USAF Aircraft Structural Integrity Program (ASIP)

San Antonio, Texas

28 – 30 November 2006

Damage Tolerance

Facts and Fiction

Dr. Ulf G. Goranson (Retired)

Boeing Commercial Airplane Company

Damage Tolerance – Facts and Fiction

- Overview
- Elements of Damage Tolerance
- Structural Maintenance Considerations
- Continuing Airworthiness Challenges
- Summary

Royal Institute of Technology - Stockholm

Department of Aeronautics 1958 - 1965

- Aeronautical Research Laboratory 1962 -1967

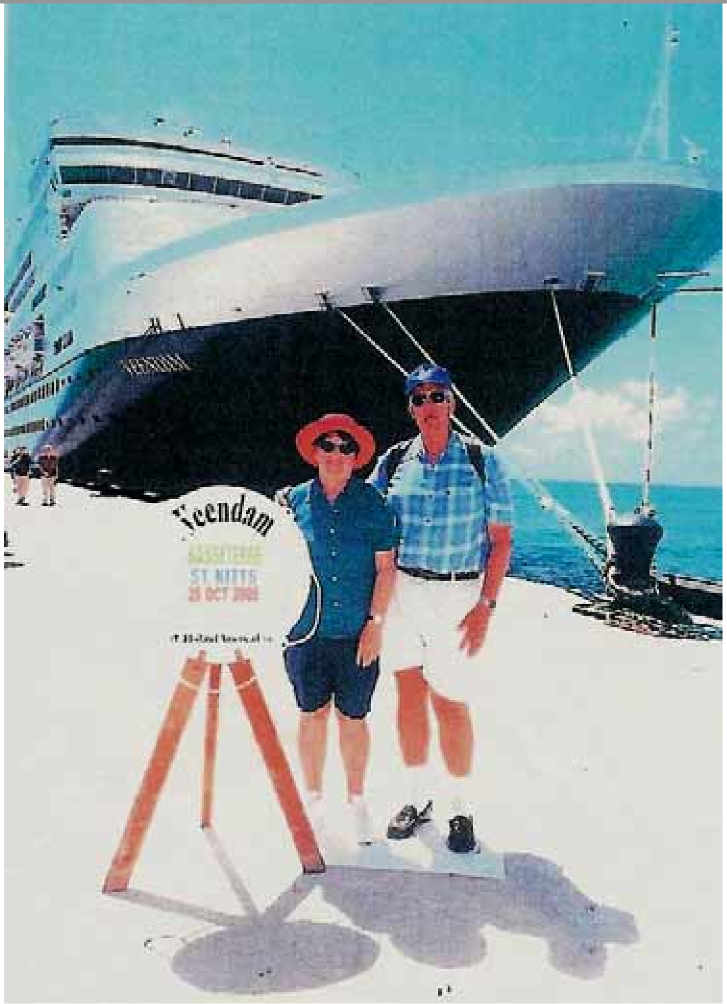
SAAB 37-Viggen - First Flight 1965

Boeing Commercial Airplane Company 1967 - 2001

Boeing B-2707 Supersonic Transport

Boeing Family of Commercial Aircraft

Inger and Ulf
50 year Celebration Cruise



Damage Tolerance – Facts and Fiction

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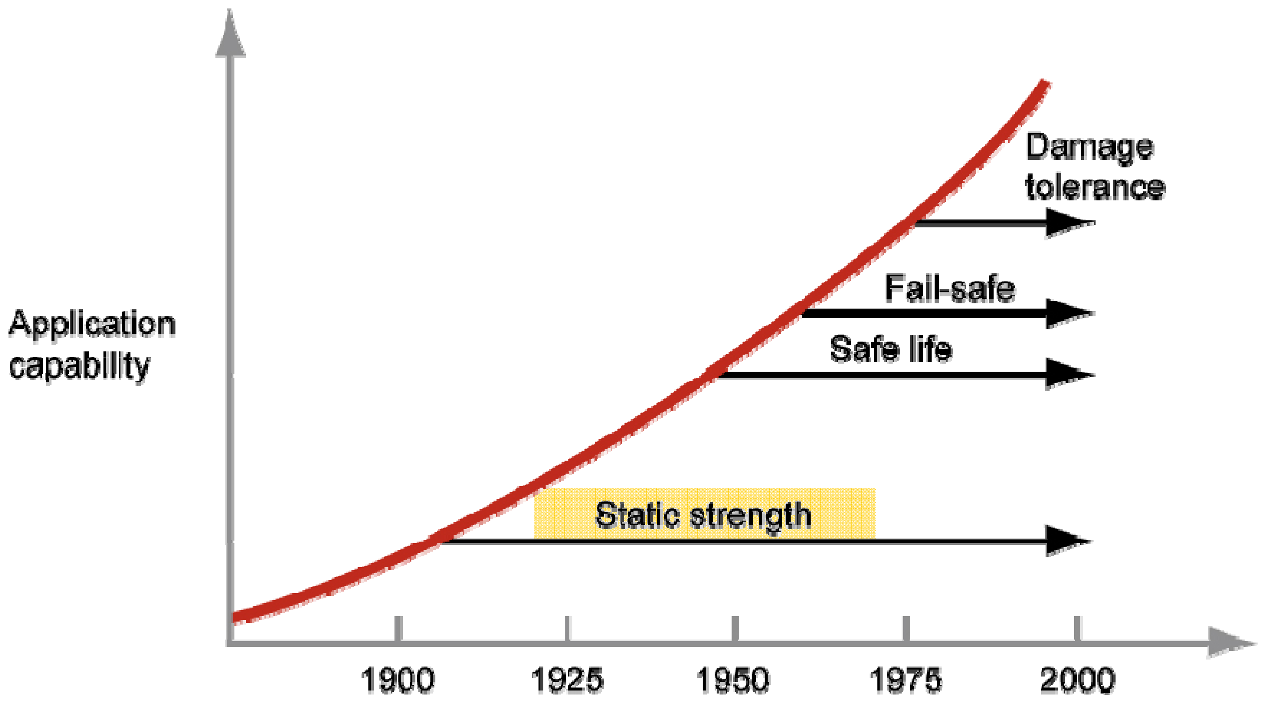
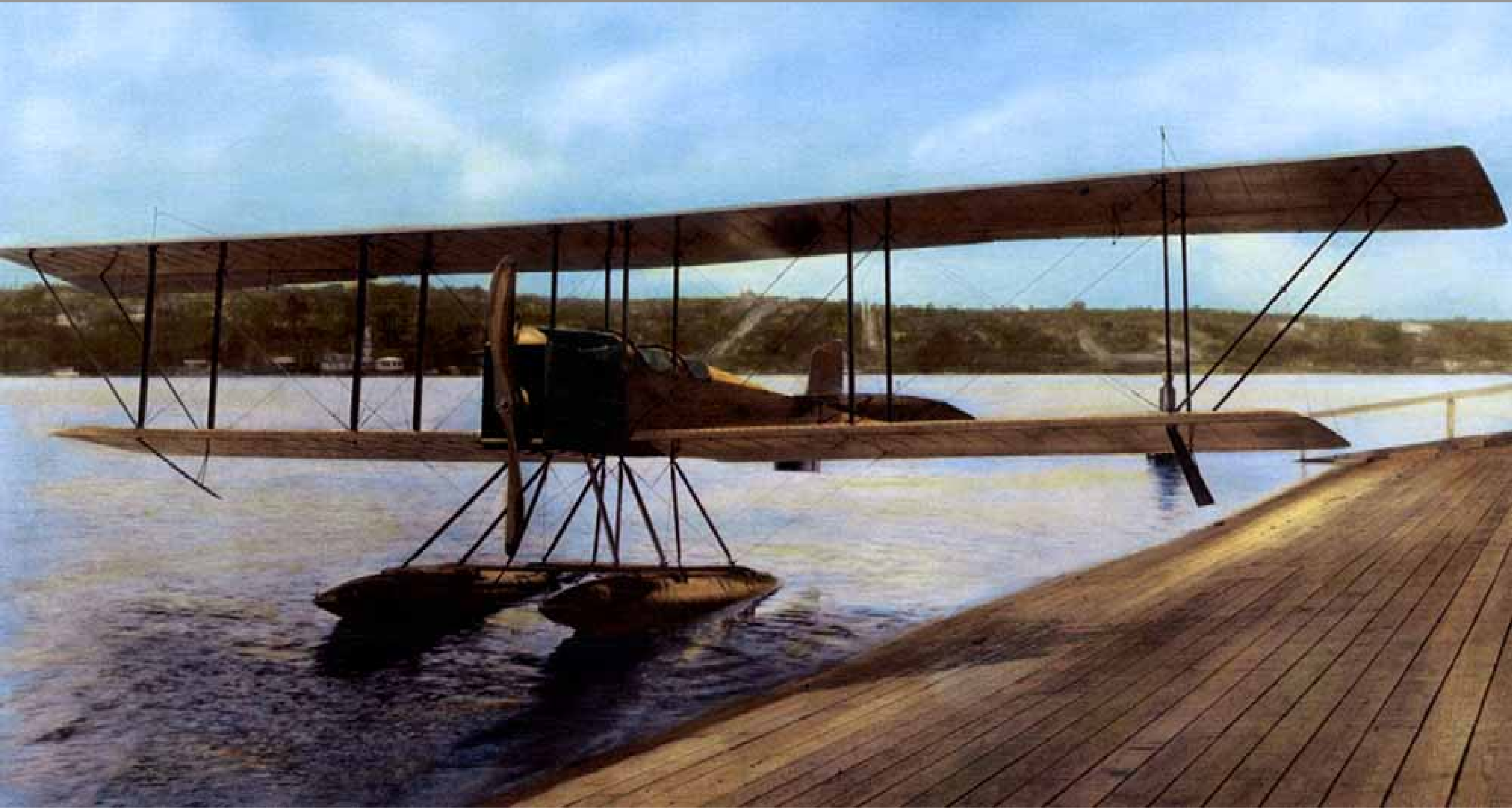
Design Principles



Boeing BW-12



Boeing BW-12 Replica
Boeing 50^{th} Anniversary 1966

Boeing Model 40

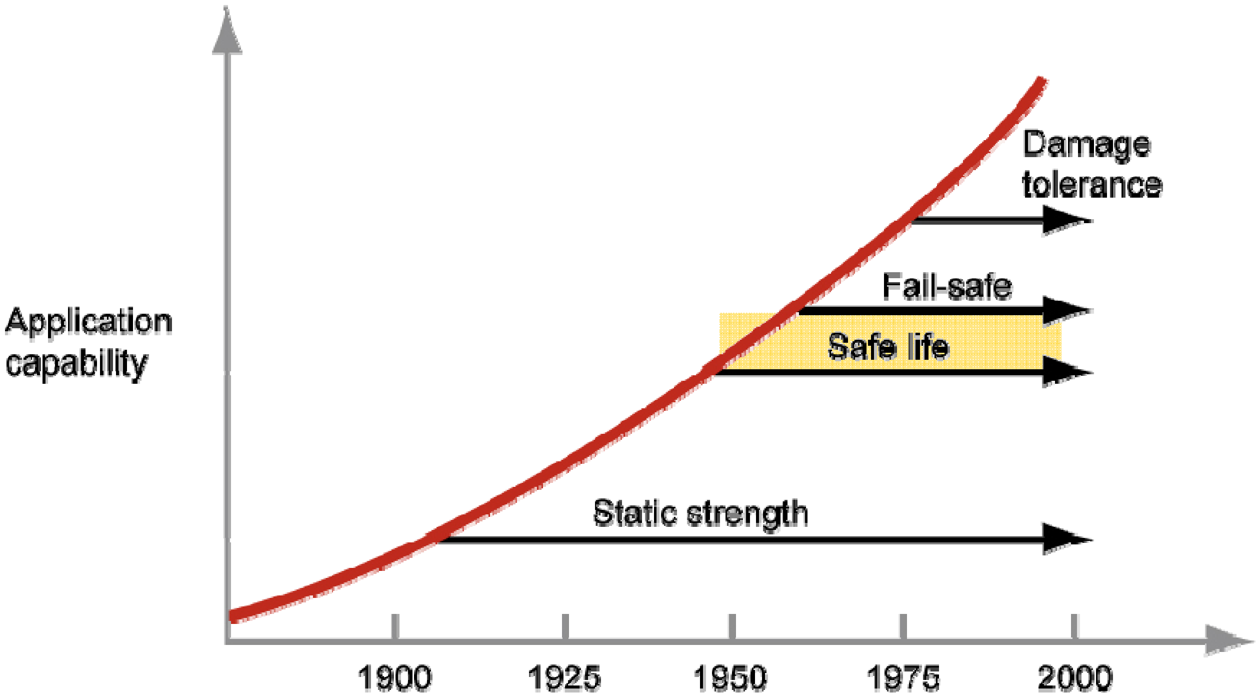
"…let no new improvement in flying and flying equipment pass us by"
W.E. Boeing - 1929

1923 Steel Fuselage Static Test

777 Static Test

- Wing Tip Deflection:
  - 18 feet & 2.50g
  - 24 feet & 3.75g

Design Principles

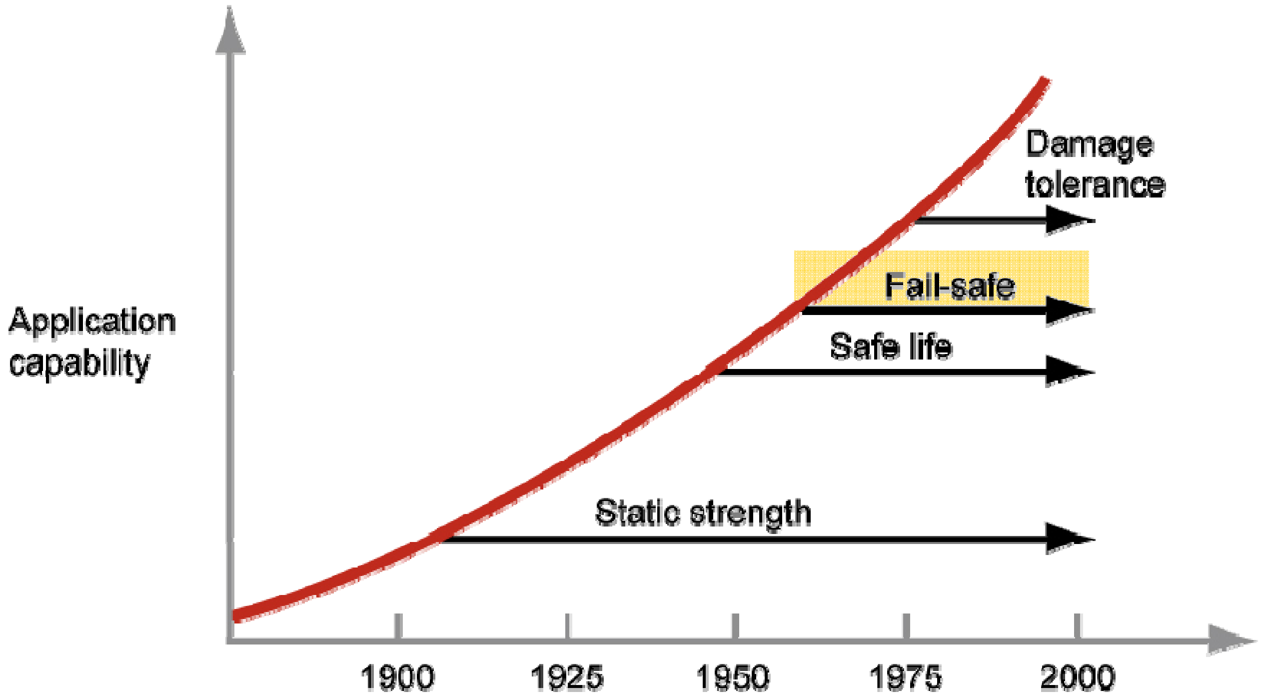


Boeing Clipper 314

Boeing 377 - Stratocruiser

De Havilland Comet

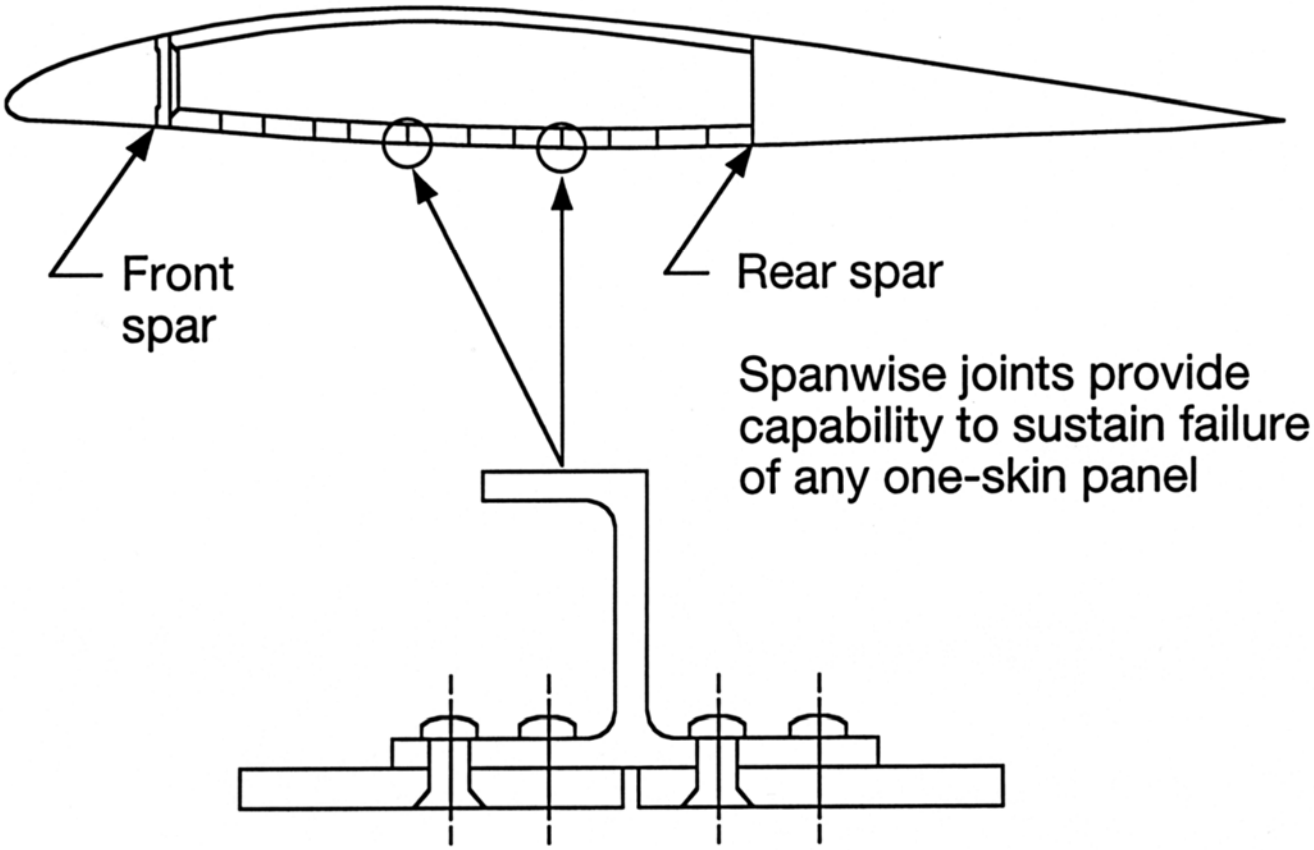
Design Principles



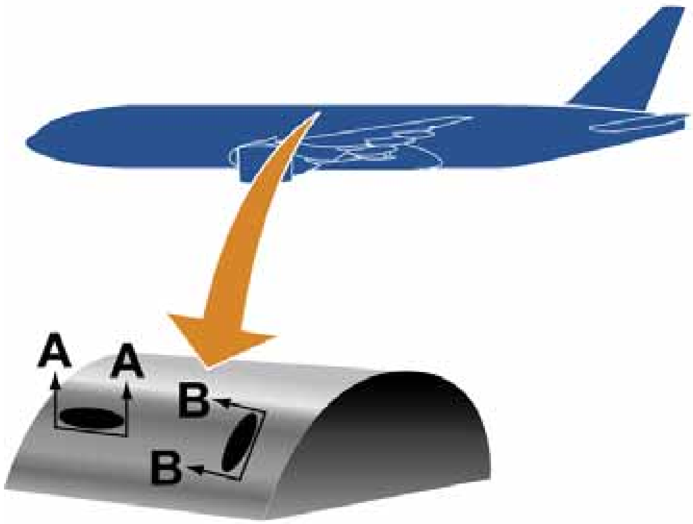
Fail-Safe Jet Transports

Boeing 707

Wing Fail Safety

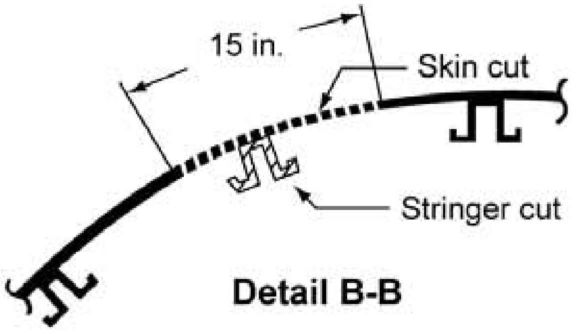


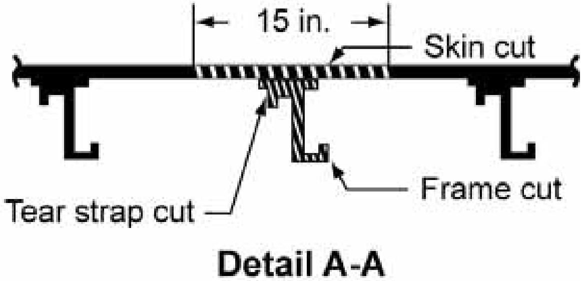
Fail-Safe Test Verification



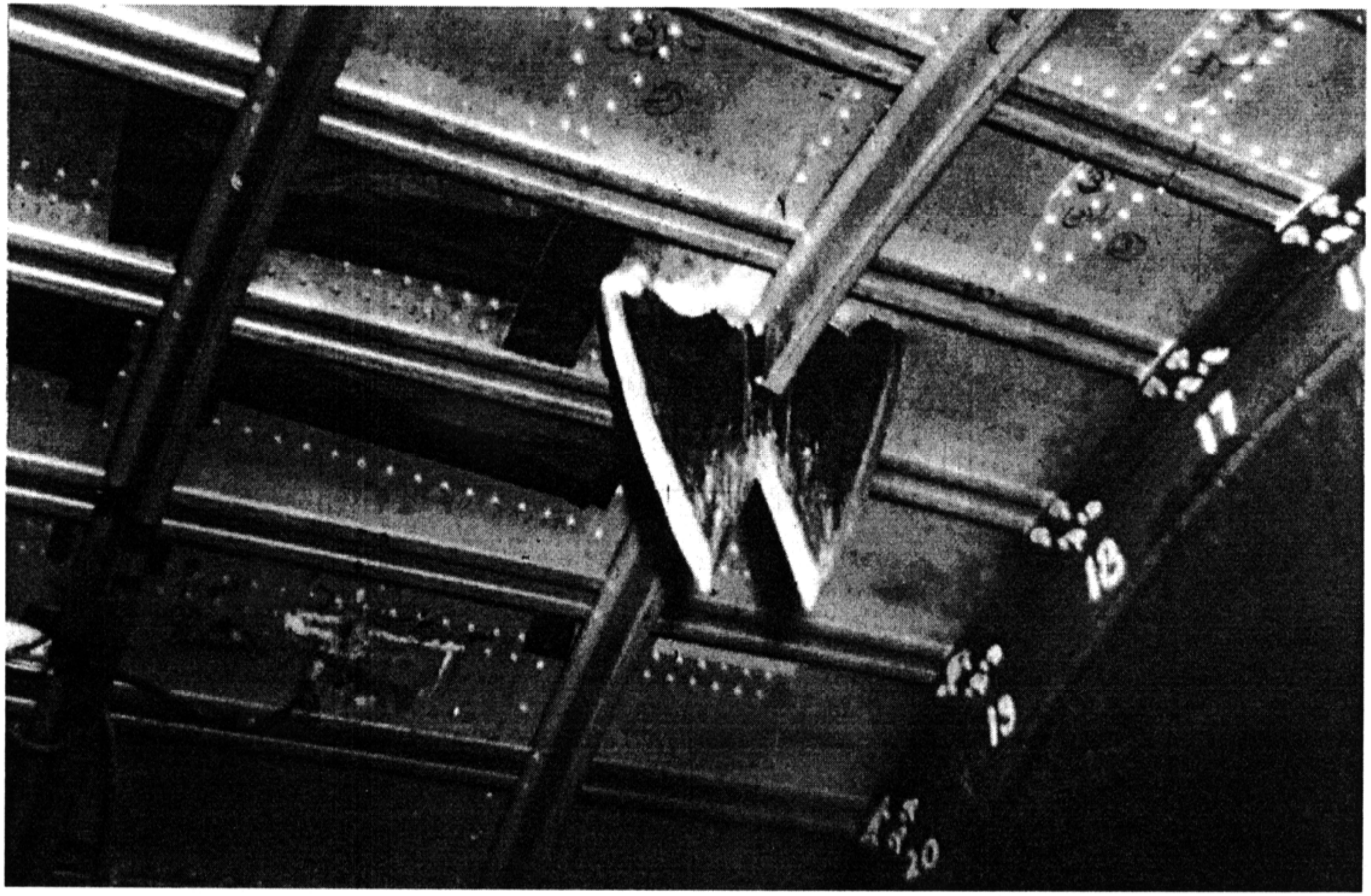
Pressurized test section

- Example of blade skin cuts made at critical locations



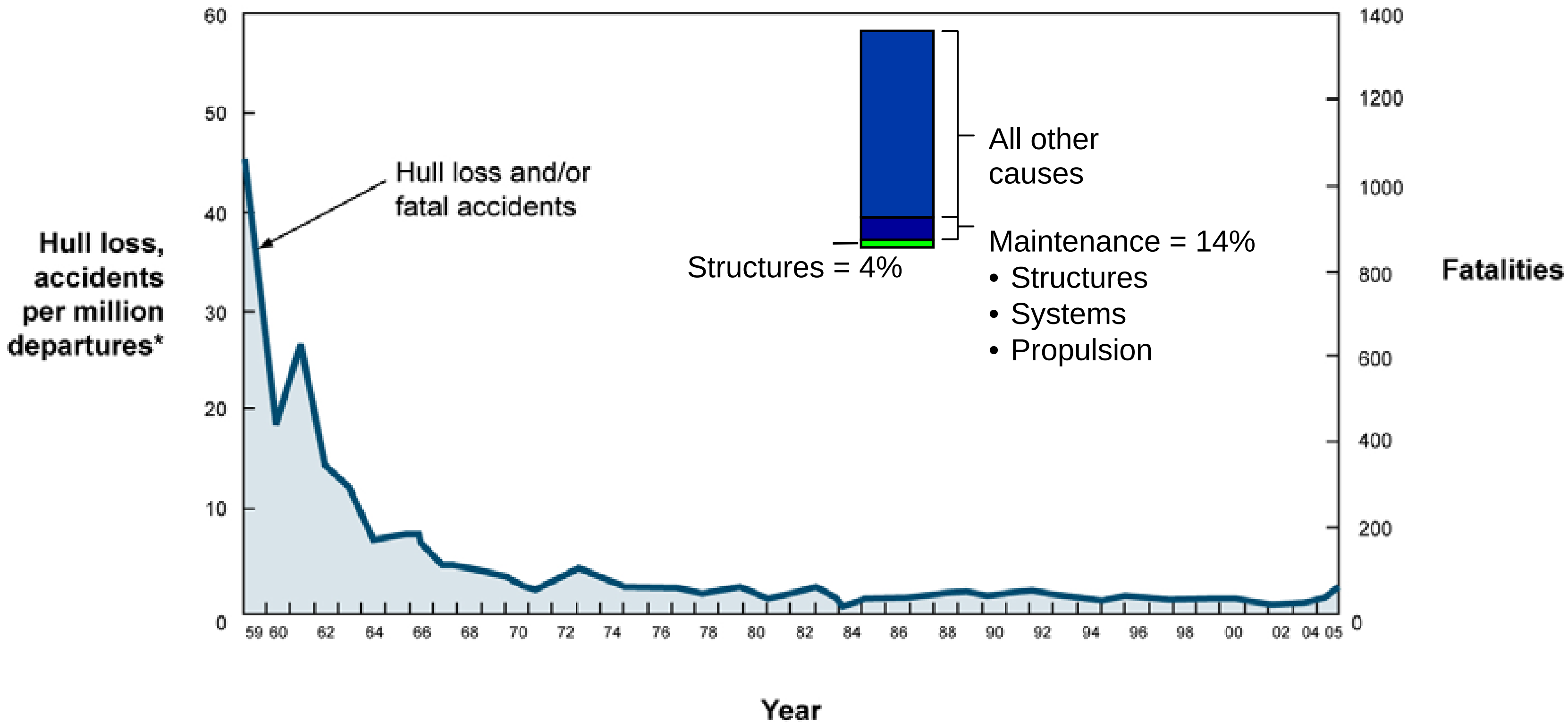


Fuselage Crack Arrest Test



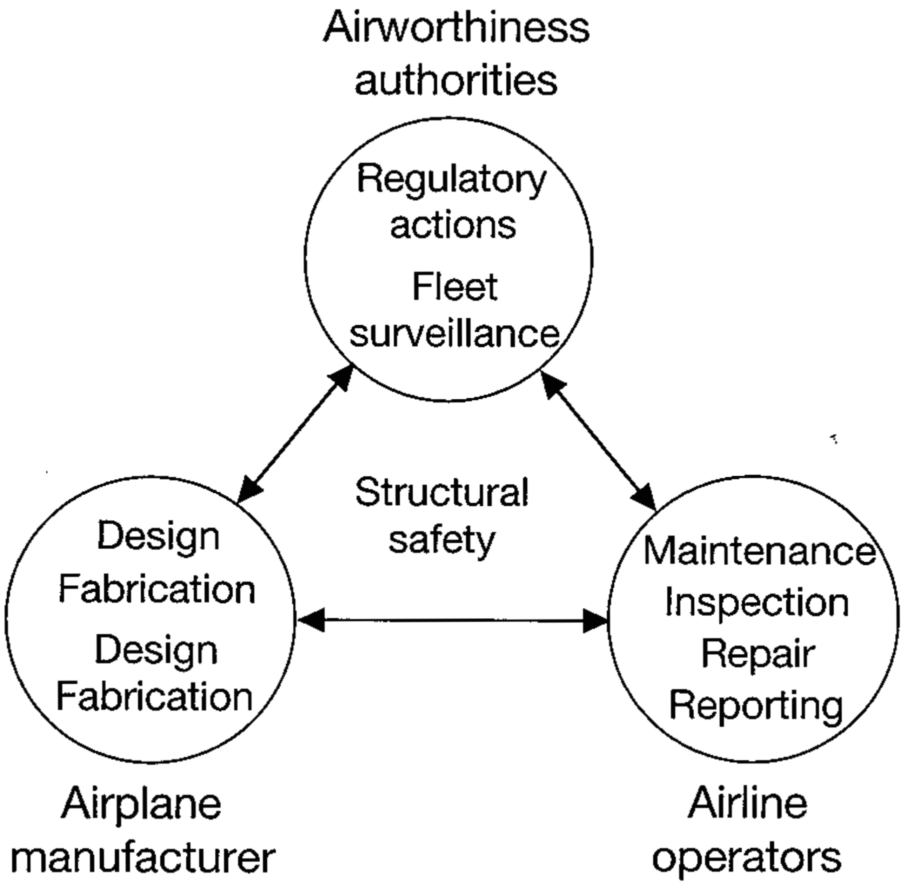
Hull Losses and/or Fatal Accidents
Per Million Departures

Worldwide commercial jet fleet — 1959 through 2005

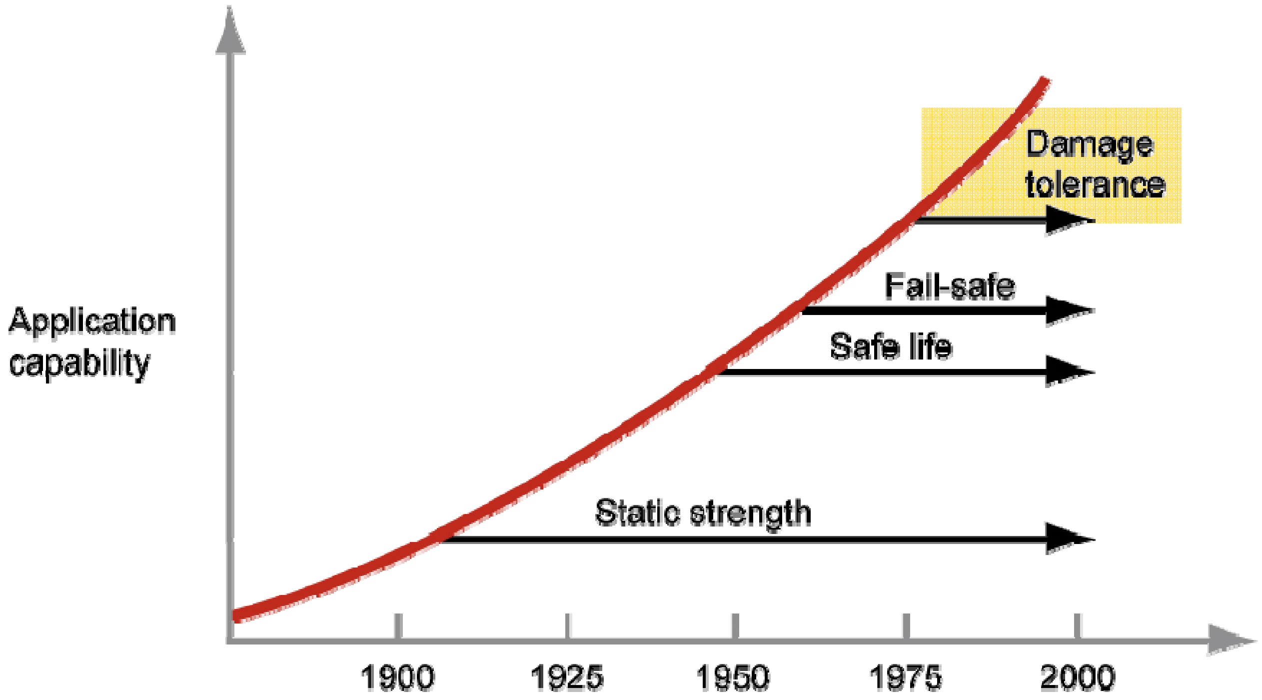


* Exludes sabotage and military action

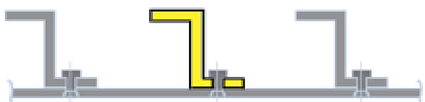
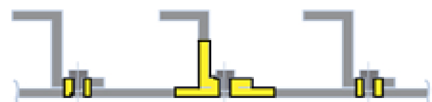
Structural Safety System



Design Principles



FAA Regulation Comparisons

Analysis	FAR 25.571 (before 1978)	FAR 25.571 (after 1978)
Residual strength	• Single element or obvious failure 	• Multiple active cracks 
Crack growth	• No analysis required	• Extensive analysis required
Inspection program	• Based on service history • FAA air carrier approval [1]	• Related to structural damage characteristics and past service history • Initial FAA engineering and air carrier approval

[1] Supplemental damage tolerance inspection. Performed per AC91-56.

