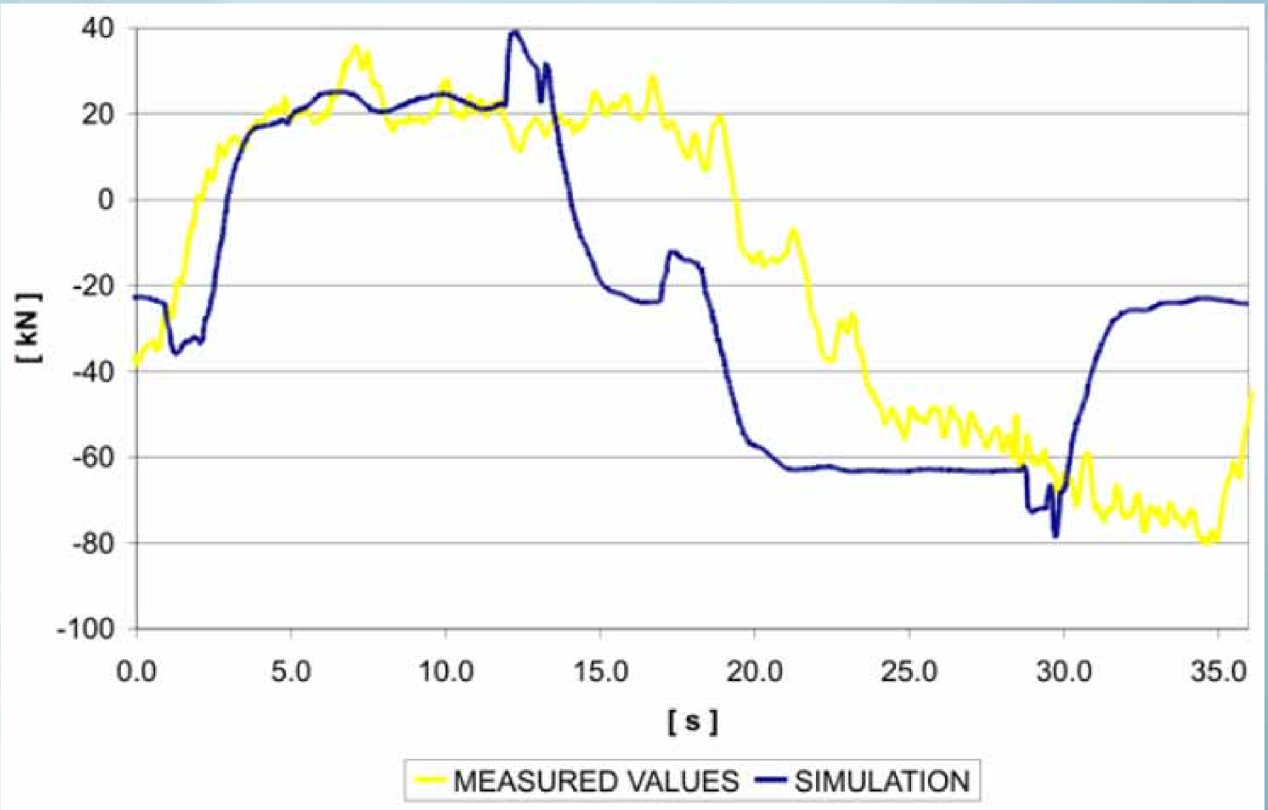
7 channels recorded

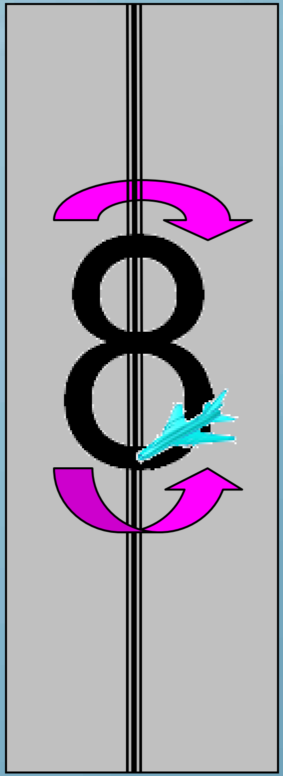
- Axial forces - rods and actuators
- Bending – trailer arm
- Strains – selected points

Recorded:

