ICAF (International Committee on Aeronautical Fatigue and Structural Integrity) – Achievements, Activities and Future Challenges

Von Karman lecture presented at ICAS 2018

Belo Horizonte, Brasil

September 9-14, 2018

Anders Blom, Marcel Bos, Carlos Chaves and David Simpson

Foundation and Uniqueness of ICAF

David Simpson

National ICAF Delegate for Canada 1985-1999
ICAF General Secretary 1999-2005

ICAF – Foundation of ICAF

- **1949 - Dr. Frederik J. Plantema** publishes *“Fatigue of Structures and Structural Components”* - ***Idea of ICAF born***
  - Identified need to share experiences to increase flight safety
  - Needed something beyond technical meetings to allow more in-depth discussion at the expert level
  - Needed to foster international cooperation
- **1951** - **Birth of ICAF**
  - Foundational meeting at College of Aeronautics, Cranfield on Sept. 14:
    - Dr. Plantema (NLL), Mr. E.J. van Beck (Fokker), Prof. W.S. Hemp (College of Aeronautics) & Mr. Bo Lundberg (FFA)
  - ICAF goal was to foster collaboration internationally but avoid sensitive military and political issues to encourage/allow wide participation
  - Challenges met by Dr. Theodor von Karman in establishing ICAS in 1957

ICAF- Foundation of ICAF

- **1952 - First ICAF Conference**, Amsterdam, 9 attendees from The Netherlands, UK, Sweden, Switzerland & Belgium
  - Initial focus: National Fatigue Specialists brief on national fatigue initiatives
    - Expert to expert in-depth briefing not available in such a condensed form
    - Build personal and professional relationships
    - Opportunity for peer comment on national programs

- **1953, 1955, 1956, 1957 ICAF Conferences,** 25-40 attendees plus another 4 countries join ICAF

- **1959 - 1st Symposium**, Amsterdam, 121 attendees
  - Biannual meetings after 1959 meeting, with 2 day Conference & 3 day Symposium

The Uniqueness of ICAF

- **Networking value of ICAF recognized**
  - National membership has grown from the initial 3 to 17!
  - Attendance has increased from basically national delegates and a few colleagues (~20) to audiences of several hundred
- **Attendees from full spectrum of <u>Structural Integrity</u> community**
  - Major differentiating characteristic of ICAF
  - Universities, government laboratories, regulators, industry
  - Military and civilian
  - Seventeen national members but many non-member international attendees
  - ICAF name changed to International Committee on Aeronautical Fatigue and Structural Integrity in 2010 -broader technology interest

The Uniqueness of ICAF

- **Format of ICAF meetings has adapted to community needs**
  - ***'Conference***' (2 days) whereby National delegates provide unique national reviews: **these reviews are the *backbone of ICAF***
  - ***'Symposium'*** (3 days) added (1959) host country proposes a theme of national interest (both presentation and poster sessions)
    - Invited Plantema Memorial Lecture and medal presentation
    - Key theme experts invited to speak, theme related papers sought
    - Jaap Schjive Student Award Lecture
  - ***Technical Visit*** – Opportunity for host nation to highlight a national initiative

- **Proceedings of both the Conference and the Symposium are published in the open literature**

The Uniqueness of ICAF

- **Strong emphasis on relationship building**
  - Social events integral part of ICAF meetings
  - National Delegates, presenters, award winners and attendees interact informally
- **ICAF is independent**
  - Managed by the General Secretary and the National Delegates
  - Meetings are organized by host National Delegate
    - Responsible for all arrangements from logistics, theme setting, call for papers, selection of papers, organization of social events
    - National Delegate responsible for all financial arrangements: set Registration fee to cover expenses
  - Concentrates on Structural Integrity issues

Summary: The Uniqueness of ICAF

- ICAF independent organization of the Structural Integrity community managed by the General Secretary and National Delegates
- National Delegates from 17 leading aerospace countries
- National Reviews provide immediate knowledge on the status and progress of national initiatives related to Structural Integrity
- Relationships are built across international boundaries and across sectoral boundaries (university, government, regulators, civil, military)
- Rotating ICAF locations provides opportunity to understand host nation priorities and capabilities

Important Events, State of the Art, and ICAF Activities

Anders Blom

National ICAF Delegate for Sweden 1985-2005
ICAF General Secretary 2005-2017

Fatigue is and old but still relevant phenomenon

1829 - Albert, Repeated Load Tests

1851 - Wöhler, First Systematic Fatigue Studies: Fatigue Limit & Stress Range
Late 1800:s - Train Crash of the Week, UK

1903 - Wright Brothers First Flight Delayed due to a Hollow Propeller Shaft Developing a Fatigue Crack. New Solid Spring Shaft from Dayton, OH, brought in to Test Site in North Carolina

1927 - First In-Flight Structural Fatigue Failure: Wing to Strut Fitting, Dornier Merkur Monoplane, Lufthansa, Germany, 6 killed

1929- Imperial Airways Handley-Page Crash into English Channel, Engine Connecting Rod, 7 killed

1934 - Swissair Curtiss Condor Biplane Failure, Wing Strut, Near Tuttelingen, Germany, 11 killed

1944 - US Air Force First Fatigue Test, B-24 Nose Landing Gear

May 2, 1952, 1st Flight deHavilland DH-106 Comet (Yoke Peter)

Wreckage recovered of crashed Comet (Yoke Peter)

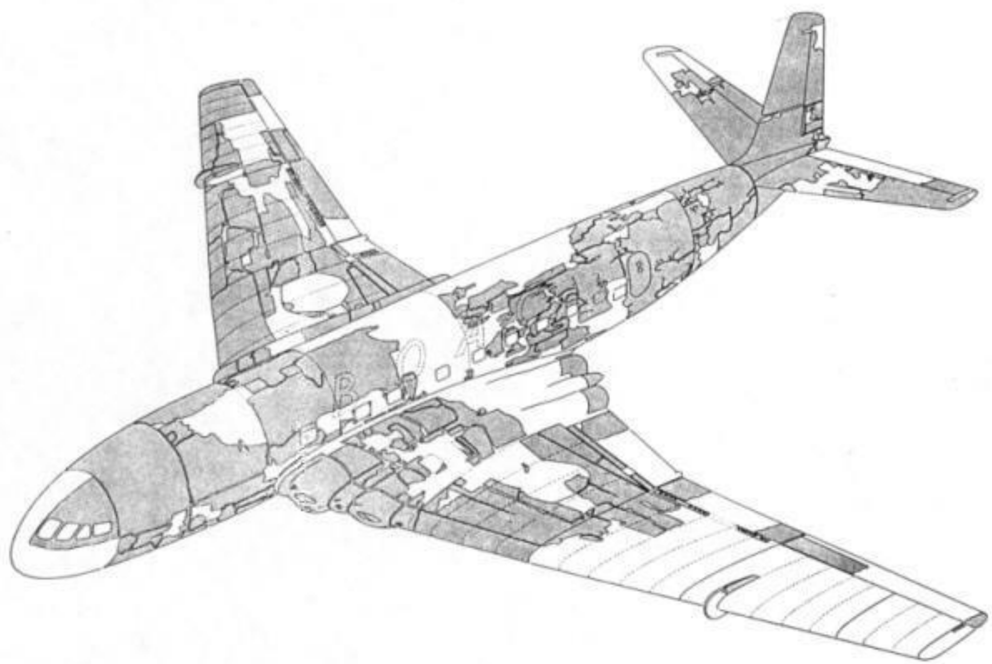
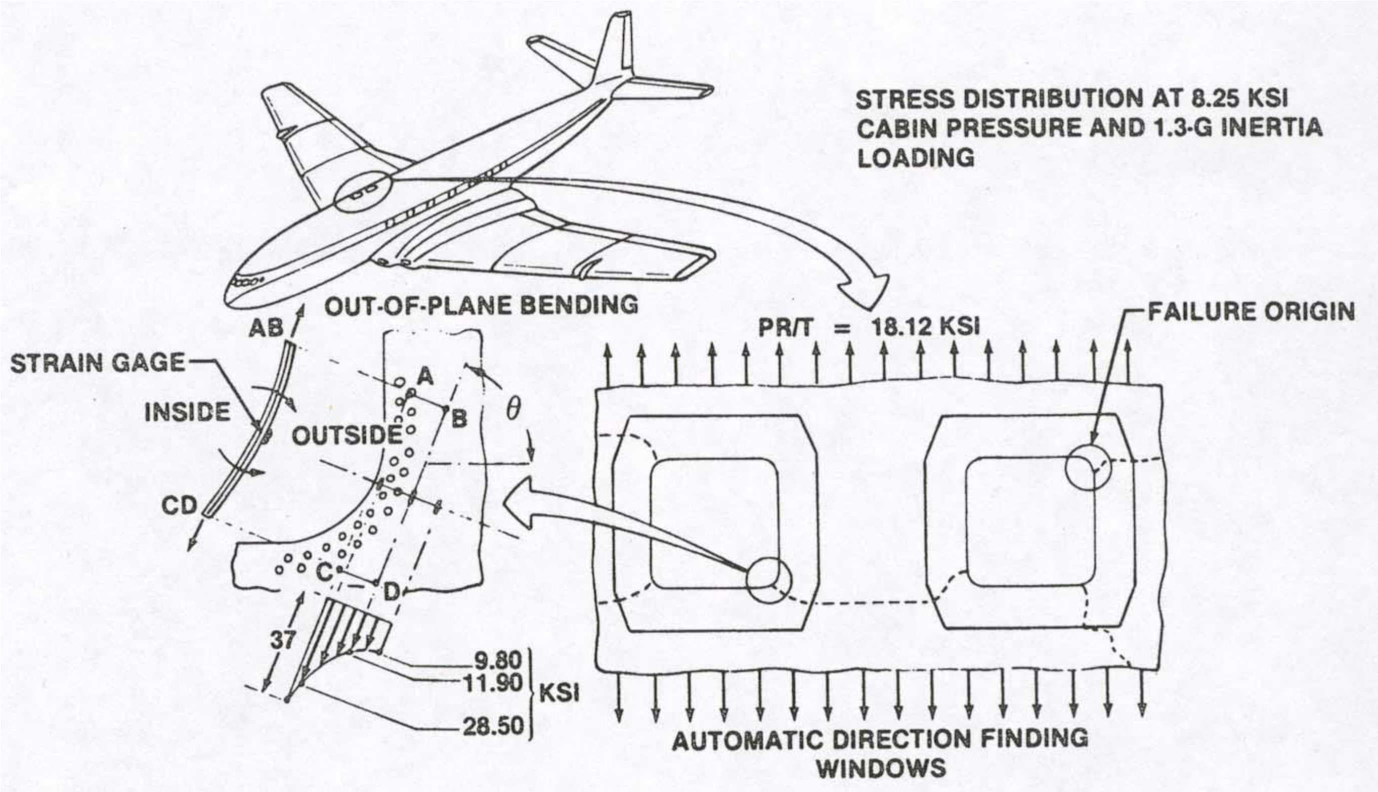


FIG. 2. DIAGRAM SHOWING AMOUNT OF WRECKAGE RECOVERED—G-ALYP.

