International Committee on Aeronautical Fatigue and Structural Integrity (ICAF)

Past Achievements, Current Activities, and Future Challenges

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ICAF General Secretary

Outline of Presentation

- What is ICAF?
- History – Overview with Past Achievements
- Current Activities
- Future Challenges
- Next ICAF meeting

What is ICAF?

- ICAF has been the major forum for international co-operation on aeronautical fatigue issues since the early 50-ies
- ICAF has 14 member countries (Australia, Canada, Finland, France, Germany, Israel, Italy, Japan, Poland, Sweden, Switzerland, The Netherlands, UK, and the USA
- Each country has appointed a National Delegate
- Every second year a meeting consisting of a two day conference and a three day symposium is held. During the conference overviews of activities in each country are presented by the national delegates and in the symposium regular technical papers are presented

History - 1

- 1829 - Albert, Repeated Load Tests
- 1839 - Poncelet Coins the Word “Fatigue”
- 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

History -2

- 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

FOUNDATION OF ICAF

- 1949 - Dr. Frederik J. Plantema publishes “Fatigue of Structures and Structural Components” - Idea of ICAF born
- 1951 - Birth of ICAF: 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)
- 1952 - First ICAF Conference, Amsterdam. Nine people from The Netherlands, UK, Sweden, Switzerland & Belgium

GROWTH OF ICAF - 1

- 1953 - 2nd Conf., Stockholm, 24 attendants
- 1955 - 3rd, Cranfield, 40 people
- 1956 - 4th, Zurich, 33 people, France and Germany new
- 1957 - 5th, Brussels, 35 people, Italy new
- 1959 - 6th Conf., Amsterdam, 30 people
- 1959 - 1st Symp., Amsterdam, 121 people
- Biannual meetings after 1959 meeting, with 2 day Conference & 3 day Symposium

GROWTH OF ICAF - 2

- Quick increase in no. of attendants, some 200 people in Symposium, Rome, 1963
- 1963, USA presents National Review
- 1959 - 1963, Meetings held with AGARD SMP
- 1966 - Dr. Plantema died. Dr. Jaap Schijve acts as secretary ad interim until Mr Jurg Branger elected new General Secretary in 1967
- 1967 - First Plantema memorial lecture given by J. Branger on the birth and growth of ICAF

Year	Conference	Symposium	Location	Plantema Lecturer *
1951	Foundation	of ICAF	Cranfield	
1952	1		Amsterdam	
1953	2		Stockholm	
1955	3		Cranfield	
1956	4		Zurich	
1957	5		Brussels	
1959	6	1	Amsterdam	
1961	7	2	Paris	
1963	8	3	Rome	
1965	9	4	Munich	
1967	10	5	Melbourne	J. Branger
1969	11	**	Stockholm	J. Schijve
1971	12	6	Miami	E. L. Ripley
1973	13	7	London	E. Gassner
1975	14	8	Lausanne	S. Eggwertz
1977	15	9	Darmstadt	H. F. Hardrath

1979	16	10	Brussels	A. J. Troughton
1981	17	11	Noordwijkerhout	O. Buxbaum
1983	18	12	Toulouse	J. Y. Mann
1985	19	13	Pisa	L. Jarfall
1987	20	14	Ottawa	T. Swift
1989	21	15	Jerusalem	J. B. De Jonge
1991	22	16	Tokyo	R. M. Bader
1993	23	17	Stockholm	U. G. Goranson
1995	24	18	Melbourne	W. Schütz
1997	25	19	Edinburgh	J. W. Lincoln
1999	26	20	Bellevue (Seattle)	J. C. Newman, Jr.
2001	27	21	Toulouse	A. F. Blom
2003	28	22	Luzern	L. B. Vogelesang
2005	29	23	Hamburg	H.-J. Schmidt
2007	30	24	Naples	J. P. Gallagher
2009	31	25	Rotterdam	J. Rouchon
2011	32	26	Montréal	G. Clark

ICAF 2013 Jerusalem & ICAF 2015

- Plantema lecturer – Jim Rudd: Digital Twin
- Some 250 participants
- Few american participants (sequester & possible political reasons)

- ICAF 2015 – Helsinki, Finland, 1 – 5 June at Marina Congress Center
- Plantema lecture will be presented by Jerzy Komorowski, NAL, Canada
- Contact US National Delegate: Ravi Chona for questions on the event

Some Early ICAF Points of Interest

- 1953, Stockholm, Bo Lundberg quotes Dr. Rhode of NACA "..present inability to calculate the fatigue life is such that any number ..on an absolute basis is meaningless"
- Same meeting, Prof. W. Weibull on "Rare Events" - "The no. of men killed by kick of a horse in the Prussian army"
- Dr. Gassner's early work (1956) on programme tests for cumulative damage
- J.Y. Mann, Historical overview on Fatigue Research, already in 1958 some 5000 papers published
- 1954 - January 10 , Comet 1 failure, Yoke Peter

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

Wreckage recovered of crashed Comet (Yoke Peter)