Boeing 757 and 767

Basic Concepts

Safety

Damage tolerance
- Residual strength
- Crack growth
- Damage detection

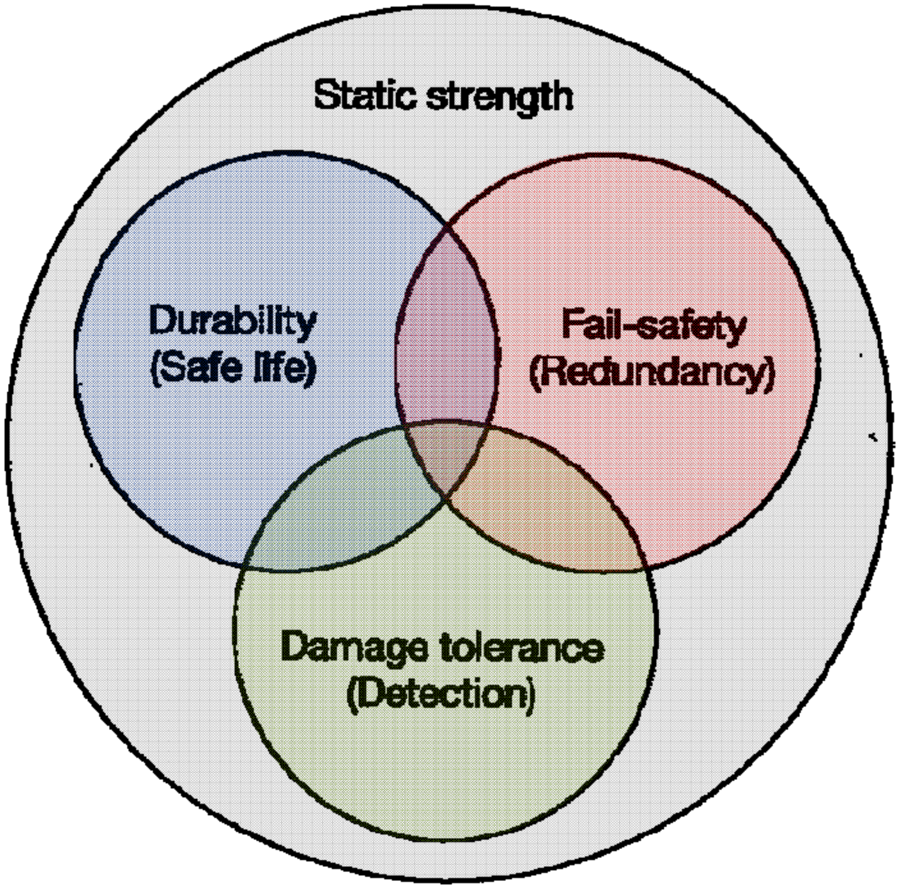
FAR 25.571

(b) Damage-tolerance (fail-safe) evaluation. The evaluation must include a determination of the probable locations and modes of damage due to fatigue, corrosion, or accidental damage. The determination must be made by analysis supported by test evidence and (if available) service experience. Damage at multiple sites due to prior fatigue exposure must also be included where the design is such that this type of damage is expected to occur. The evaluation must include repeated loads and static analyses support by full-scale test evidence. **Sufficient full-scale testing must be accomplished to ensure that widespread multiple-site damage will not occur within the design lifetime of the airplane.** The extent of damage for residual strength evaluation at any time within the operational life must be consistent with the initial detectability and subsequent growth under repeated loads. The residual strength evaluation must show that the remaining structure is able to withstand loads (considered as static ultimate loads) corresponding to the following conditions:

Economics

Durability
- Fatigue
- Corrosion
- Maintenance

Damage Tolerance Constituents



Damage Tolerance – Facts and Fiction

- Overview
- **Elements of Damage Tolerance**
- Structural Maintenance Considerations
- Continuing Airworthiness Challenges
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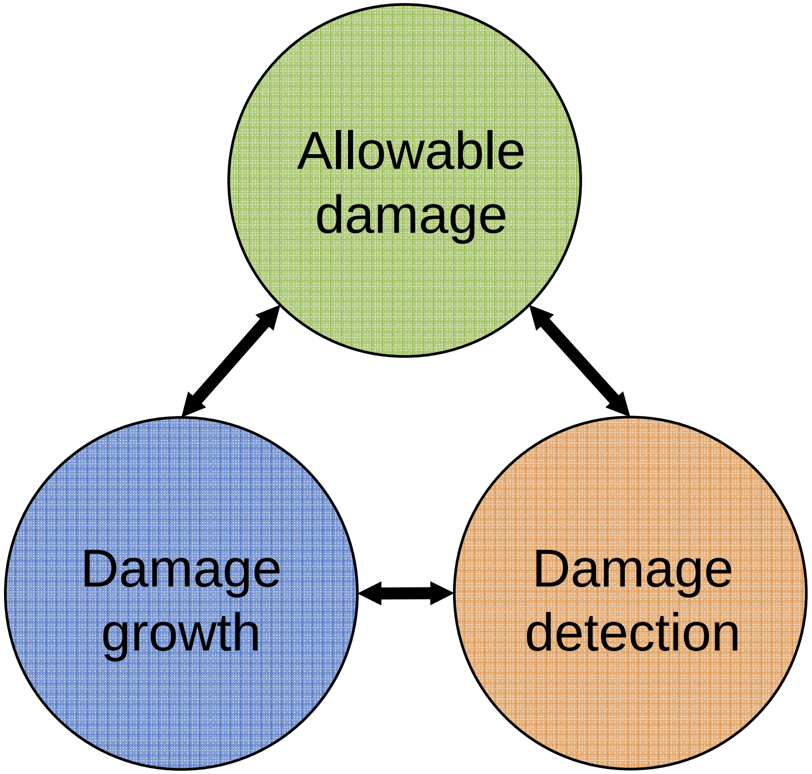
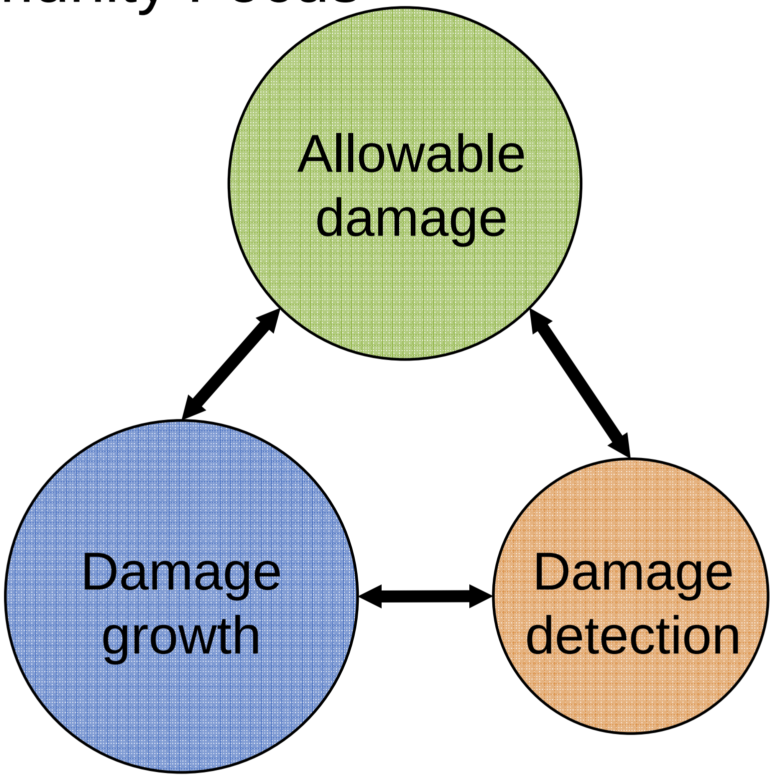
Elements of Damage Tolerance

- Vision



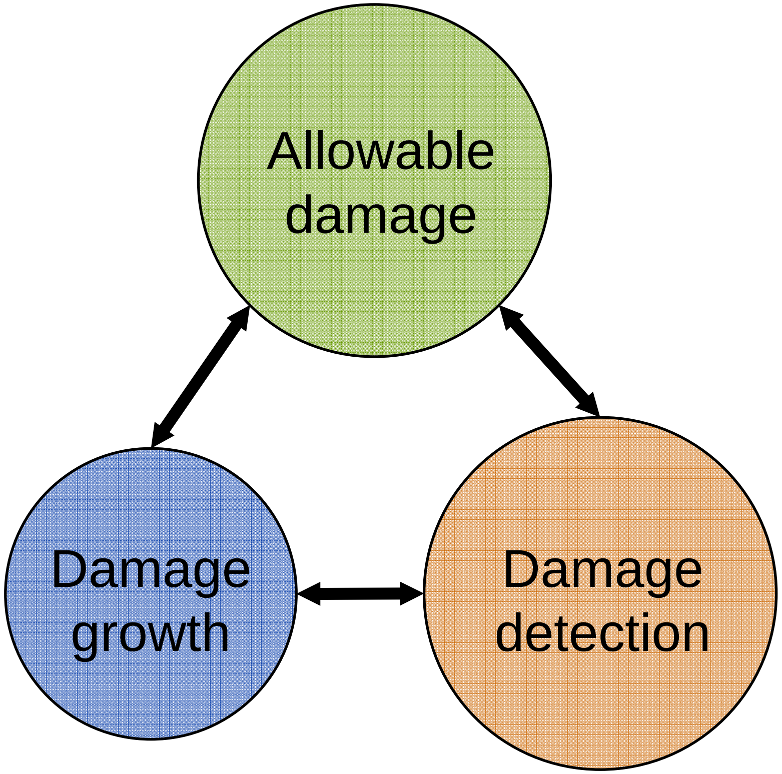
Elements of Damage Tolerance

- Research Community Focus

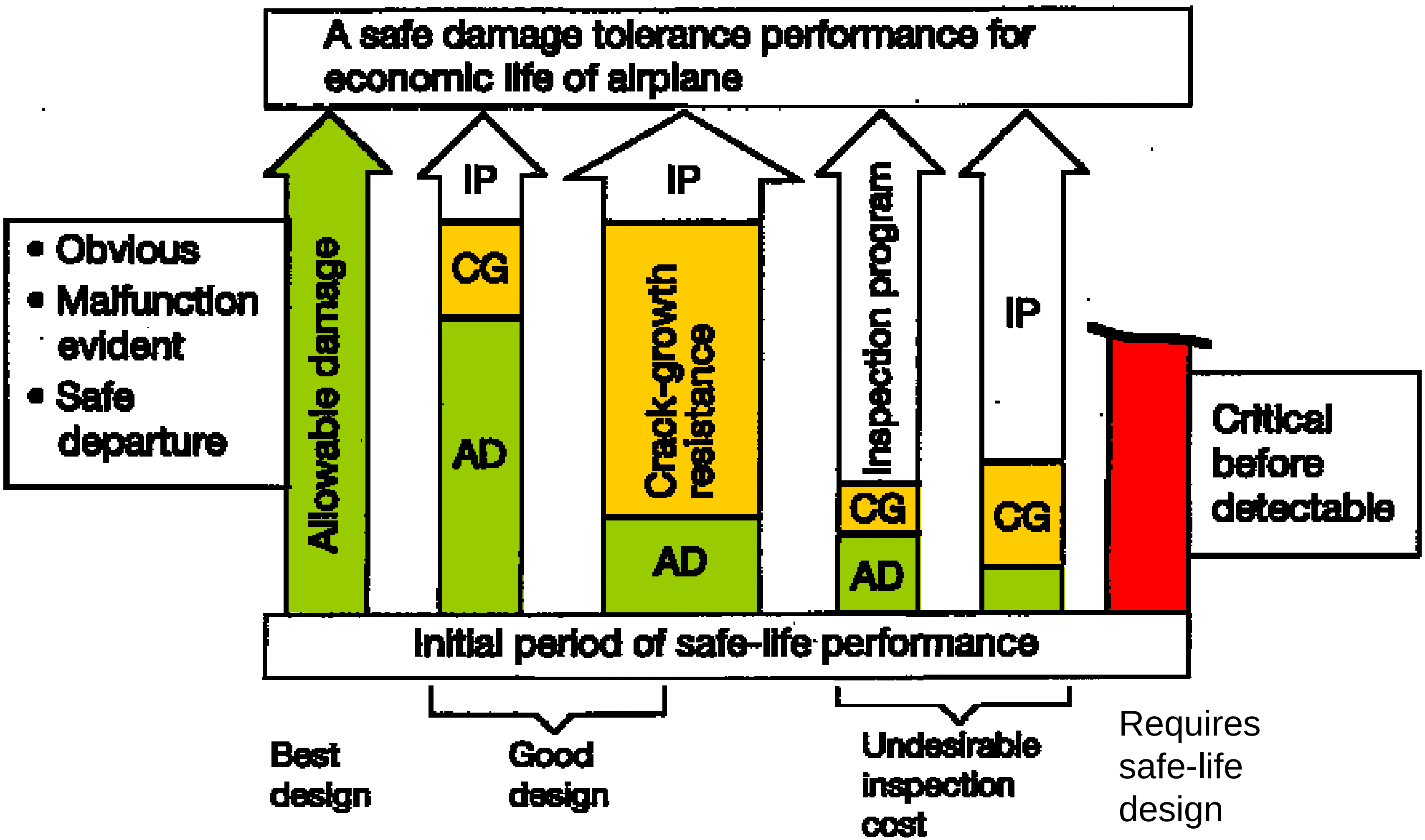


Elements of Damage Tolerance

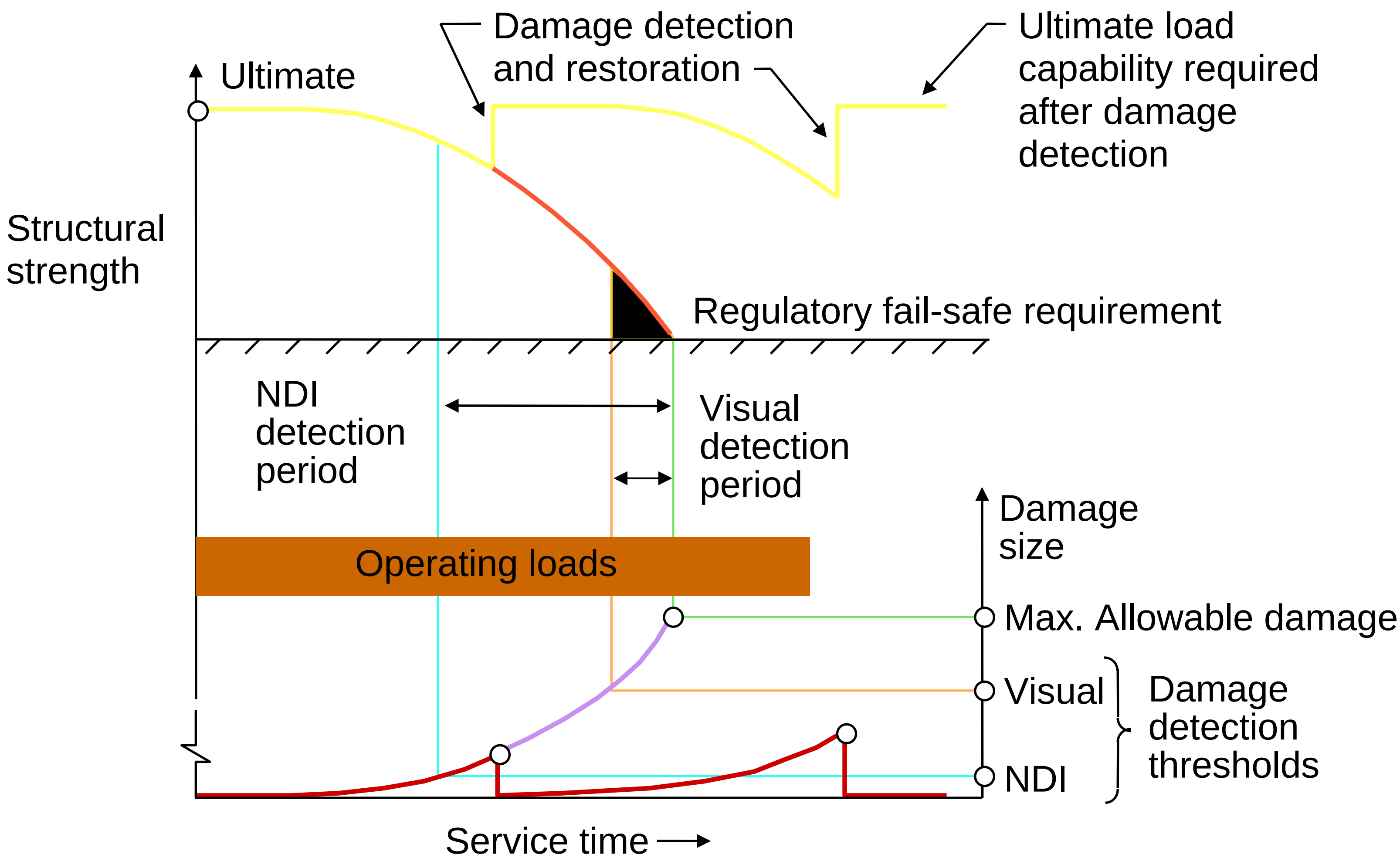
- Lecture Focus



Interaction of Damage Tolerance Elements



Damage Tolerant Structure

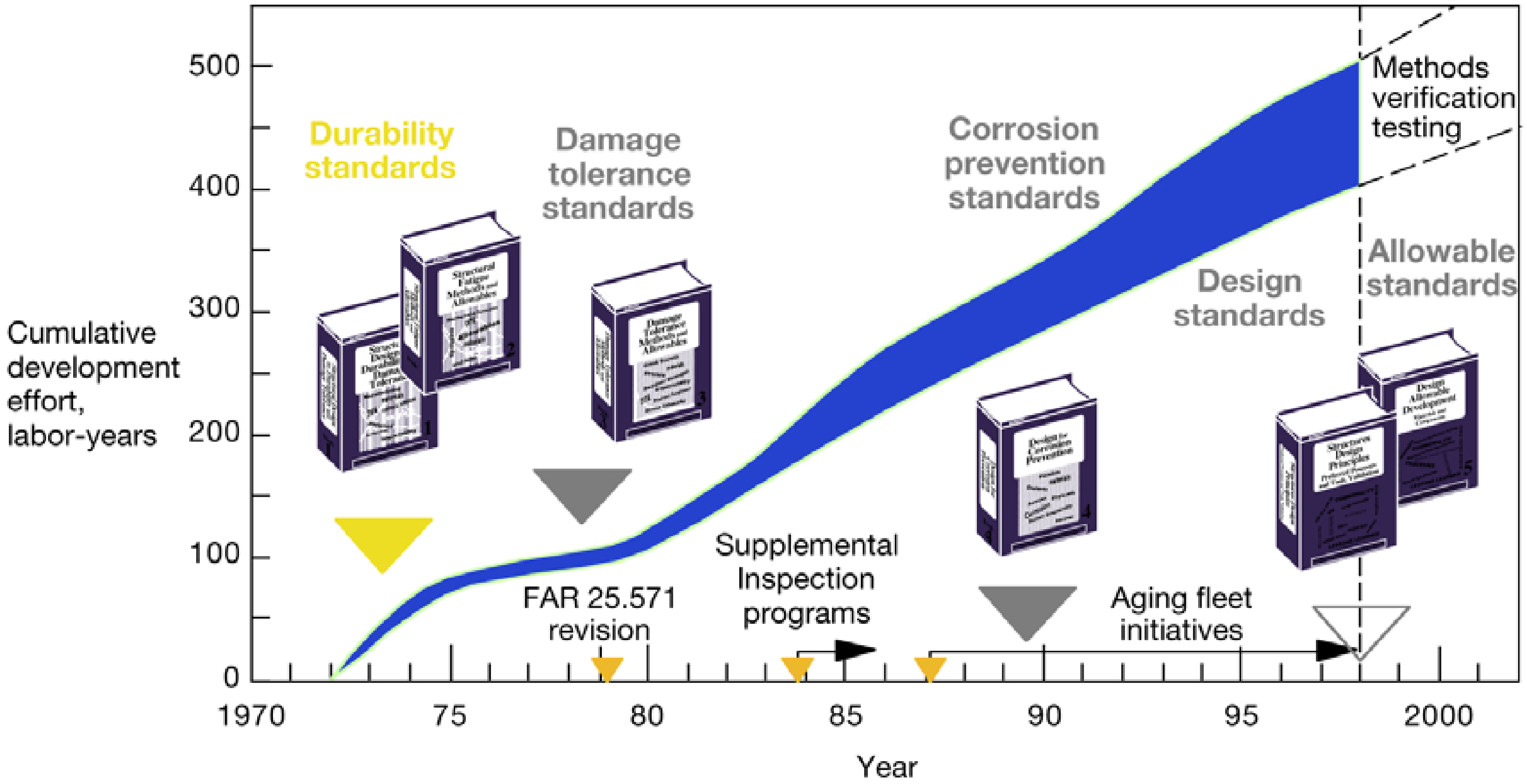


Classification of Structures

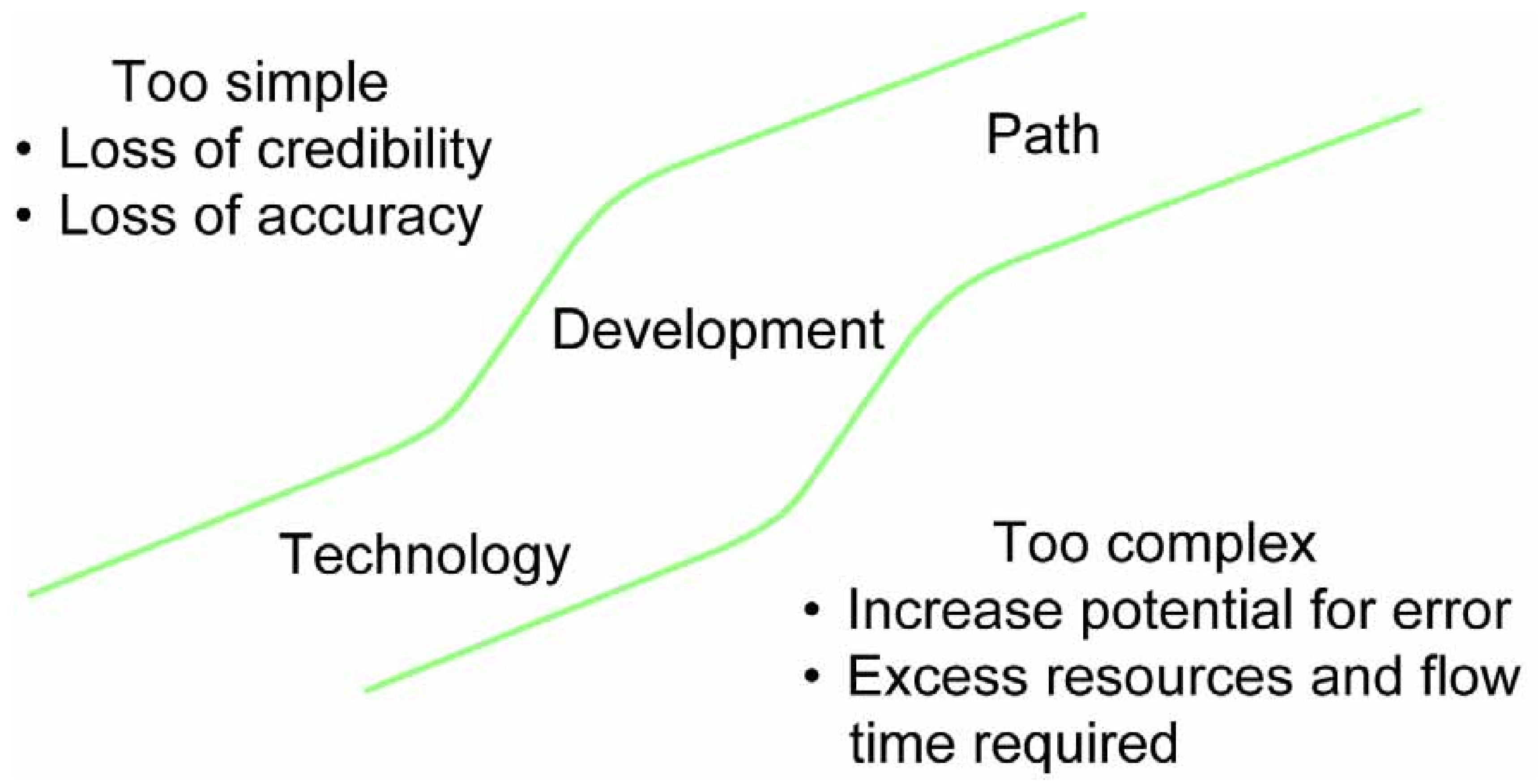
Category 3 : Inspections match Structural Characteristics

Structural category			Technique of ensuring safety	Safety analysis requirements	Structural classification examples
Other structure	Damage tolerant design	1 Secondary structure	Design for loss of component or safe separation	• Continued safe flight	Wing spoiler segment (safe separation or safe loss of function)
Structurally significant items or principal structural elements (primary structure)		2 Damage obvious or malfunction evident	Adequate residual strength with extensive damage obvious during walkaround or indicated by malfunction	• Residual strength	Wing fuel leaks
		3 Damage detection by planned inspection	Inspection program matched to structural characteristics	• Residual strength • Crack growth • Inspection program	All primary structure not included in categories 2 or 4
	Safe-life design	4 Safe life	Conservative fatigue life	• Fatigue	Landing gear structure (conservative fatigue life)

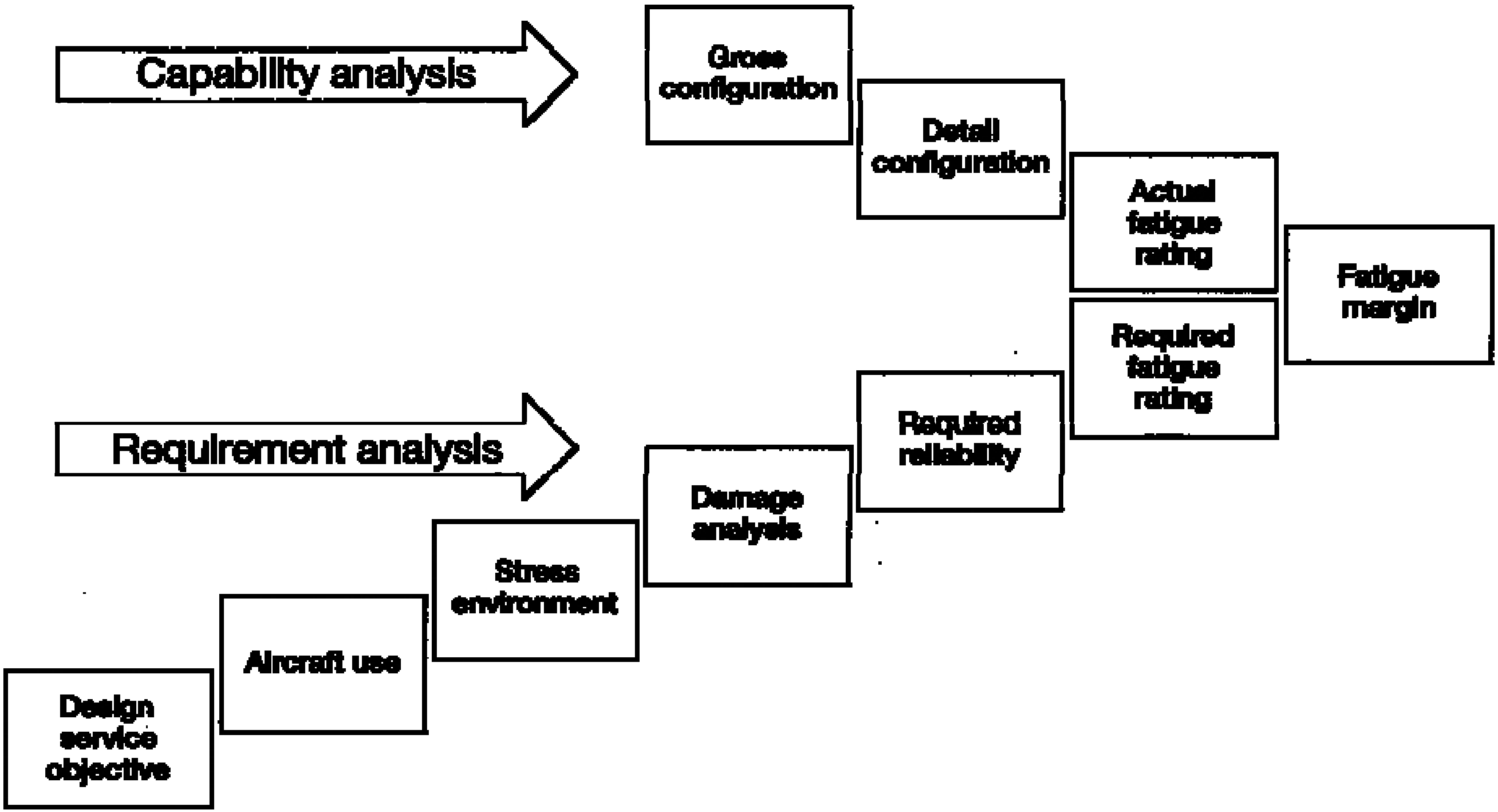
Structural Technology Standards
Durability Methods and Allowables



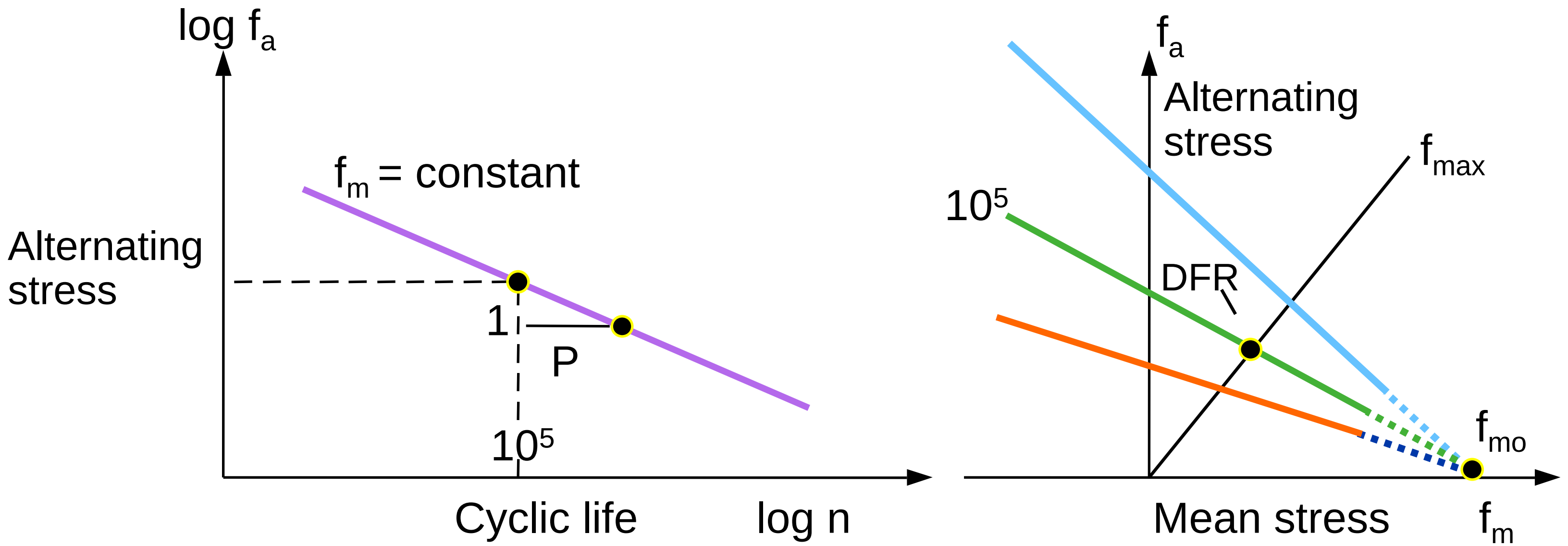
Technology Standards Development



Fatigue Check Procedure
Structural Capability Analysis



Fatigue Damage Model



$$f_a = \left(\frac{f_{mo} - f_m}{2\left(f_{mo} / DFR \right) - 1} \right) \cdot \left(\frac{10^5}{\phi N} \right)^{1/P}$$