Probable failure origin in Comet (Yoke Peter)



General Dynamics F-111A Aardvark

Design Service Life: 4,000 hours
4,000 flights

Dec. 22 1969

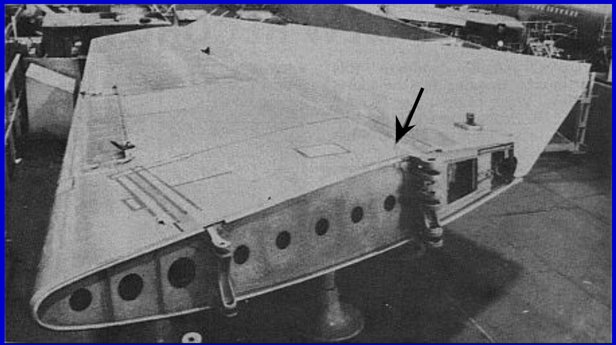
USAF F111 #94 - New Mexico

105 hours & 107 flights

Dan Air G-BEBP - Lusaka Airport

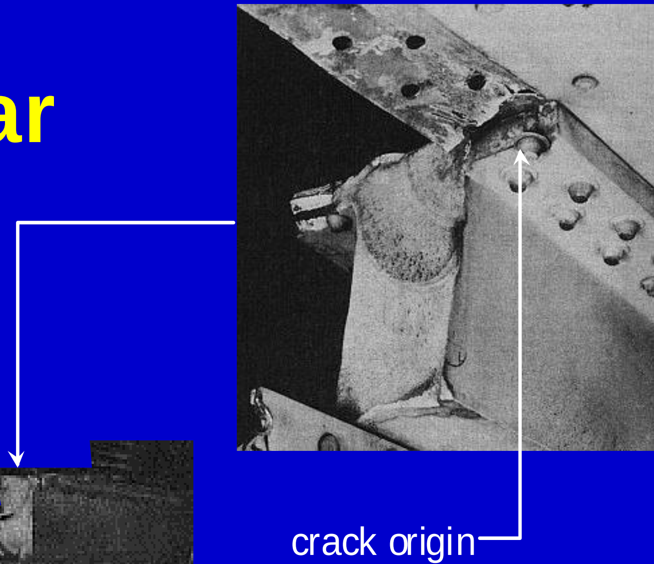
May 14 1977

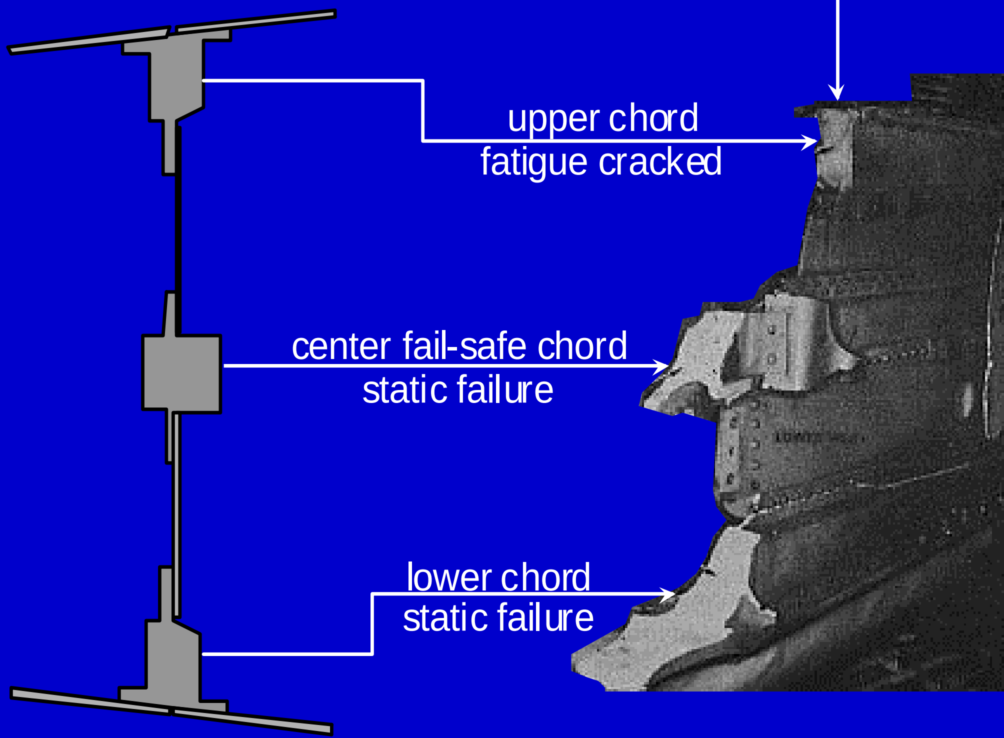
47,621 hours & 16,723 flights



Boeing 707-321C
Design Service Life: 60,000 h

Failed Tailplane Spar

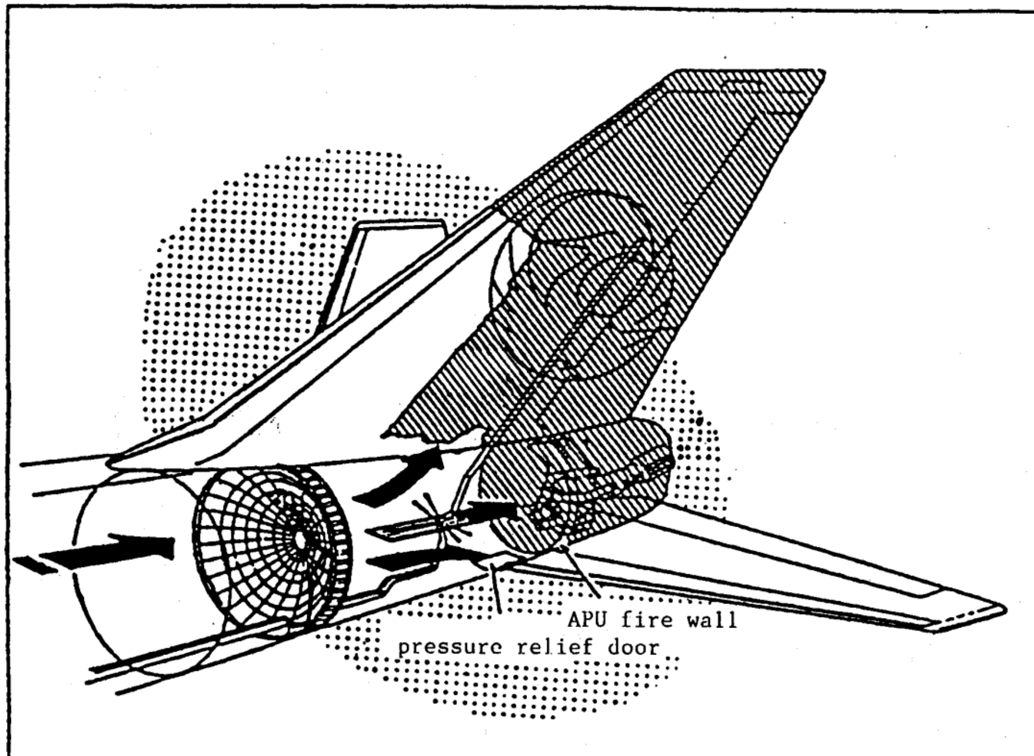




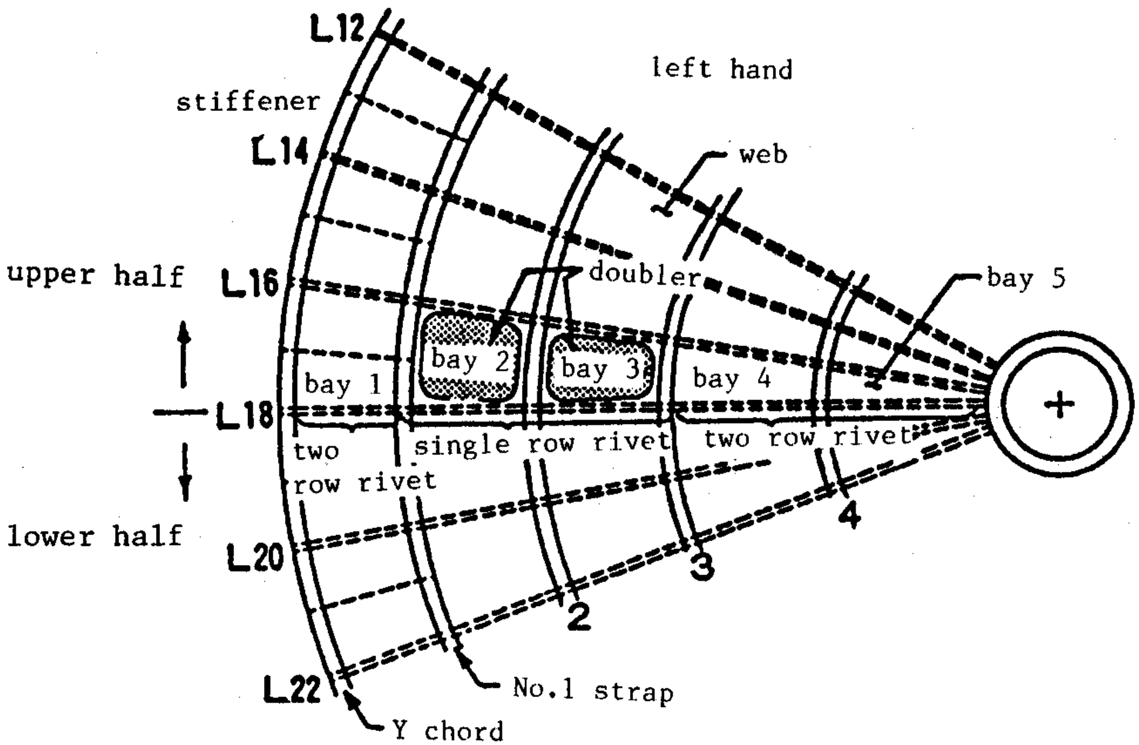
ICAF in the 80-ies

- Good funding available in most countries
- Basic research in fracture mechanics (K-solutions, failure criteria)
- FCG studies on mechanisms, closure, thresholds, aging effects (planar slip/wavy slip), overloads, compression loading, spectrum loading etc
- Standardized load sequences (Falstaff, Twist, Helix, Felix, Enstaff, Carlos etc) used for data exchange
- Basic work on Composites, focus on basics (humidity, temp)
- Joints (load transfer, secondary bending, fastener systems, cold working, fretting etc)
- Exchange of documents between member countries
- Close links to AGARD (NATO Advisory Group for Aeronautical Research and Development)