- 11 flights
- Ground maneuvers
- Engine test

COMPARISON OF RESULTS



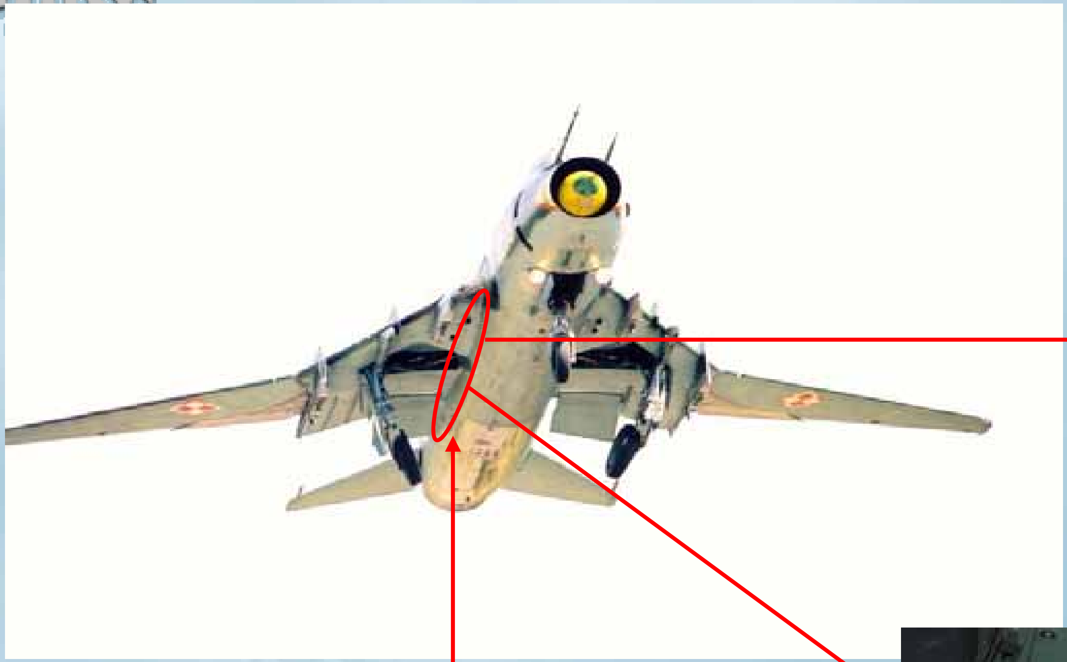


The axial force of the right lower side brace during taxiing (“eight” maneuver)

COMPARISON OF RESULTS (2)