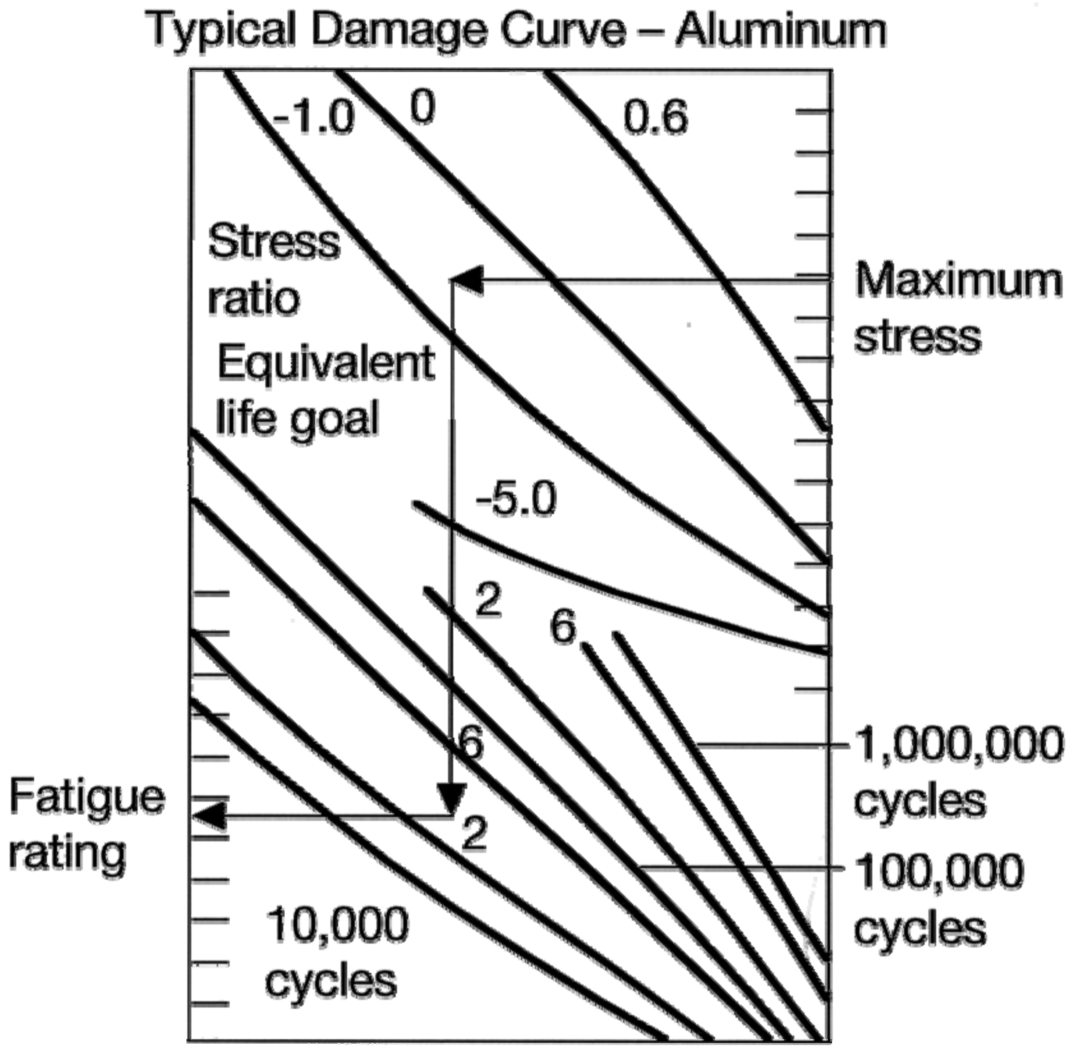
DFR = fatigue rating (f_{max} at N=10^5 and R = 0 with 95% reliability and 95% confidence)

f_{mo} = focal mean stress

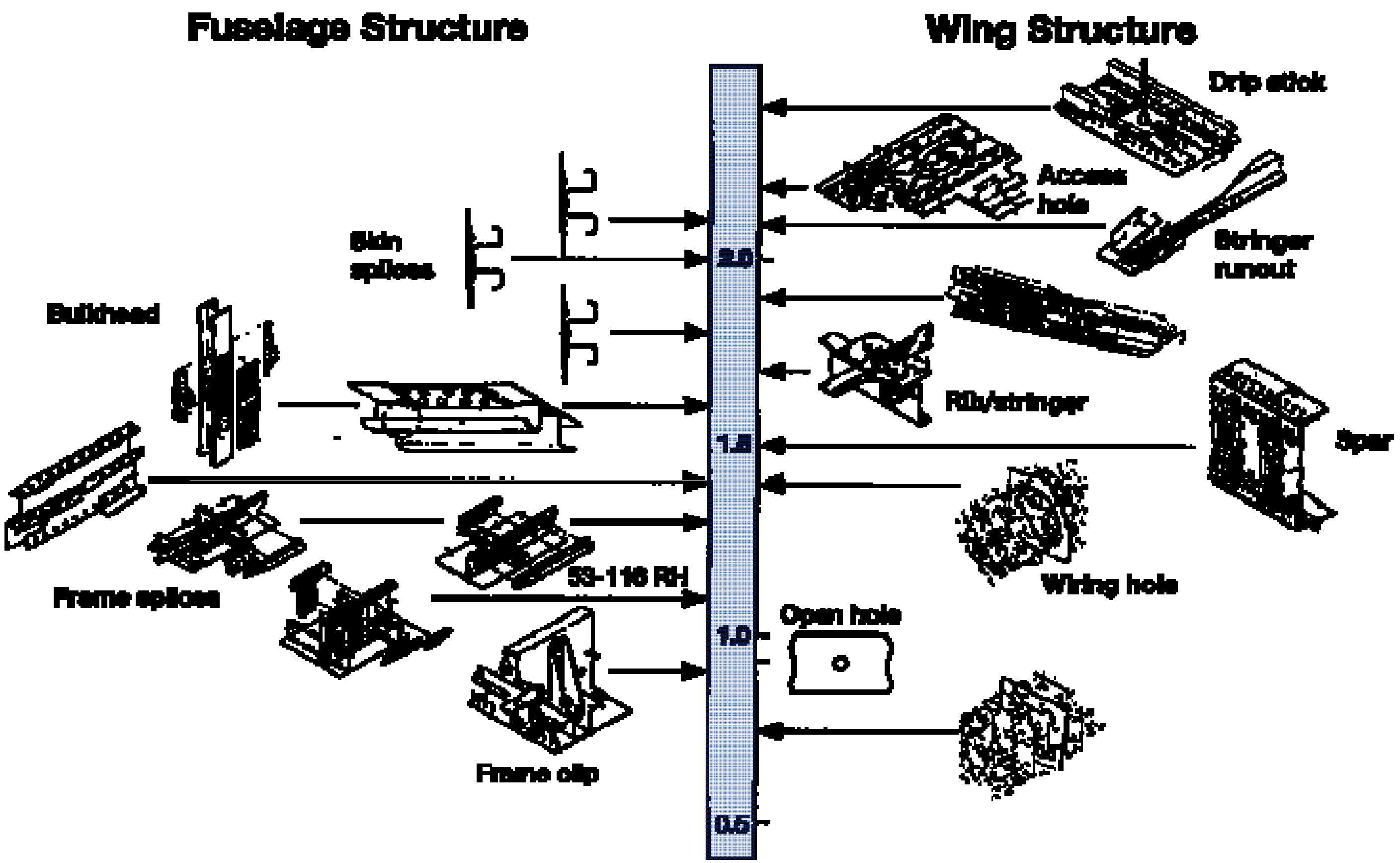
P = slope

ϕ = load sequence factor

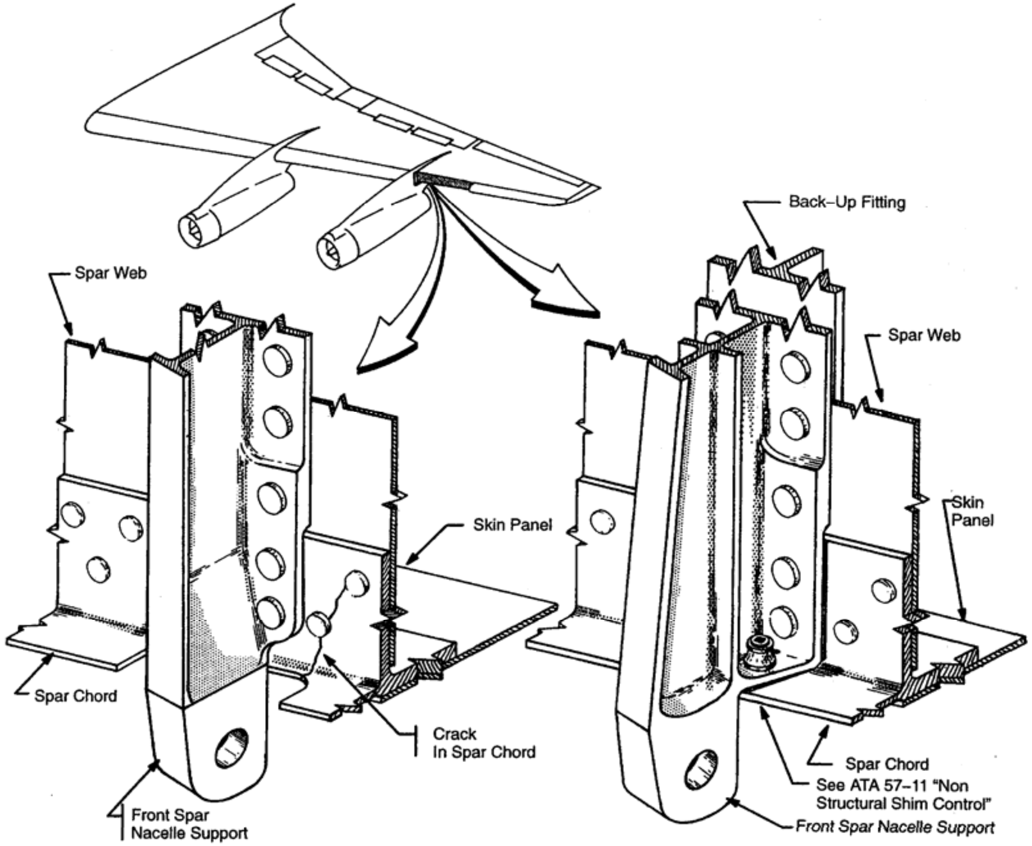
Required Fatigue Rating Solution



Relative Operating Stress Levels
Wing & Fuselage Capability Examples



Durability Design Guide Example
Spar Chord Discontinuity



Inactive

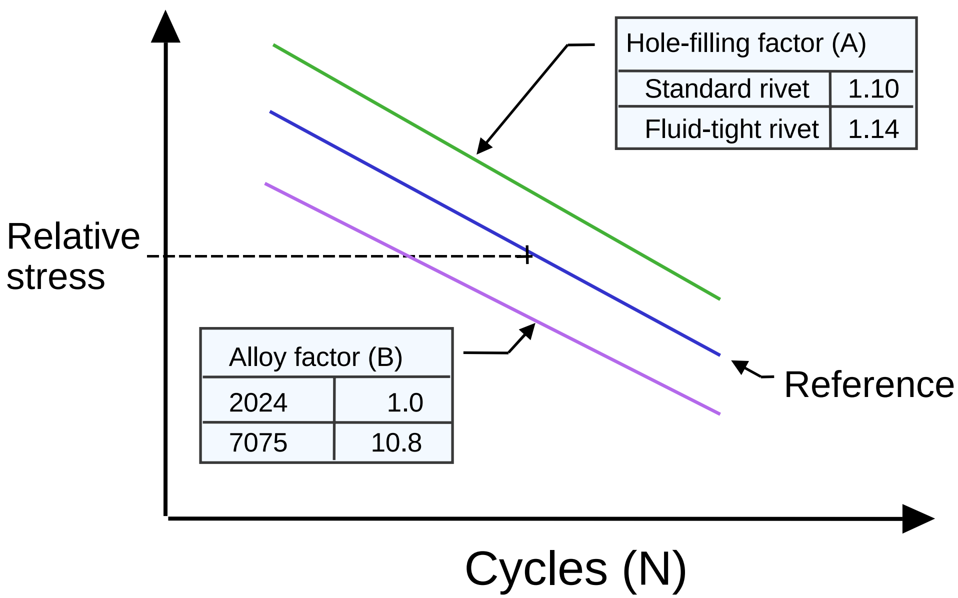
- Crack occurs at cutout in spar chord due to high stress concentration from small transition radius.

Acceptable

- Design support fittings to avoid notching spar chord.
- Back–up fitting may be required to efficiently react eccentric load.
- Gives right of way to the most critical part.

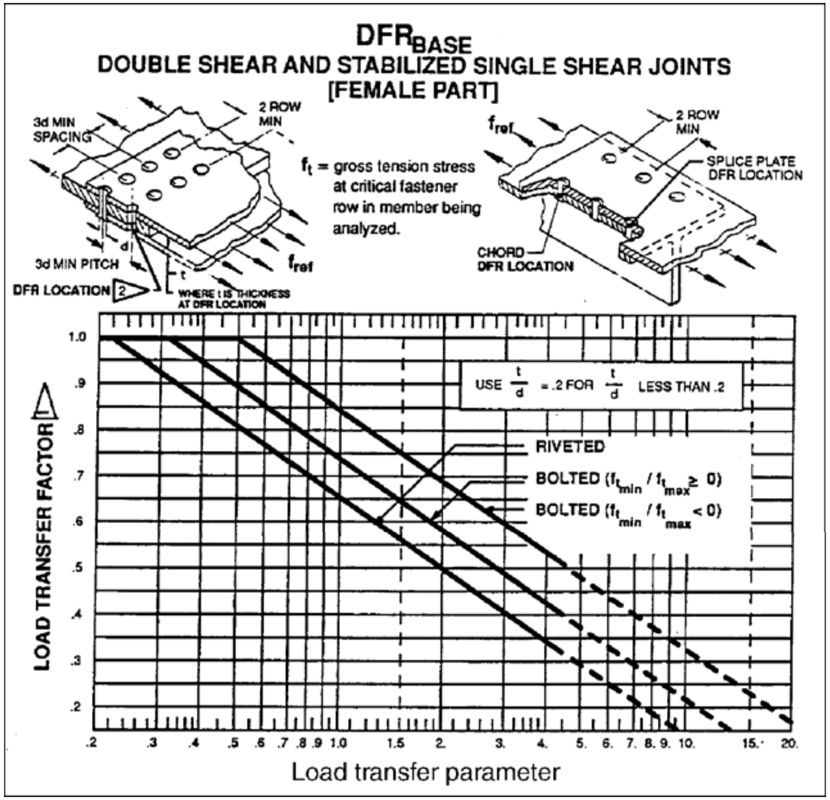
Analytical Detail Fatigue Ratings

$DFR = DFR_{BASE} \times ABCDEU$

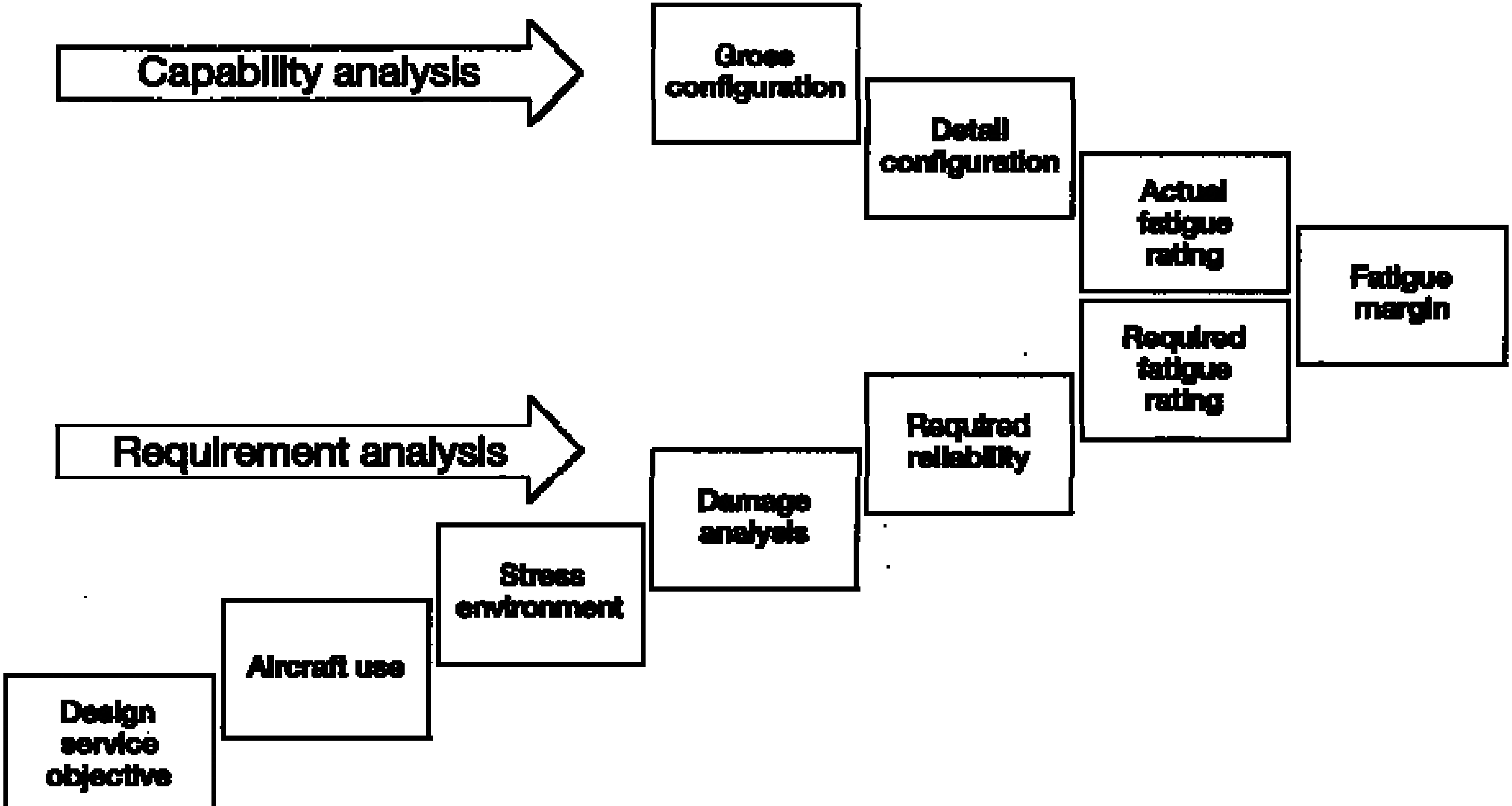


Hole-filling factor (A)	
Standard rivet	1.10
Fluid-tight rivet	1.14

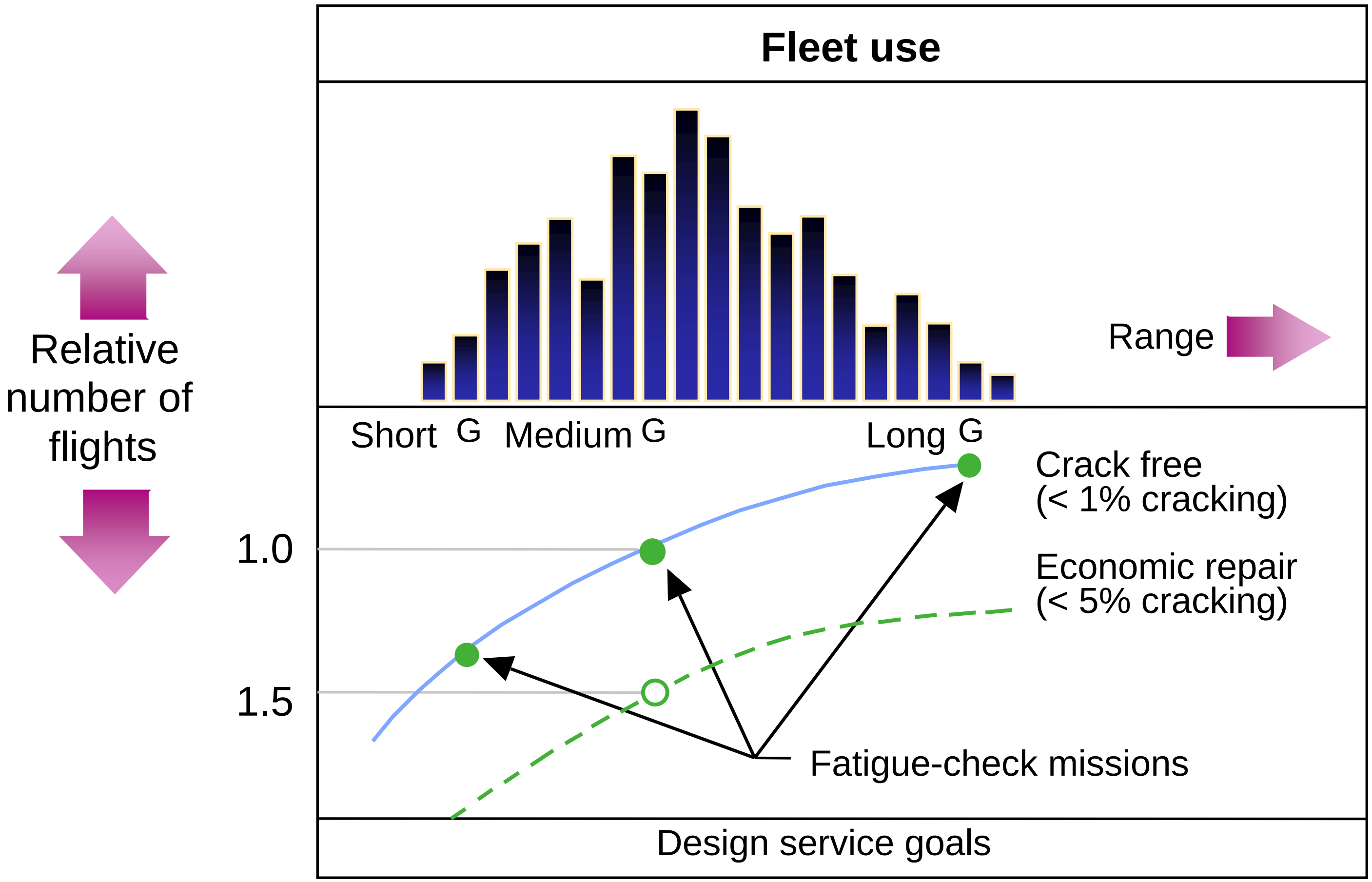
Alloy factor (B)	
2024	1.0
7075	10.8



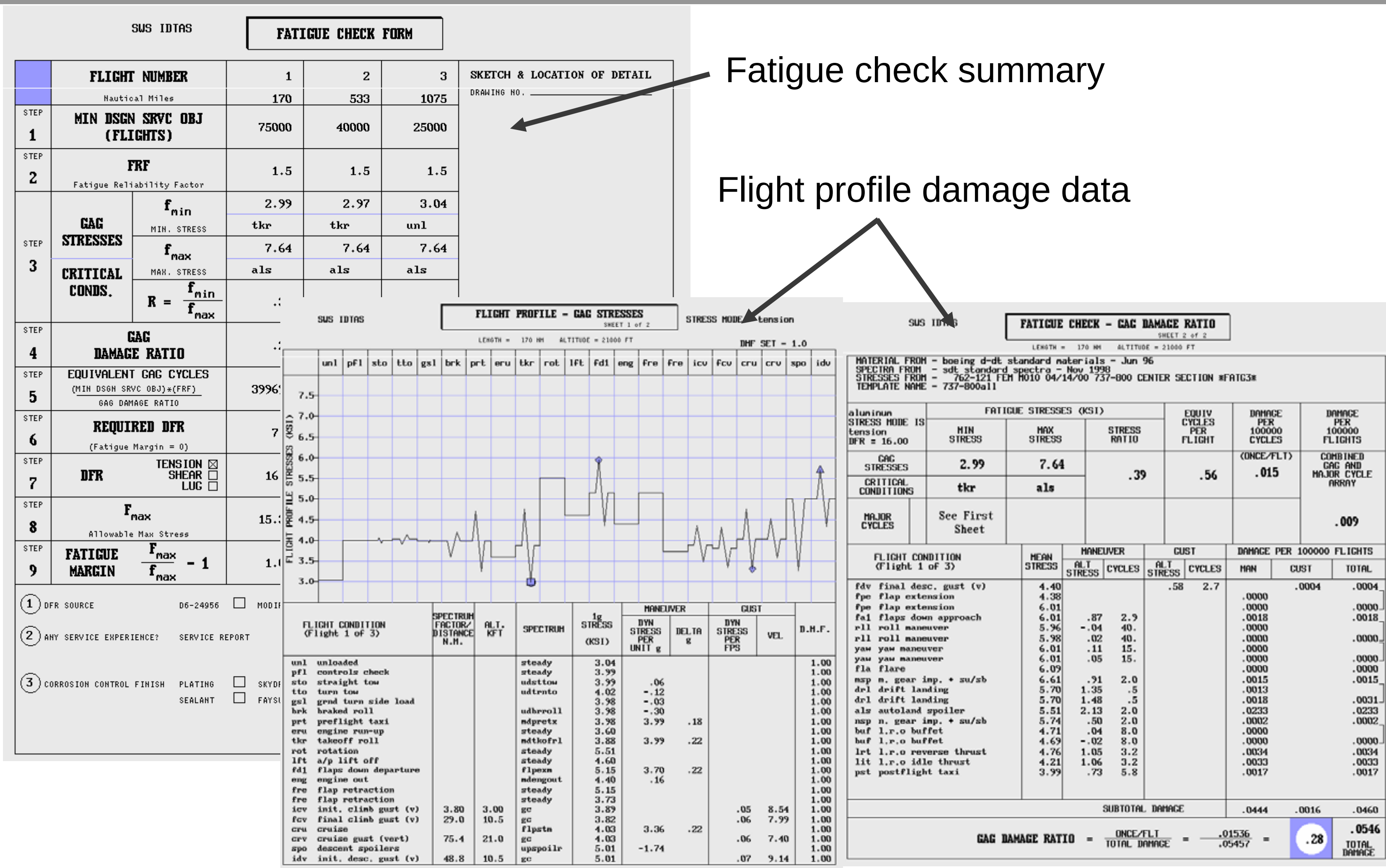
Fatigue Check Procedure
Requirement Analysis



Design Service Objectives



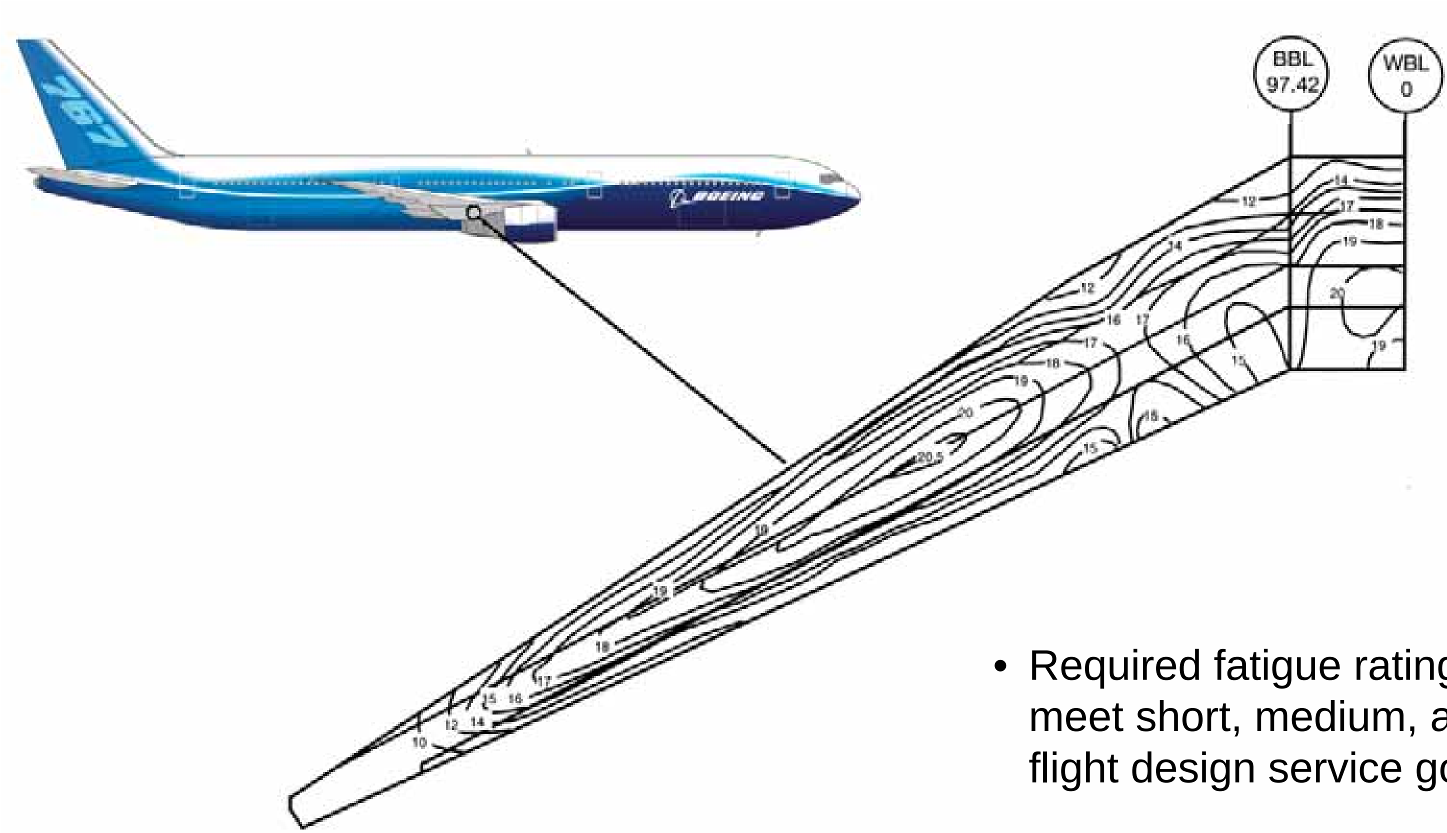
Fatigue Check Examples



Fatigue check summary

Flight profile damage data

Fatigue Design Requirement Contours



- Required fatigue rating to meet short, medium, and long flight design service goals