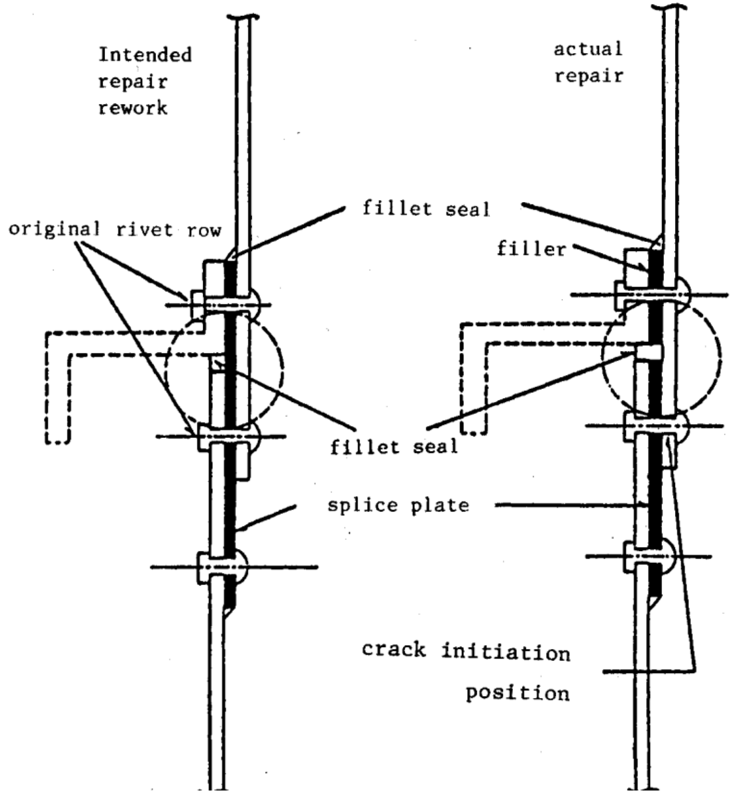
Estimated fracture of rear section of JA 8119 Boeing 747 SR-100 crashed in Japan
August 12, 1985



Aft pressure bulkhead of JA 8119 Boeing 747 SR-100 crashed in Japan, 1985



L18 splice section. Intended repair and actual incorrect repair



ICAF
International Commi
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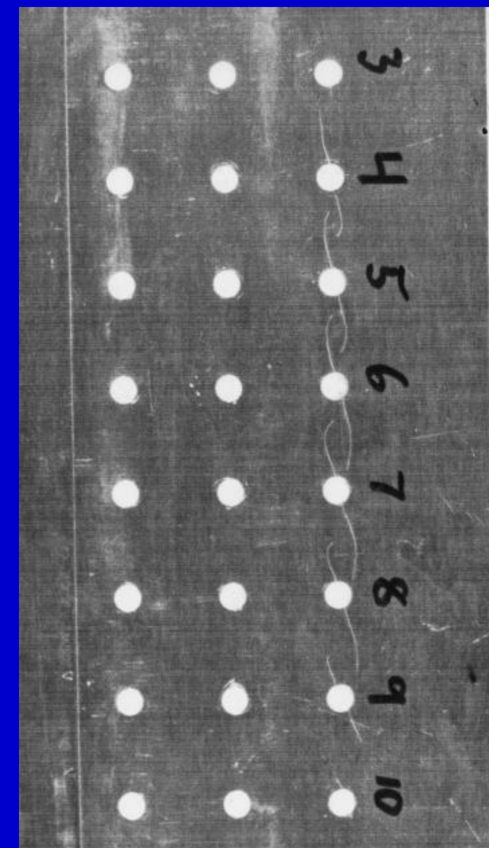
and Structural Integ

April 28 1988

Aloha Airlines - Flight 243

35,493 hours & 89,090 flights



Boeing 737-200
Design Service Life: 51,000 hours
75,000 flights

ational Council of
ronautical Sciences

Evolution of Design Principles

Static
Safety-by-margin → **Safe-life**
Safety-by-retirement

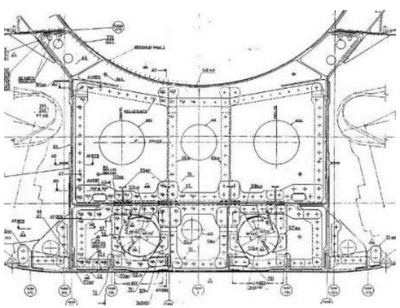
↓ ↓ (↑)

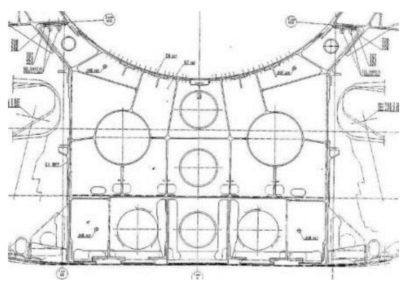
Fail-safe
Safety-by-design → (←) **Damage tolerance**
Safety-by-inspection

↓ ↓

Condition Based Maintenance
Health & service life monitoring

Parts count reduction → integral design solutions

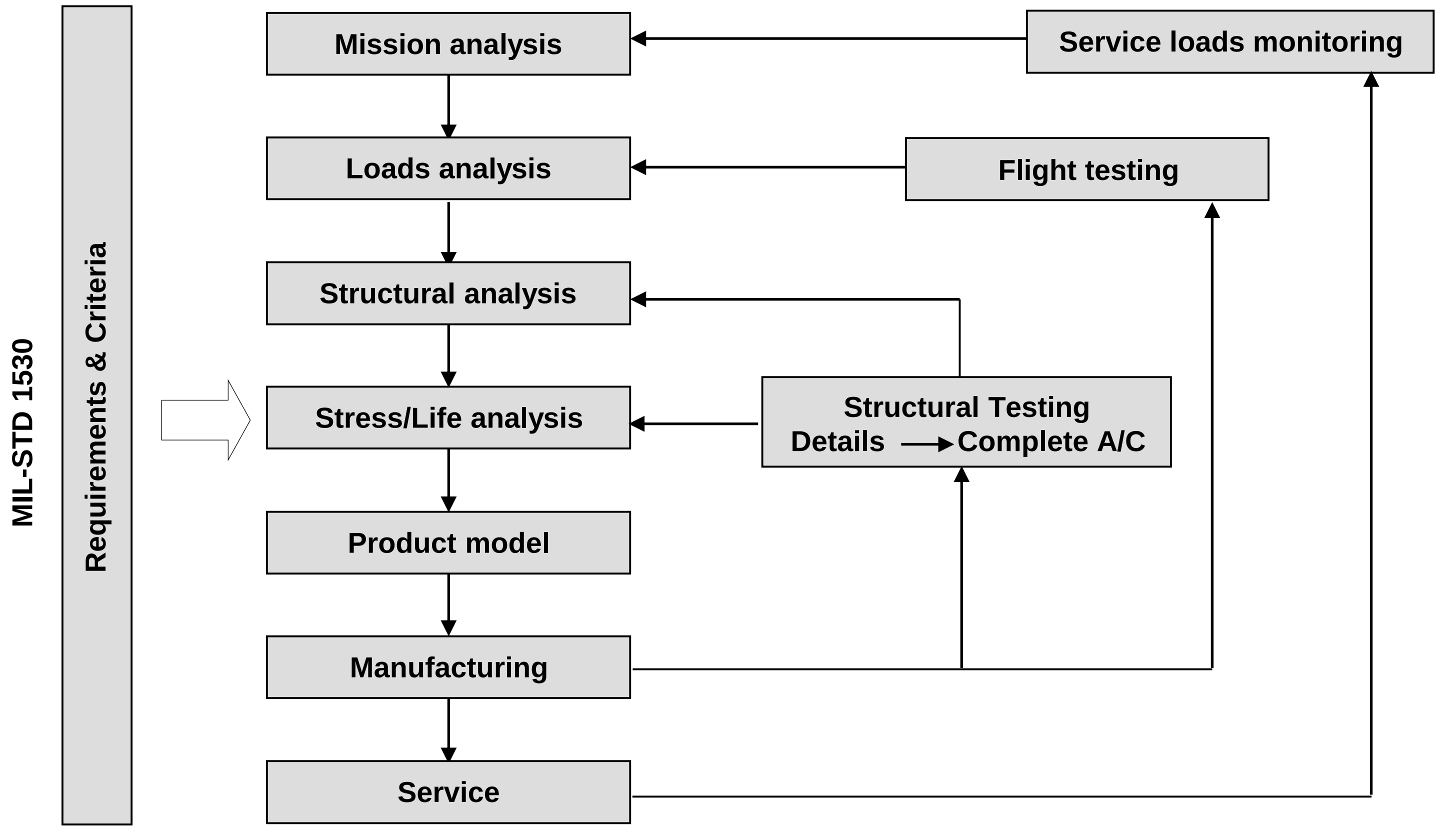




→

- Design for inspectability
- Attention to robustness and fail safe
- Lessen the inspection burden
- Keep track on actual structural conditions - CBM
- Design for reparability

Structural integrity management



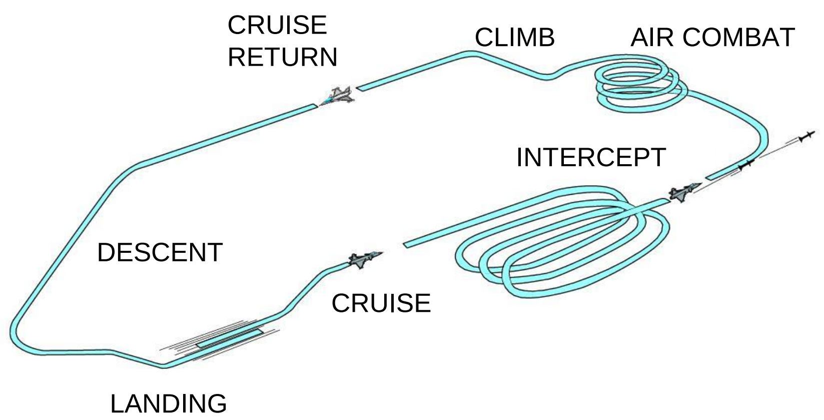
MISSION ANALYSIS

- **Previous Experience**
- **Expected Threat**
- **Future Tactics**

<u>Mission Types</u>
- basic training
- air-to-air
- air-to-surface
- reconnaissance