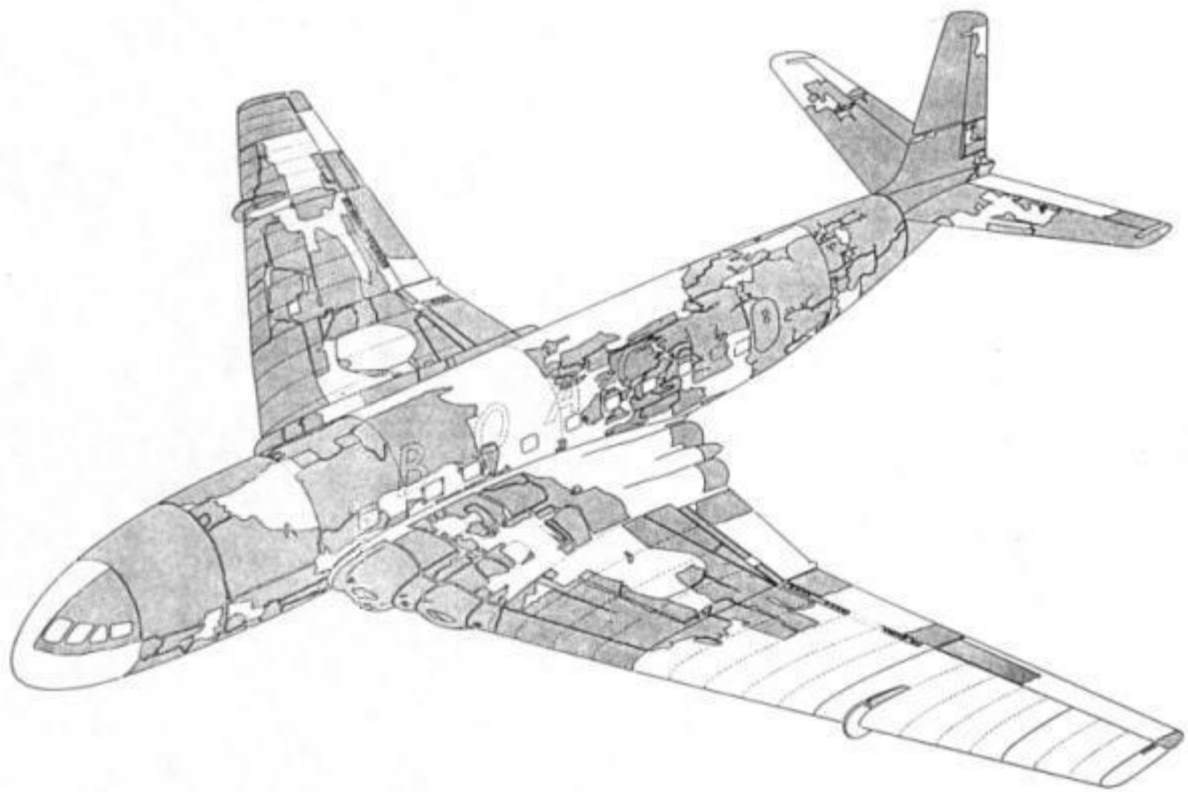
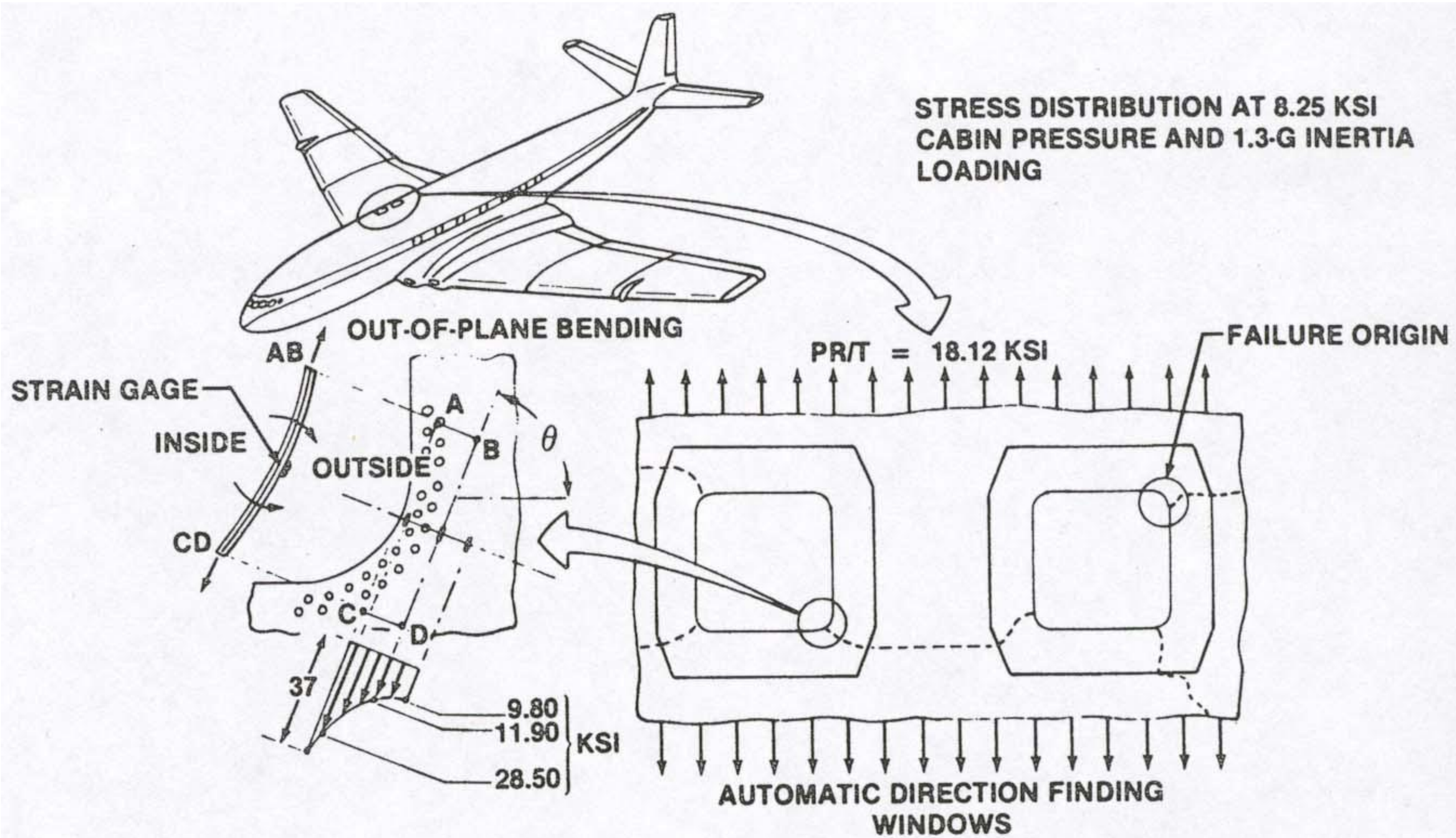


FIG. 2. DIAGRAM SHOWING AMOUNT OF WRECKAGE RECOVERED—G-ALYP.

Probable failure origin in Comet (Yoke Peter)



SOME IMPORTANT CONTRIBUTIONS

- Late 50-ies: H.C. Johnson, Closed Loop Servohydraulic Test System
- 1961: P.C. Paris, Fracture Mechanics Approach to FCG, Rejected in 3 leading journals
- Late 60-ies: W. Elber, Fatigue Crack Closure
- 1967: T. Endo, Rainflow Cycle Counting Method
- Early 70-ies: Finite Element Method introduced in teaching at technical universities
- 1974: USAF Damage Tolerance following failure of F-111 in 1969 & fatigue problems of C5-A Cargo aircraft

General Dynamics F-111A Aardvark

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

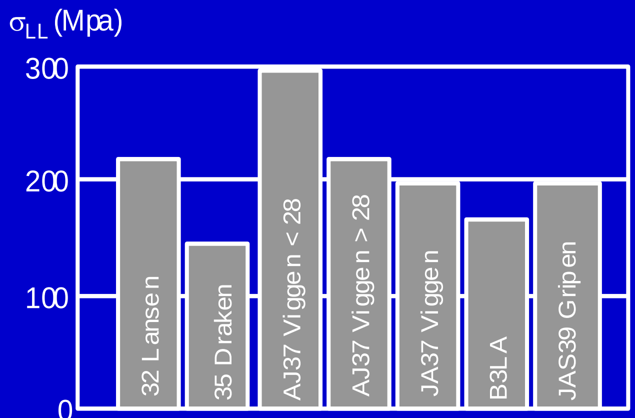
Dec. 22 1969

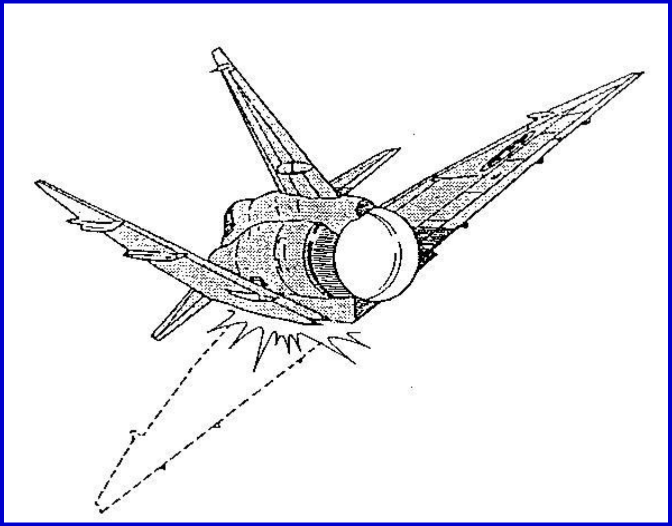
USAF F111 #94 - New Mexico

105 hours & 107 flights

July 1974 - Oct. 1975

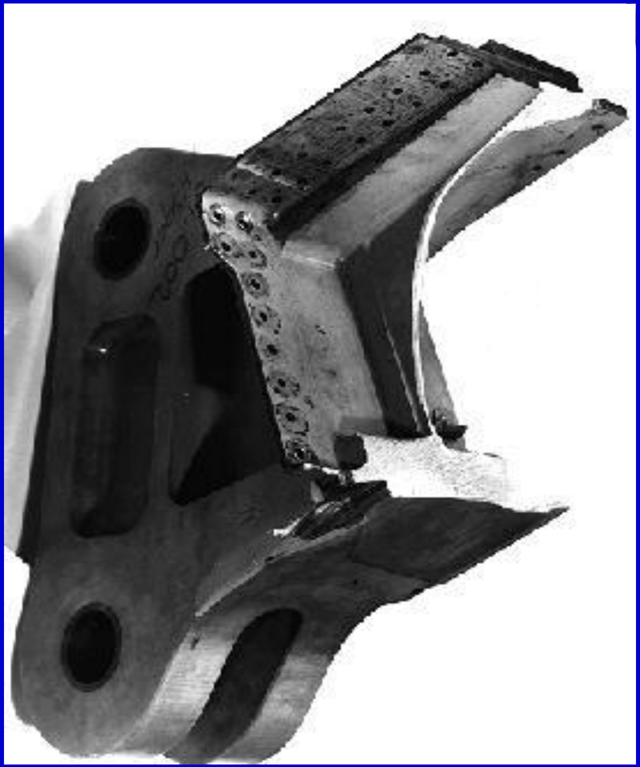
Saab AJ37 Viggen - Main Wing Spar Failure