The axial force of the right lower side brace during landing

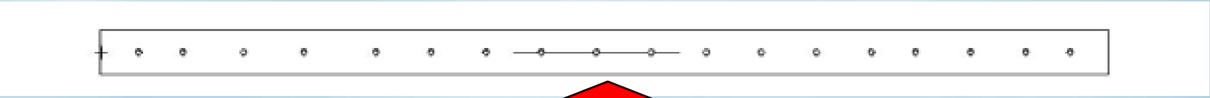
WIDESPREAD FATIGUE DAMAGE



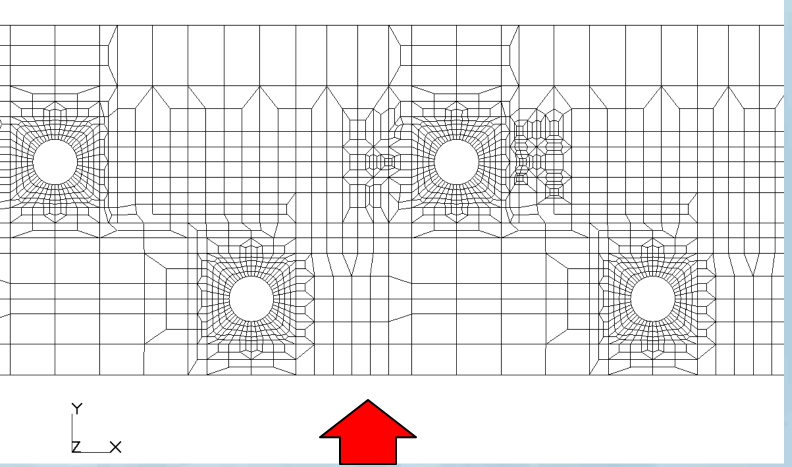
Area of interest

- No evidence of WFD
- Theoretical assumption

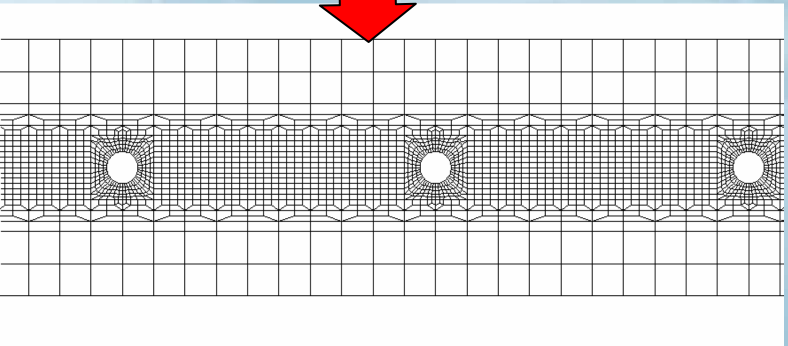
METHODOLOGY OF WFD CALCULATIONS



Intermediate level model



Detailed models



- Global model
- Intermediate models
- Local models

<u>Crack criterions:</u>

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

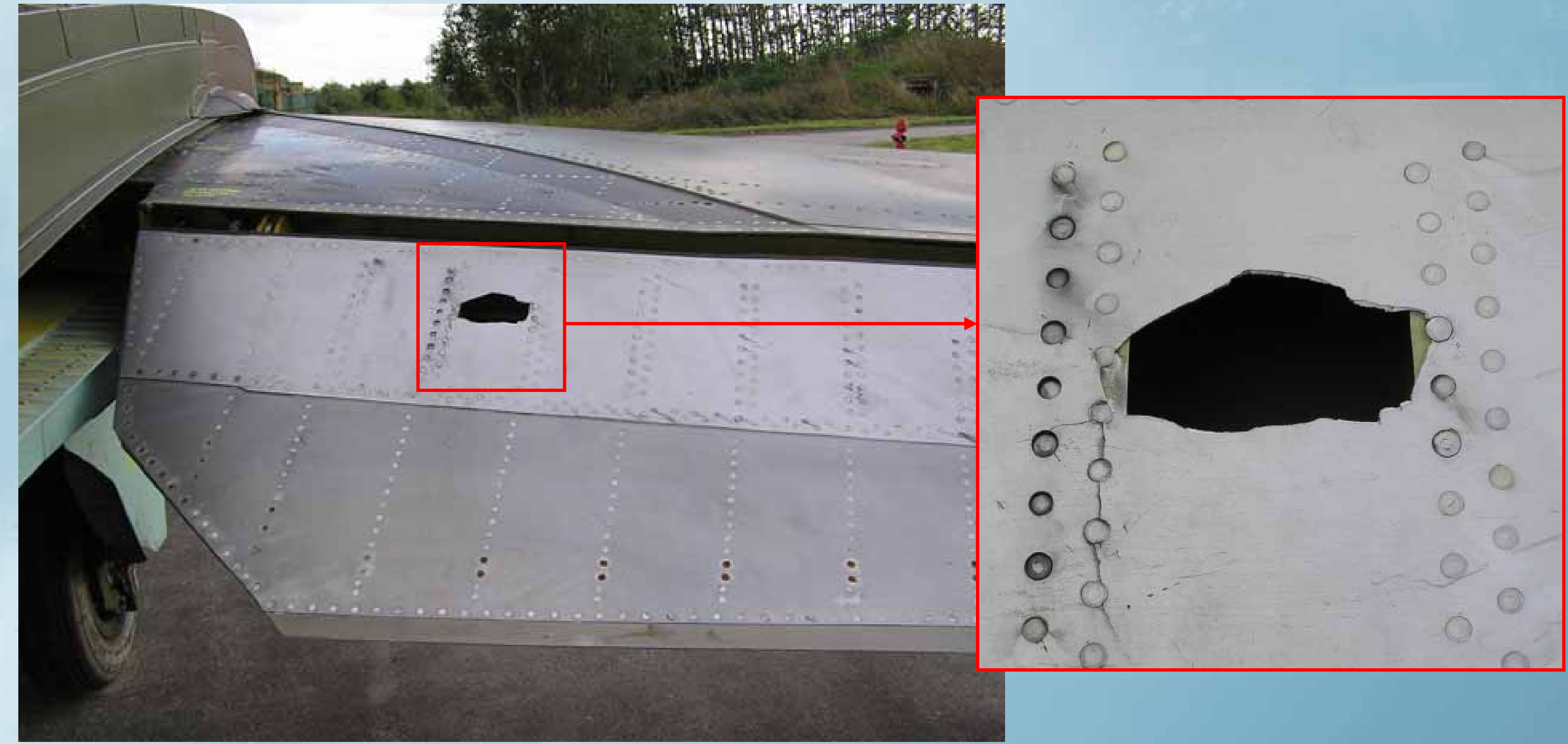
<u>Solver:</u>

- MSC.Marc
- Own procedures

Findings:

Critical crack lengths for different crack scenarios (with and without MSD)

CAUSED BY MSD ?