<u>Mission Segments</u>
- safety and function tests
- ground manoeuvring
- combat manoeuvring
- store separation
- gun firing
- landing

<u>Example: Combat Air Patrol</u>



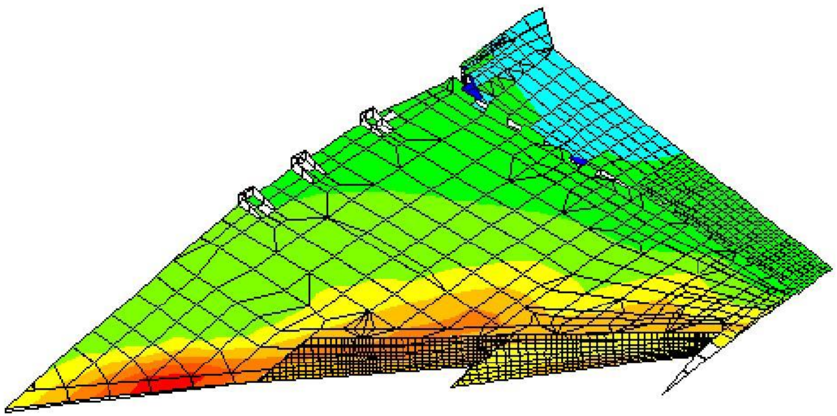
<u>Flight Parameters</u>
- accelerations
- angular velocities
- speed
- altitude
- control surface deflections
- thrust
- fuel consumption
- store configurations

LOADS ANALYSIS

Analysis
- Finite element - static & dynamic response
- Computational Fluid Mechanics
- Flight Mechanics simulations

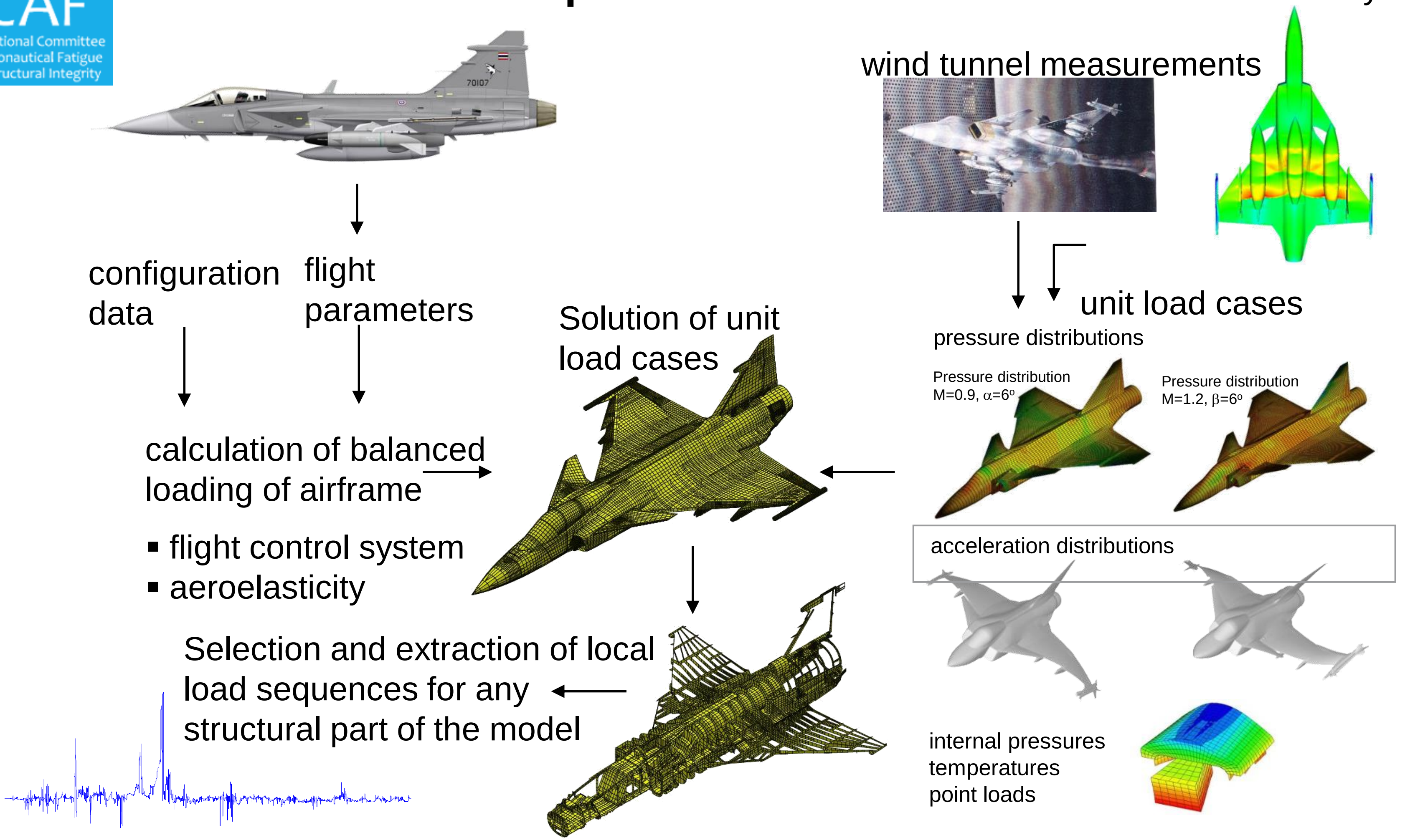
Testing
- Wind tunnel
- Loads survey test flights

Example: Pressure distribution on the main wing during a pull-up manoeuvre



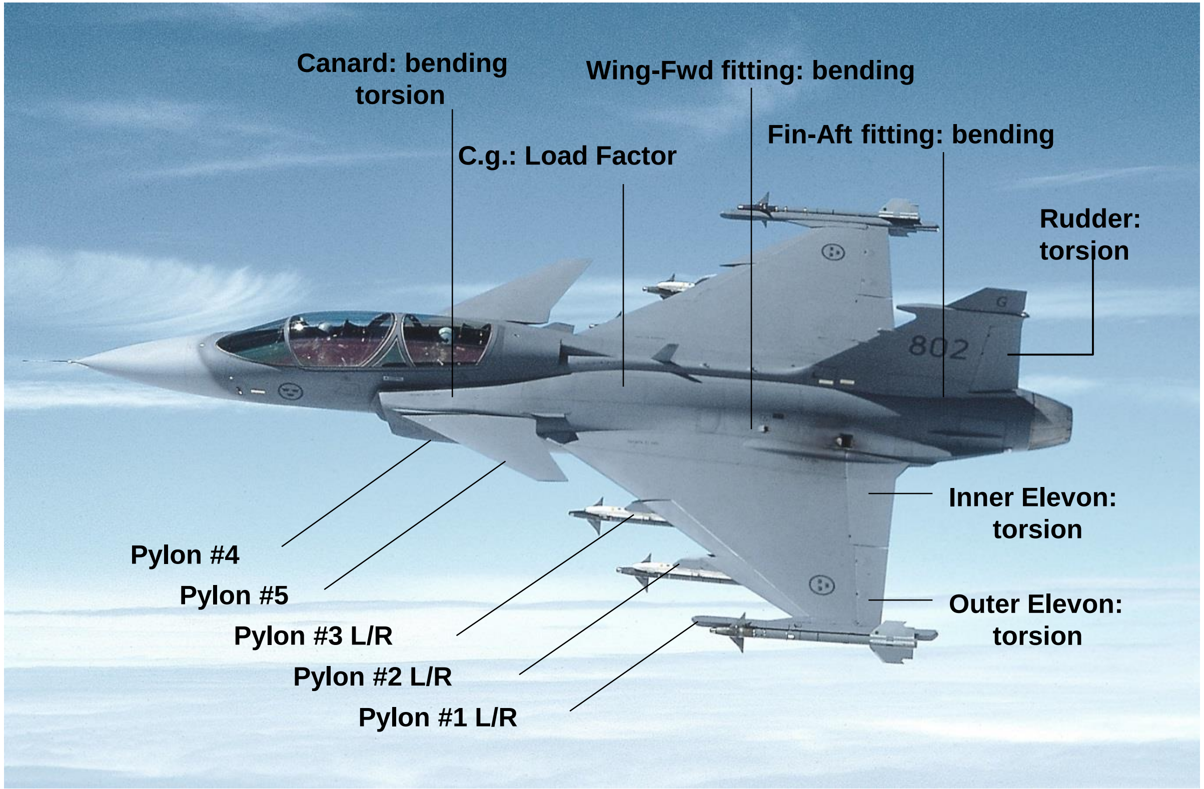
- Aerodynamic loads
- Inertia loads
- Dynamic loads
- Store separation loads
- Ground loads
- Gun loads
- Gust loads
- Flight control system loads
- Temperature loads
- Internal pressure loads
- e.t.c

Principles of loads model



ICAF International Committee on Aeronautical Fatigue and Structural Integrity

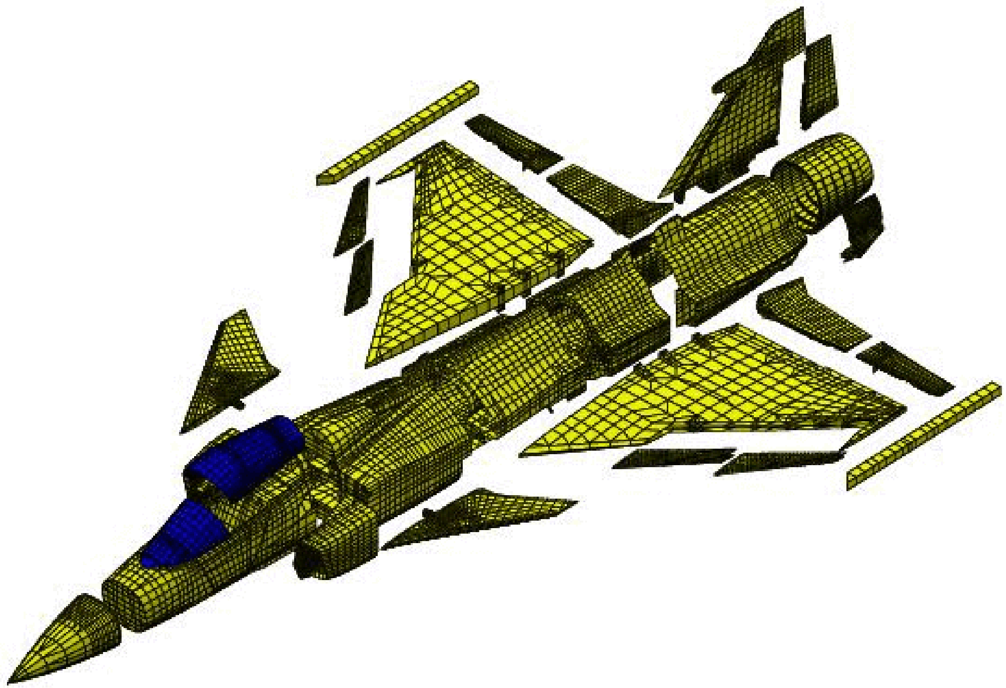
MONITORED STRUCTURE AND LOAD ENTITIES



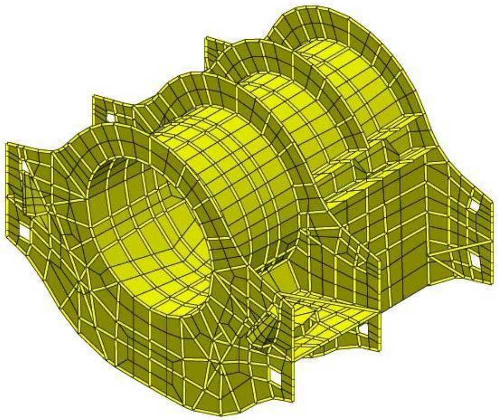
STRUCTURAL ANALYSIS

<u>Finite Element Model</u>
- sub-structured models
- 80,000 elements/400,000 d.o.f