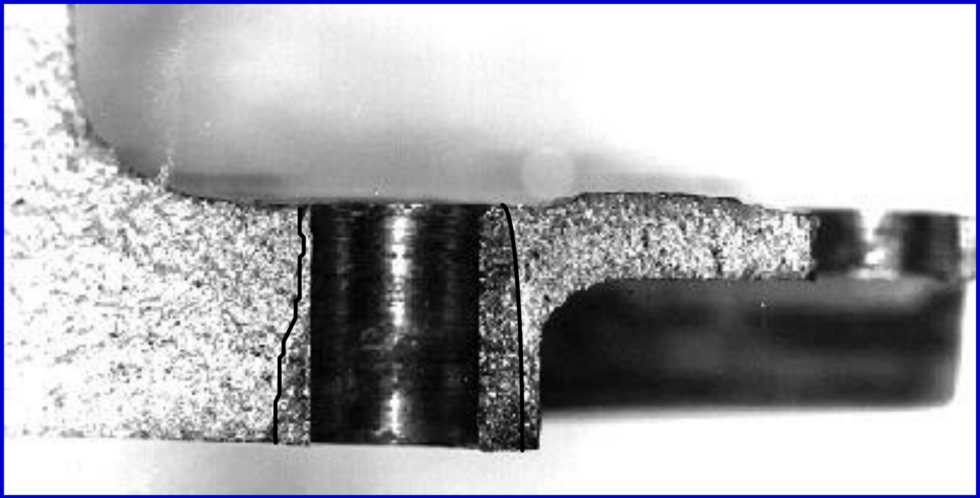




- 37.011 152 hours
- 37.005 286 hours
- 37.014 275 hours

Design Service
Life: 2,000 h

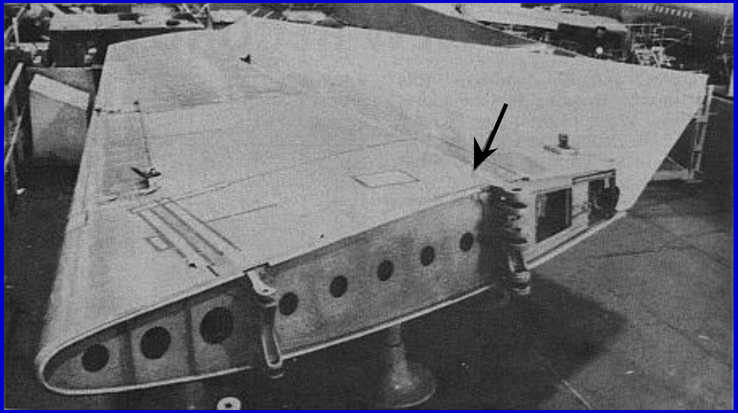




May 14 1977

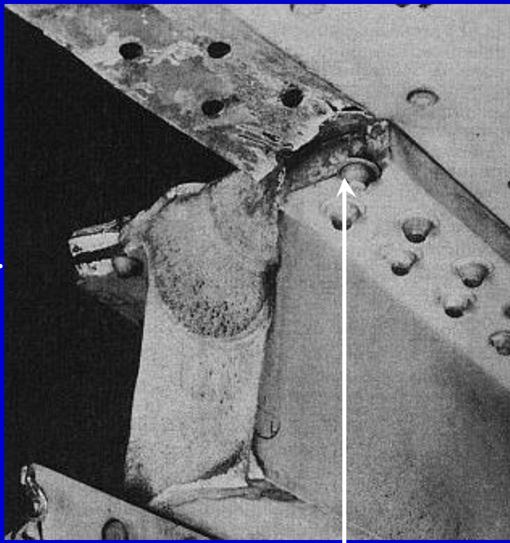
Dan Air G-BEBP - Lusaka Airport

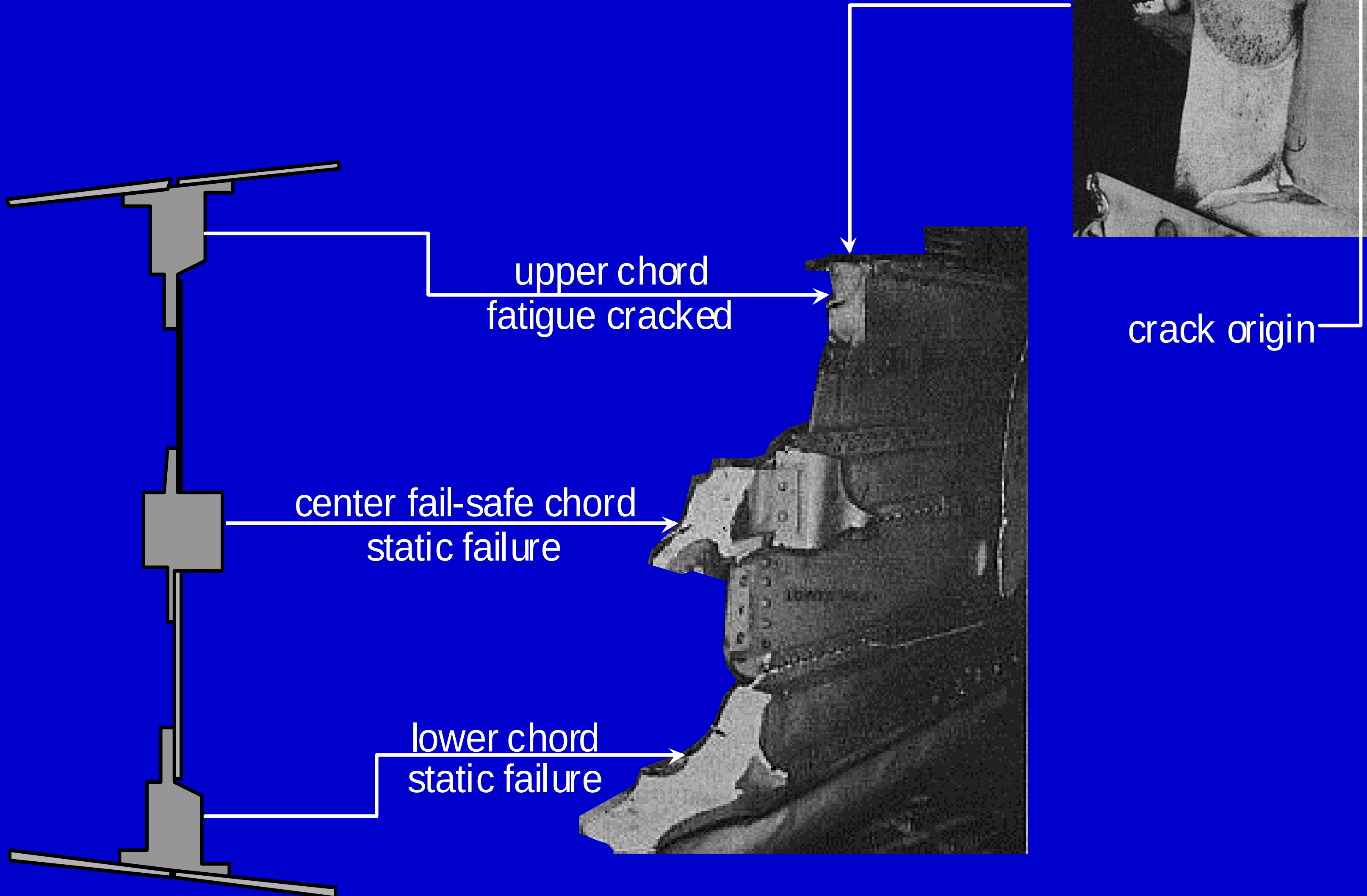
47,621 hours & 16,723 flights



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