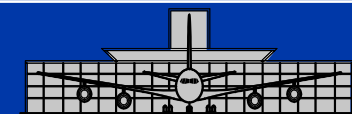
Structural Durability Validation

Sources for Detail Fatigue Ratings

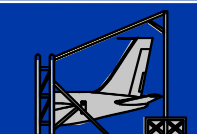
Most Preferred

- Fleet Experience

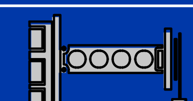
- Full-Scale Airplane Test



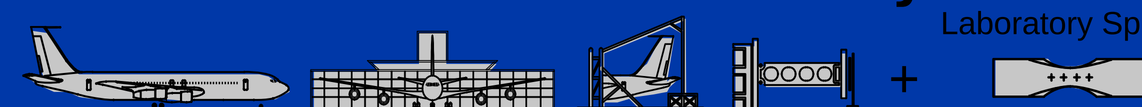
- Part Airplane Test



- Component Test



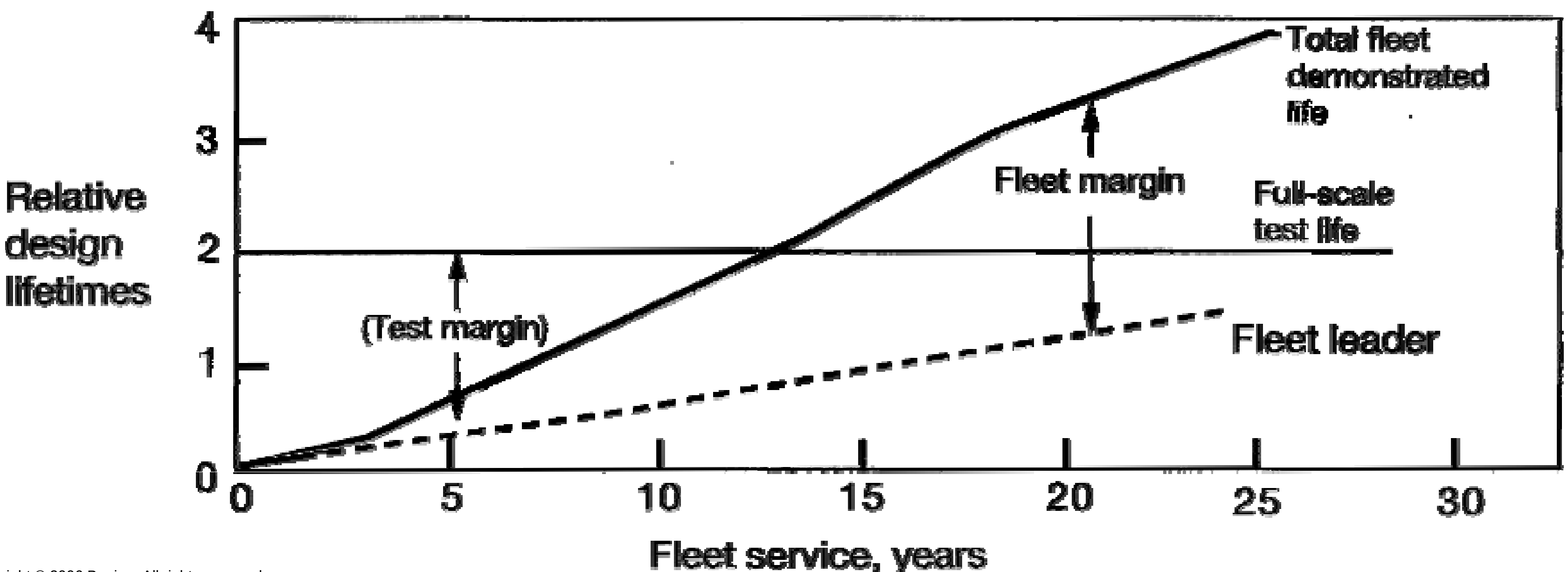
- Fleet Full-Scale Part Airplane Or Component Test } Modified Using Small-Scale Laboratory Specimen



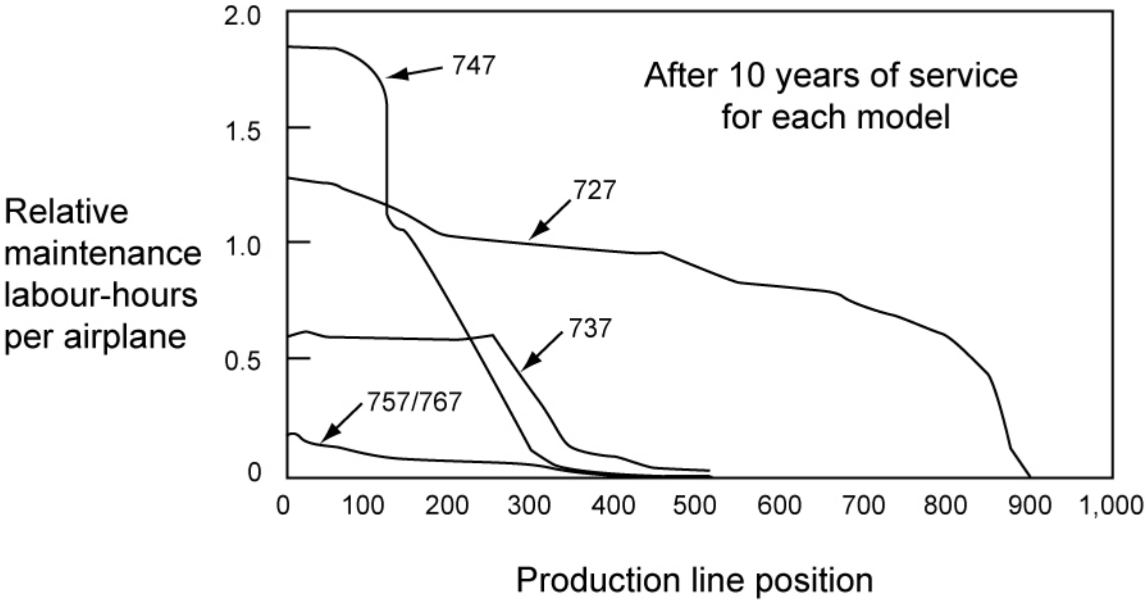
- Small-Scale Laboratory Specimen

Test Versus Service

- Pros and Cons
  - Full-scale fatigue testing provides useful information in early service life to correct details that may exhibit early cracking
  - Service-demonstrated fatigue performance rapidly exceeds value of single fatigue test

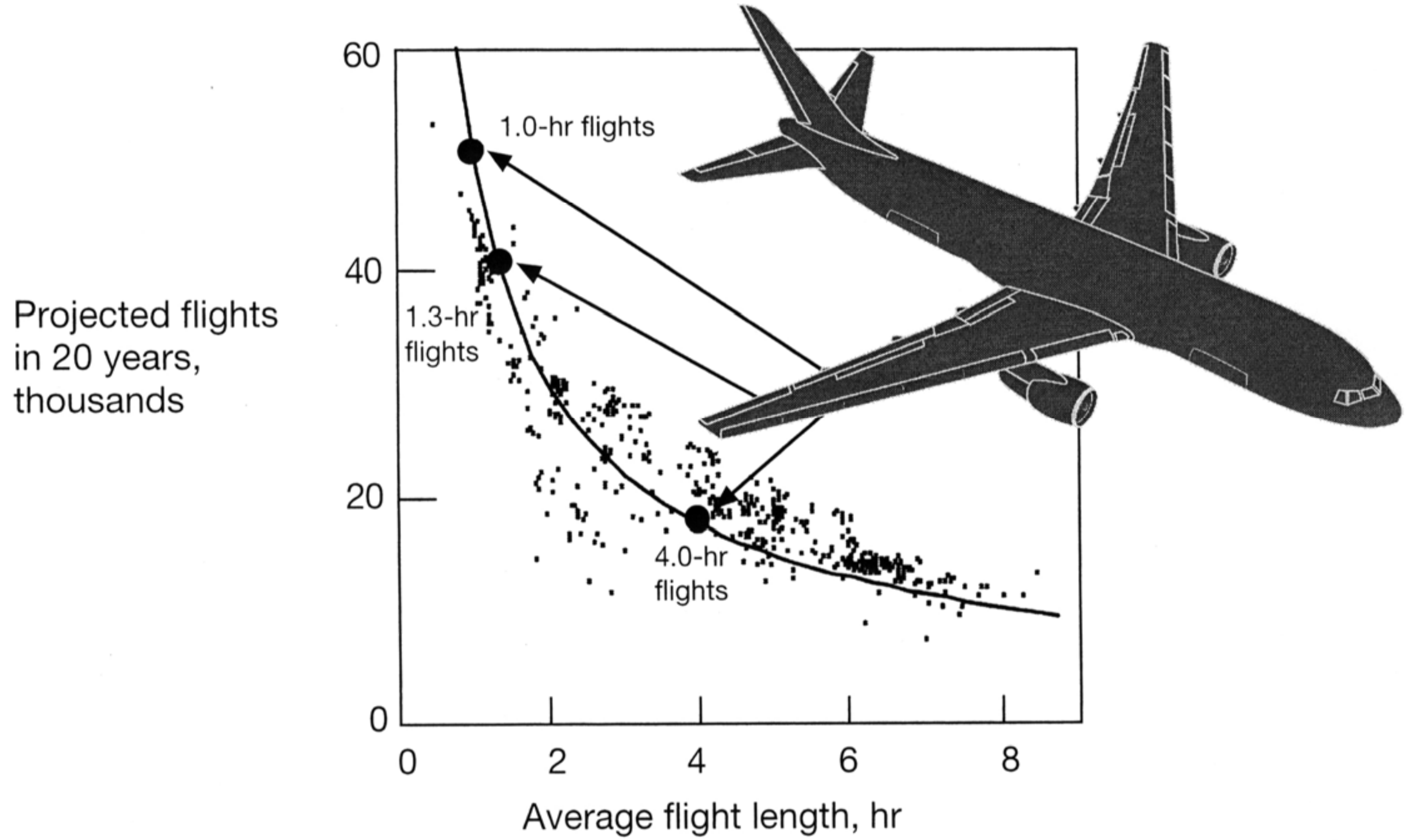


Service Bulletin Modifications - Labor-Hours
Corrosion and Fatigue

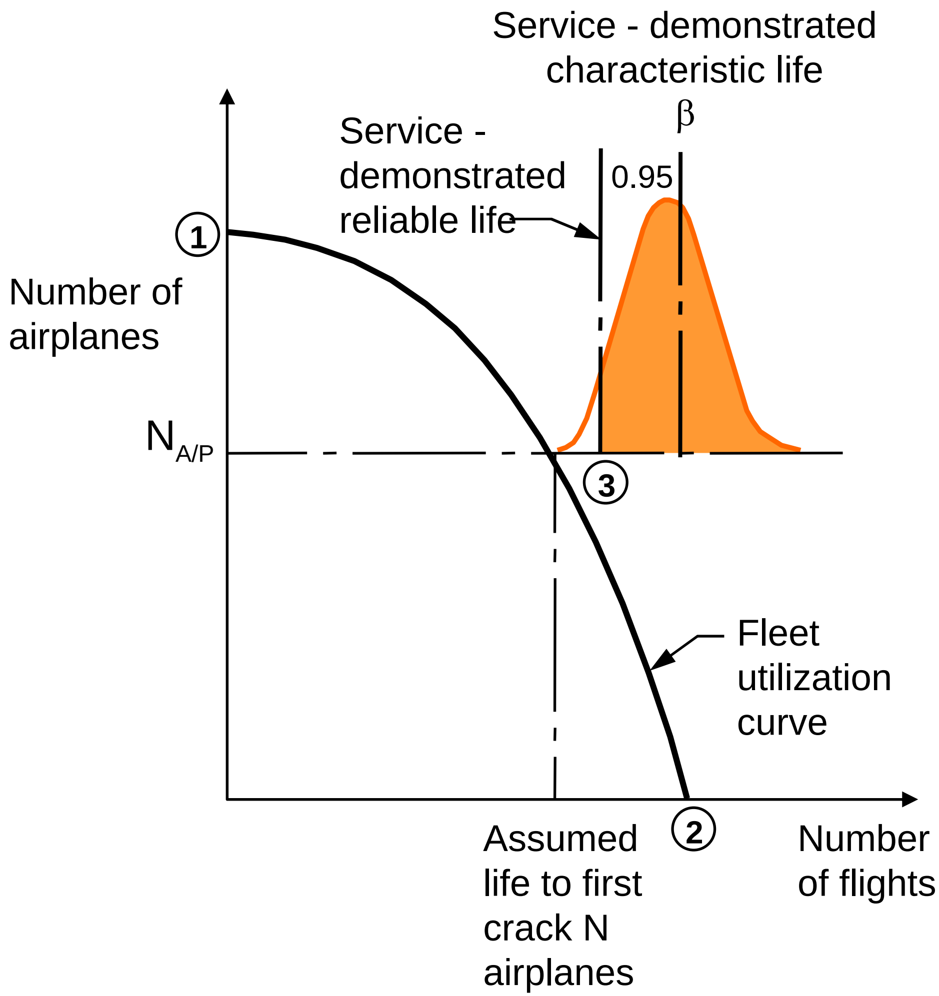


Design Service Objectives
767 Jet Transports

- Database from 586 active 767s

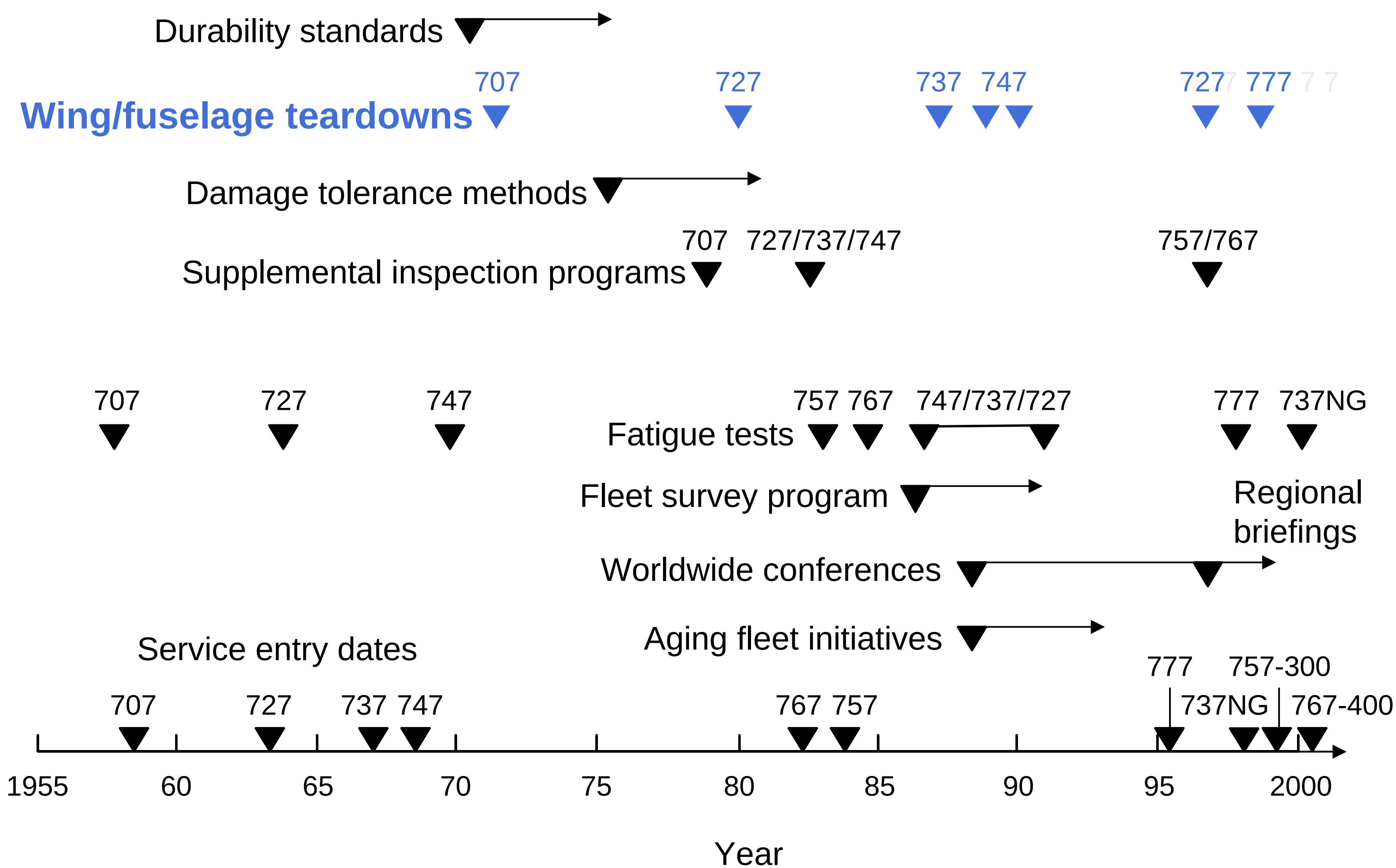


Service-Demonstrated Fatigue Lives



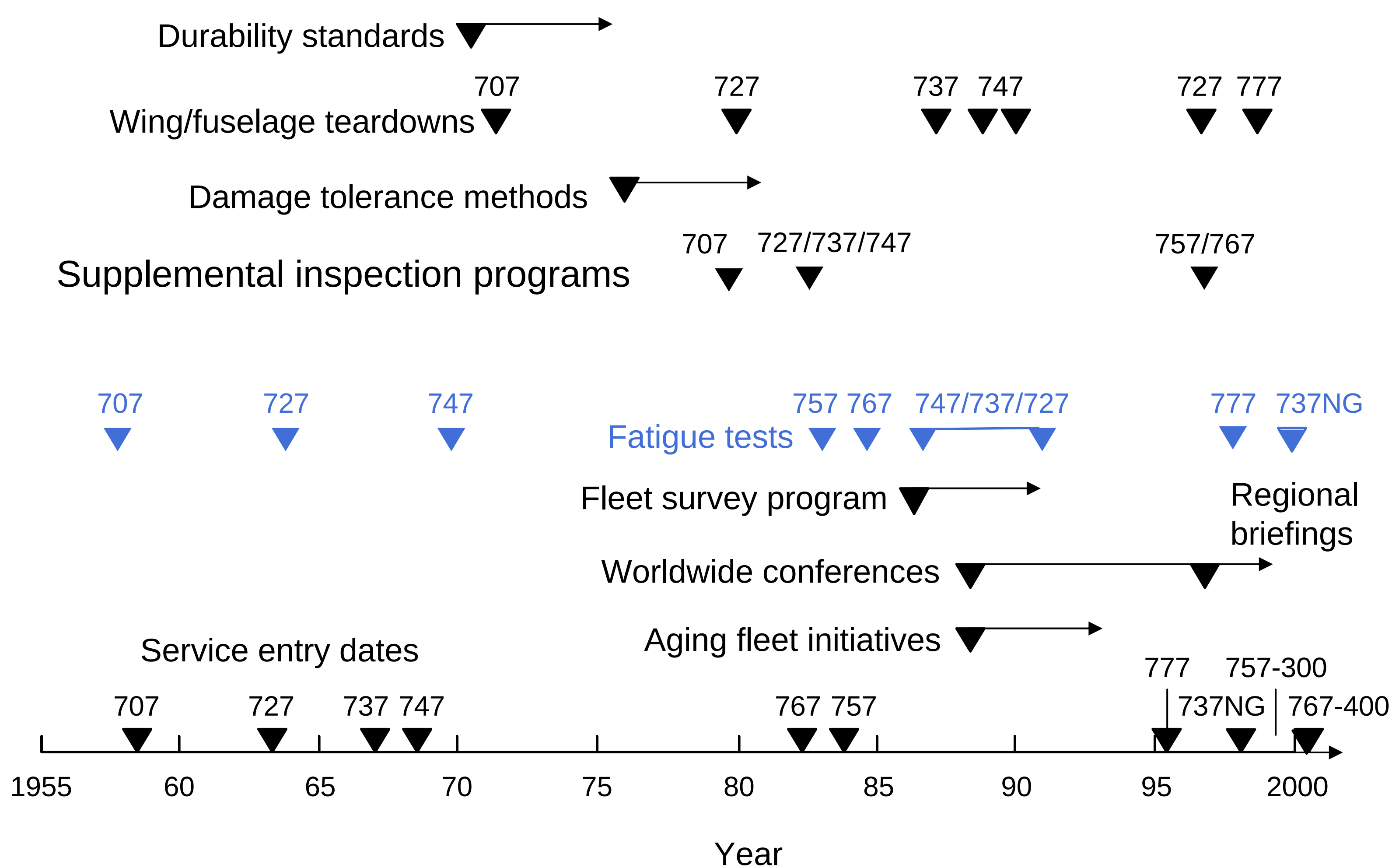
1999 commercial fleet data			
Model	Number of airplanes delivered (1)	Highest flights 10^3 flights (2)	Demonstrated life 10^3 flights (3)
707	735	36	39
720	153	45	35
727	1,822	77	103
737	3,440	92	109
747	1,214	33	33
757	880	27	25
767	753	33	28
777	239	4	2
737NG	351	TBD	TBD

Boeing Fleet Support Actions
Wing/Fuselage Teardowns

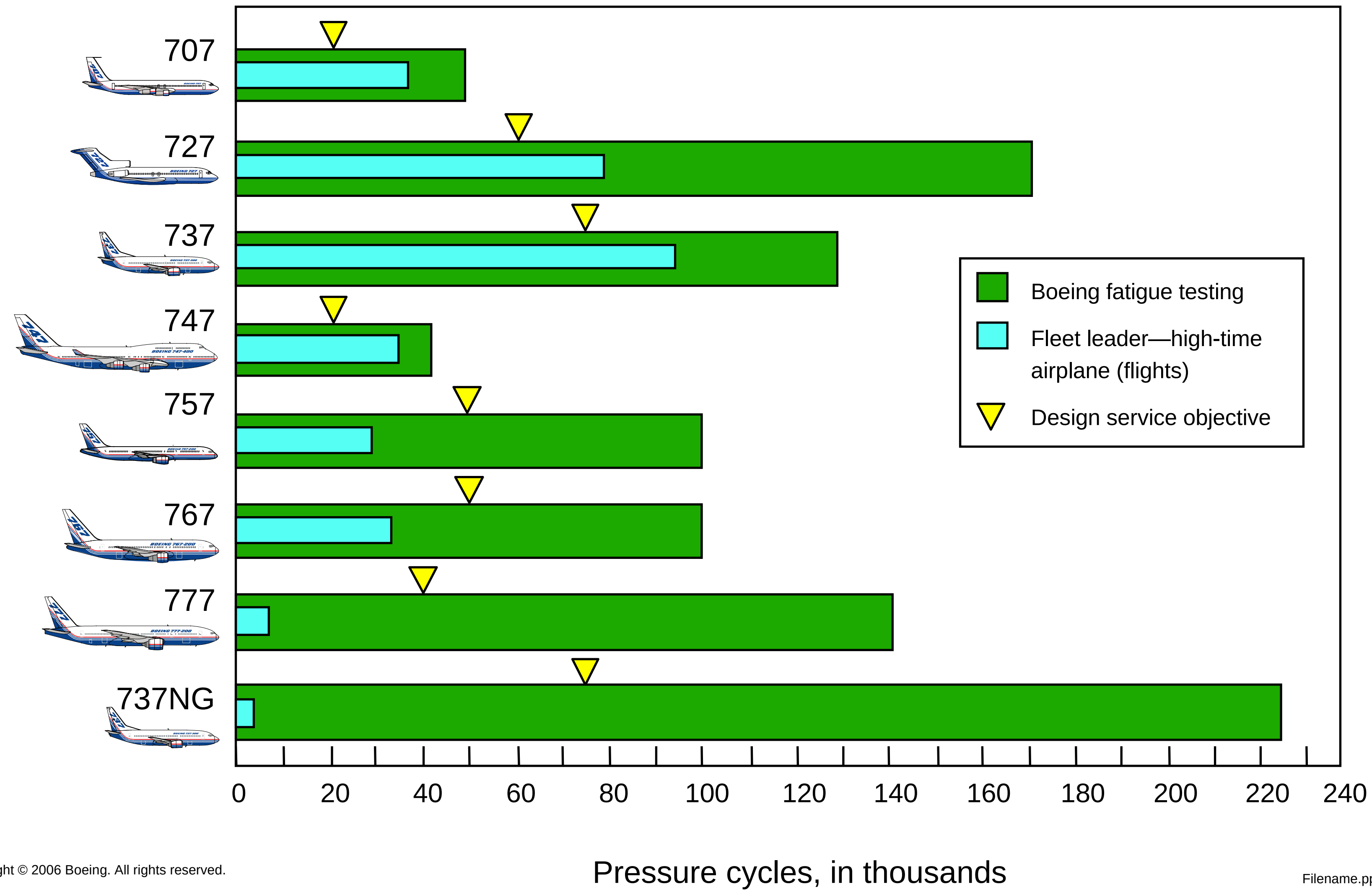


737 Teardown Site

Boeing Fleet Support Actions
Full Scale Fatigue Tests

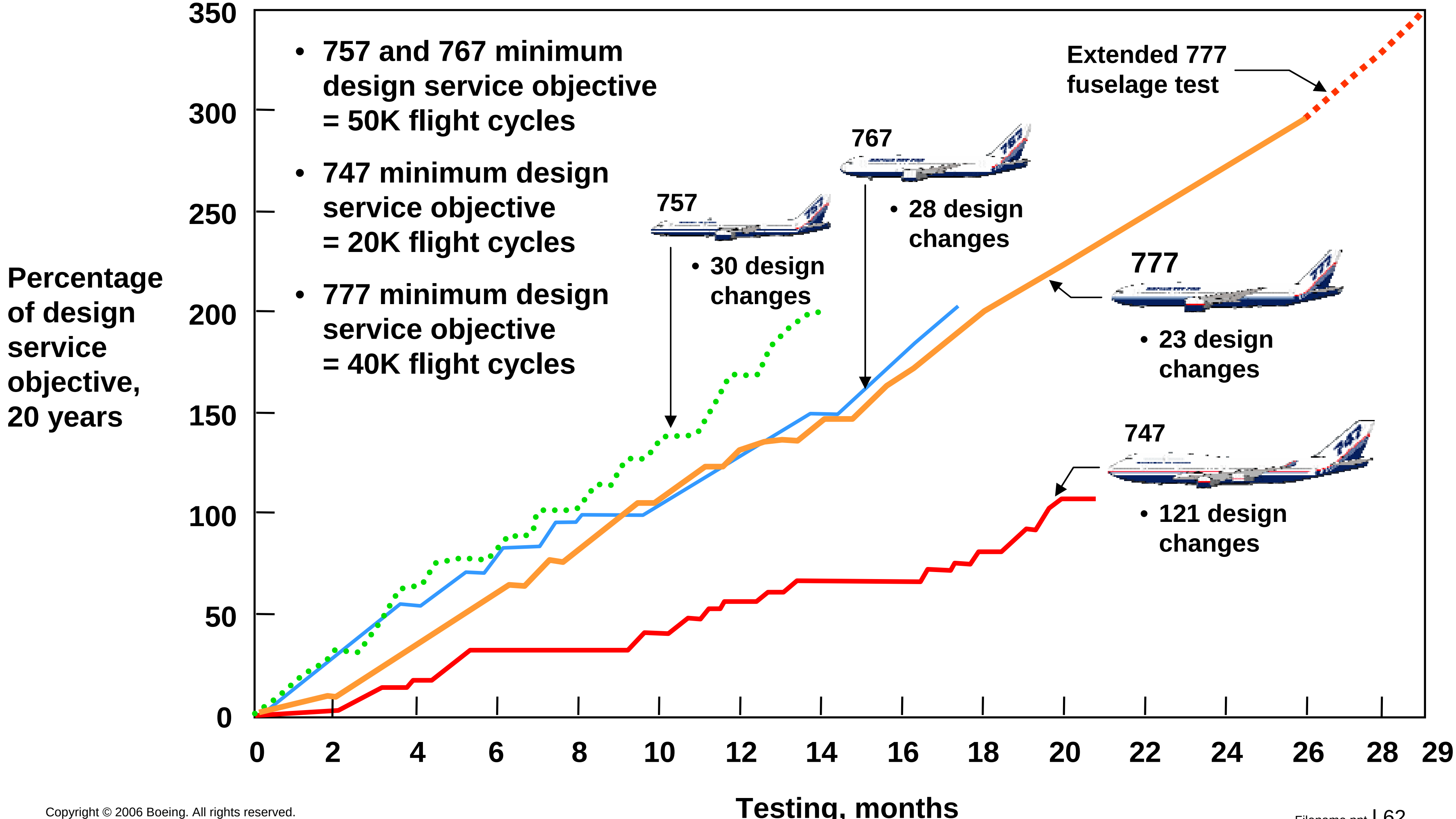


Boeing Full-Scale Fatigue Tests
Fleet Leader Test Margins

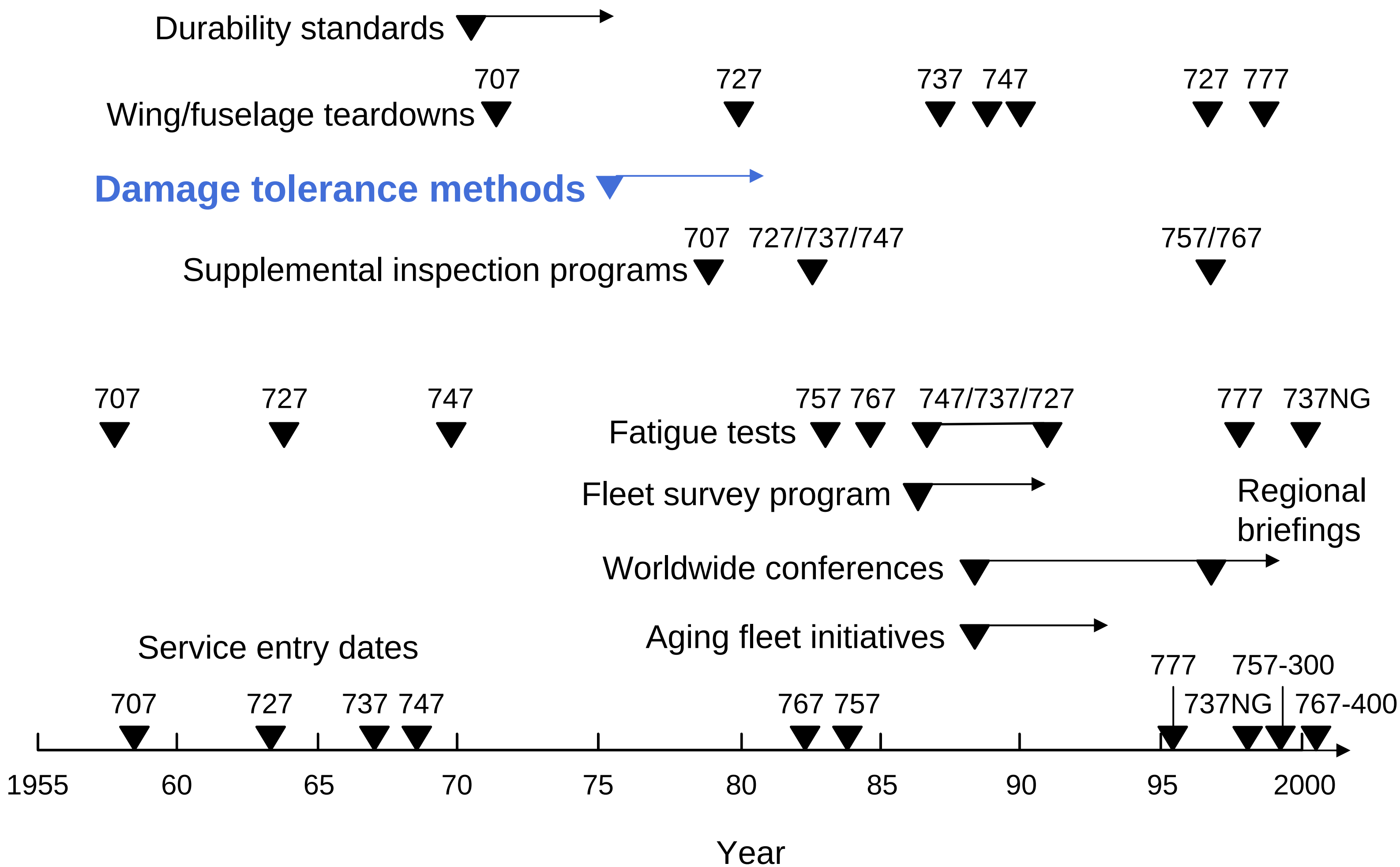


747 FATIGUE TESTS
Service Airplane and Redesigned Section 41

Major Airframe Fatigue Tests



Boeing Fleet Support Action
Damage Tolerance Methods



Elements of Damage Tolerance

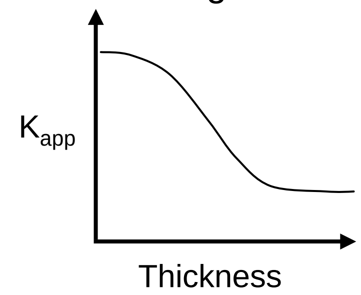
- **Residual Strength**
  - **Technology Standards**
  - **Test Verification**
  - **Lessons Learned**