<u>Load Cases</u>
- 750 unit load cases solved
- 13,000 unique balanced load cases in mission profile



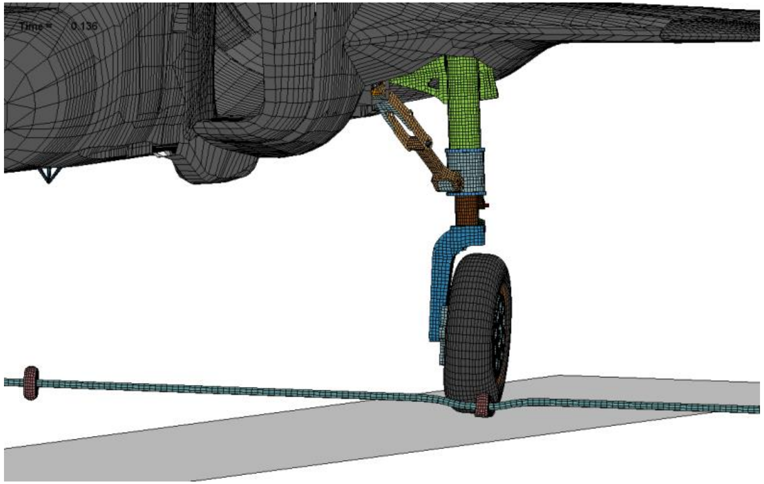
Example: Sub-structure of wing attachment unit



Trend: **Increasing computational resources**

- Faster computers
- Larger and cheaper data storage
- Increasing number of available commercial software tools

Possibilities:



- Faster and more complex calculations.
- Enables Model-Based-Design.
- New types of simulations become feasible (productions processes, multi-body-dynamics, multi-physics, non-linear analysis, etc)
- Parametric studies and optimization.

Challenges:

- Validation. Fast and advanced calculations are not necessarily reliable.
- Finding right balance between accuracy and rapid response in different project stages.
- A large number of different analyses tools may lead to a very complex process which can be difficult to maintain over time.

Trend: More multidisciplinary analysis processes

Possibilities:

- Better designs can often be found by avoiding to separate the overall design problem into a number of problems for each discipline at an early stage.
- More global view of the engineering task by solving coupled problems.
- The same models can be used by several disciplines.

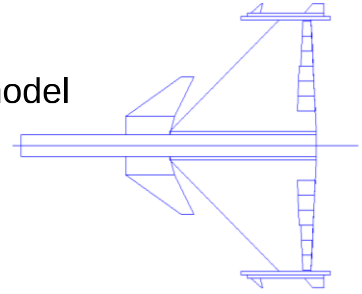
Challenges:

- Development of analyses tools and practical applications will be more complex to perform with several technical disciplines closely involved in the same process.

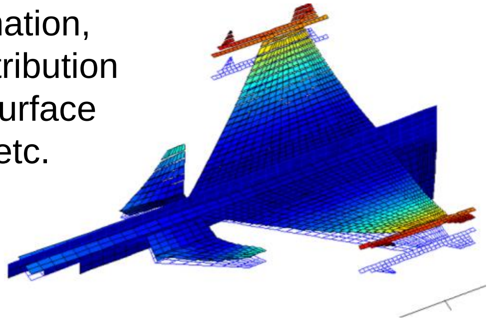
Example: Static aeroelastic analysis

Structural model

+ Aerodynamic model

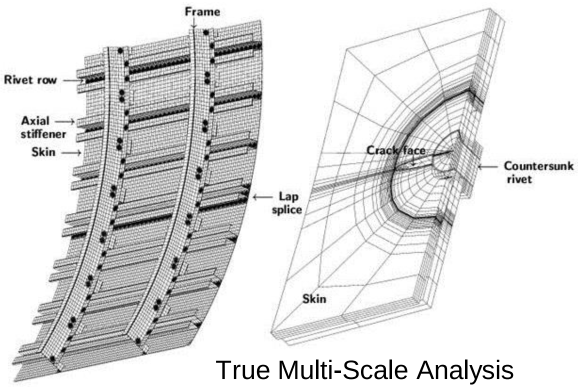


Static deformation, Pressure distribution and control surface effectivenes etc.

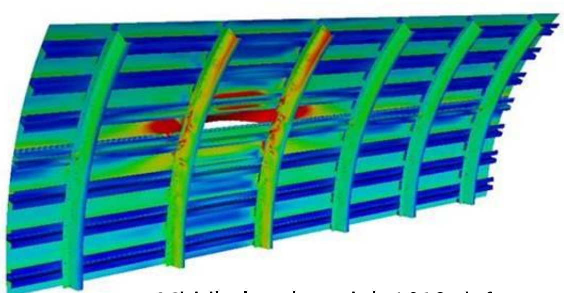


Large Scale Analysis

Statistical Fatigue and Residual Strength Analysis of Corroded A/C



True Multi-Scale Analysis



Middle level model, 10^8 dofs

Example: Statistical Fatigue Analysis

FOI-US Air Force cooperation 2002-2009

Objects

- C5
- C17
- F16

Financing

US Air Force

Unique experience HPCN

Development /analysis on largest computer systems available.

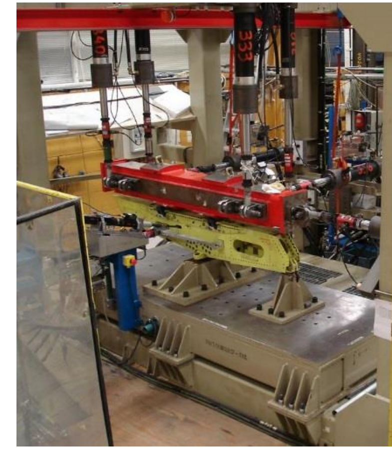
Ex. MSRC-systems available to project

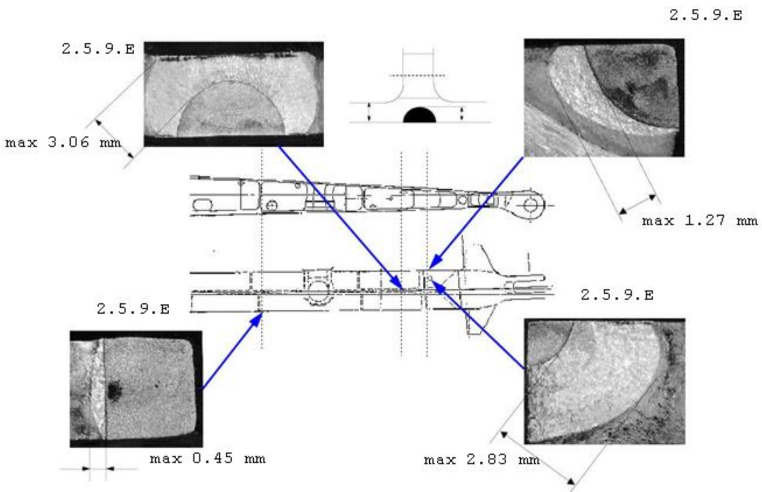
- total 14 000 CPu's
- 50 TFLOPS, 20 TB memory

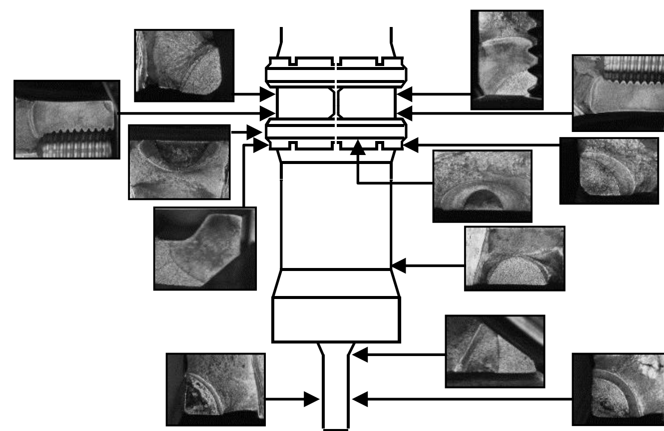
Full-scale fatigue and damage tolerance testing

All structure of airframe and systems

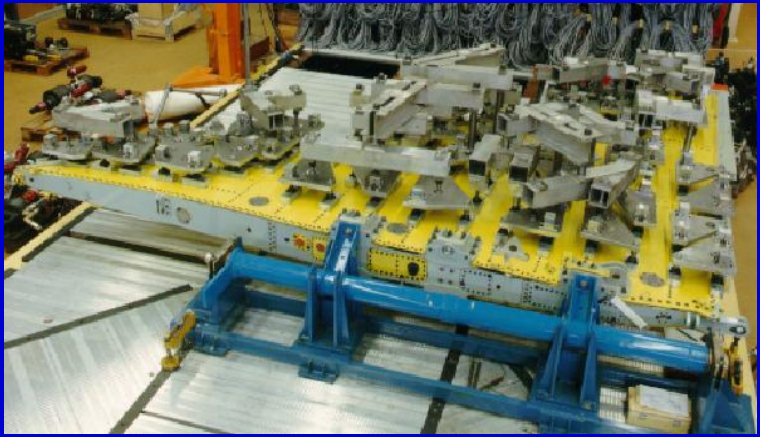
Abt. 800 initial flaws installed in full-scale component testing