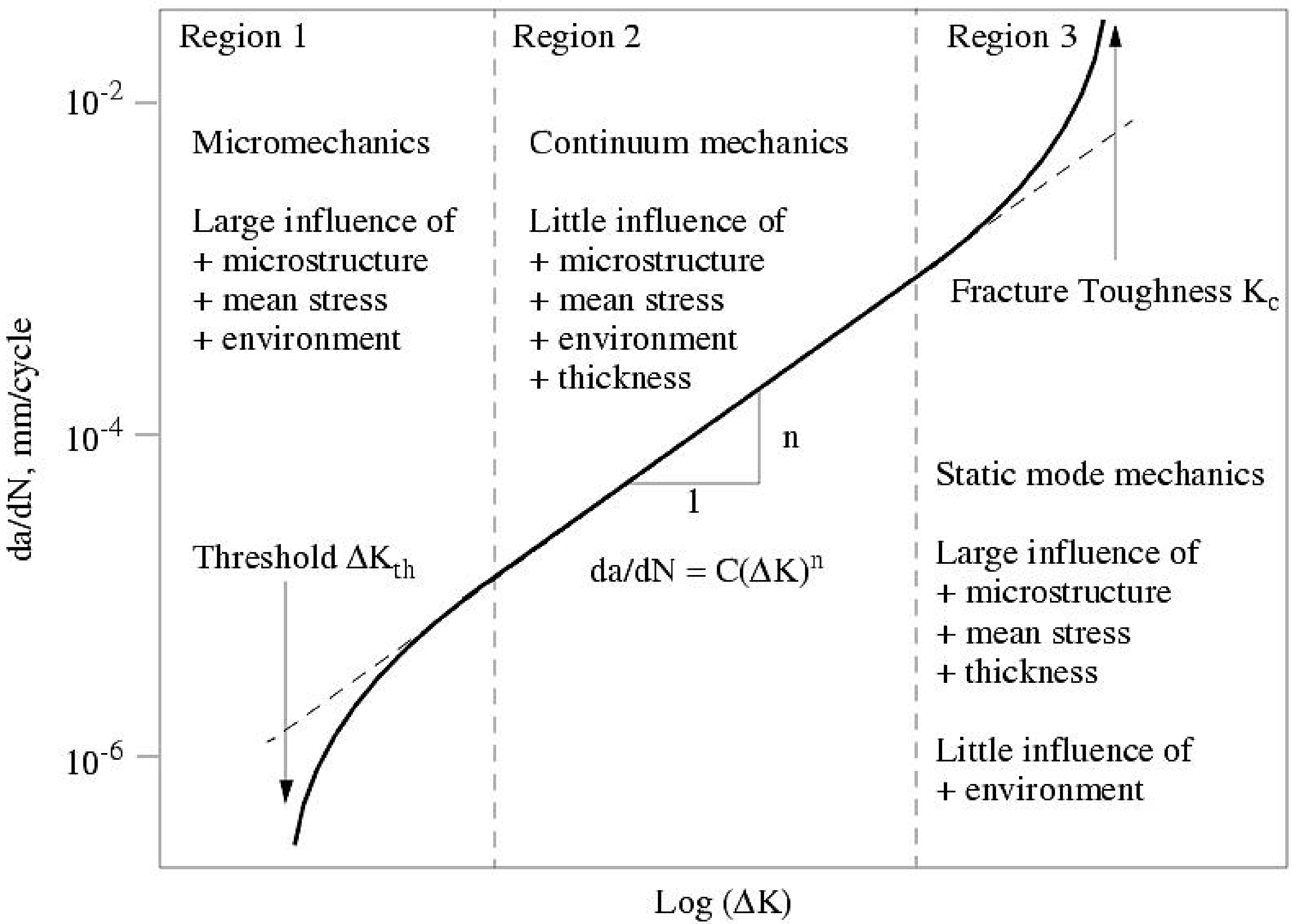
Failed Tailplane Spar





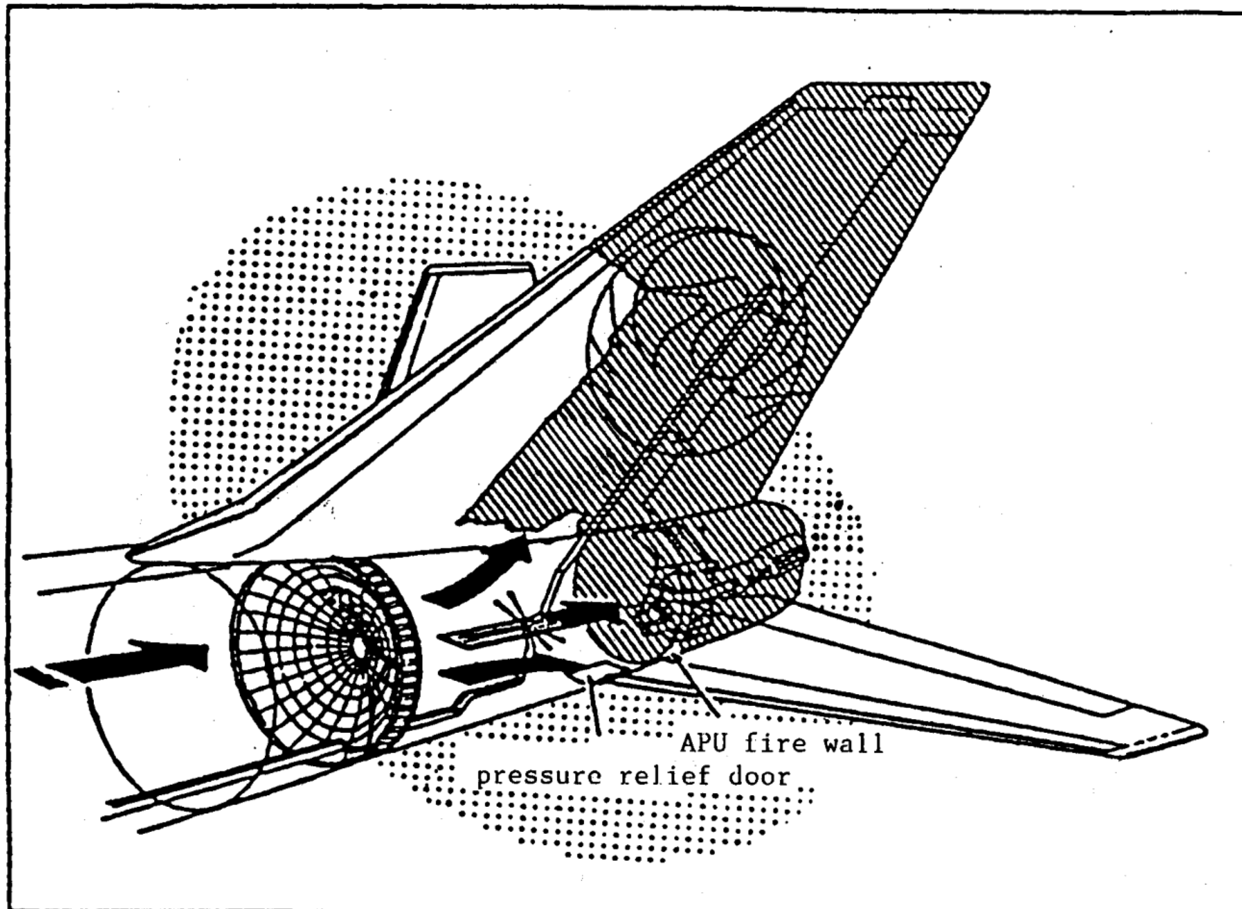
ICAF in the 80-ies

- 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

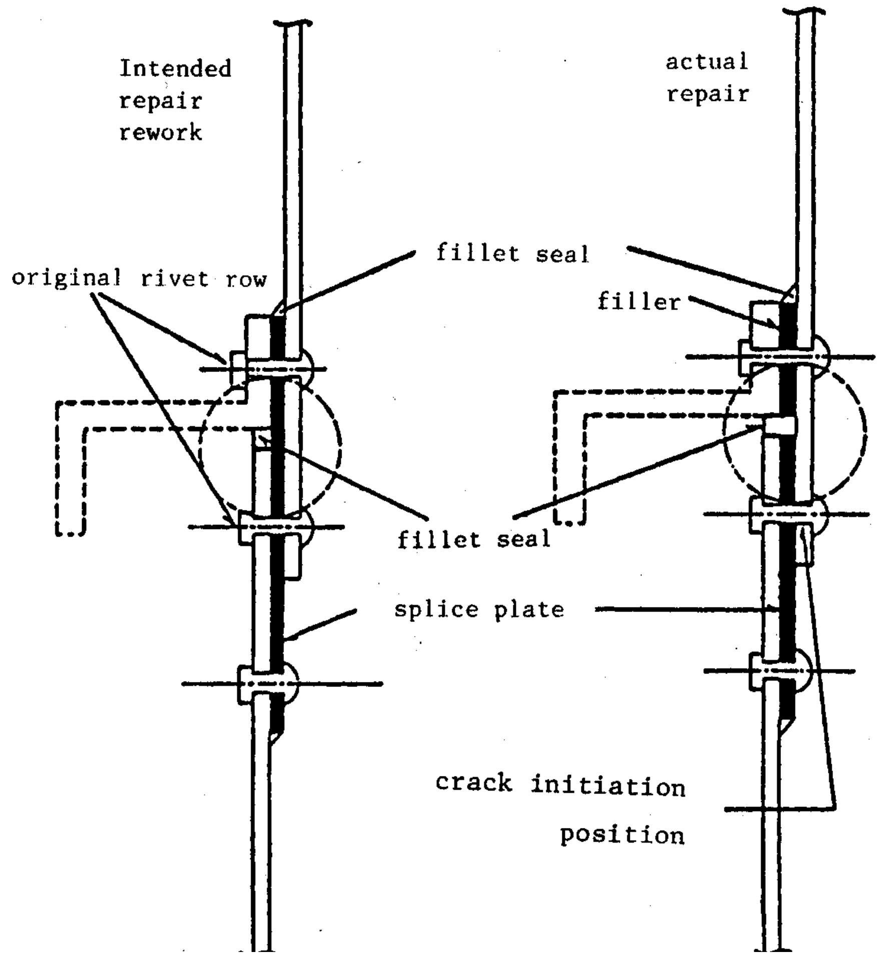


Region 1
Region 2
Region 3
10-2
10-4
10-6
Micromechanics
Large influence of
+ microstructure
+ mean stress
+ environment
Threshold ΔKth
Continuum mechanics