Residual Strength

Residual Strength Parameters

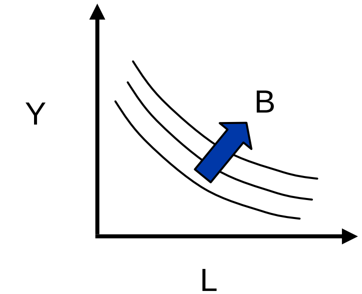
Material

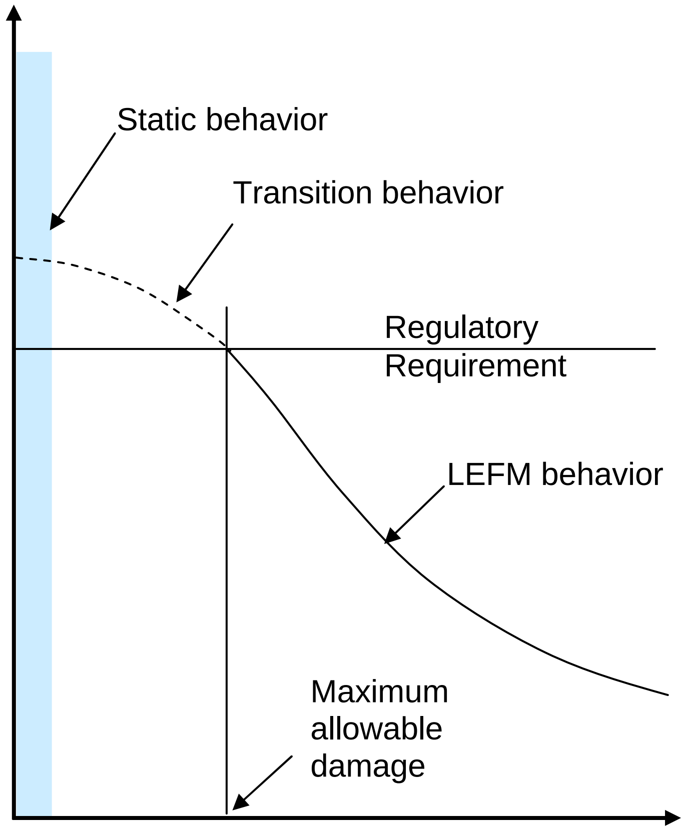
Fracture Toughness



Geometry

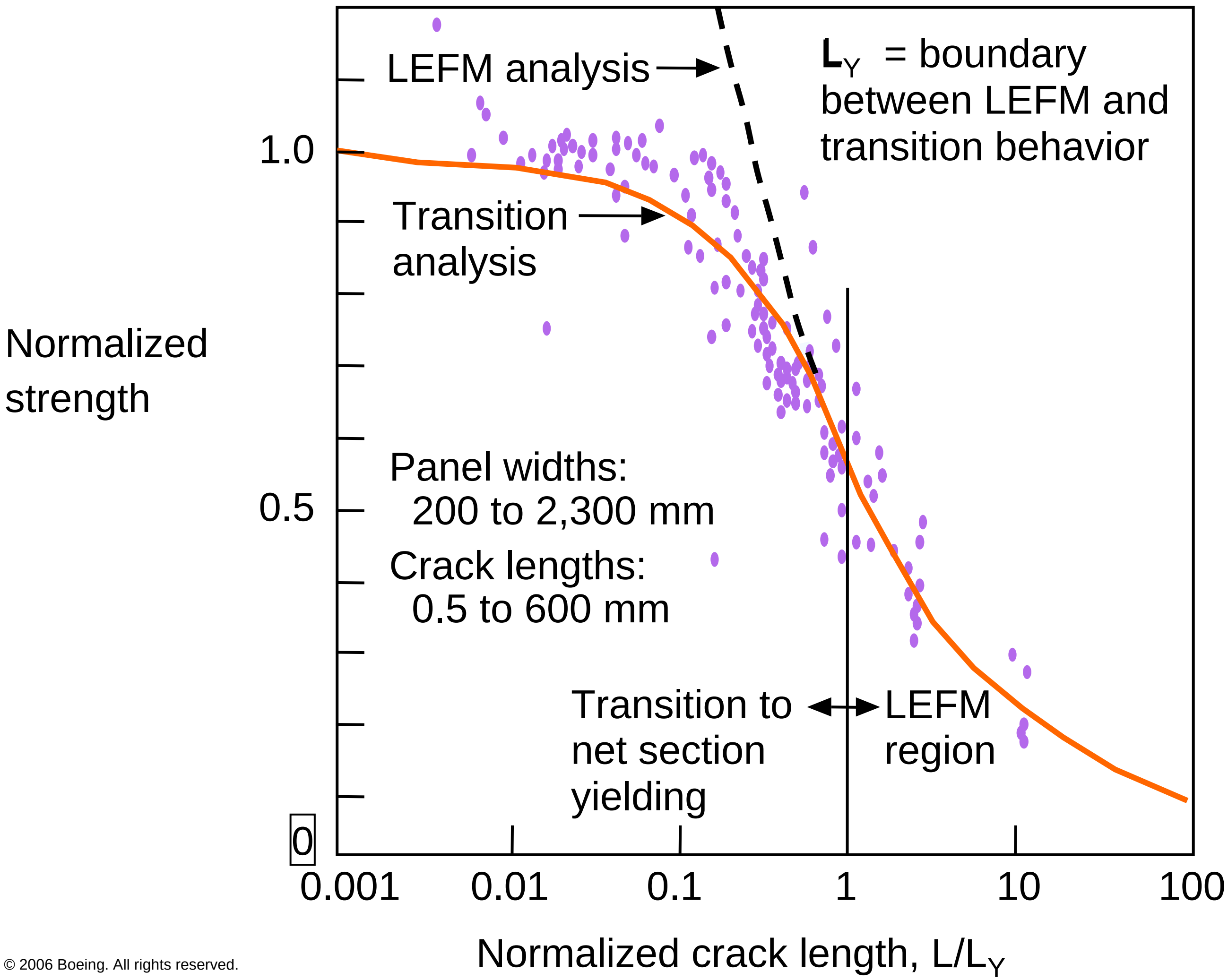
Geometry Correction Factor





Residual Strength Verification Data

Panel widths: 8”- 90” Crack Lengths: .02” - 24”

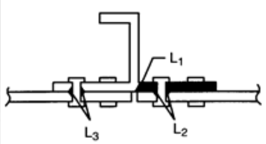
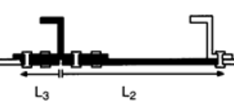


Cracking Patterns

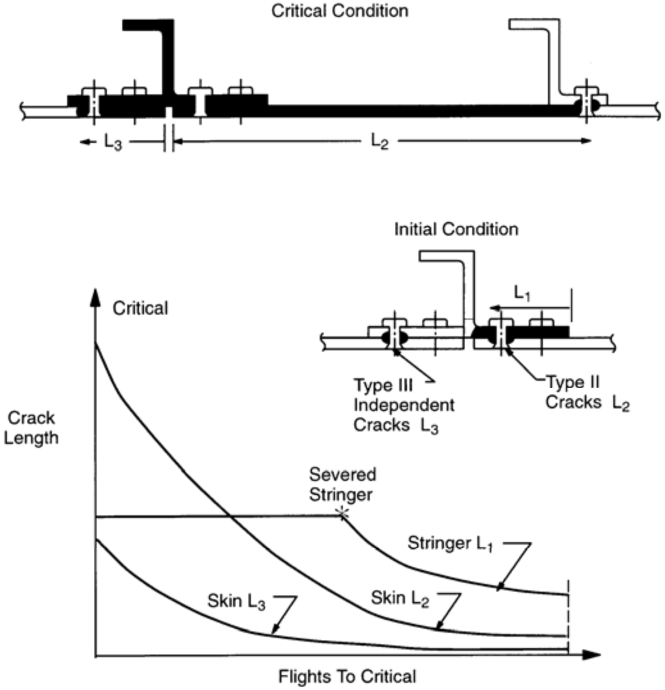
Stress Intensity Factors - Y   Redistribution Factors - C

- **Recommended crack configurations**
- **Based on experience and engineering judgement**

Cracking Pattern
Splice Stringer – Wing Lower Surface

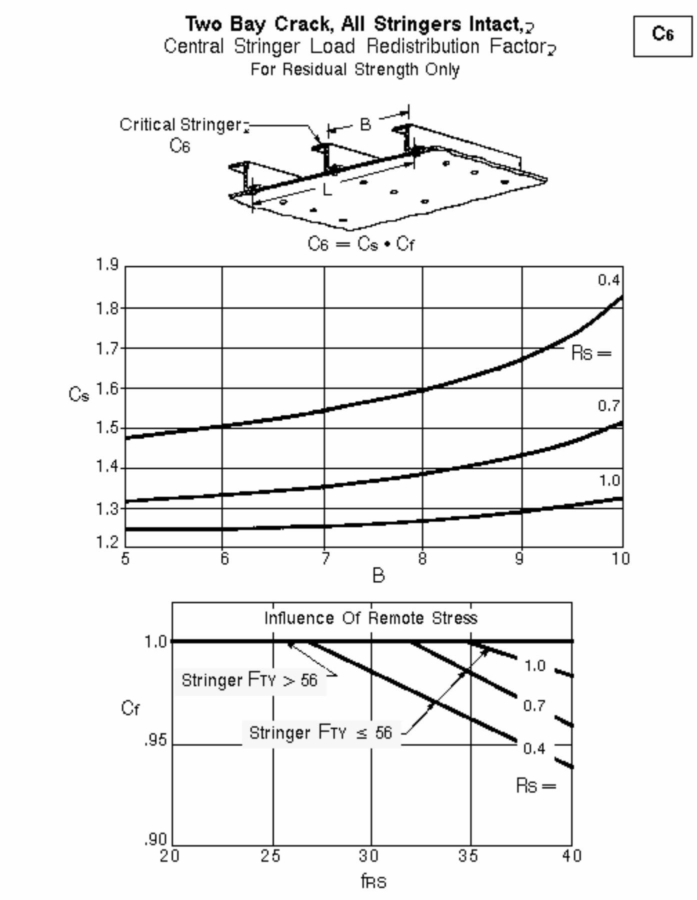
Damage Condition			Y And C Factor: Splice Stringer L_1	Y And C Factor: Skin L_2	Y And C Factor: Skin L_3	Y And C Factor: Adjacent Stringer
INITIAL		CRACK GROWTH	Lead $Y_{51.04}$ C = 1.0	Type II $Y_{51.11}$ $C_{23.1}$	Type III $Y_{51.11}$ $C_{23.2}$	Type III $Y_{50.01}$ C = 1.0
		RESIDUAL STRENGTH	$Y_{51.04}$ C = 1.0	$Y_{51.11}$ $C_{23.1}$	$Y_{51.11}$ $C_{23.2}$	$Y_{50.01}$ C = 1.0
INTERMEDIATE	 See Sec. 3 – Detail C	CRACK GROWTH	Severed	$Y_{51.18}$ C = 1.0	$Y_{51.17}$ C = 1.0	$Y_{50.01}$ C_{15}
		RESIDUAL STRENGTH	—	$Y_{51.20}$ C = 1.0	$Y_{51.19}$ C = 1.0	$Y_{50.01}$ C_{16}
ADVANCED		CRACK GROWTH	—	$Y_{51.28}$ C = 1.0	$Y_{51.28}$ C = 1.0	$Y_{50.01}$ C_{15}
		RESIDUAL STRENGTH	—	Y – N.A. C – N.A.	Y – N.A. C – N.A.	$Y_{50.01}$ C_{16}

Cracking Pattern
Splice Stringer – Wing Lower Surface

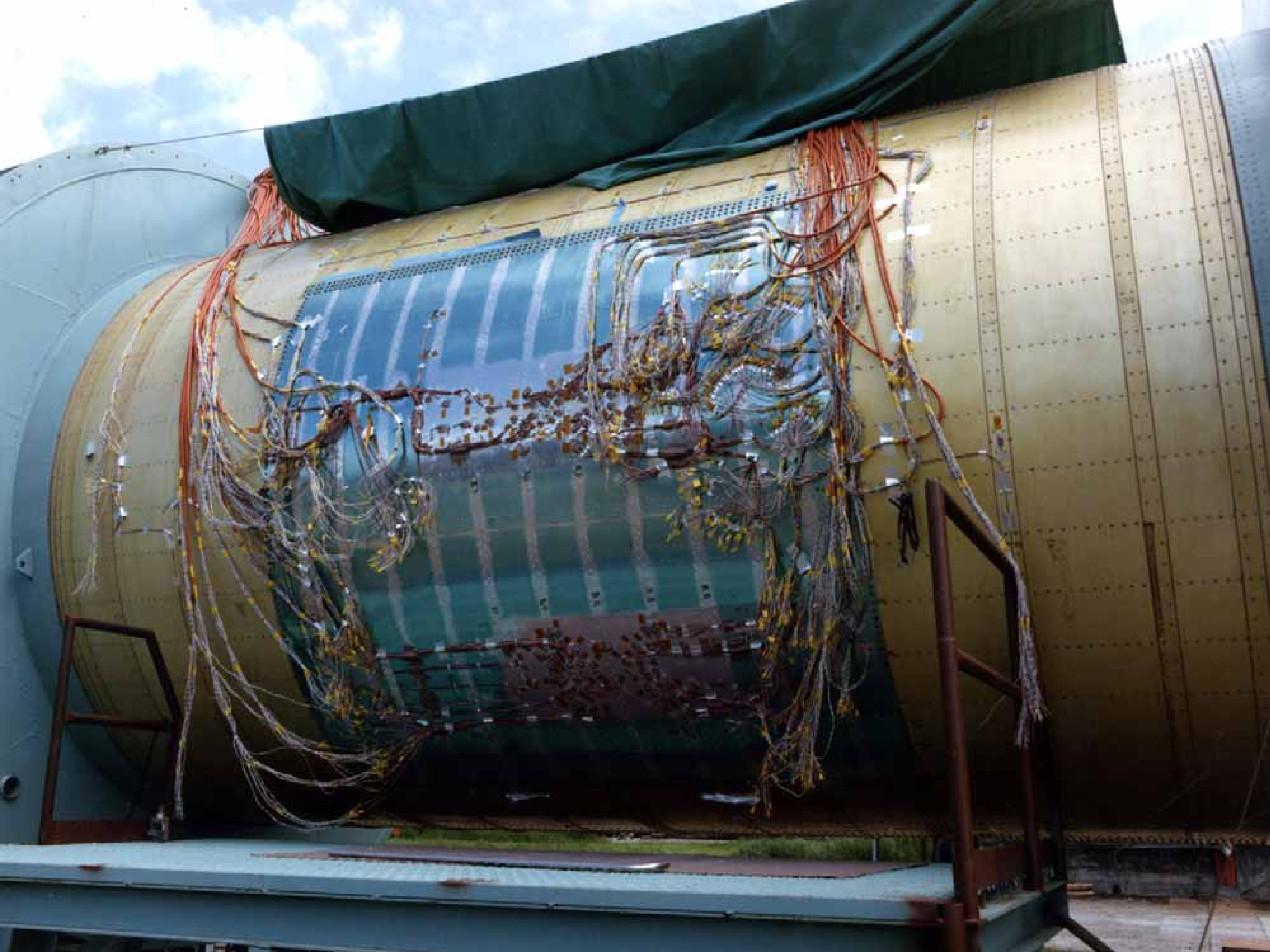


Load Redistribution Factors - C

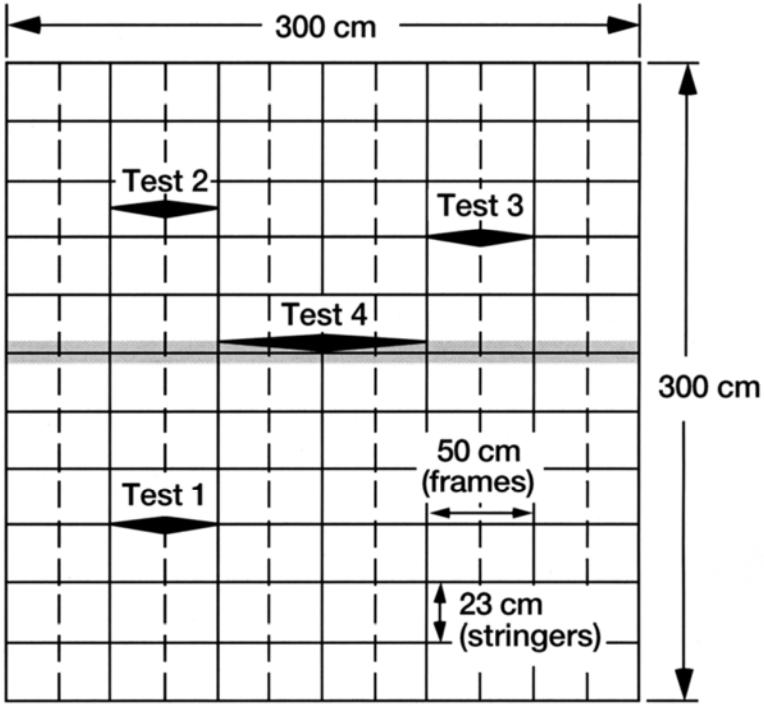
- **C factors account for change in reference stress due to cracks in adjacent parts**



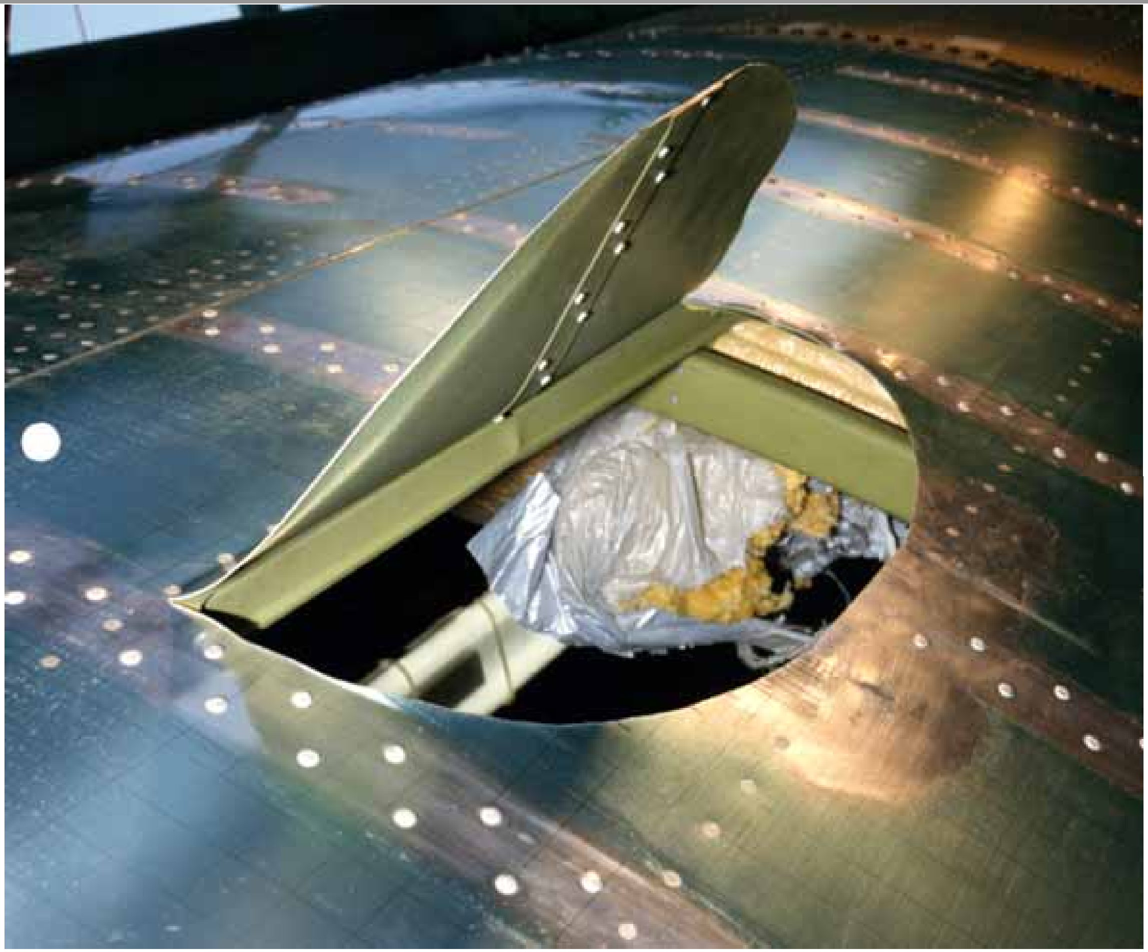
Fuselage Pressure Test Fixture



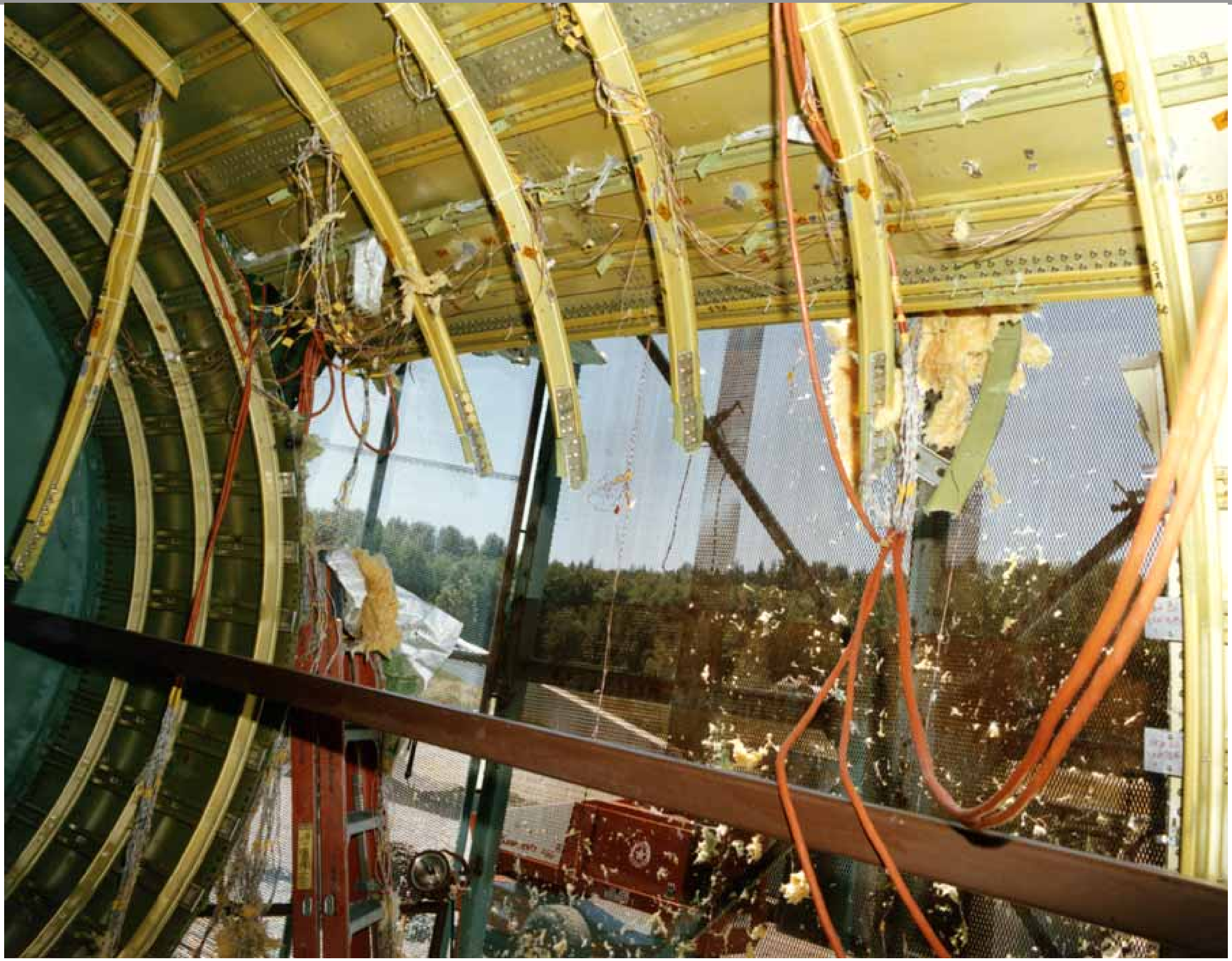
Typical Pressure Test Panel



Verification Test - Safe Decompression

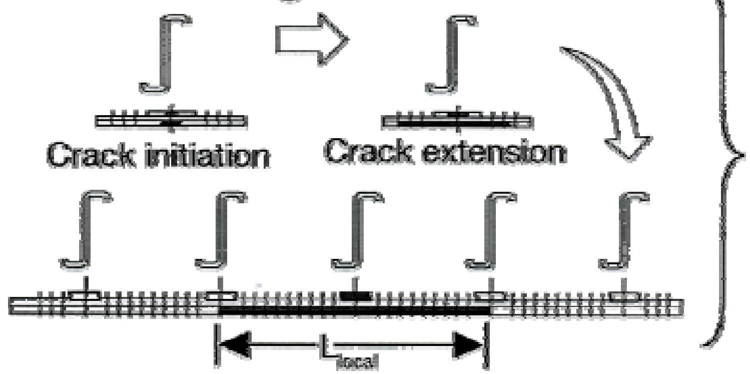


Fuselage Test Panel - Riveted Tear Straps
Dynamic Crack Extension (20 in. to 100 in.)



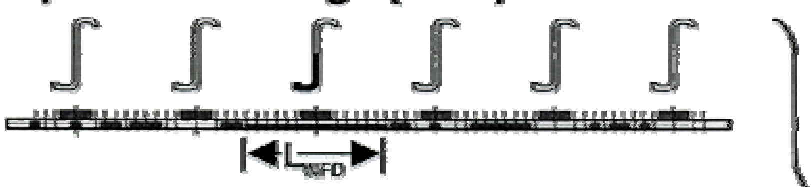
Local Damage Versus MSD or MED

- **Local damage**

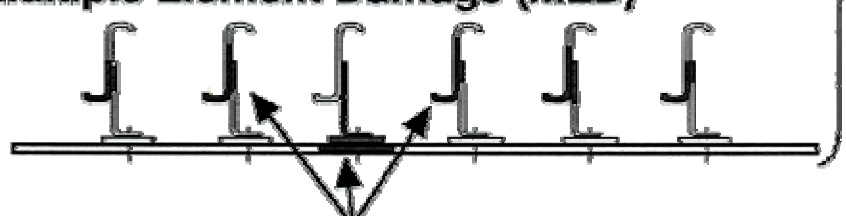


- Maximum allowable damage shown
- Damage connection up to this size is tolerated
- No significant damage beyond this region
- All MSD or MED within this area is local and already accounted for in damage tolerance analysis

- **Multiple Site Damage (MSD)**

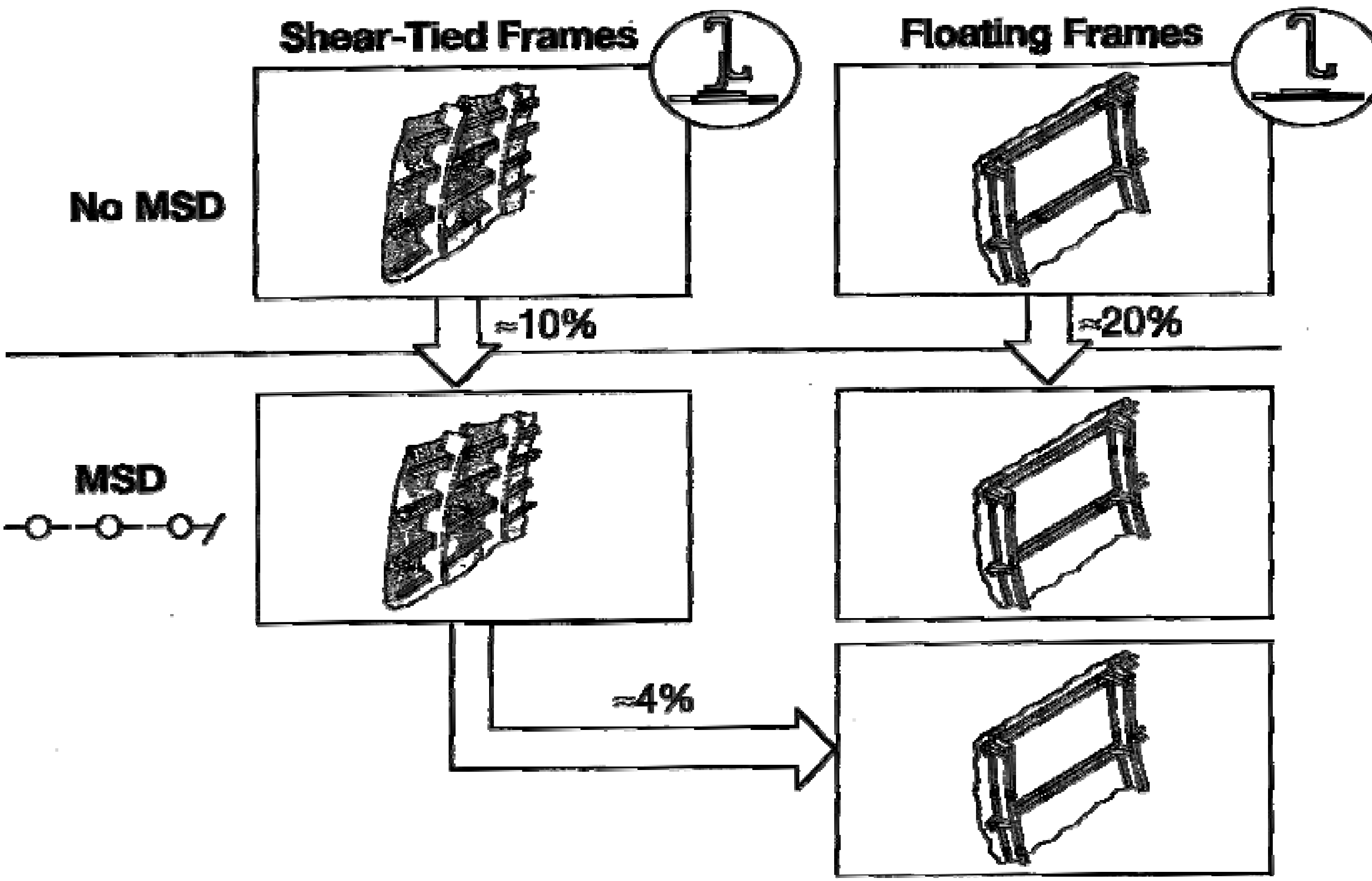


- **Multiple Element Damage (MED)**



- Widespread similar details
- Similar stresses
- Structural interaction with reduced allowable damage

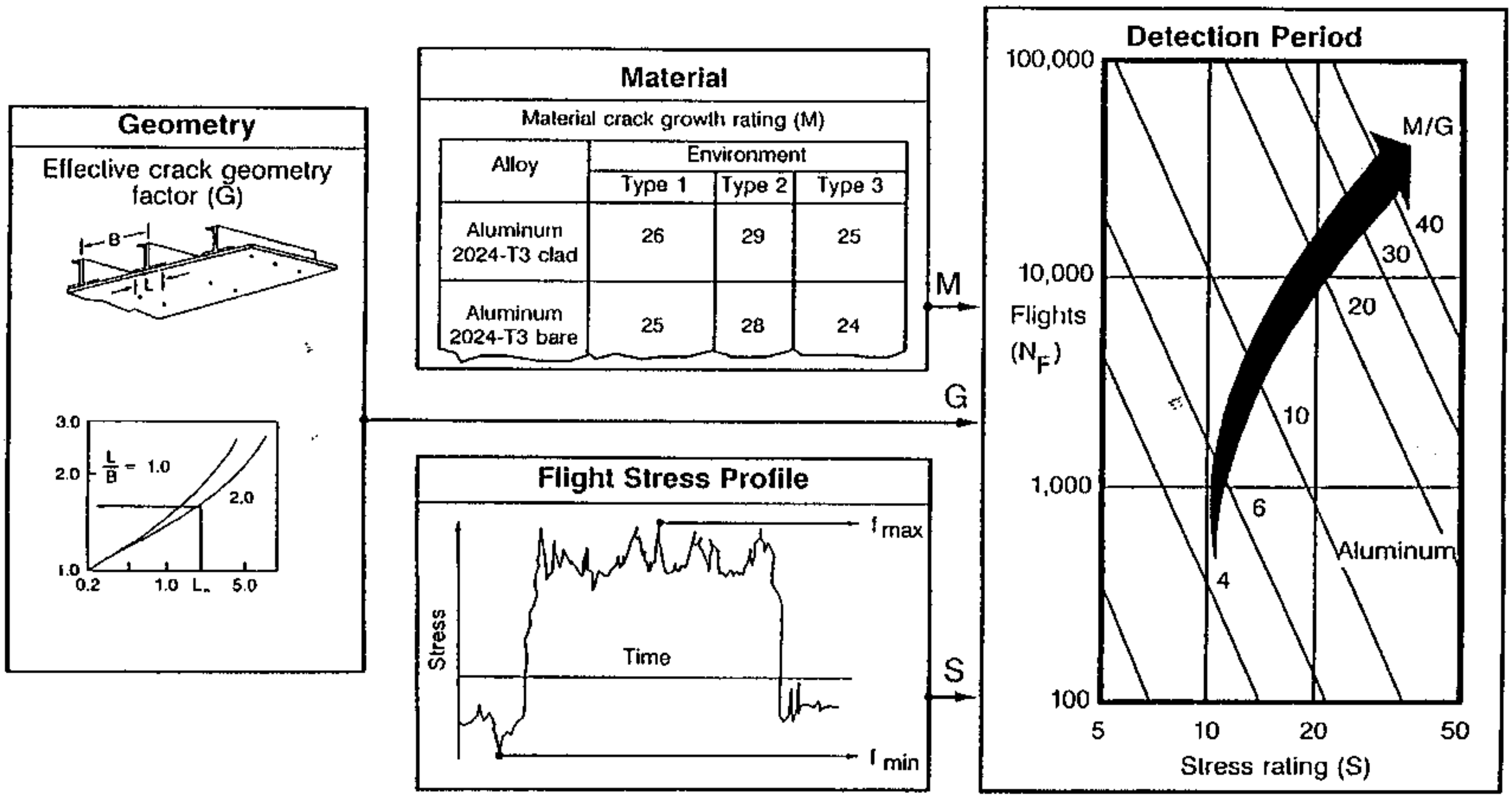
Lap Joint Residual Strength Comparison



Elements of Damage Tolerance

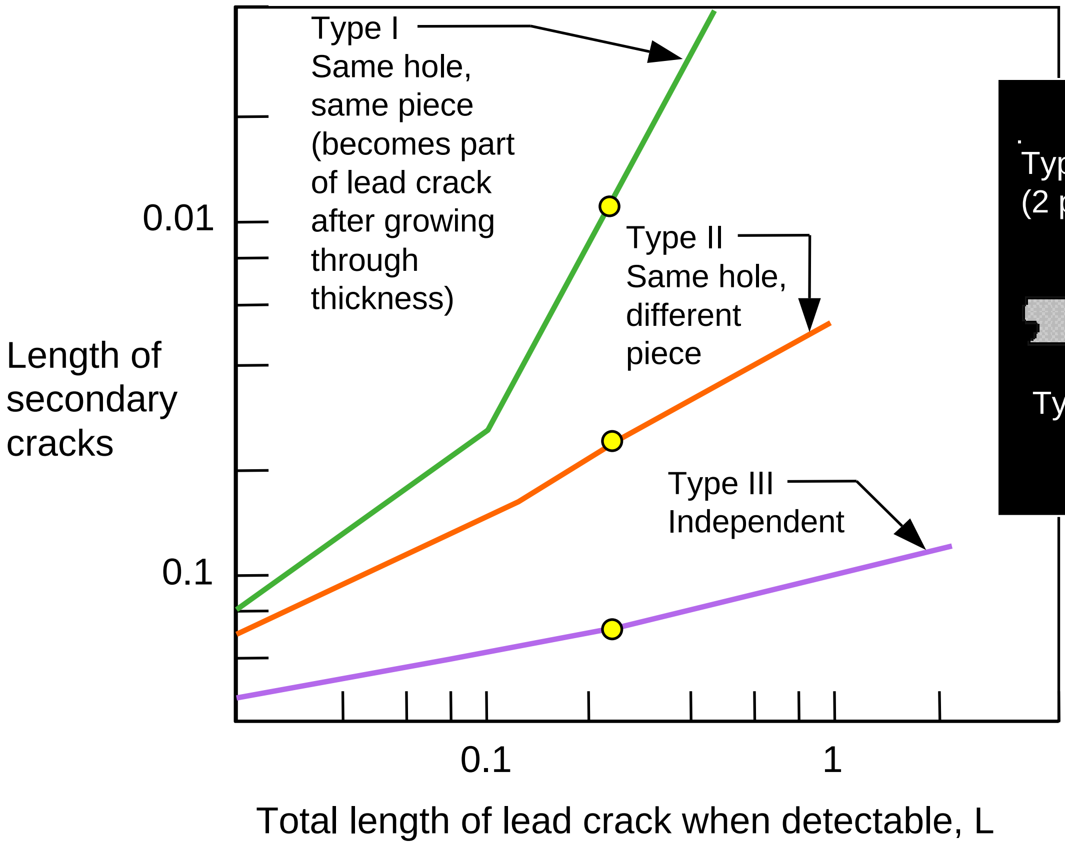
- Residual Strength
- **Crack Growth**
  - **Technology Standards**
  - **Test Verification**
  - **Lessons Learned**