HIDDEN CORROSION INSPECTION (1)

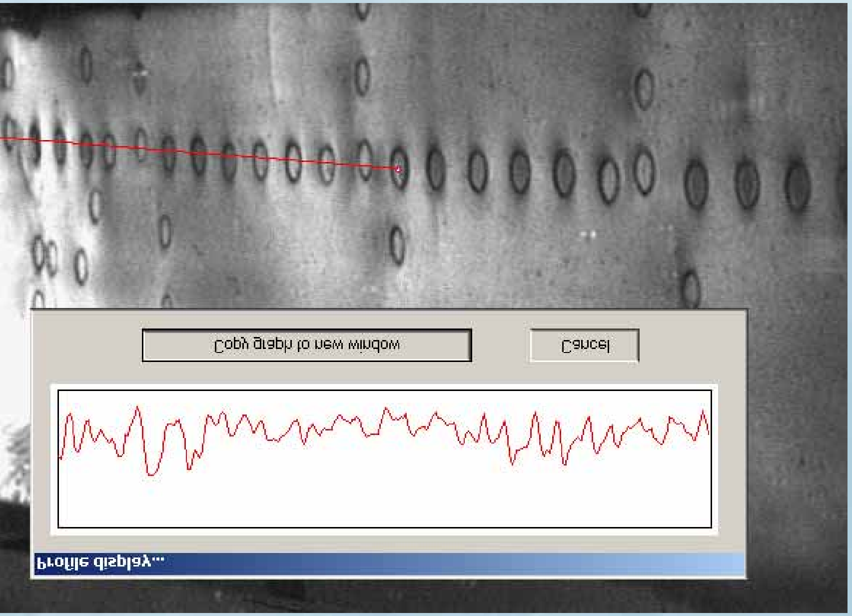
DAIS® (D-Sight™ Aircraft Inspection System)

- 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



$$D-Sight\ index = \left(\frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}\right) * 100$$

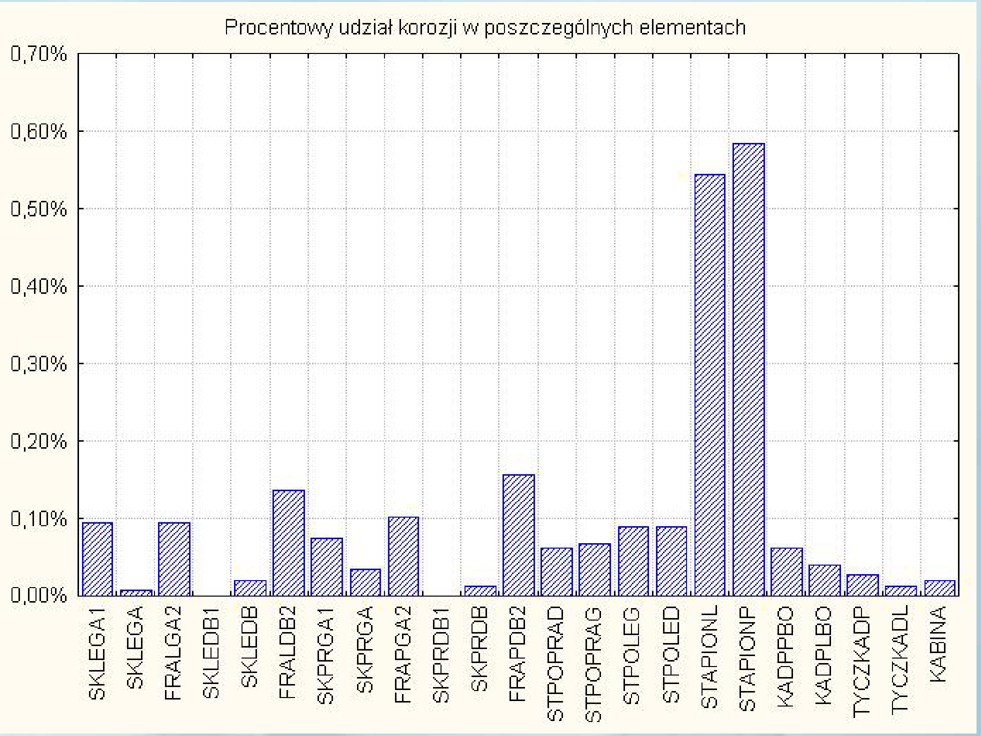
$$I_{\max} \Rightarrow \frac{\partial I_n}{\partial x} = 0 \ \& \ \frac{\partial I_{n-1}}{\partial x} > 0 \wedge \frac{\partial I_{n+1}}{\partial x} < 0;$$