Little influence of
+ microstructure
+ mean stress
+ environment
+ thickness
n
1
da/dN = C(ΔK)n
Fracture Toughness Kc
Static mode mechanics
Large influence of
+ microstructure
+ mean stress
+ thickness
Little influence of
+ environment
da/dN, mm/cycle
Log (ΔK)

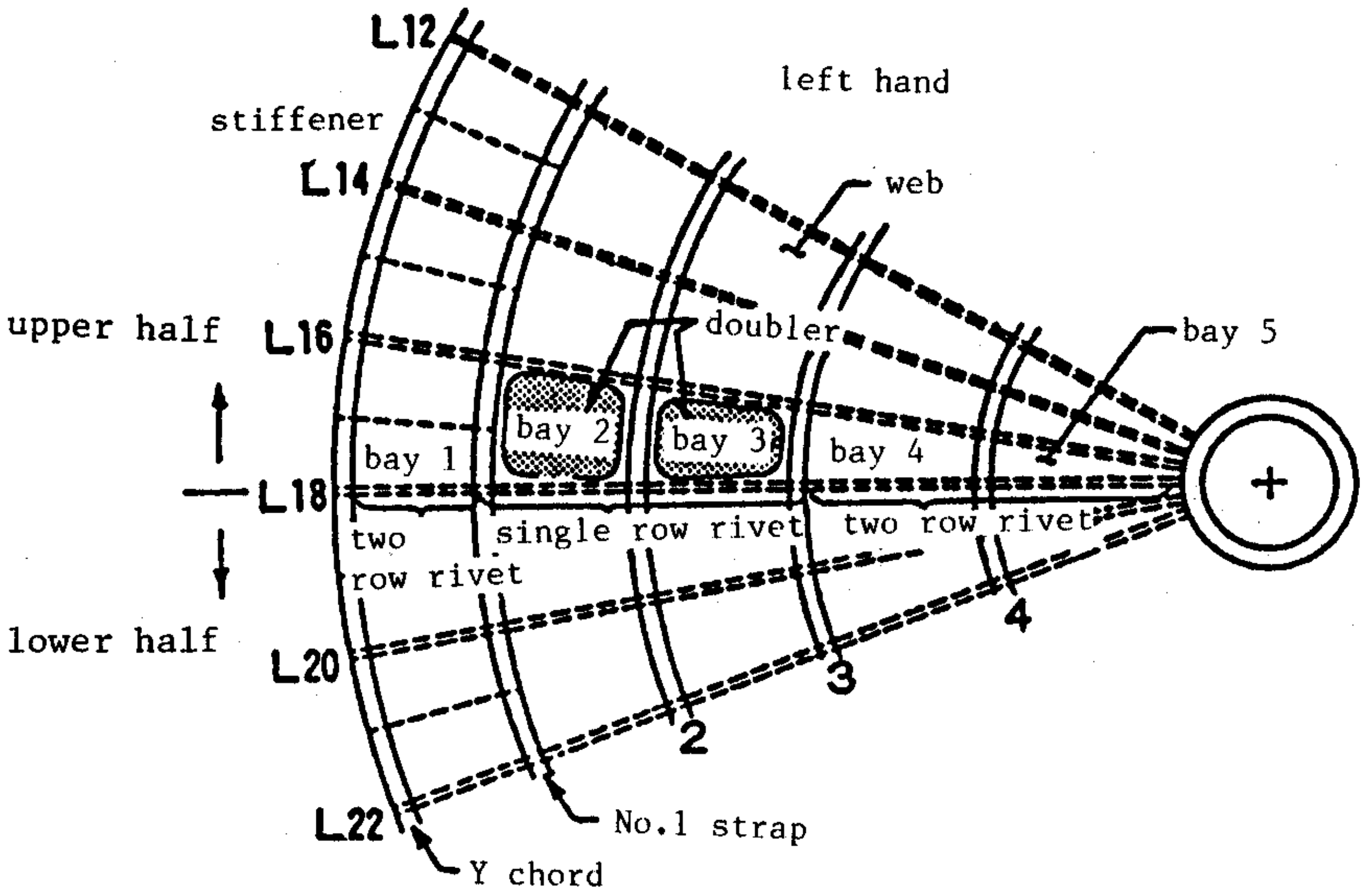
Estimated fracture of rear section of JA 8119 Boeing 747 SR-100 crashed in Japan August 12, 1985