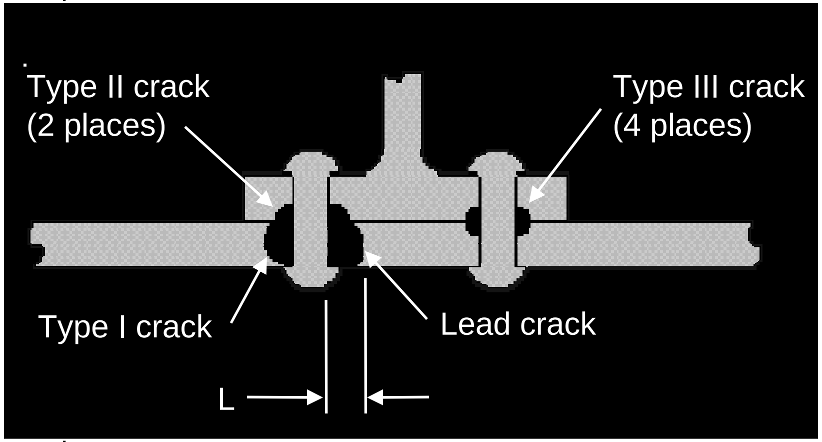
Crack Growth Technology Standards



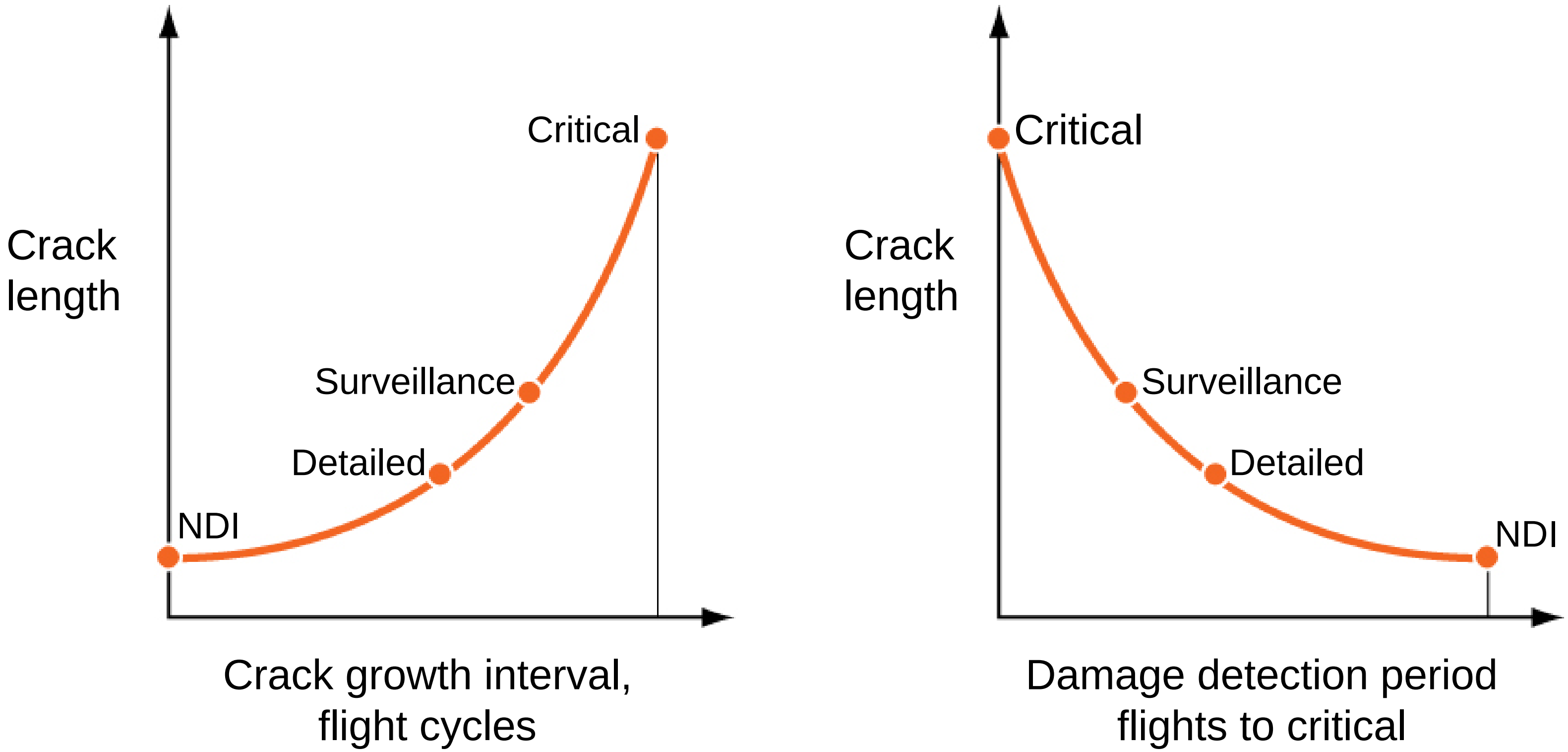
Local Multiple-Site Criteria

I: Same Hole & Piece   II: Same Hole / Different Piece

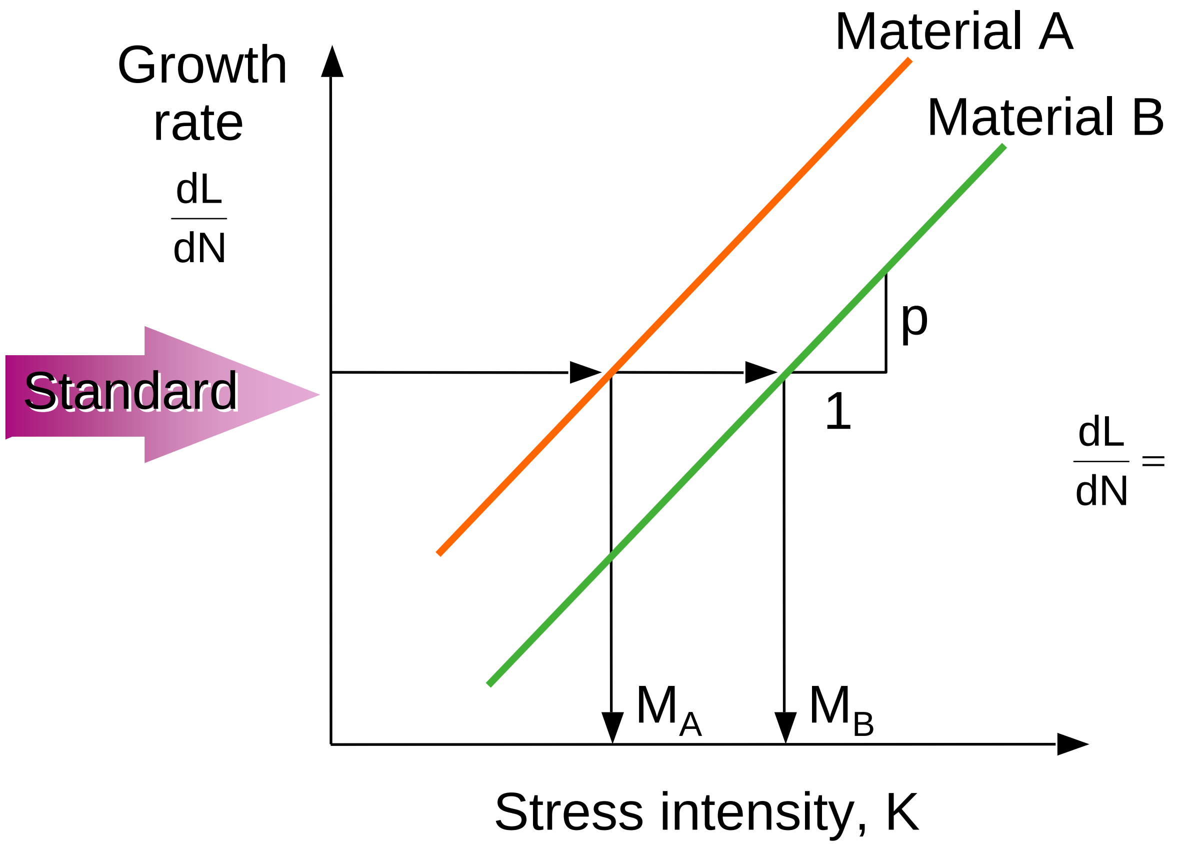




Damage Detection Period
Flights to Critical Crack Size



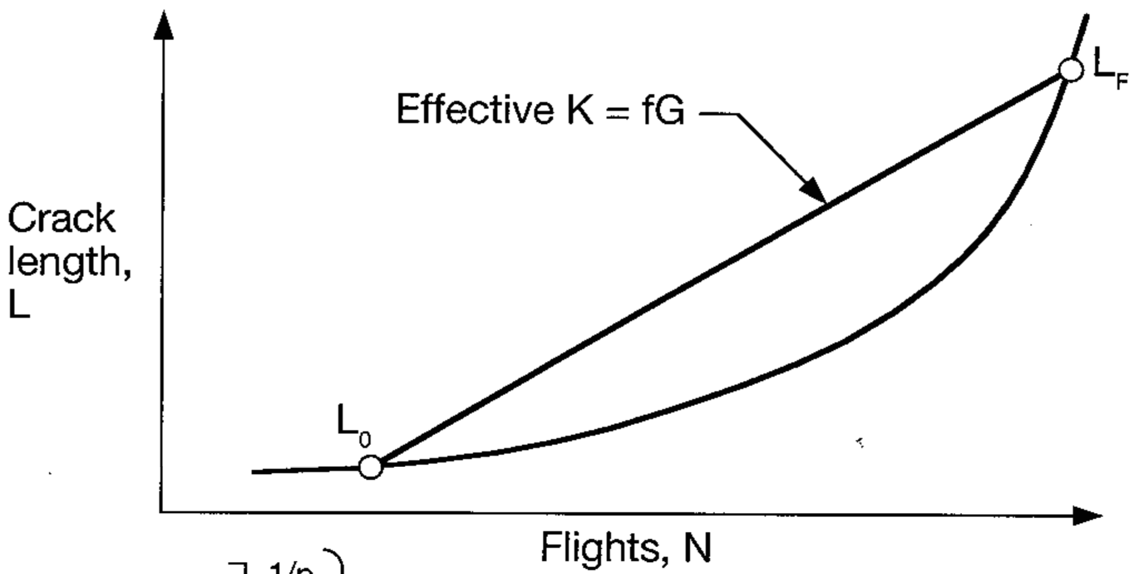
Material Crack Growth Rating Concept



$$\frac{dL}{dN} = n \cdot 10^{-4}\left(\frac{K_{max}Z^{p}}{M}\right)$$

M—Measures relative material resistance to crack growth

Geometry Factor Concept
Stress Intensity Factor for Unit Stress - (L1 to L2)

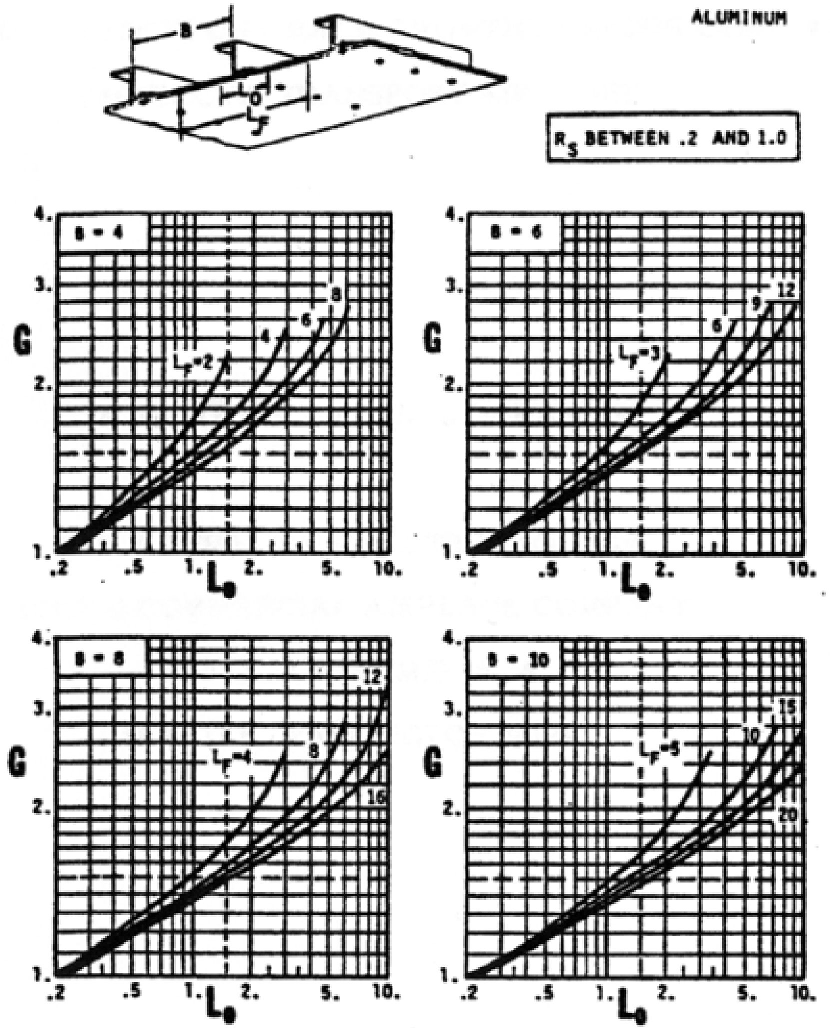


$$G = \left[\frac{1}{n} \int_{L_0}^{L_F} \frac{dL}{\left(\sqrt{\frac{\pi L}{n}}\, Y \right)^p} \right]^{-1/p}$$

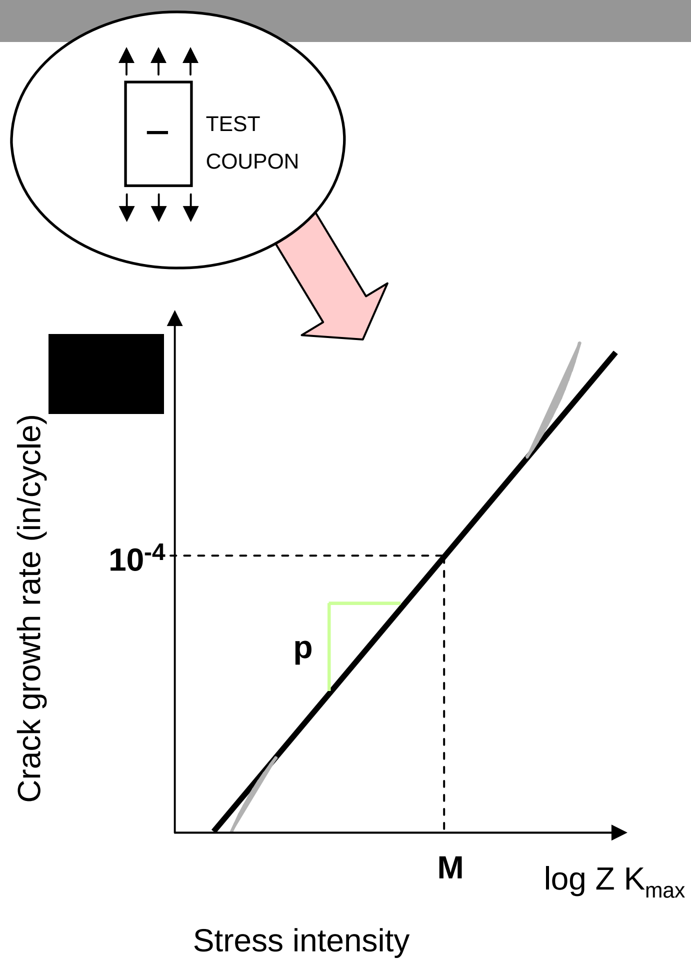
where $K = f \sqrt{\frac{\pi L}{n}}\, Y$

G is effective stress intensity for unit stress

Simple Chart for Geometry Integral G



Crack Growth Rate Equation



M & p = Material crack growth rate parameters

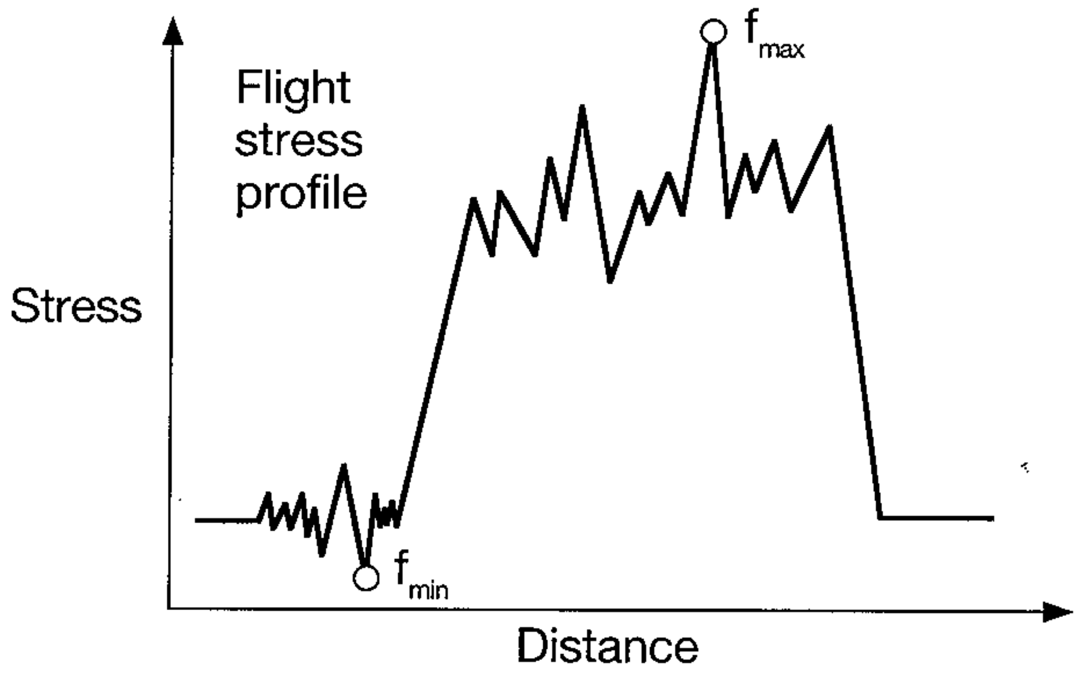
- Measures relative material resistance to crack growth
- Reflects effect of environment

$$\frac{dL}{dN} = n \cdot 10^{-4} \left(\frac{Z \cdot K_{max}}{M} \right)^{p}$$

where

$$Z = \begin{cases} (1-R)^{q} & 0.0 < R < 1.0 \\ 1-0.1 \cdot R & -1.0 < R \leq 0.0 \\ 1.1 & R \leq -1.0 \\ 0 & R \geq 1.0 \end{cases}$$

Stress Rating – Equivalent Stress Concept
Crack Growth Spectrum Effects Measure



Ground-
Air-
Ground-

Maximum stress - f_{max}
Minimum stress - f_{min}
Damage ratio

S is a normalized measure of these three values

Test Spectra Characteristics

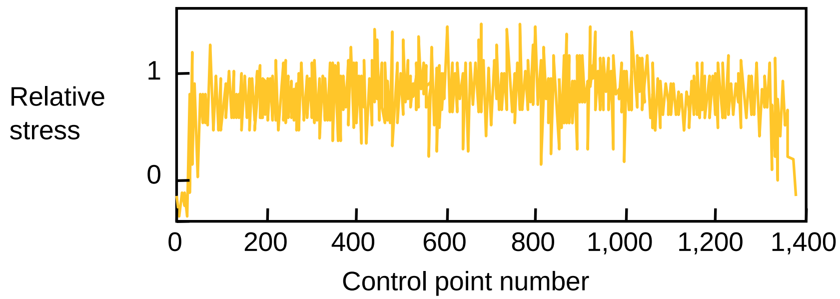
5x5 Spectra: 5 Flight Types & 5 Levels per segment

Spectrum type		Spectrum loaded segments	Spectrum load levels	Average cycles per flight	Flight types
10 x 5,000	• Half cycles selected at random (peak follows valley • Sequence of segment severity selected at random	8 per flight	**10** per segment	100	**5,000**
5 x 5 [1]	• Half cycles selected at random (peak follows valley) • Distribution of flight types selected at random	8 per flight	**5** per segment	50	**5**
1 x 1	• Load magnitudes selected at once-per-flight occurrence level	8 per flight	**1** per segment	25	**1**

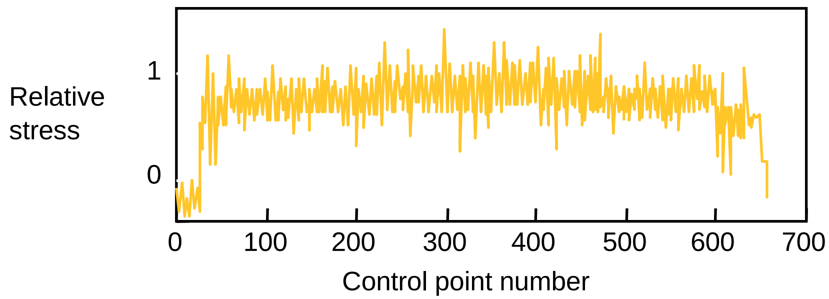
[1] More than 10 repeated load sequences per design service objective.

Wing Lower Surface Spectrum
(5x5 Spectra - Flight Mix)

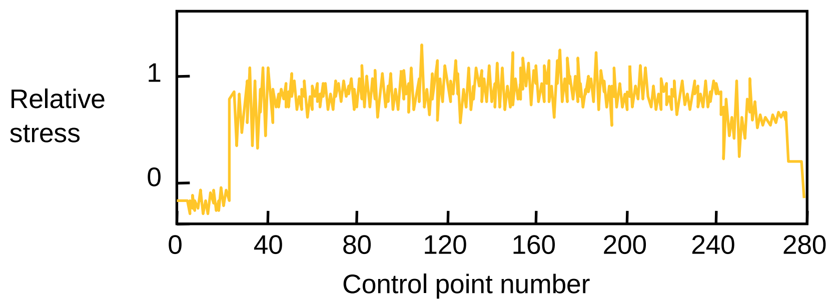
Flight A (Applied One Times per 5,000 Flights)



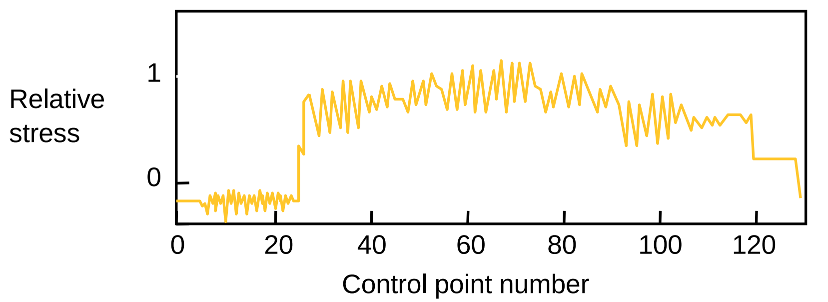
Flight B (Applied 13 Times per 5,000 Flights)



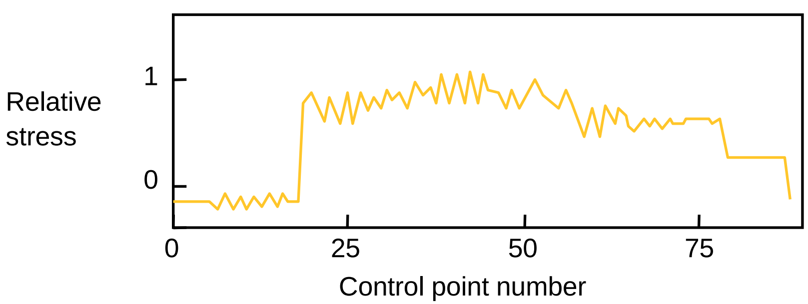
Flight C (Applied 215 Times per 5,000 Flights)



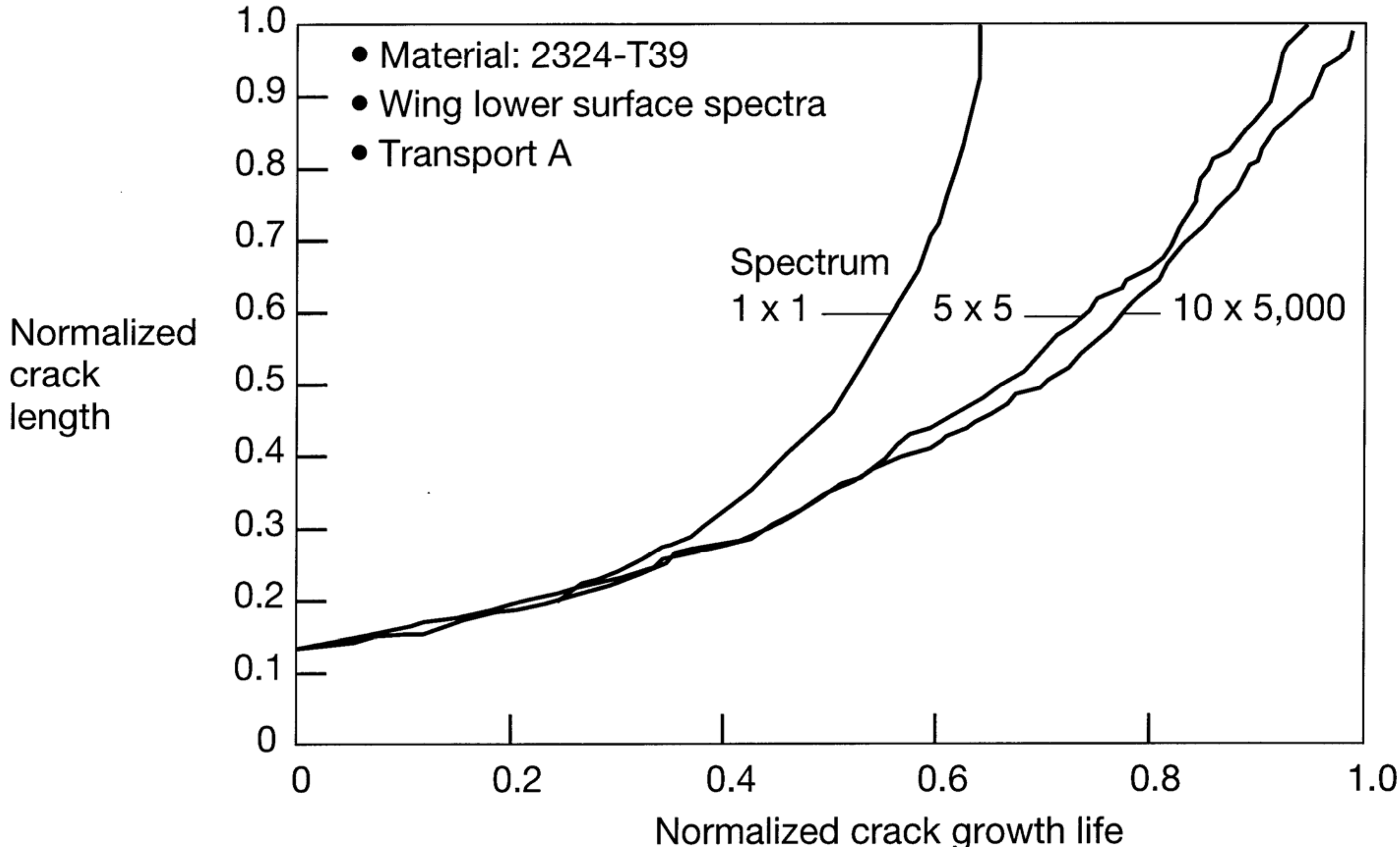
Flight E (Applied 1,067 Times per 5,000 Flights)



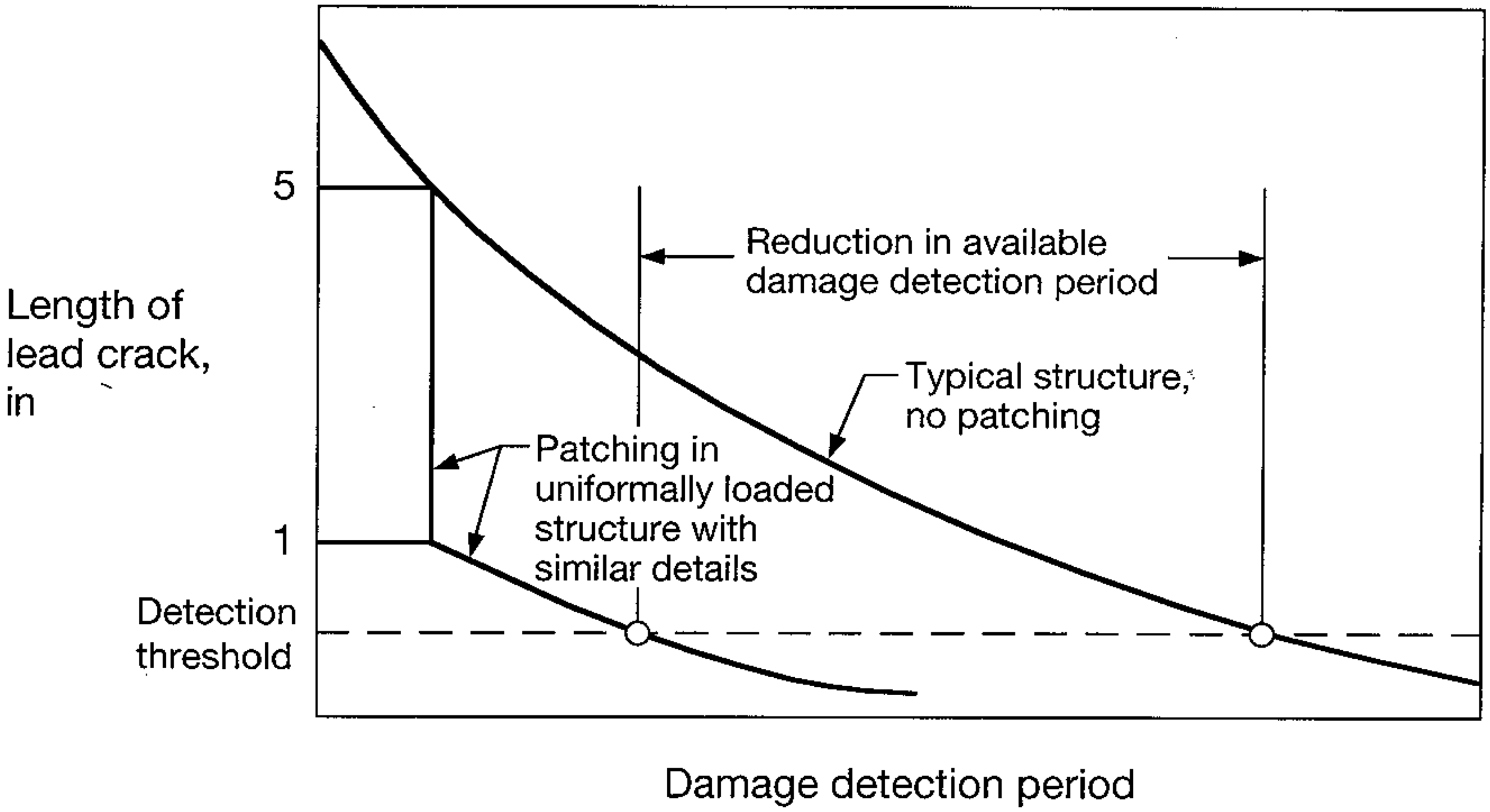
Flight E (Applied 3,704 Times per 5,000 Flights)