Test No 5.5.2
Complete Airframe



ICAF in the 90-ies

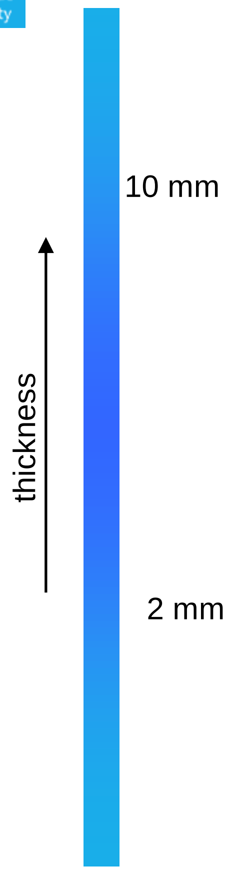
- Still decent funding, but less than during 80-ies
- Damage tolerance of structures become required for all civil aircraft. Military aircraft only damage tolerant design in the USA and Sweden
- Aging aircraft issues become largest research topic ever
- Composites gradually introduced even more, focus is on low energy impact damage and BVID
- Numerical modelling advanced (Dofs, p-version FEM, convergence rates, error control)

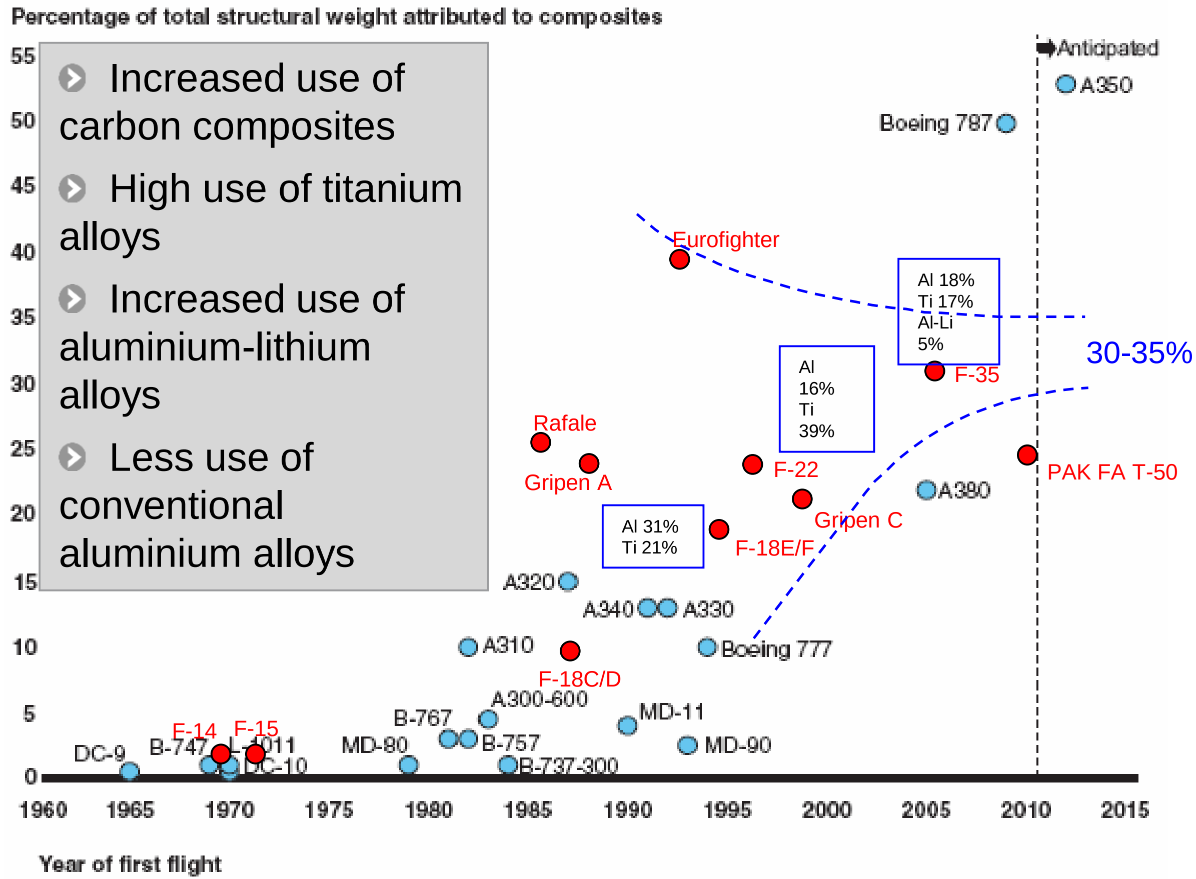
Structural concepts - present

- Detachable half wings mounted on a wing carry through box
- Constant wing aspect ratio optimized against speed requirements of the principal designed role
- Separated tail planes (US) or
- Full delta configuration and additional control by fully active canards (EU)
- Single fin (EU) or
- Twin fins (US)
- Single or twin low bypass turbofan engines
- Weapons wing and fuselage mounted mostly external
- In flight refueling
- Internal weapon bays (US)

Structural Materials

- Increased use of carbon composites
- High use of titanium alloys
- Increased use of aluminium-lithium alloys
- Less use of conventional aluminium alloys





Sources: GAO analysis of information from FAA, NASA, Boeing Company, *Jane's All the World's Aircraft*, and *Jane's Aircraft Upgrades*.

Material selection issues

- Composites show most advantage at intermediate thicknesses, e.g. combat aircraft wing skin - tough with in-plane strength

- Anisotropic nature of composites allow for optimization of stiffness and strength, e.g. flutter alleviation

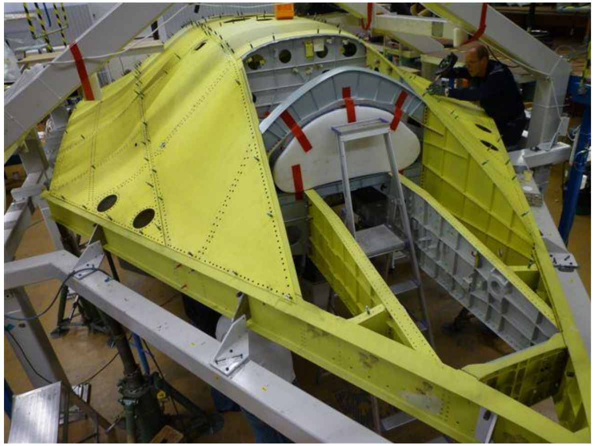
- Composite constructions allows for incorporation of sensors and properties for signature control

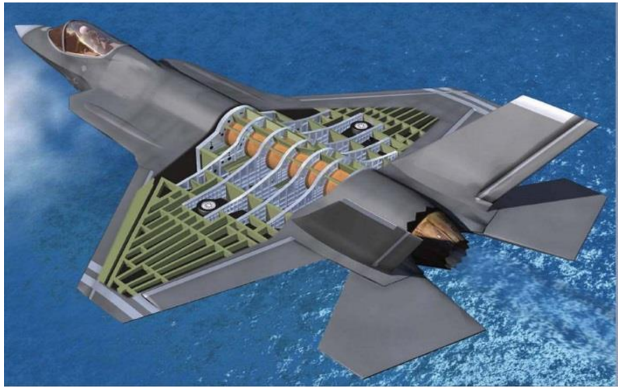
- Thinner sections: weight advantage for metals and particularly where there is a thermal requirement, e.g. fuselage skin

- Heavier structures requiring three-dimensional load capability are preferably machined from metals

- Metal structure perform better than composite structure under impact conditions including battle damage

- Metal structure suffers from fatigue and are prone to corrosion





Remark on fleet size and operational life

A/C 35 Draken
Number of aircraft: ~600
Design service life: 1500 h

A/C 37 Viggen
Number of aircraft: ~300
Design service life: 2800 h

A/C 39 Gripen (C/D)
Number of aircraft: ~100
Design service life: 8000 h

Operational ability
↓
Systems complexity
↓
Cost
↓
Fewer aircraft
↓
Longer life

- Design for future systems and tactical changes
- High demands on availability
- Increased demands on survivability

ICAF in the 00-ies until now

- Significantly less funding for military purposes
- Significantly fewer aircraft projects
- Risk for losing experience and repeating mistakes from the past
- Need for knowledge transfer to young generation
- Risk for trust in huge calculations without substantiated input data, load cases, boundary conditions, and structural testing
- Aeronautics cost driven but safety should come first
- More focus on Helicopters and Systems
- ICAF broadens scope to fatigue and structural integrity
- Most important aeronautical countries previously not members of ICAF become members (China, Russia, Brazil)

Why new countries want to join ICAF and current challenges for civil aeronautics

Carlos Chaves

National ICAF Delegate for Brazil 2017-

With input by:

Degang Cui
National ICAF Delegate for China 2015-

Boris Nesterenko
National ICAF Delegate for Russia, 2017-

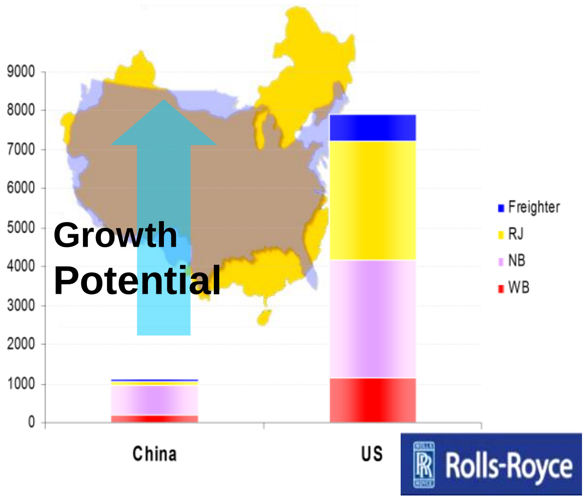
Aeronautical Fatigue and Structural Integrity in China

China CAE ICAF Office

Why China Joins into ICAF

- **Huge Market Demands on Commercial Aircraft In China**

  Aviation industry represents the economical growth situation of the country. The forecast number of new commercial Aircraft of China airline can reach to **8575** during 2017-2036.



Rolls-Royce forecast of the China passenger aircraft growth for next 20 years

- **Characters of ICAF**

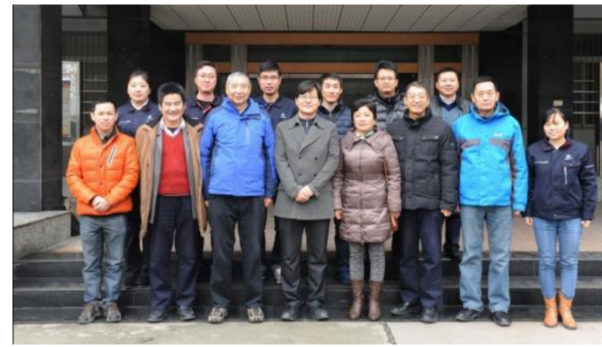
  It aims to encourage contacts between people engaged in aeronautical fatigue and structural integrity and to exchange information, experience, and ideas. Its specialty attracts China to be a member of ICAF and to improve its research level in aviation fields.