$$I_{\min} \Rightarrow \frac{\partial I_n}{\partial x} = 0 \ \& \ \frac{\partial I_{n-1}}{\partial x} < 0 \wedge \frac{\partial I_{n+1}}{\partial x} > 0$$

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)



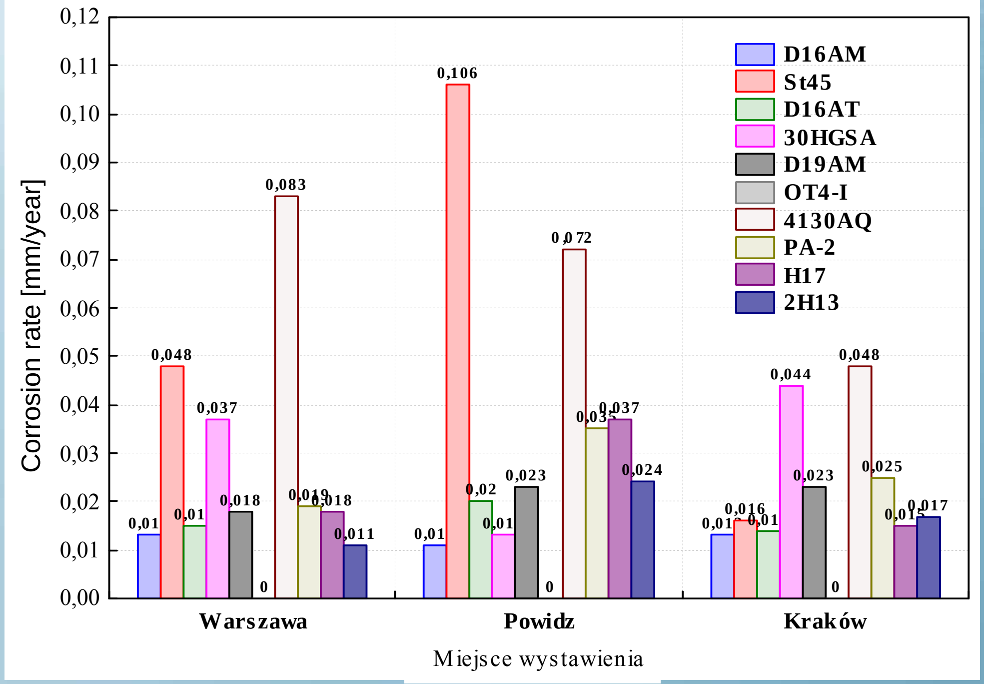
- Average service life: 17 years
- Not uniform corrosion distribution;
- Higher for vertical stabilizer;
- Detailed corrosion distribution and rate of growth were made;
- Hazardous areas were described
- Corrosion-resistant structure

27 A/C population data results

Function	Number of Measurements/ A/C	Number of Indications/A/C
AVERAGE	640	15
Std. Deviation	349	22
SUM	14731	343