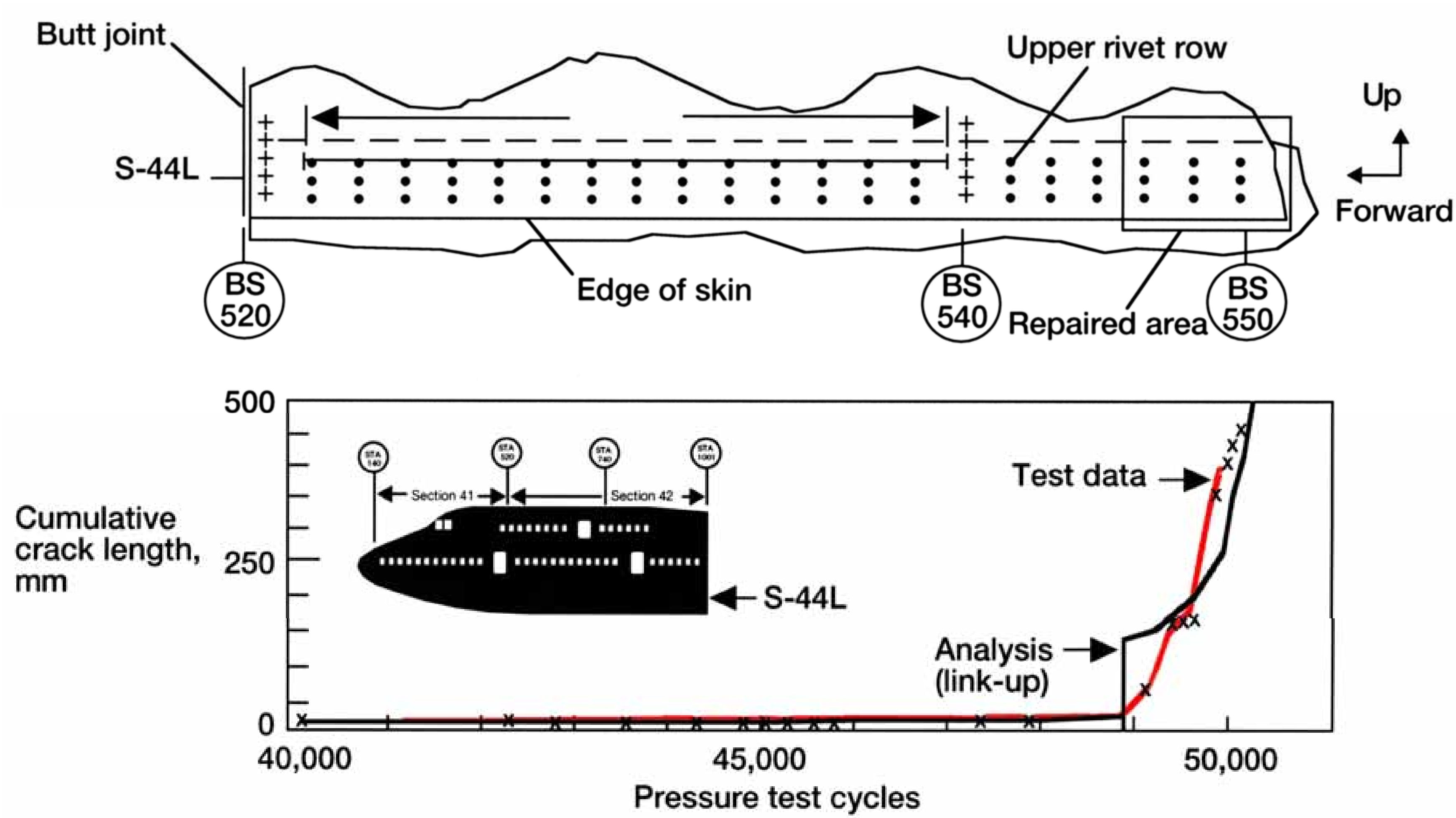
Effect of Spectrum Complexity



Multiple-site Damage - Link-up Criteria
Effects on Detection Period



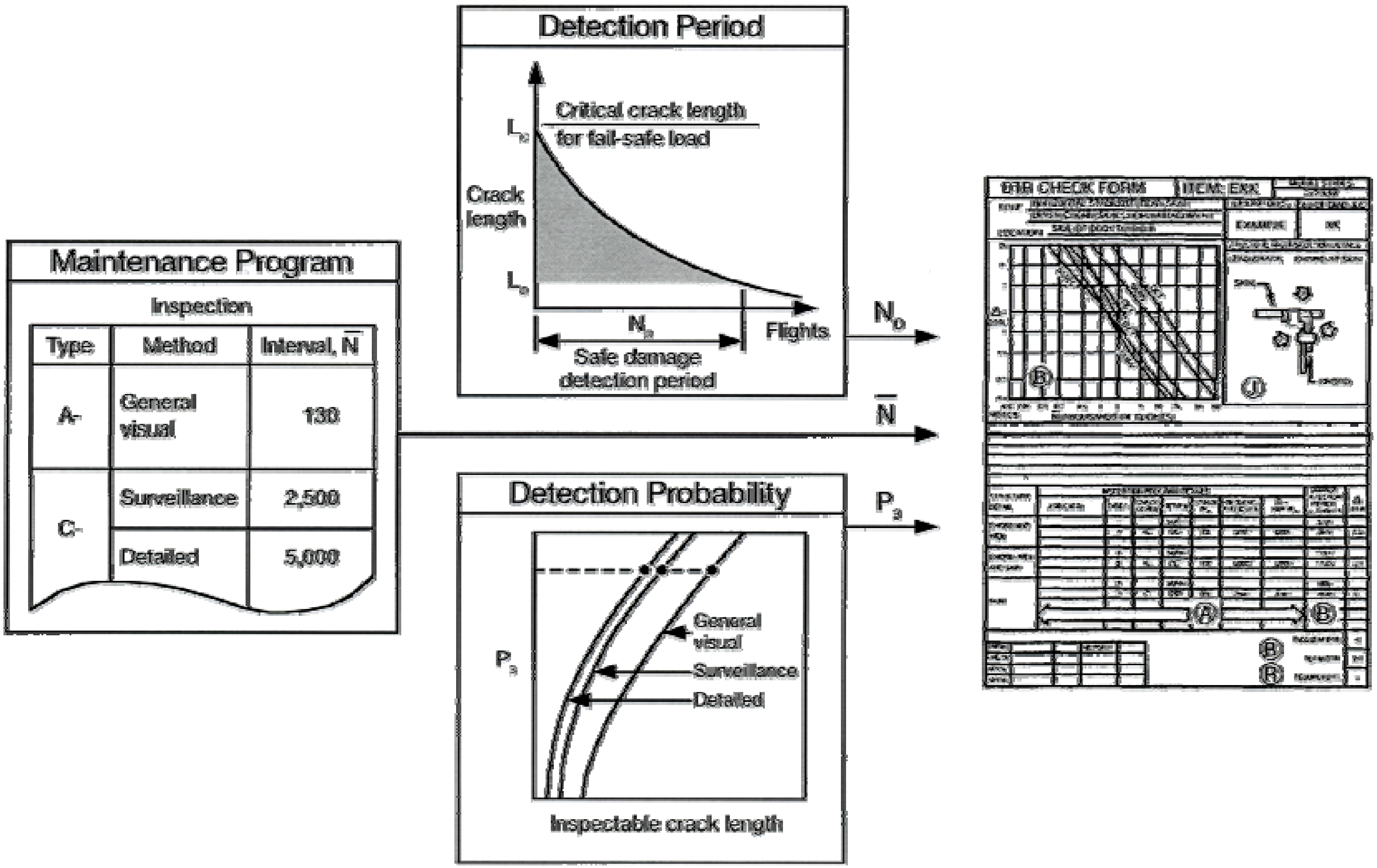
MSD Link- up Comparison
747-400 Fuselage Lap Splice Test – Stringer 44Left



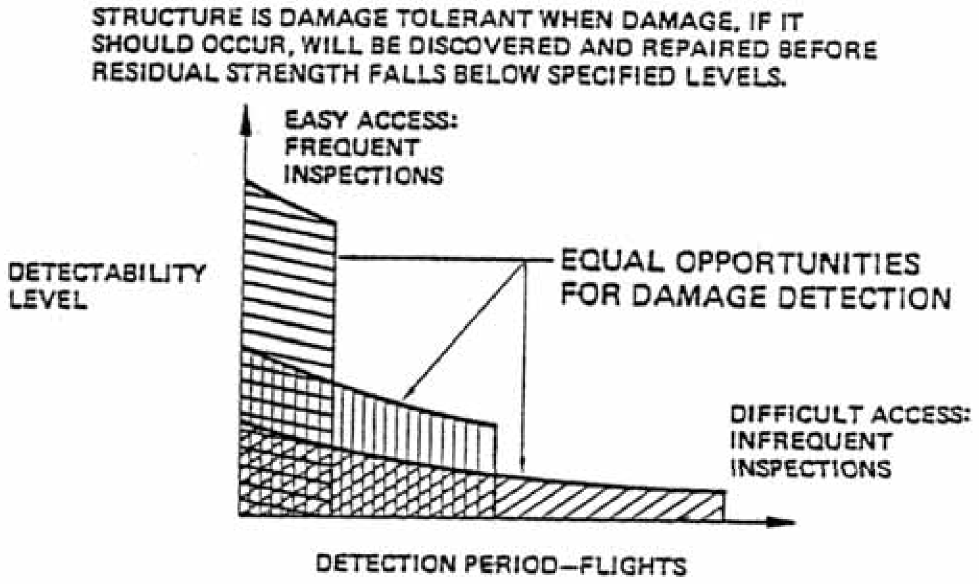
Elements of Damage Tolerance

- Residual Strength
- Crack Growth
- **Damage Detection**
  - **Technology Standards**
  - **Test Verification**
  - **Lessons Learned**

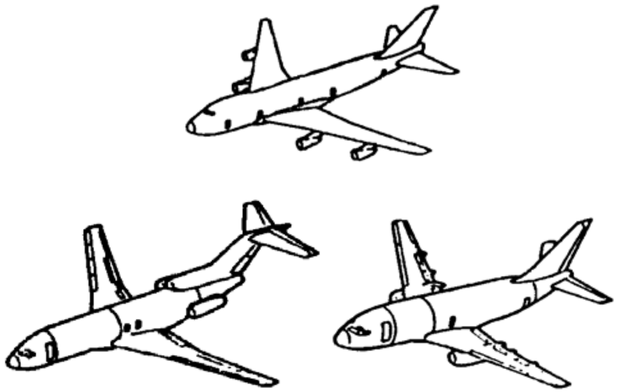
Damage Detection Parameters

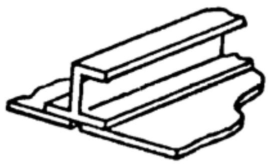


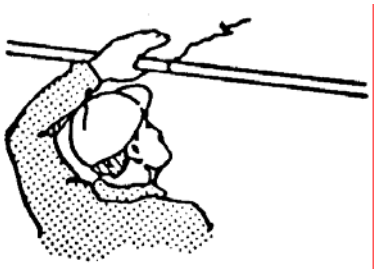
Opportunities for Damage Detection



Damage Detection Considerations







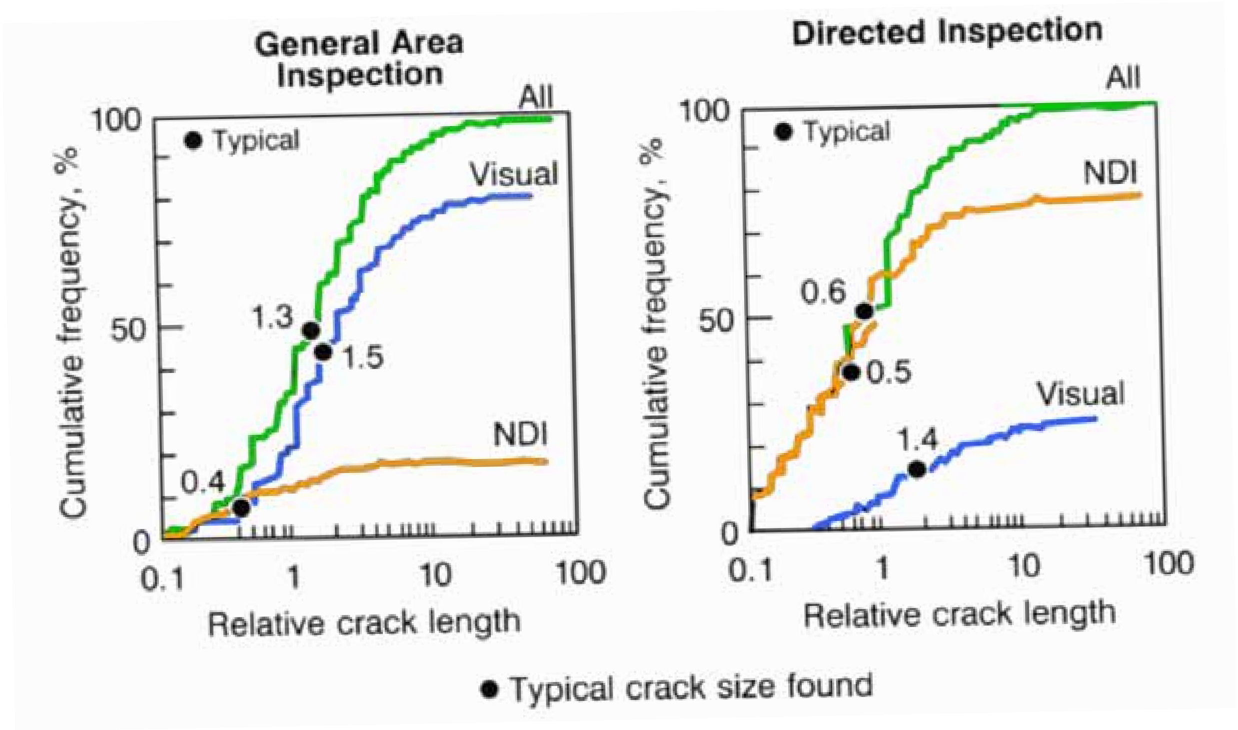
Probability of inspecting an aircraft with damage

Probability of inspecting detail considered

Probability of crack detection

Probability of detecting damage

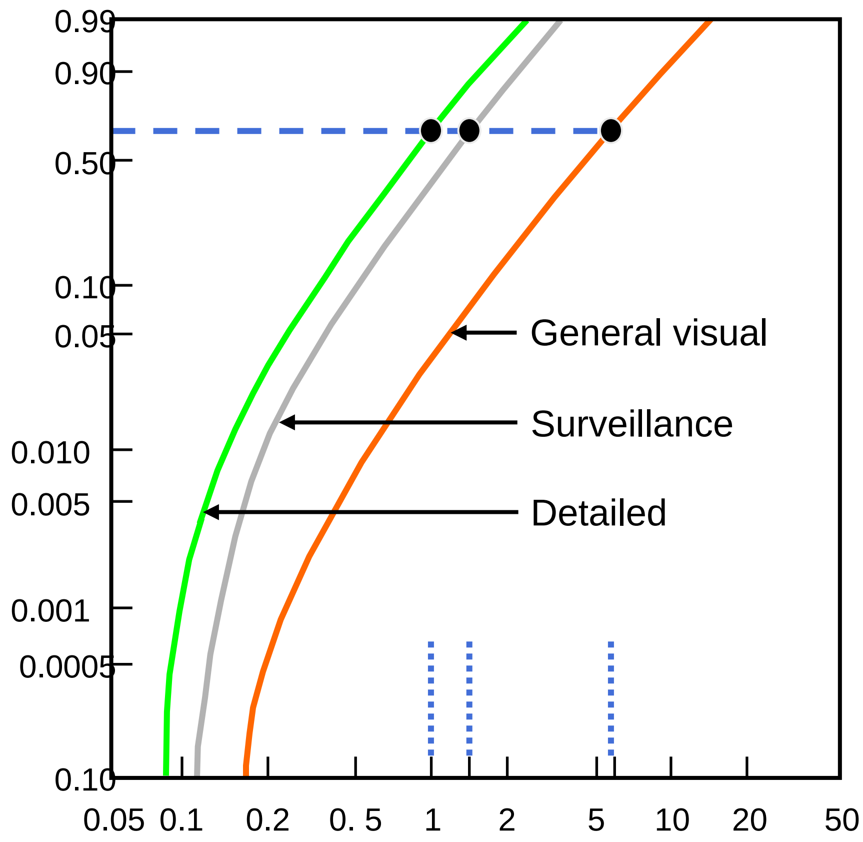
Distributions of Cracks Found in Service



Relative Probability of Detection
Visual Inspection Methods

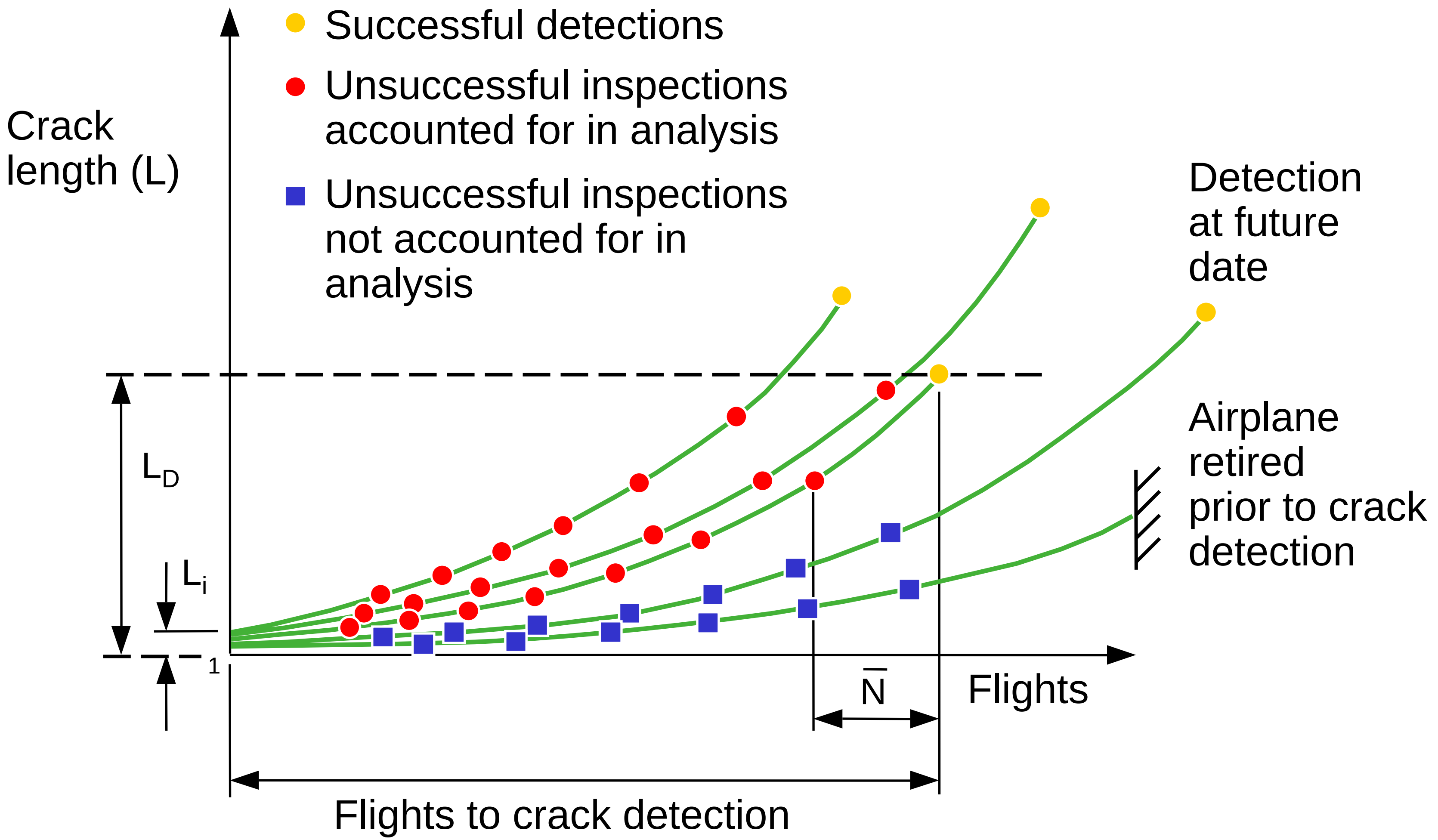
Probability of detection

$(\hat{P}_3)$

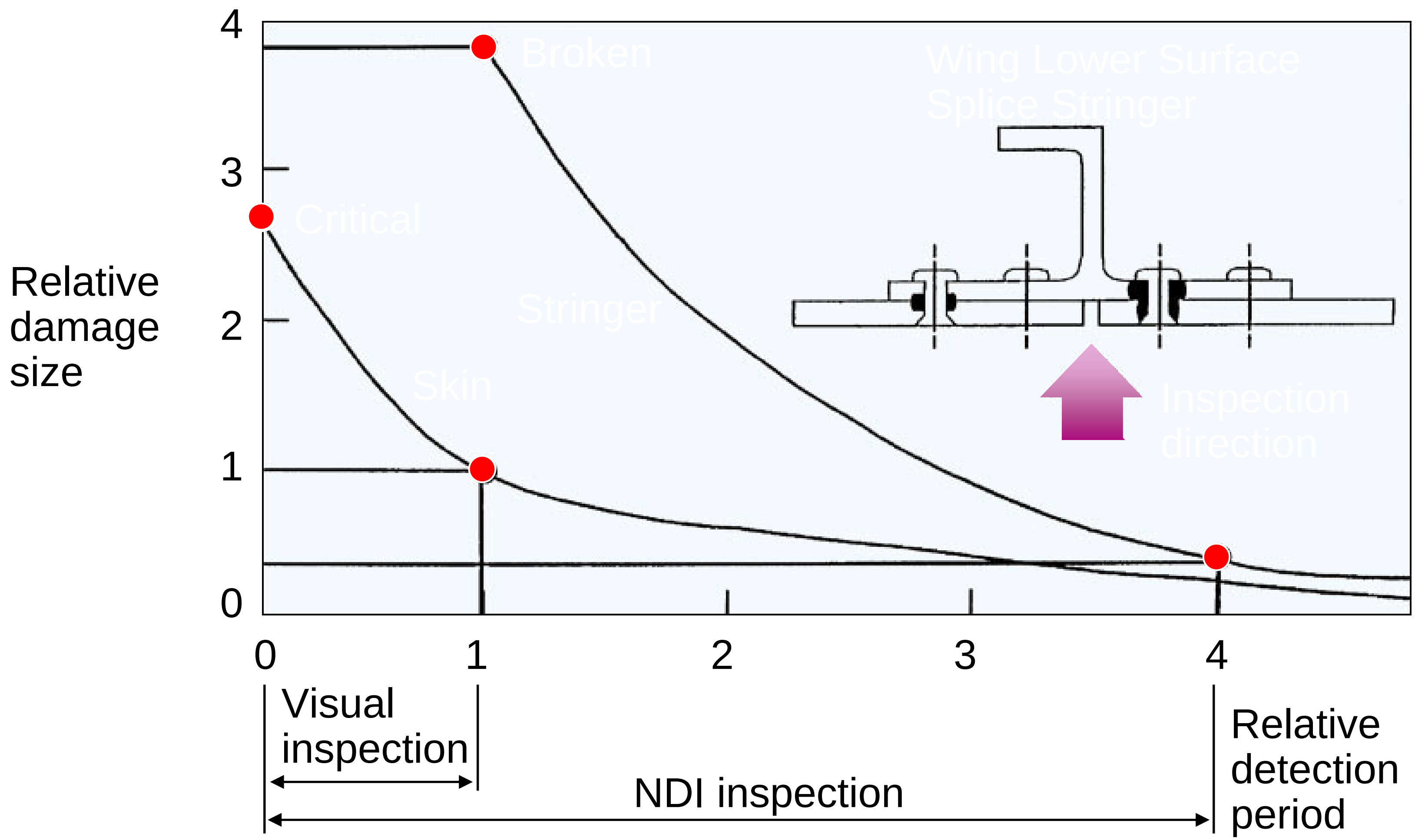


Relative inspectable crack length

Detection and Non-detection Events

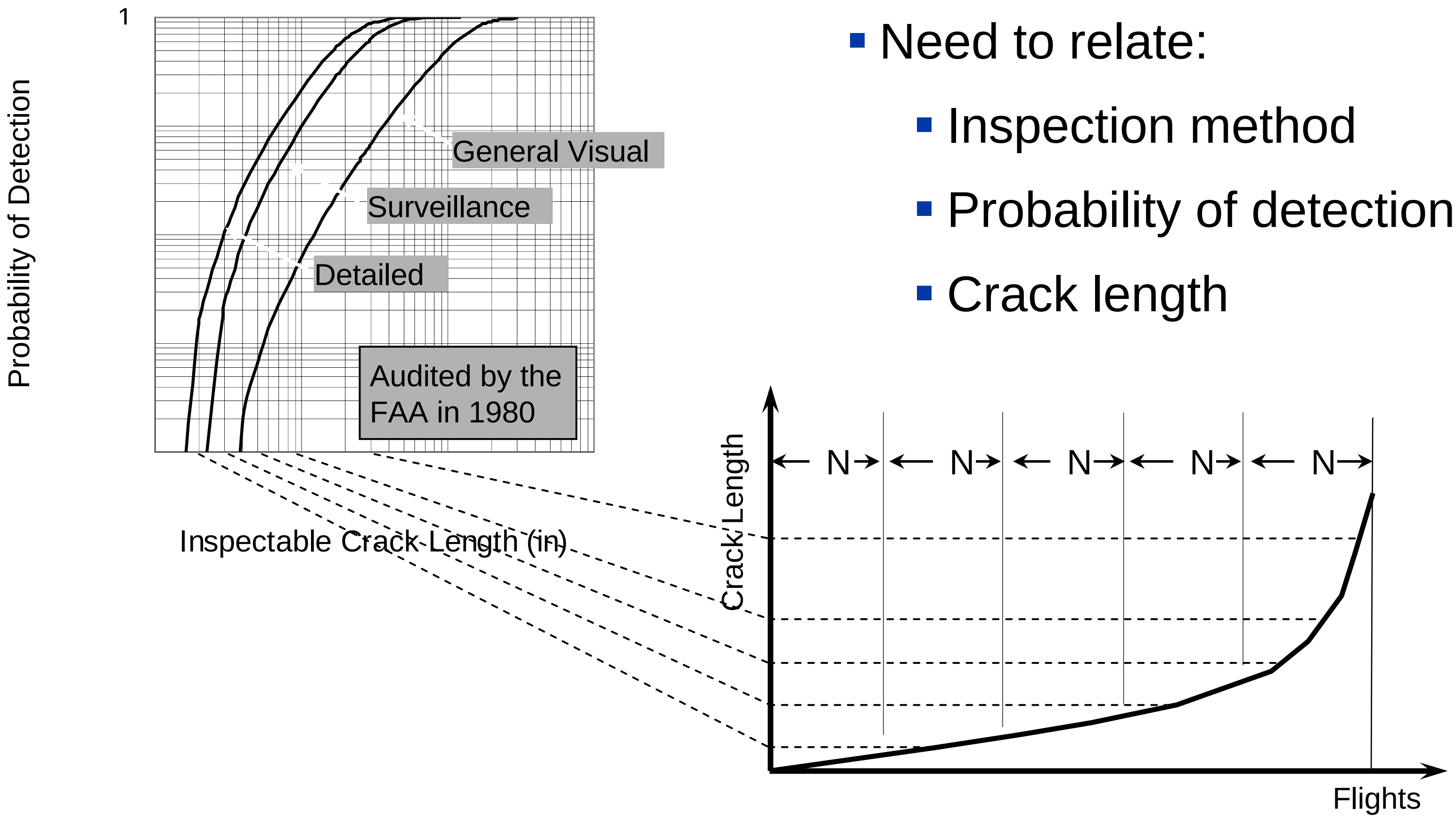


Visual and NDI Damage Detection Periods



Probability of Detection Parameters
Visual Inspections

- Need to relate:
  - Inspection method
  - Probability of detection
  - Crack length



Safe damage detection period

Probability of Crack Detection, P_D

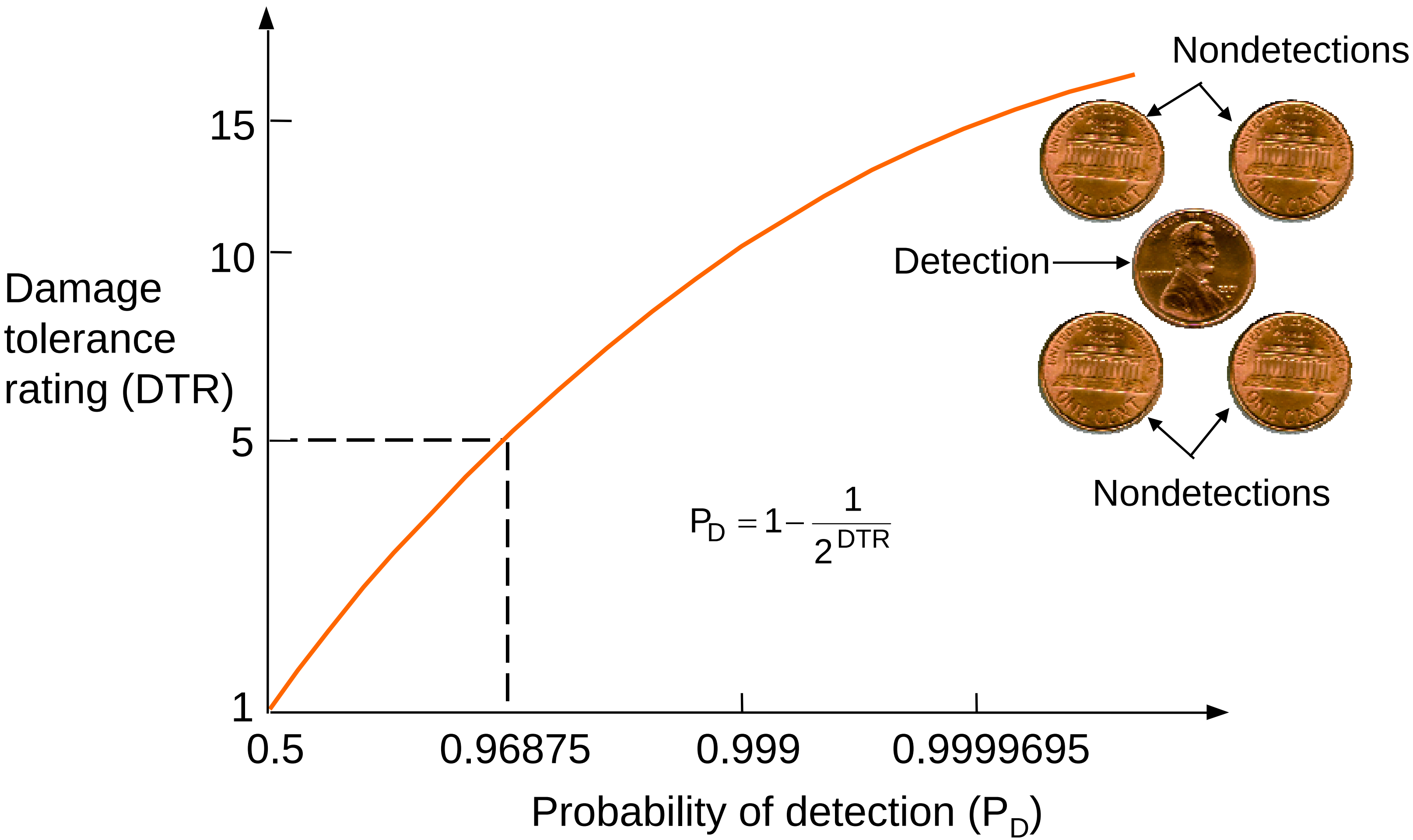
- Cumulative probability of damage detection during the safe damage detection period N is given by

$$P_D = 1 - \left[\prod_{i=A}^{S} (1 - P_{D_i}) \right]$$

Where 1 = applicable inspection levels (A, B, C, D, or S)

- A-check: Visual inspection conducted from ground level
- B-check: Close visual inspection of aircraft exterior
- C-check: Close visual inspection of aircraft exterior and easily accessible interior areas
- D-check: Detailed inspection of entire aircraft
- S (special): Directed visual or NDI inspection of specific components

Measurement of Detection Probability, DTR



$$P_D = 1 - \frac{1}{2^{DTR}}$$

Damage Tolerance Rating (DTR) Form

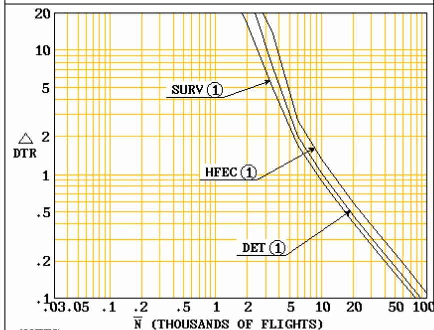
Detection Probability versus Inspection Intervals & Methods

DTR CHECK FORM | ITEM: Example | MODEL-SERIES: 767

TITLE: Wing Lower Surface Skin Panel (Dry Bay)

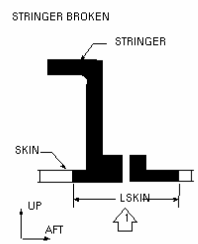
LOCATION: Stringer 8

OPERATOR(S) | NO. OF CAND. A/C



STRUCTURE AND INSPECTION DETAILS

LEAD CRACK:



NOTES:

STRUCTURE DETAIL	INSPECTION PROGRAM DETAILS: JOB CARD	DIREC. ⇨	CHECK LEVEL	METHOD	%SAMP R_o	FREQUENCY F-FLIGHTS	$\bar{N} = 100F/R_o$	DAMAGE DETECTION PERIOD N_o FLIGHTS	△ DTR
skin		1	c	SURV	100	3000	3000	4200	6.8
		1		DET				4200	
		1		HFEC				4200	

ENGR.		01/30/01	REVISED	
CHECK				
APPR.				
APPR.				