ICAF
International Committee on Aeronautical Fatigue and Structural Integrity

ICAF with China

China has been the 15th ICAF member since ICAF-2015 in Helsinki. China CAE ICAF office was established and led by Chinese Aeronautical Establishment (CAE) in 2016. It is responsible for organizing academic cooperation with ICAF. China delegation attended ICAF-2017 in Nagoya.

China delegation in ICAF-2015 Helsinki.



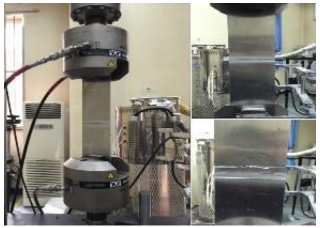
Members of China CAE ICAF office

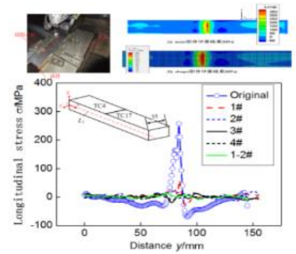
China delegation attended ICAF-2017 in Nagoya.

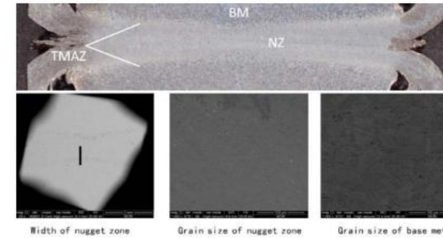
ICAS International Council of the Aeronautical Sciences

International Committee on Aeronautical Fatigue and Structural Integrity

Recent Research Achievements







- **The fundamental research on theories, standards and handbooks, materials and processes for FSI;**
- **Application research on load spectrum, structural health monitoring, durability and damage tolerance design and analysis, test concept, life enhancement;**

Challenges of China aviation development

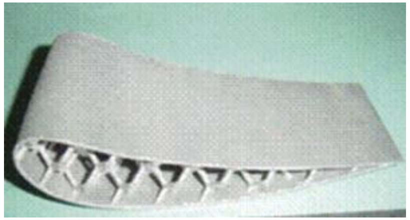
- Strong requirements for new aviation products
- Application of advanced FSI theories, technology, materials and processes into aviation design

Products of China aviation

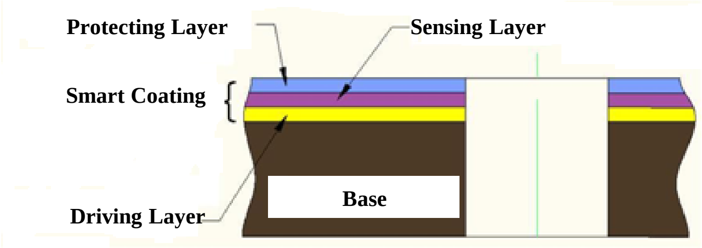
Particulate reinforced aluminum matrix composite

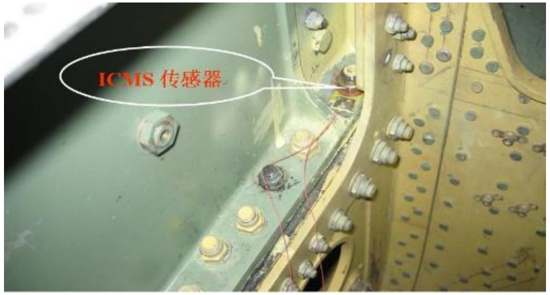
Research and Development in China ICAF

- Real-time health monitoring of structures
- New testing technology for FSI
- New type of structure on FSI
- New FSI theories and technology applied on structure

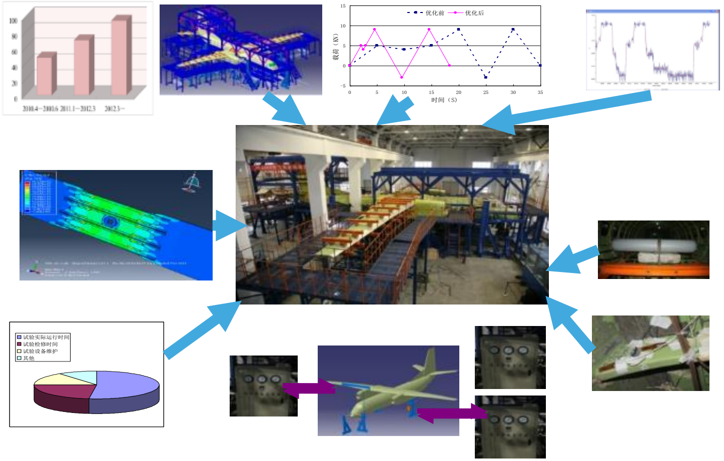


New type of structure





Intellective Coating Monitoring System in Full-Scale Fatigue Test of Aircraft



Application of accelerated fatigue life testing in MA600 full-scale test

ICAF
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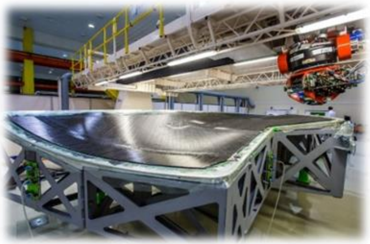
Russian Federation @ ICAF

Participation of Russian research organizations, academia and universities jointly with industrial aviation companies in ICAF activities is aimed for the close cooperation of scientists, engineers and aviation specialists in the field of aeronautical fatigue and structural integrity, share of knowledge and experience and adoption of the best practices and effective solutions in

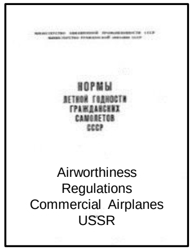
- **New advanced designs of aircraft and rotorcraft in compliance with regulation requirements**
- **Application of innovative technologies and engineering ideas in aircraft and rotorcraft structures**
- **Providing operational safety of aging fleet with individual approach to specific aircraft**



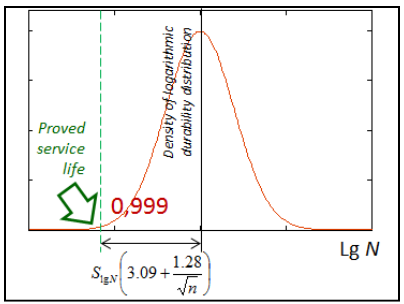
<u>Participation in ICAF scientific and engineering society should Improve safety, efficiency and economical value of Russian aviation transport</u>

ICAS International Council of the Aeronautical Sciences

RUSSIAN HISTORICAL BACKGROUND IN FATIGUE AND DAMAGE TOLERANCE OF COMMERCIAL AND MILITARY AVIATION

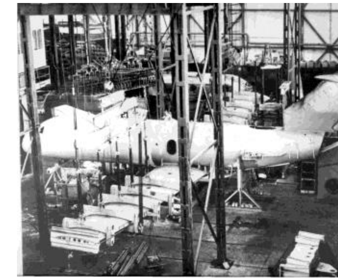


Airworthiness Regulations Commercial Airplanes USSR



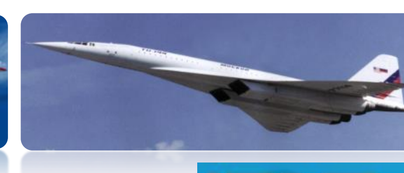
Safety factor determination approach

- Original methodology of structural safety provision
  - ❖ Local service experience-based Airworthiness Regulations for commercial (NLGS) and military (NPVS) aircrafts, 1967-1984
  - ❖ Original probability-based approach to establish fatigue life limits supported by service experience
  - ❖ Fleet residual service life control by means of integrated on-board analyzers
- Unique technologies of full scale fatigue testing
  - ❖ Tested more full scale airplanes than in any other country
  - ❖ The methodology to conduct static & fatigue testing on the same article developed and verified
  - ❖ Experience of FSFT with thermal loading in environmental chamber (supersonic Tupolev 144)
- Original approach to aging fleet airworthiness provision
  - ❖ Full scale testing of aged airplanes with long service history
  - ❖ Individual approach to each airplane in aging fleet



Full scale fatigue test of Yakovlev 40

Full scale fatigue test of fuselage section



TECHNOLOGIES FOR FATIGUE AND DAMAGE TOLERANCE SUBSTANTIATION OF NEW-GENERATION AIRCRAFT IN RUSSIA

GOALS

- Improve weight efficiency of airframe
- Maintain required level of safety
- Accelerate certification program
- Reduce cost of development and certification


MC-21


SSJ-100

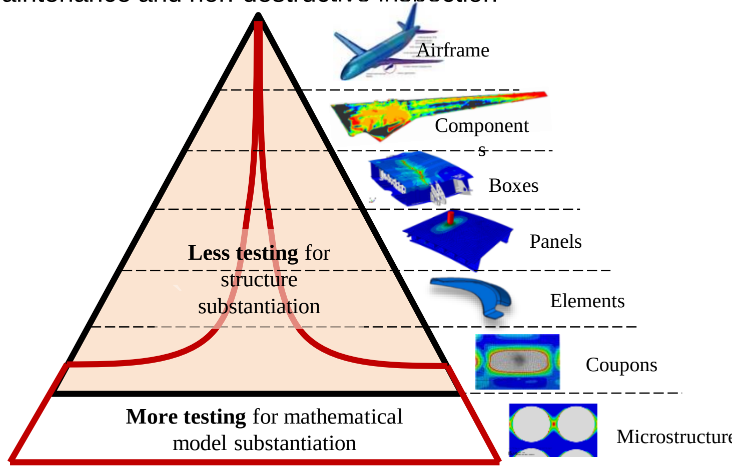

Sukhoi 57

CHALLENGES

- The composite-friendly design and certification methods are needed to increase allowable stresses and weight efficiency of composite structures
- Introduction of new materials (e.g. composites and metal alloys) require comprehensive qualification programs
- The fatigue-related issues of new fabrication and assembling methods (one-step molding, high speed machining e.t.c.) should be thoroughly addressed

TOOLS

- More experiment for mathematical model verification, less experiment for direct compliance demonstration
- Introduction of virtual experiment and testing of “digital twins”
- Probabilistic design to increase weight efficiency of composite structures
- Shift from “defect-based” to “property-based” paradigm in aircraft maintenance and non-destructive inspection



From the “Testing Pyramid” to the “Virtual-testing pyramid”

Key activities in Russian aviation industry related to ICAF topics

Improving fatigue and structural integrity of SSJ-100 modifications

Full-scale SSJ-100 body tests to be performed at TsAGI facilities in Zhukovsky

Full-scale fuselage tests to be performed to prove structural damage tolerance of SSJ-100

Tests of wing structure to validate SSJ-100 DSO of 60000 flights

Residual strength tests demonstrated already the large damage capability of wing structure

Providing structure integrity of MS-21 and certification of structure

Number of varios configuration wing panels have been tested to be followed by full-scale wing tests

More than 30 fuselage panels of different configuration have been tested to support certification

Successful empennage and horizontal stabilizer tests have been performed

Brazil in ICAF

Brazilian participation as an ICAF member has been supported by ABCM since 2015.