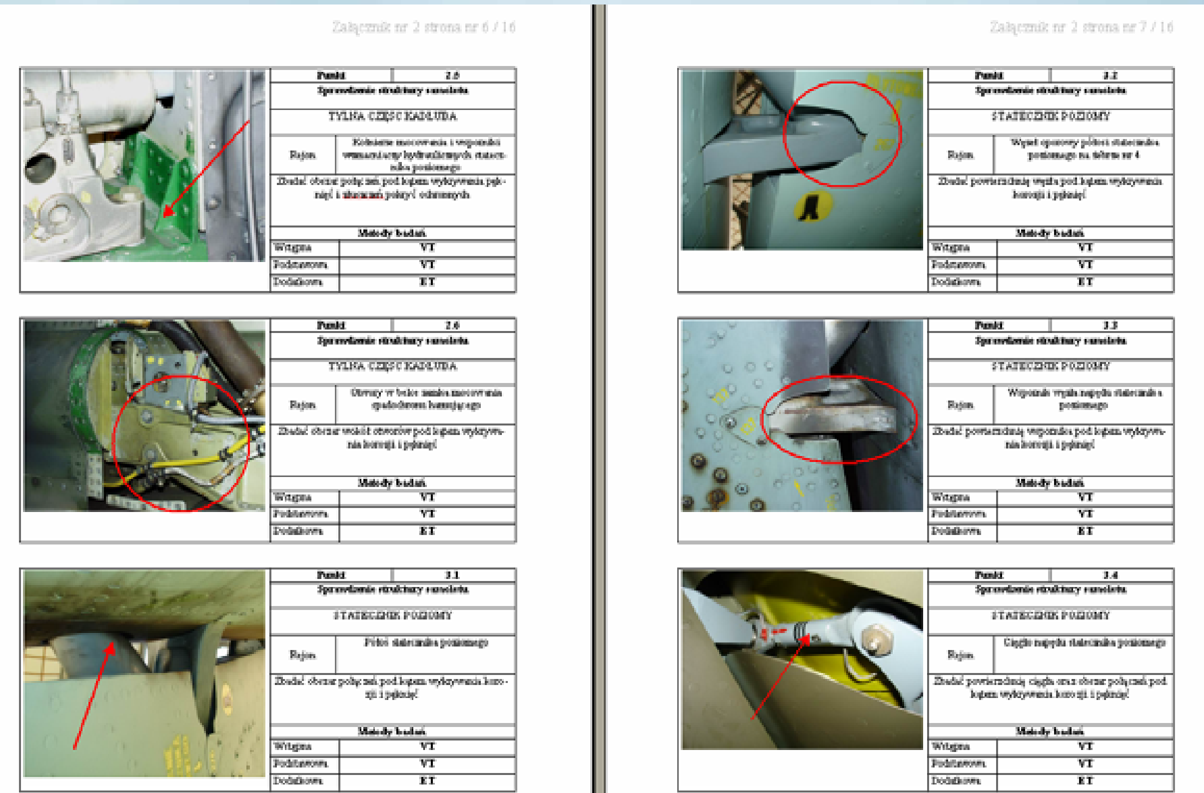
ATMOSPHERIC CORROSION

- 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

BULLETINS AND NDI INSTRUCTIONS



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

Nose landing gear

Fatigue Crack Inspection:

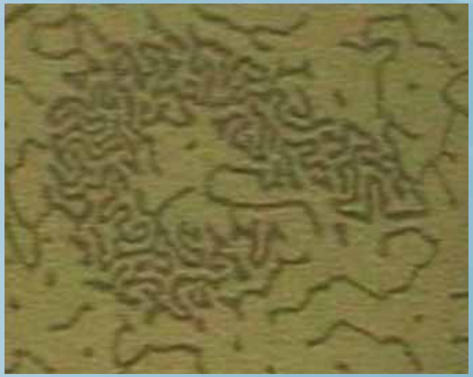
- Landing Gear;
- Wing skin;
- Structural components (wing attachment)

Strip on the edge of landing-gear door

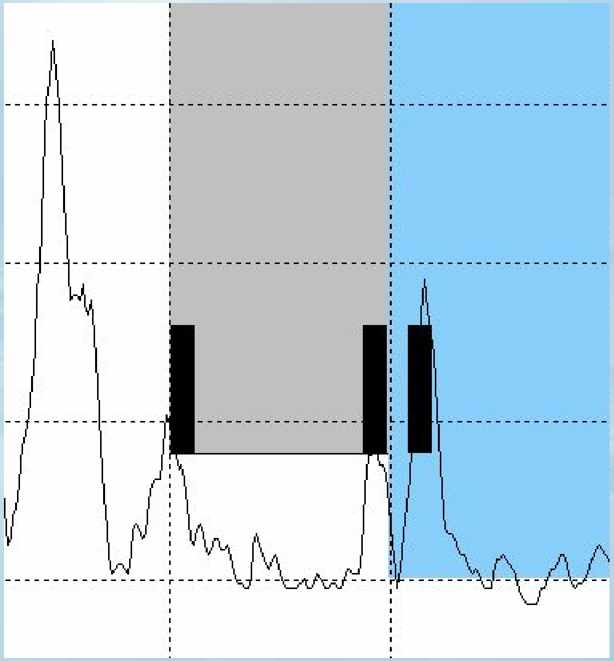
Hydraulic actuator bracket
- tail part of fuselage

CRACK INSPECTION

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



Magneto-Optic Crack Indication



Ultrasonic crack indication

Visual Crack Indication

SUMMARY

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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