L18 splice section. Intended repair and actual incorrect repair

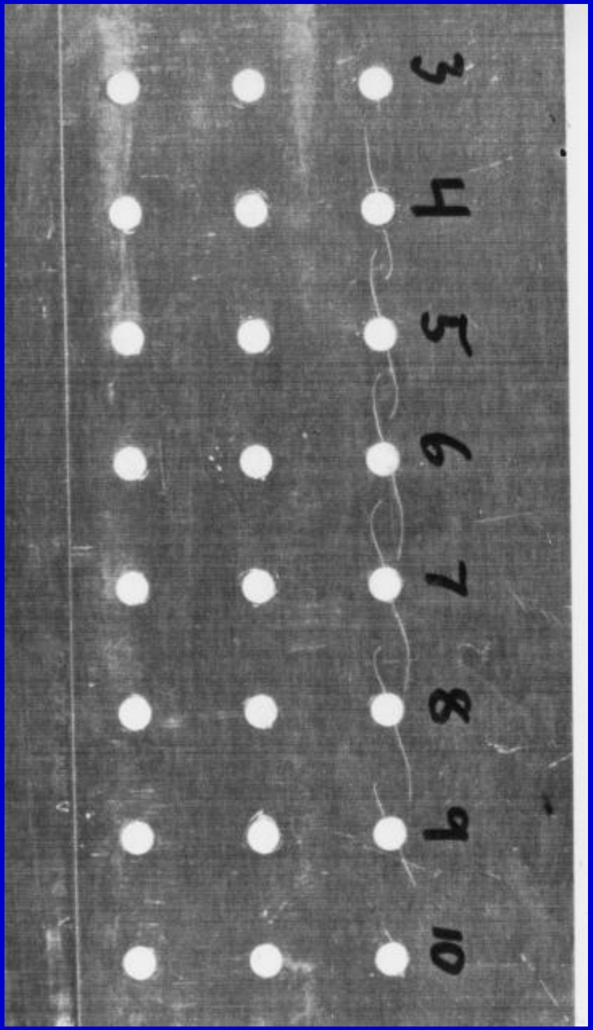


Aft pressure bulkhead of JA 8119 Boeing 747 SR-100 crashed in Japan, 1985



Aloha Airlines - Flight 243

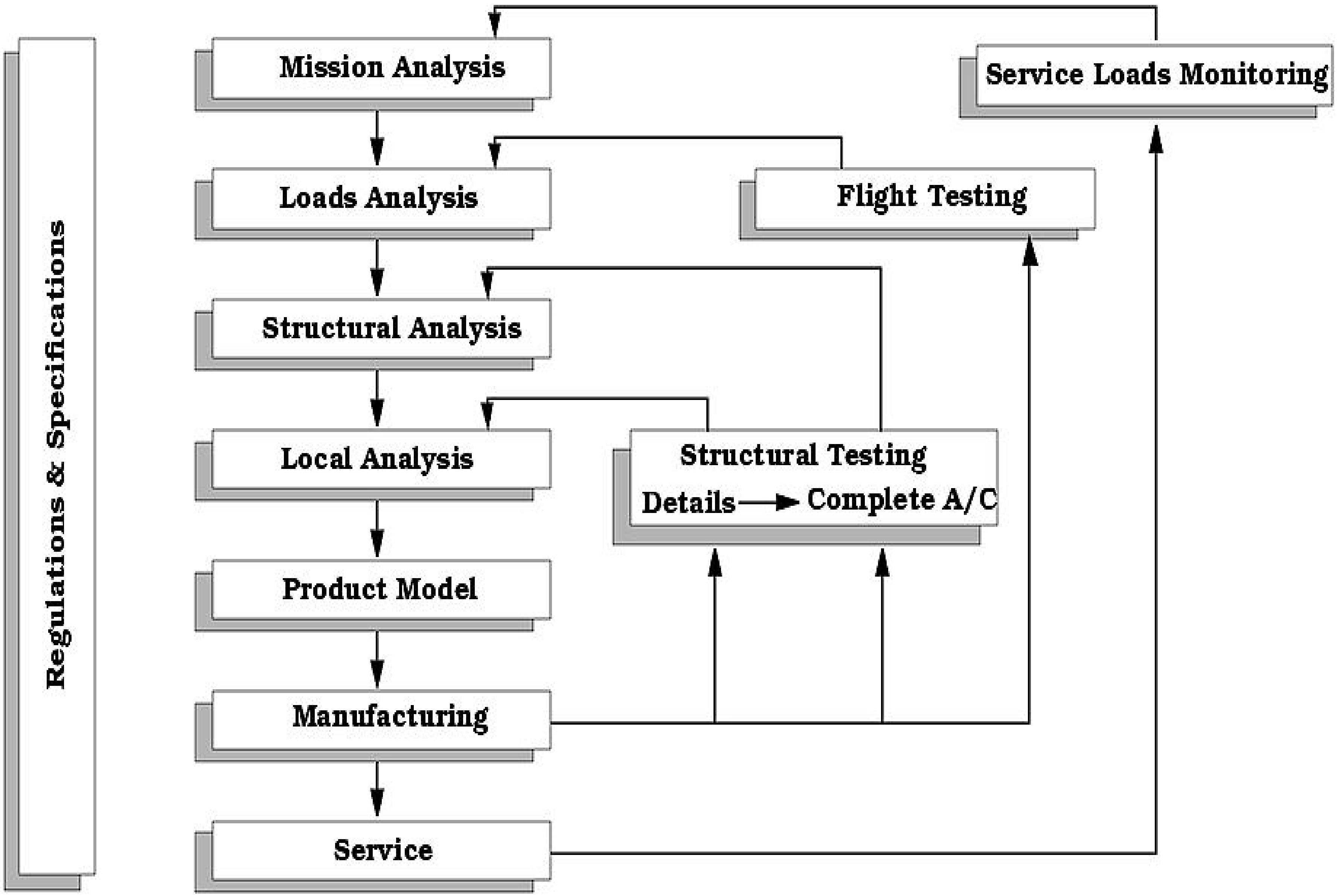
35,493 hours & 89,090 flights



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

ICAF in the 90-ies

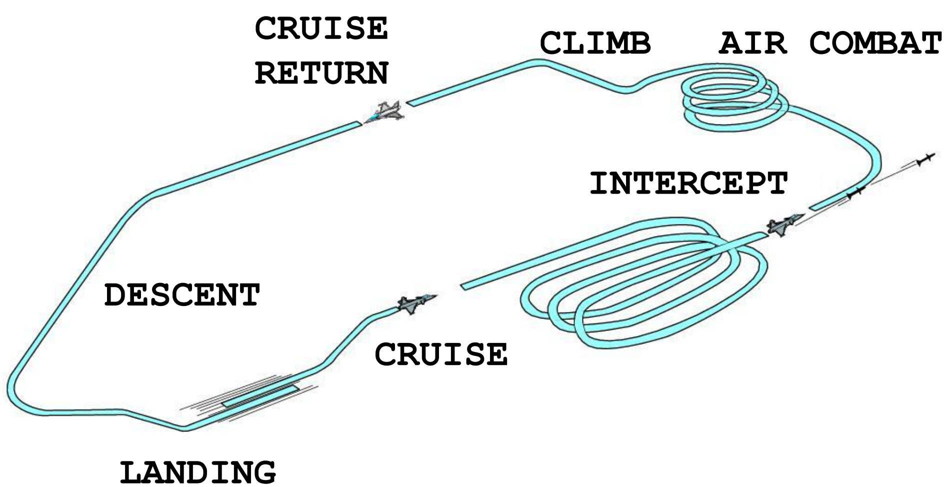
- Still decent funding, but less than during 80-ies
- Damage tolerance of structures become required for all civil aircraft. Military aircraft only damage tolerant design in the USA and Sweden
- Aging aircraft issues become largest research topic ever
- Composites gradually introduced even more, focus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


Regulations & Specifications
Mission Analysis
Service Loads Monitoring
Loads Analysis
Flight Testing
Structural Analysis
Local Analysis
Structural Testing
Details → Complete A/C
Product Model
Manufacturing
Service

Mission Analysis

- Previous Experience
- Expected Threat
- Future Tactics

Example: Combat Air Patrol



Mission Types
- basic training
- air-to-air
- air-to-surface
- reconnaissance

Mission Segments
- safety and function tests
- ground manoeuvring
- combat manoeuvring
- store separation
- gun firing
- landing

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

Loads Analysis

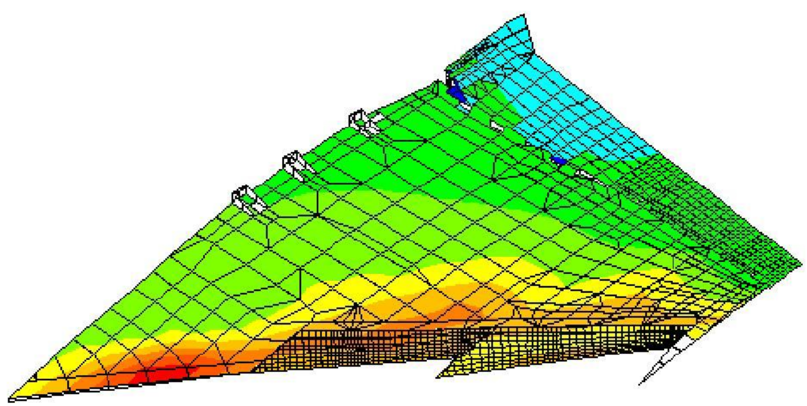
Analysis

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

Testing

- Wind tunnel
- Loads survey test flights

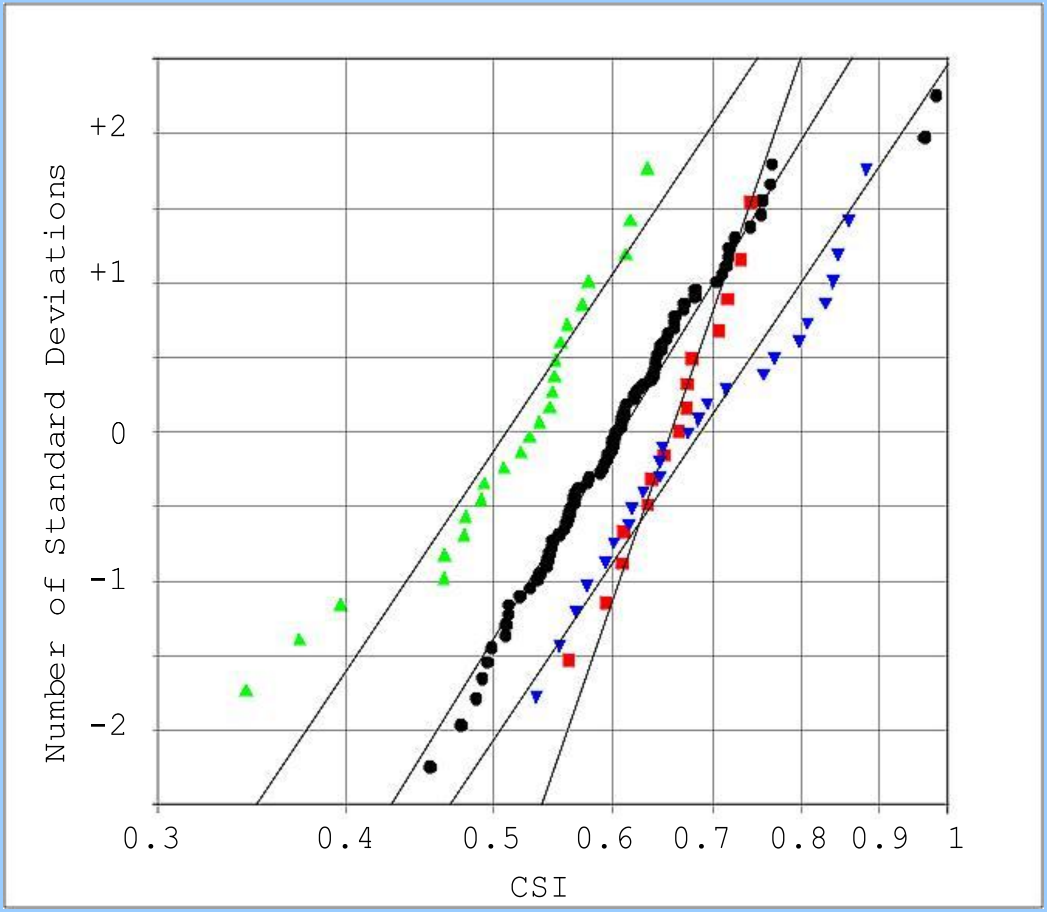
Example: Pressure distribution on the main wing during a pull-up manoeuvre