Brazil presented 2 national reviews, first in Helsinki in 2015, and more recently in Nagoya, in 2017. Following ICAF directives, Brazil became an ICAF member country in 2017.

Brazil joined the ICAF because it has an expressive aerospace industry (commercial aviation, executive aviation and defense), and it has been developing an increasing amount of research related to aeronautic fatigue.

Besides, the participation in ICAF is important to keep the brazilian research community always aware about recent trends in the field of aeronautical fatigue.

ICAF – Brazilian Delegation

ICAF Main Partners in Brazil

ICAF
International Committee on Aeronautical Fatigue and Structural Integrity

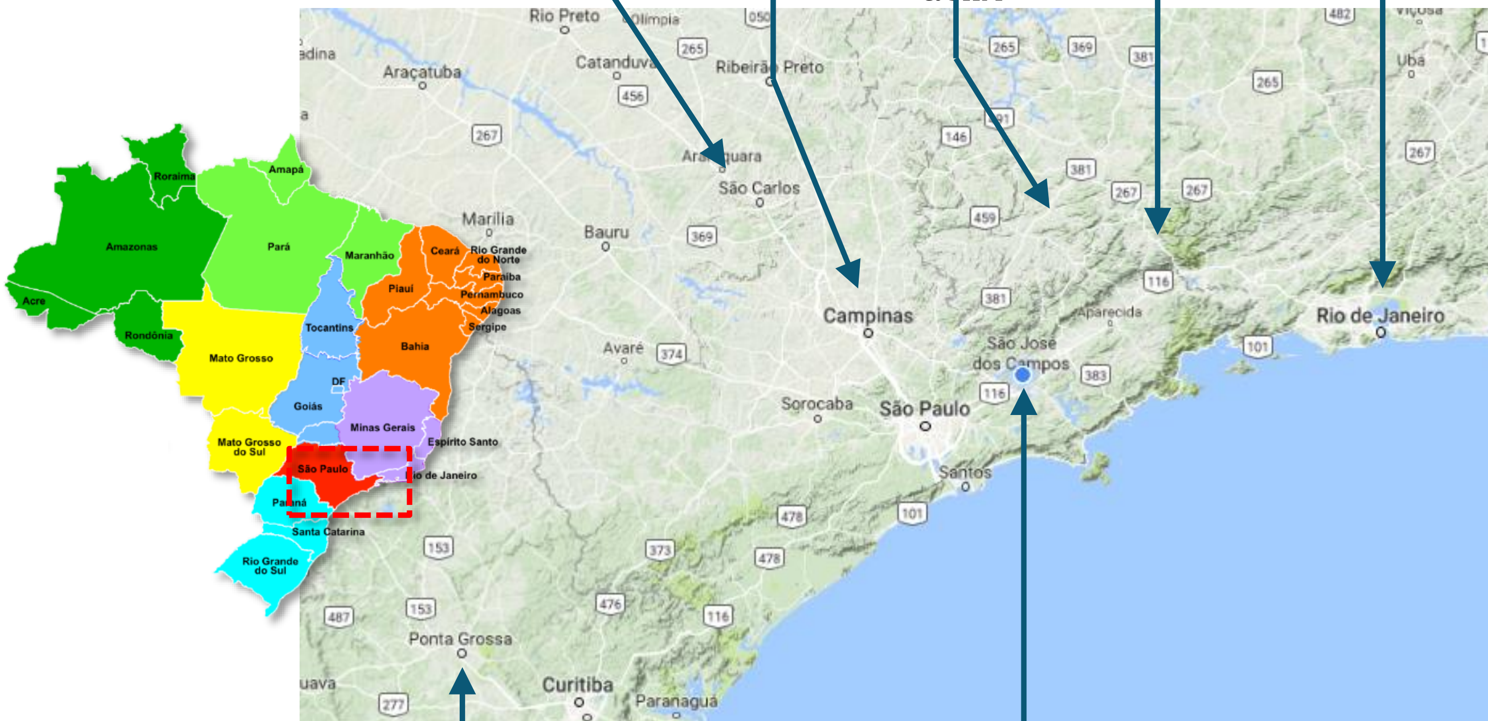
USP
Analysis and Simulation

UNICAMP
Bonding

Composites & SHM

USP
Processes

ABCM
Associação Brasileira de Engenharia e Ciências Mecânicas
Administrative Support



UEPG
Processes

CTA
Materials & Processes

EMBRAER
Structures & SHM

ITA
Composites & Structures

national Council of the Aeronautical Sciences

Challenges in Civil Aviation Development

Continued airworthiness for an increasing world fleet

Airworthiness regulations

Emerging materials & technologies

Future of ICAF and Challenges in Military Aviation

Marcel Bos

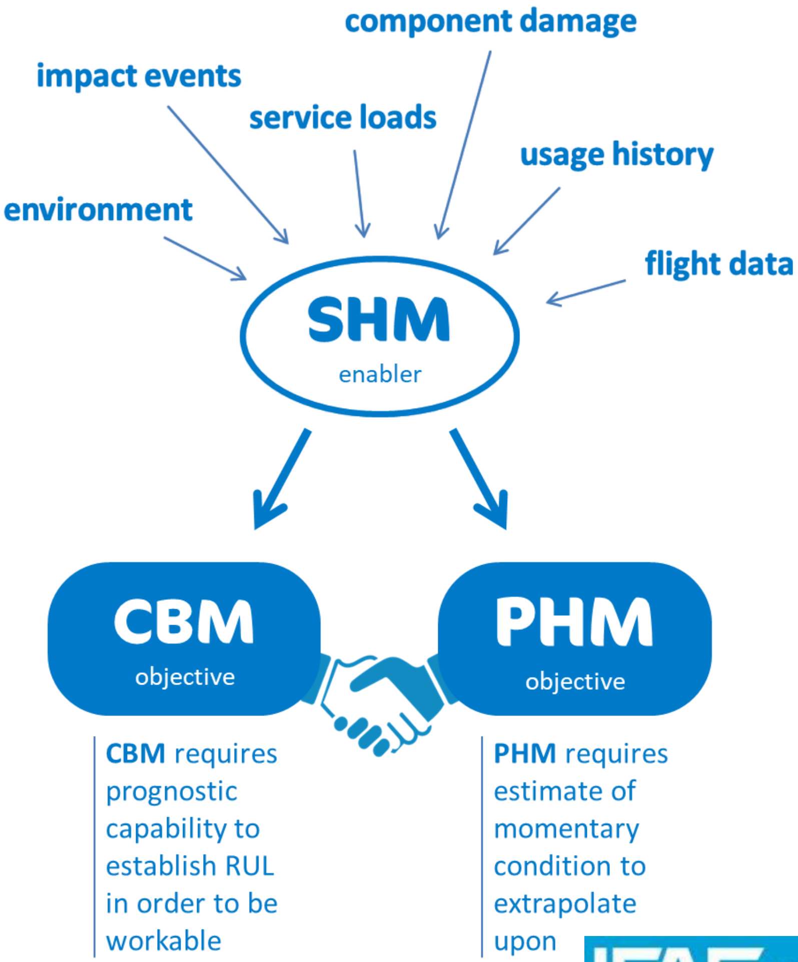
National ICAF Delegate for the Netherlands 2005-2017
ICAF General Secretary 2017-

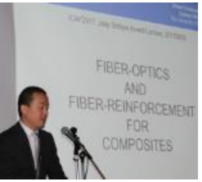
Military aviation

Challenges

Credit: SIEMENS

- New structural concepts
- Additive manufacturing
- Unmanned aircraft
- New maintenance concepts
- Non-traditional OEMs
- Complacency
- Aging fleets
- Education





The story continues...

- ICAF is unique
  - we bring together <u>all</u> ASI stakeholders
    - industry, operators, regulators, universities , research institutes
  - both military and civil
  - from all over the world


Swordfish Mk II, LS 326, operated by the Royal Navy Historic Flight

- ICAF remains relevant
  - do not take structural integrity for granted... the devil is in the detail !
  - we contribute to the education of young engineers
    - Young Researcher's Session
    - Poster Pitches
    - Jaap Schijve Award

- ICAF is here to stay
  - founded in 1951 and still going strong
  - some flying aircraft are older than we are!

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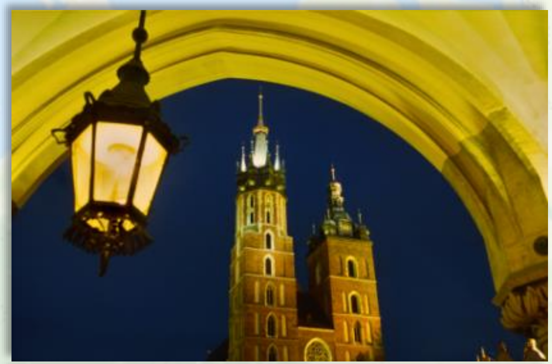
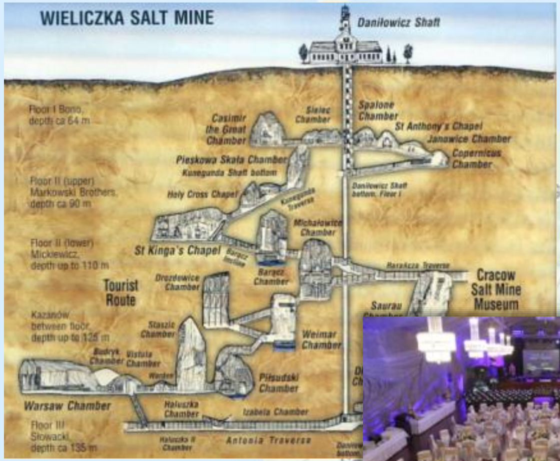
Upcoming events

UNESCO
United Nations Educational, Scientific and Cultural Organization

ICAF 2019

- Kraków, Poland, 3-7 June 2019
- Important topic: Additive Manufacturing
- Abstract submission deadline: 31 October 2018
- https://icaf2019.syskonf.pl/





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International Committee on Aeronautical Fatigue and Structural Integrity

Upcoming events

ICAF 2021

- Xi'an, China, Early June 2021

ICAS International Council of the Aeronautical Sciences

The end