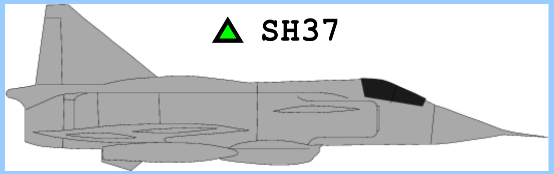


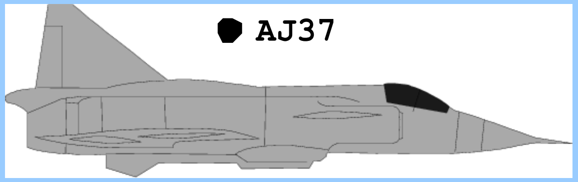
- Aerodynamic loads
- Inertia loads
- Dynamic loads
- Store separation loads
- Ground loads
- Gun loads
- Gust loads
- Flight control system loads
- Temperature loads
- Internal pressure loads
- e.t.c

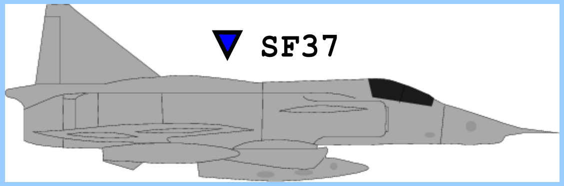
Variability in Load Factor n_z

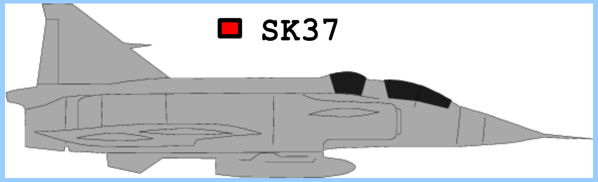
The group of 145 Viggen aircraft split into 4 variants.
SH37-Sea recce SF37-Photo recce AJ37-Strike SK37-Trainer











Possible Causes of Variability in Service Loading

Multi-role

Swing-role

Flight control system revisions

Care-free handling

Changed tactics

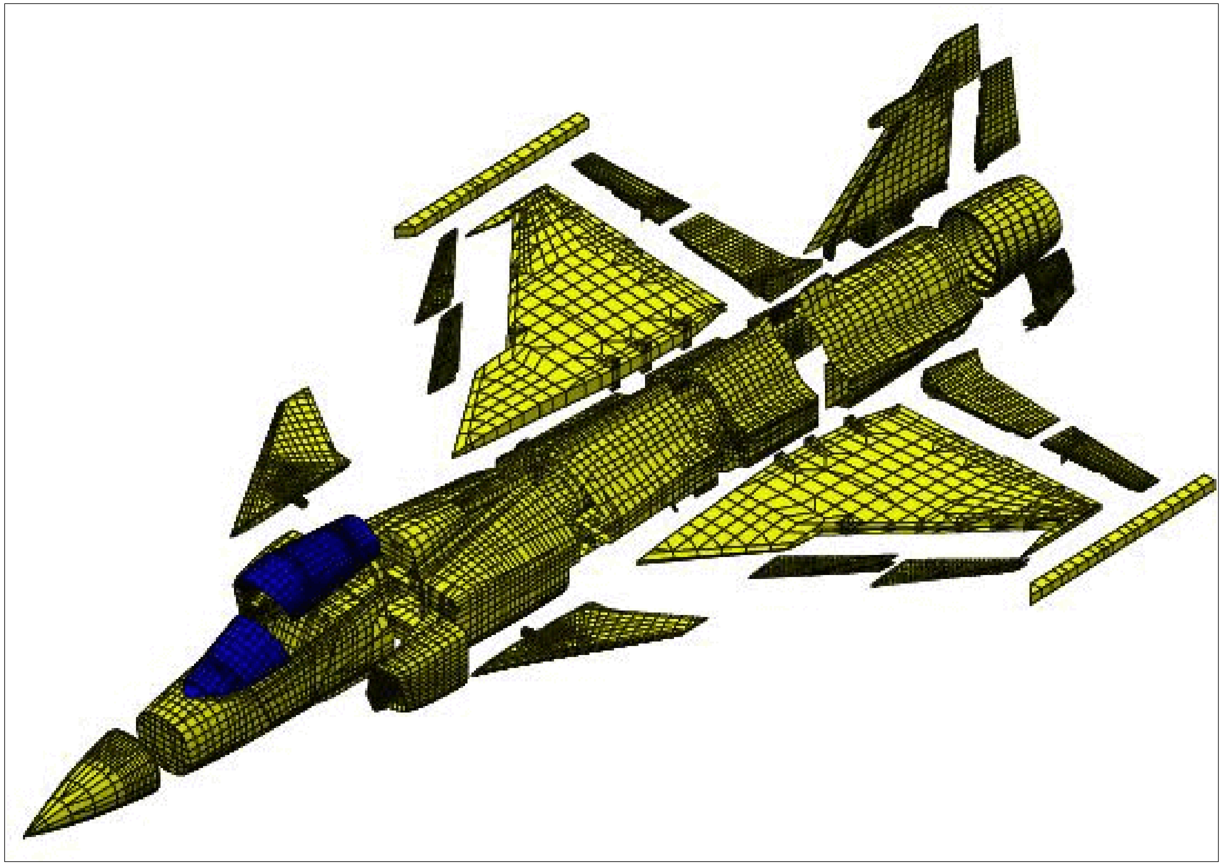
New operational needs

New armaments

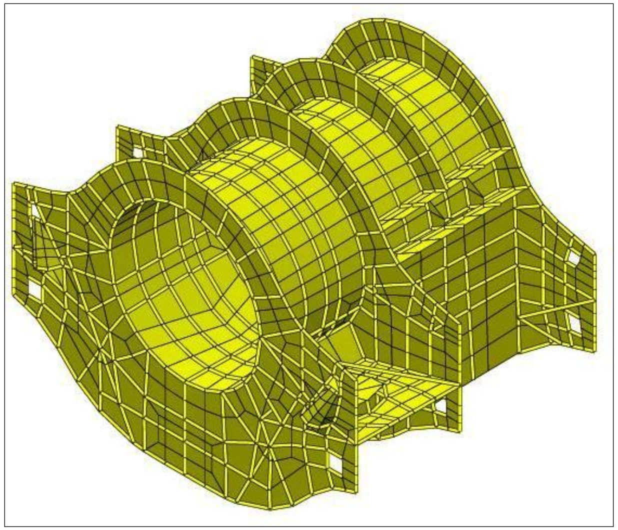
Structural Analysis

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

Load Cases
- 750 unit load cases solved
- 13,000 unique balanced load cases in the mission profile

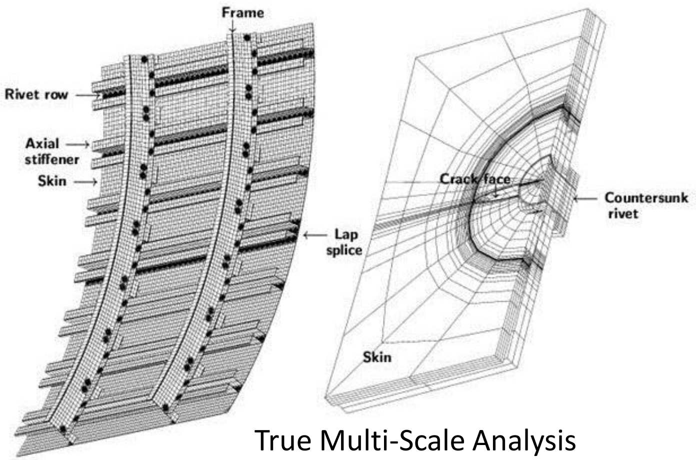


Example: Sub-structure of wing attachment unit

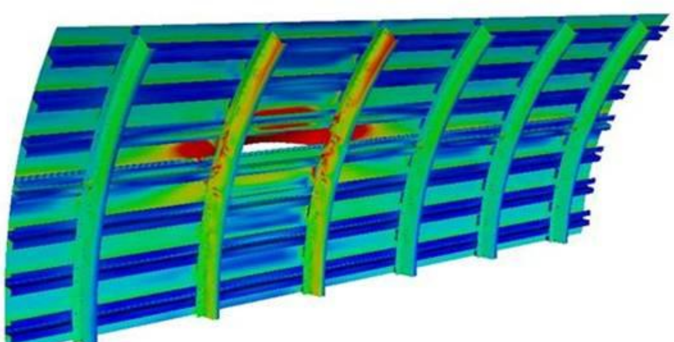


Large Scale Analysis

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

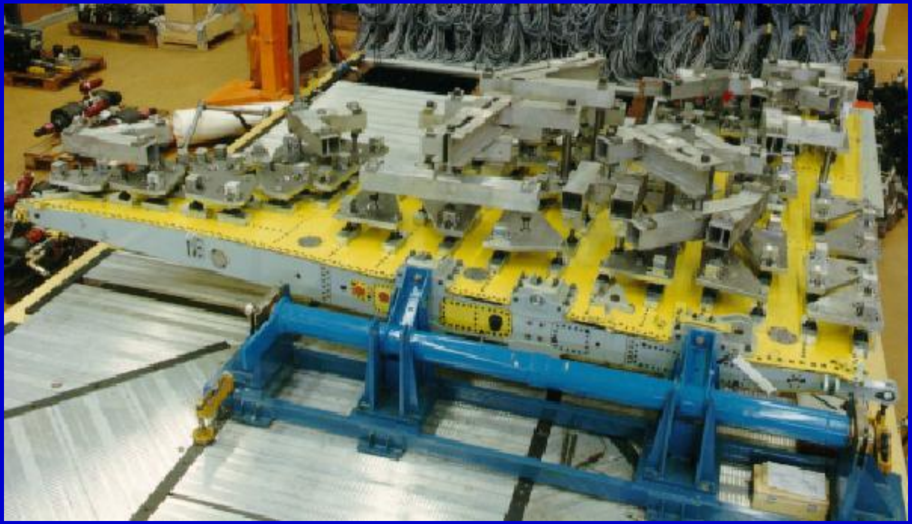
Unique experience HPCN

Development /analysis on largest computer systems available.

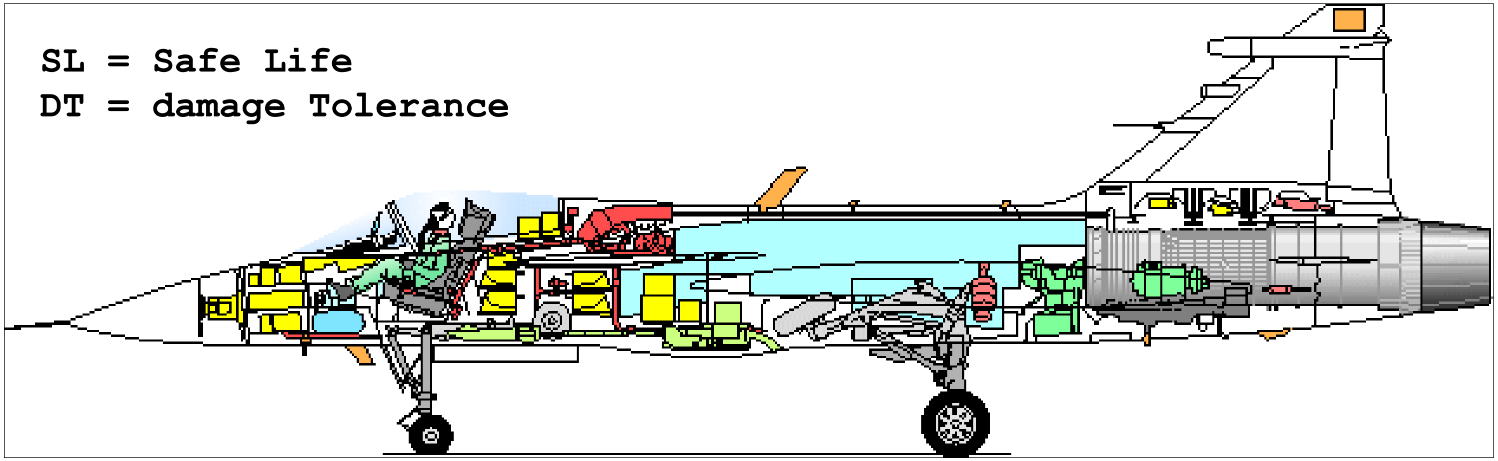
Ex. MSRC-systems available to project

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

Test No 5.5.2
Complete Airframe



Full-Scale Test Programme - Mechanical Systems



Flight control system
- servo actuators (SL+DT)
- pedal housing (SL+DT)
- control stick assembly (SL+DT)
- leading edge flap control system

Landing gear system
- nose and main landing gear (SL)
- actuators (SL)
- wheels and brakes (SL)

Escape and oxygen system
- pressure vessel (SL)

Hydraulic system
- tubes and fittings (SL)
- pumps (SL)
- valve units (SL)
- accumulators (SL)

Secondary power systems
- auxiliary power unit (SL)
- air turbine starter (SL)
- aircraft gear box (SL)
- power transmission shaft (SL)

Fuel system

Environmental system
- reduce and shut off valve (SL)
- heat exchangers (SL)
- engine bleed systems (SL)

Gun and armament install.
- Gun deflector (SL+DT)
- Gun fwd attachment (SL+DT)
- weapon pylons (SL)

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

New Developments and Potential Problems: 1

- Production costs
- Manufacturing techniques (laser welding, friction stir welding, casting, High Speed Machining)
- Passenger comfort (cabin noise)
- Environmental issues (engine &noise emissions)
- Fewer but larger aircraft companies
- How to maintain development with less military efforts at reasonable costs?

New Developments and Potential Problems: 2

- High speed machining - Worse fatigue properties, Residual stress fields and their relaxation, Integral (Monolithic) structures with hazardous damage tolerance properties
- Resin transfer moulding - Composites in general (and sandwich structures) likely to allow higher applied strains to compete with metals - Fatigue may result
- Personal opinion is that composite design is empirical and not science based. Future developments can either solve that problem (too expensive) or incorporate 3D reinforcements for locations with out of plane loading
- Hybrid Composites (Metal / Composites) create certification problems
- New large transport aircraft suffer weight problems, High strength materials, Higher stresses
- To prevent ageing aircraft problems, lower stresses are needed
- Aging aircraft problem well understood but not solved. Corrosion models are typically of micro-mechanics type, i.e. dependent on planar geometry

New Developments and Potential Problems: 3

- Decline in military spending, no longer technology leader
- Less interest in higher education
- Young generation less educated than parents for first time since beginning of last century
- Industry must fight to stimulate very young persons, increase salaries, compete with sexy new technical fields
- The best engineers/scientists/workers need to be motivated to apply for the aeronautical sector
- Future competence problem may become a major problem
- These are all valid points for Europe and USA. However, the aeronautics industry is changing fast.

ICAF in the future

- Expand organization with new countries:
- China (38000 scientists) almost in, Russia (5500 scientists) and Brazil in pipeline
- Initial contacts with India
- Maintain international cooperation in exchanging ideas, data, and solutions to all structural integrity related issues

WELCOME TO ICAF 2015

HELSINKI, FINLAND