FUEL LEAK DTR:

TOTAL DTR: 6.8

REQUIRED DTR: 4

REV SYM

BOEING 110 No. PAGE

The total DTR resulting from a surveillance inspection at 3000 flights is more than the required DTR for this structure.

Damage Tolerance – Facts and Fiction

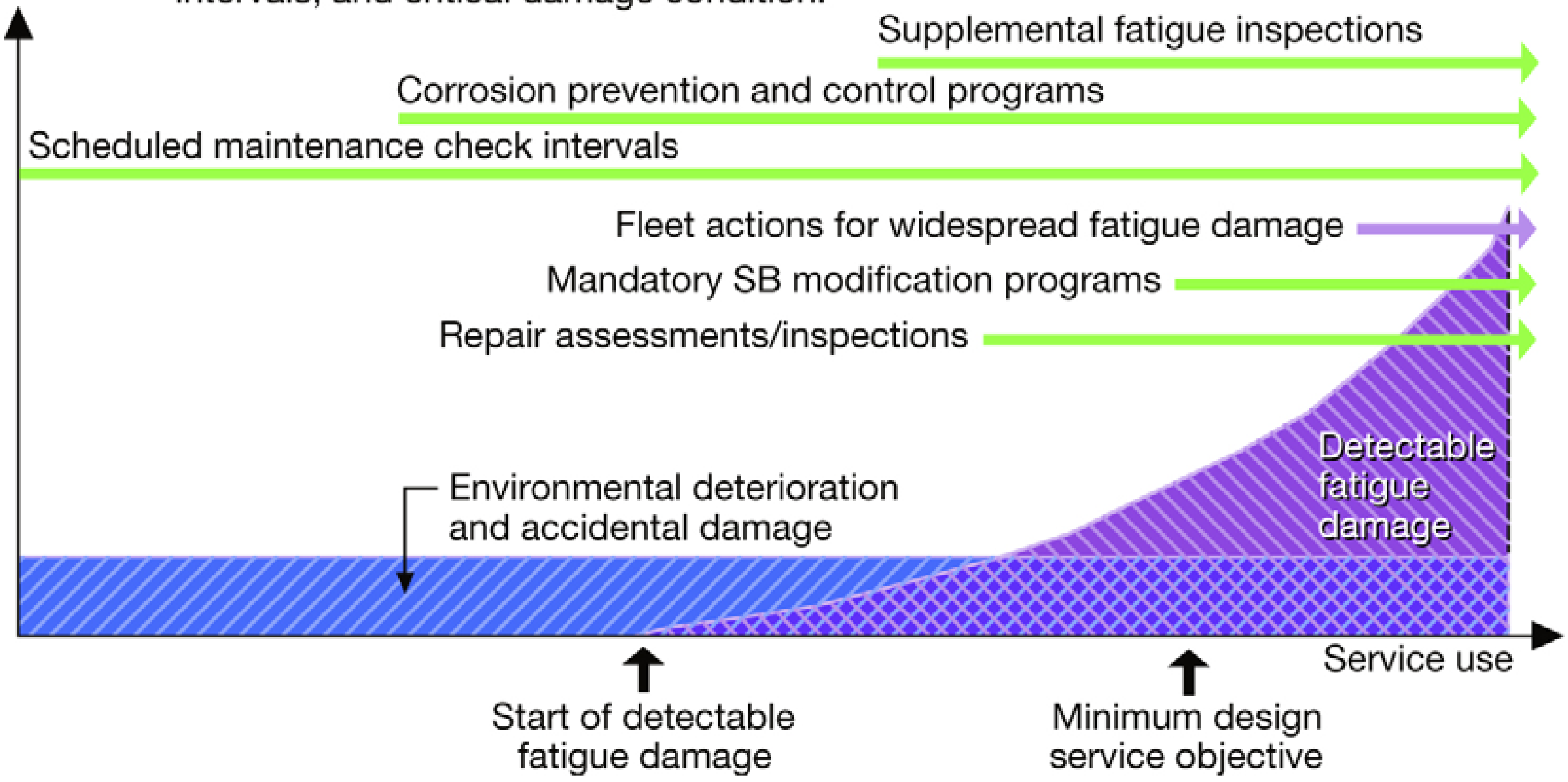
- Overview
- Elements of Damage Tolerance
- **Structural Maintenance Considerations**
- Continuing Airworthiness Challenges
- Summary

Structural Maintenance Considerations

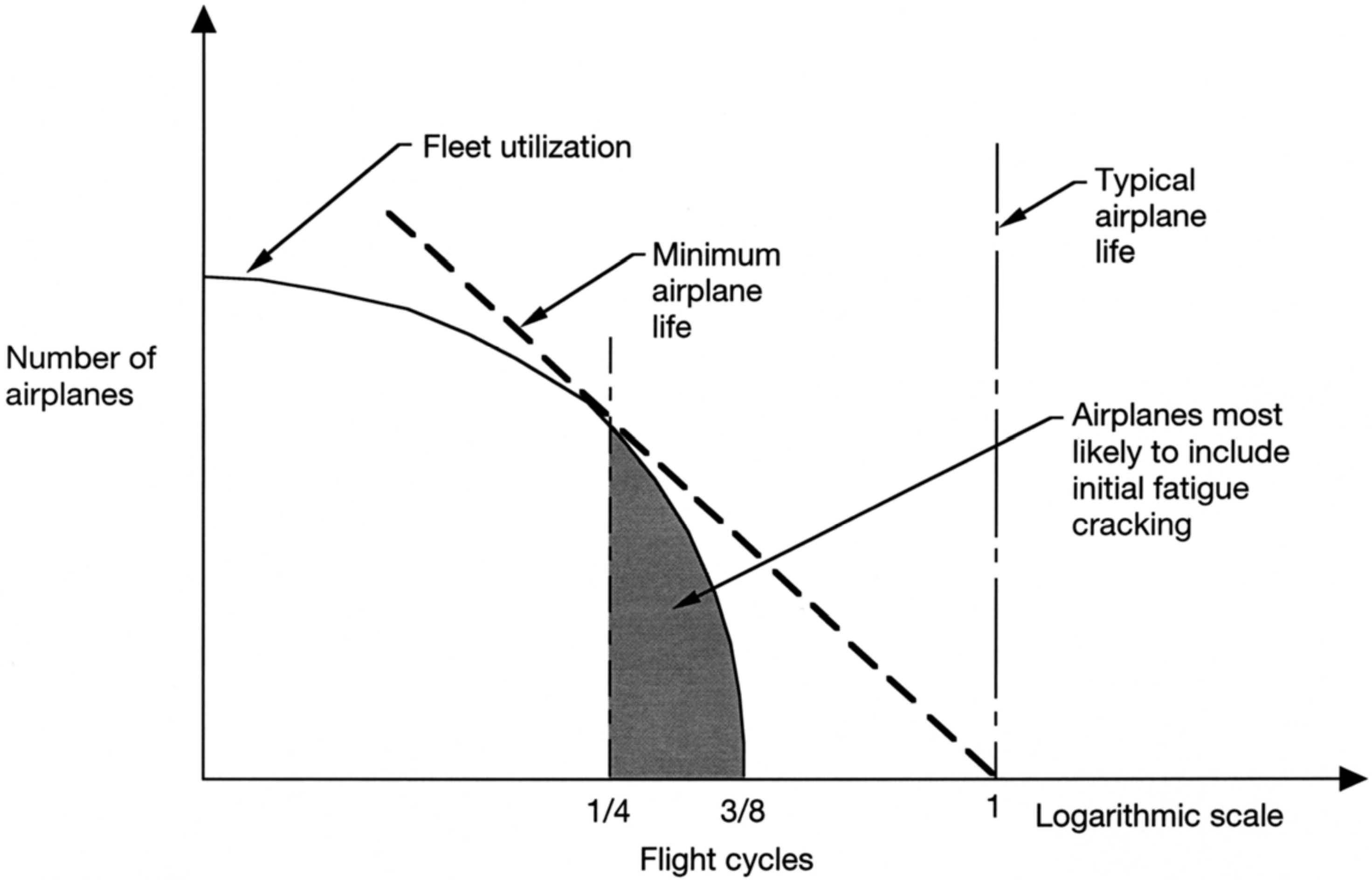
- **Inspection thresholds**

Fleet Damage Sources
Inspection Program Phases

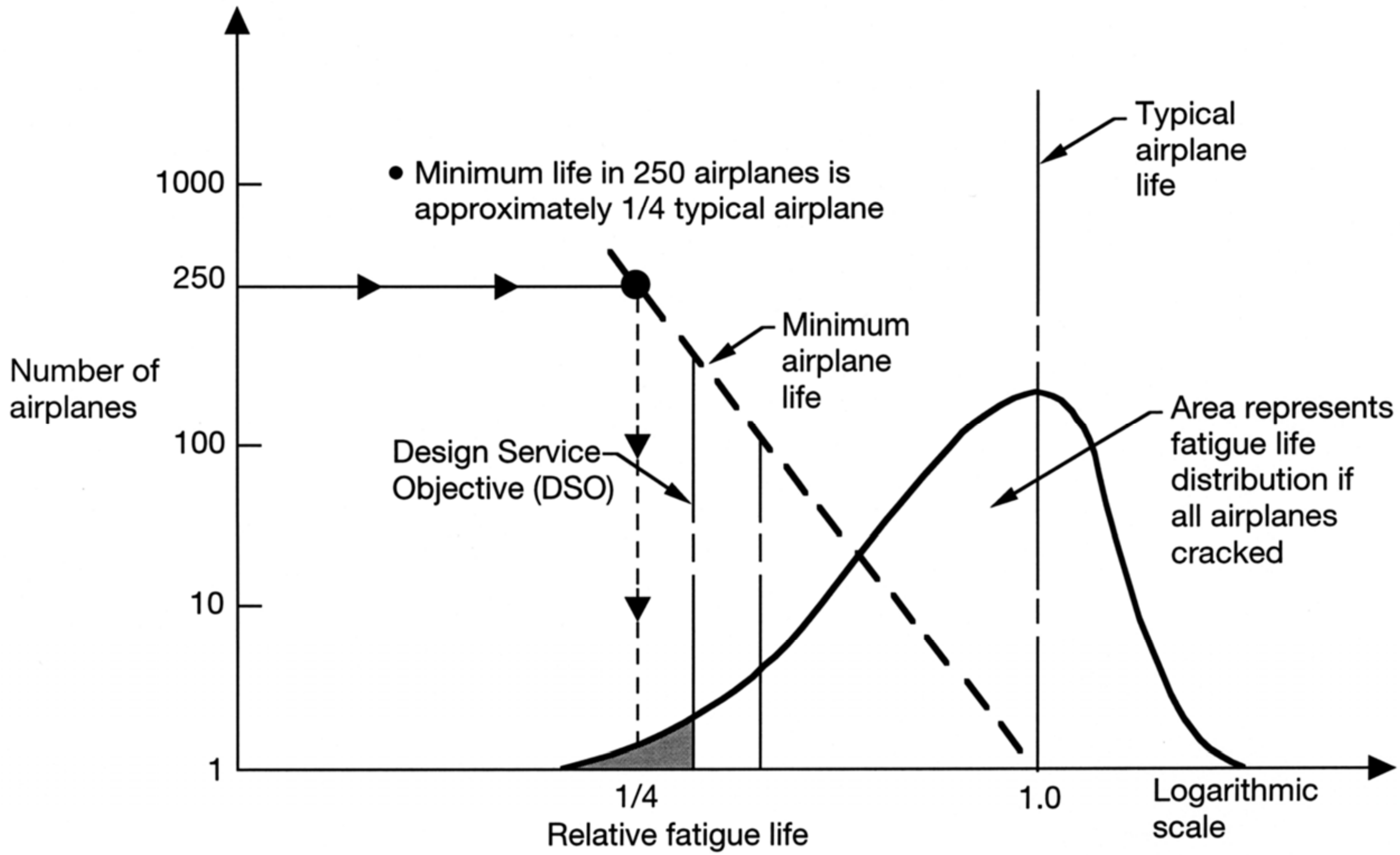
- Damage tolerance inspection thresholds set by classic fatigue approach are typically 50% to 75% of design service objective.
- Damage tolerance analysis determines detectable fatigue damage, inspection intervals, and critical damage condition.



Fleet Cracking Order



Variation of Minimum Life With Fleet Size

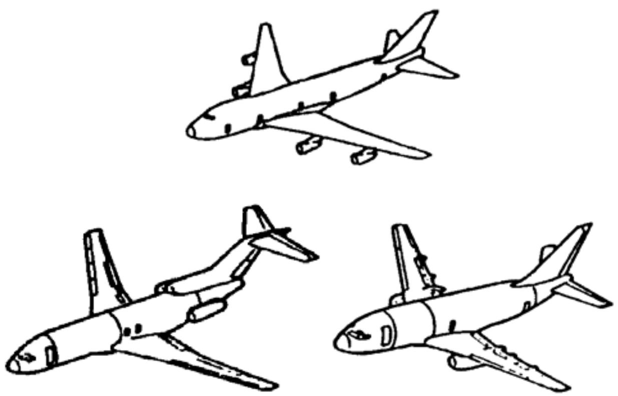


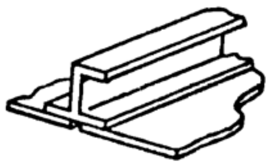
Structural Maintenance Considerations

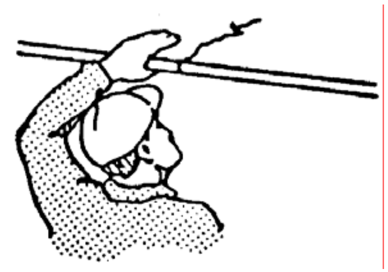
- Inspection Options
- **Fleet Sampling Options**

Probability of Damage Detection

P1 – Probability of Inspecting Airplane with Damage







Probability of inspecting an aircraft with damage

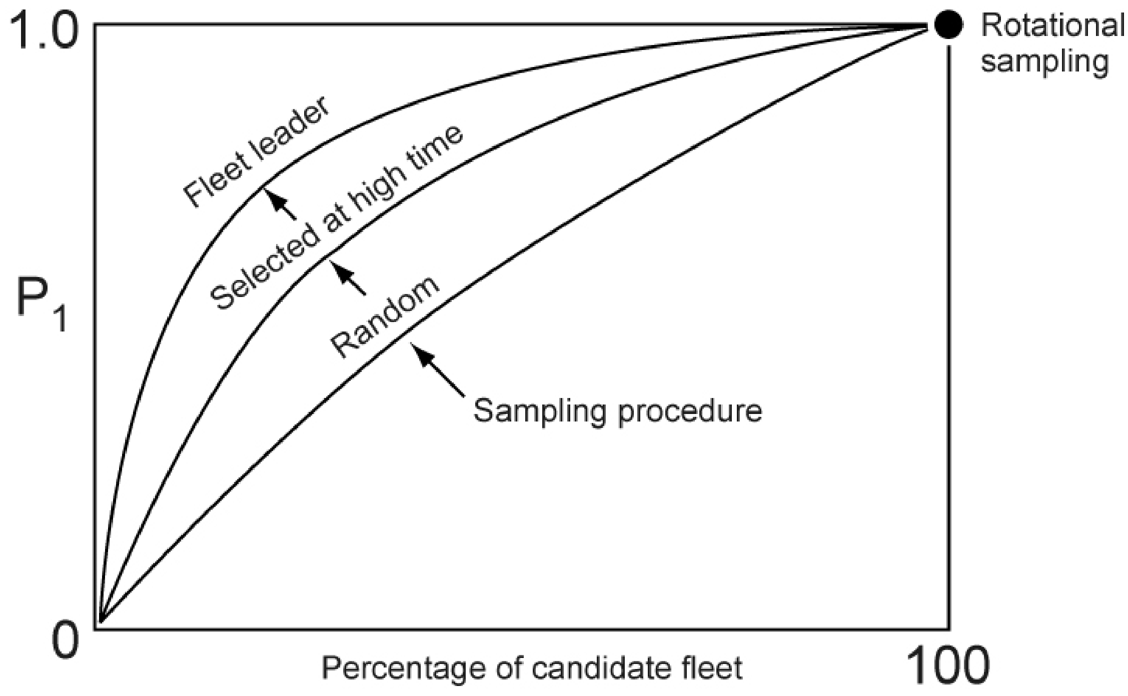
Probability of inspecting detail considered

Probability of crack detection

Probability of detecting damage

Probability of Inspecting Damaged Aircraft - P_1

Rotational Sampling : Sequential Inspections of all Airplanes

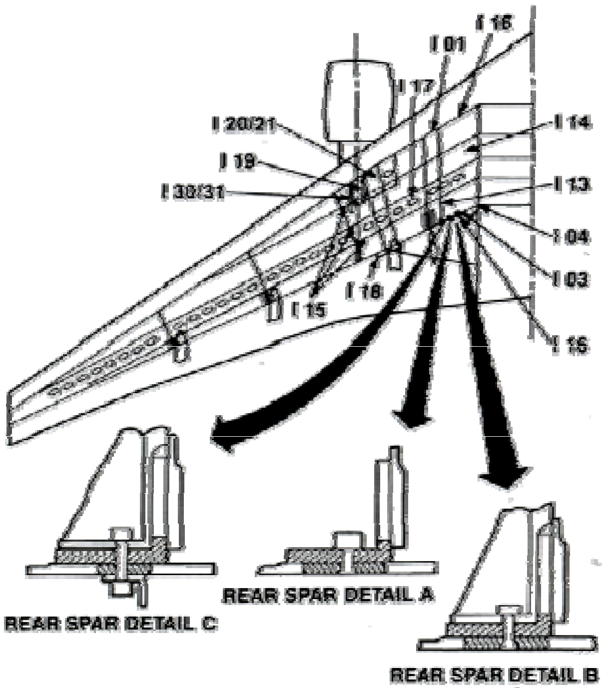


Structural Maintenance Considerations

- Inspection thresholds
- Fleet Sampling Options
- **Inspection Intervals**

Structurally Significant Items
767 Outer Wing Box

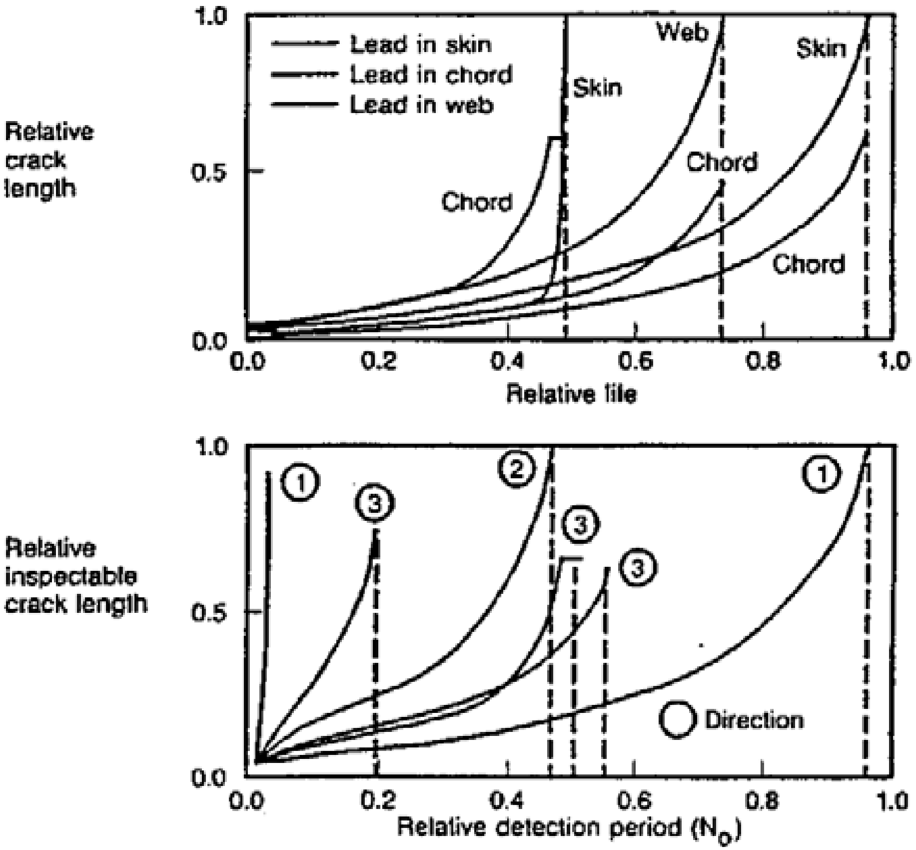
NOTE: Only selected items for zones 531/631 and 532/632 are shown for clarity.

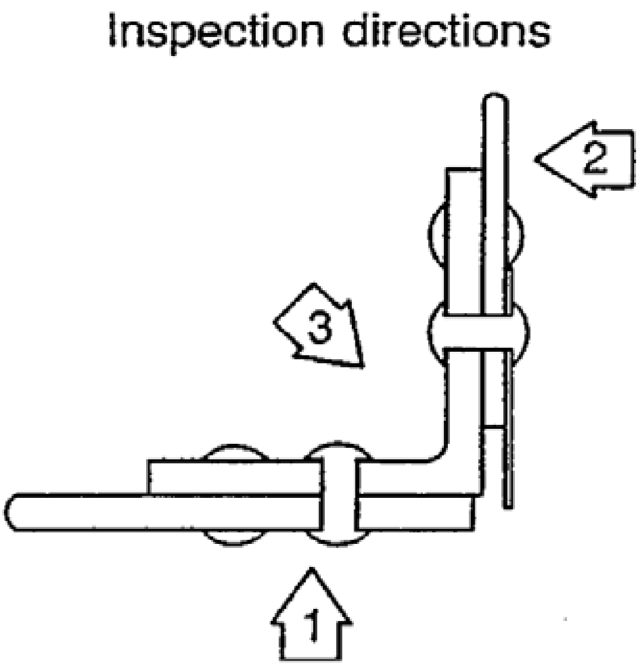


SSI ITEM NO.	TITLE
57-20-I 01	Front spar—typical details
57-20-I 02	Front spar—nacelle fitting installation
57-20-I 03	Rear spar—typical details
57-20-I 04	Rear spar (from SOB to rib 1)
57-20-I 05	Rear spar—foward trunnion fitting installation
57-20-I 06	Rear spar—MLGB outboard support fitting installation
57-20-I 07	Rear spar—flap support fitting installation (ribs 17 and 24)
57-20-I 08	Non-shear-tied ribs (except details of I 09)—typical details
57-20-I 09	Ribs Nos. 1 and 2—internal fittings and adjacent web
57-20-I 10	Shear-tied ribs (Nos. 4, 7, 8, 10, 17, 24)(except details of I 11)—typical details
57-20-I 11	Shear-tied ribs in dry bay (Nos. 7 and 8)
57-20-I 12	Outboard wing lower surface—typical stringer
57-20-I 13	Outboard wing lower surface—rib shear tie and support fittings
57-20-I 14	Outboard wing lower surface—drain installation
57-20-I 15	Outboard wing lower surface—spanwise splice
57-20-I 16	Spar chords to lower wing skin attachment
57-20-I 17	Access hole—lower wing surface
57-20-I 18	MLGB outboard support fitting to lower surface attachment
57-20-I 19	Nacelle fitting attachment to lower wing surface
57-20-I 20	Dry bay typical skin/stringer construction
57-20-I 21	Dry bay barrier installation
57-20-I 22	Dry bay flame arrester installation
57-20-I 23	Typical skin/stringer and rib shear tie attachment upper surface
57-20-I 24	Upper wing skin spanwise splice and spar chord attachment
57-20-I 25	MLGB outboard support fitting and trunnion to upper skin attachment
57-20-I 26	Upper surface fuel filler cap
57-20-I 27	Nacelle strut to upper skin attachment
57-20-I 28	Nacelle support side load backup fitting
57-20-I 29	Rear spar pitch load fitting
57-20-I 30	Outboard side load fitting
57-20-I 31	Inboard side load fitting
57-20-I 32	Nacelle side brace support fitting
57-20-I 33	Front spar pitch load fitting

Crack Growth Analysis Example
Spar Chord Details

Wing Center Section



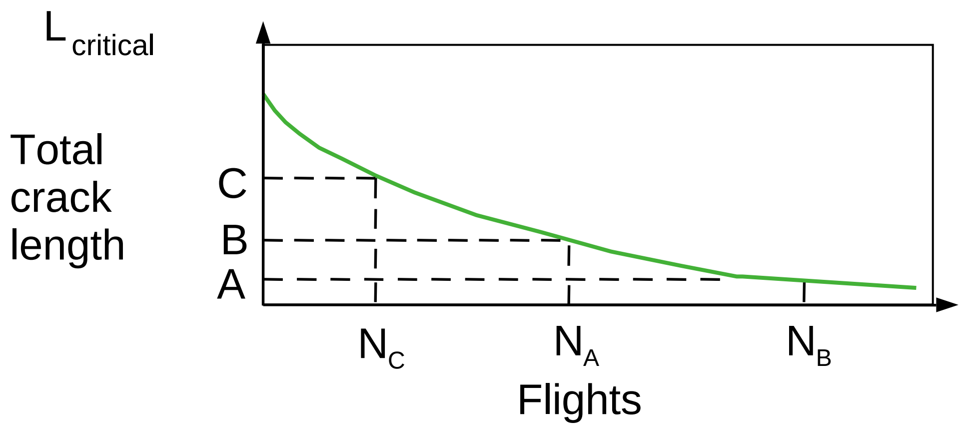


Structural Maintenance Considerations

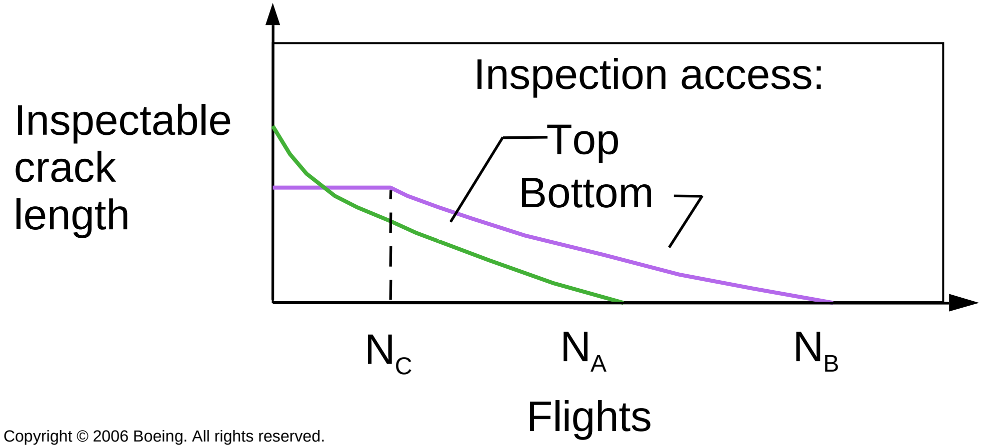
- Inspection thresholds
- Fleet Sampling Options
- Inspection Intervals
- **Damage Detection Considerations**

Inspectable Crack Length

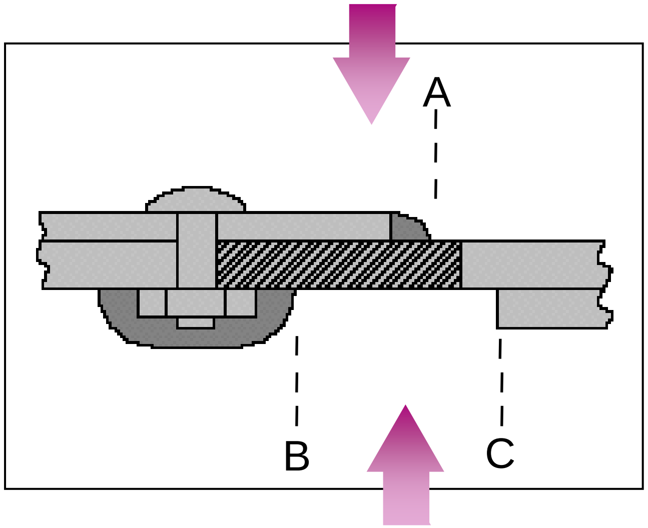
Actual Crack Growth Curve



Inspectable Crack Growth Curves



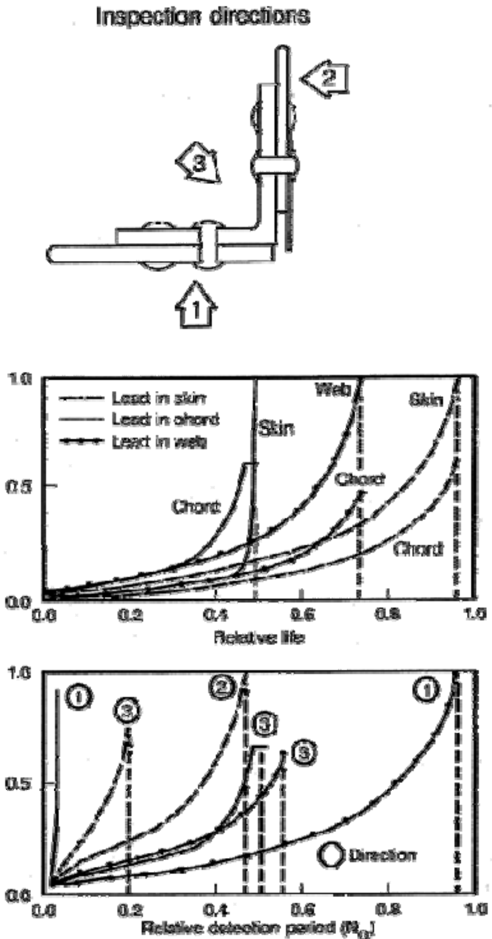
Inspection access: top

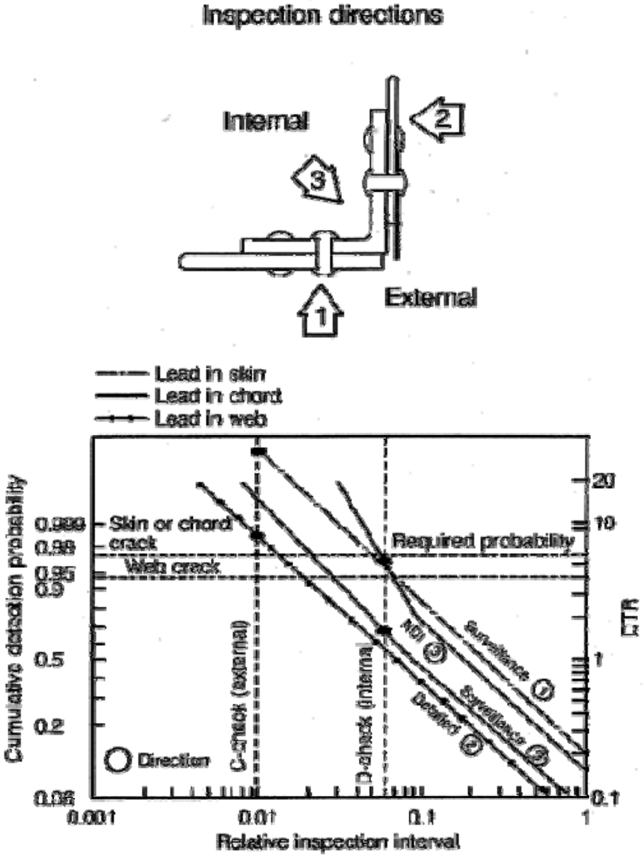


Inspection access: bottom

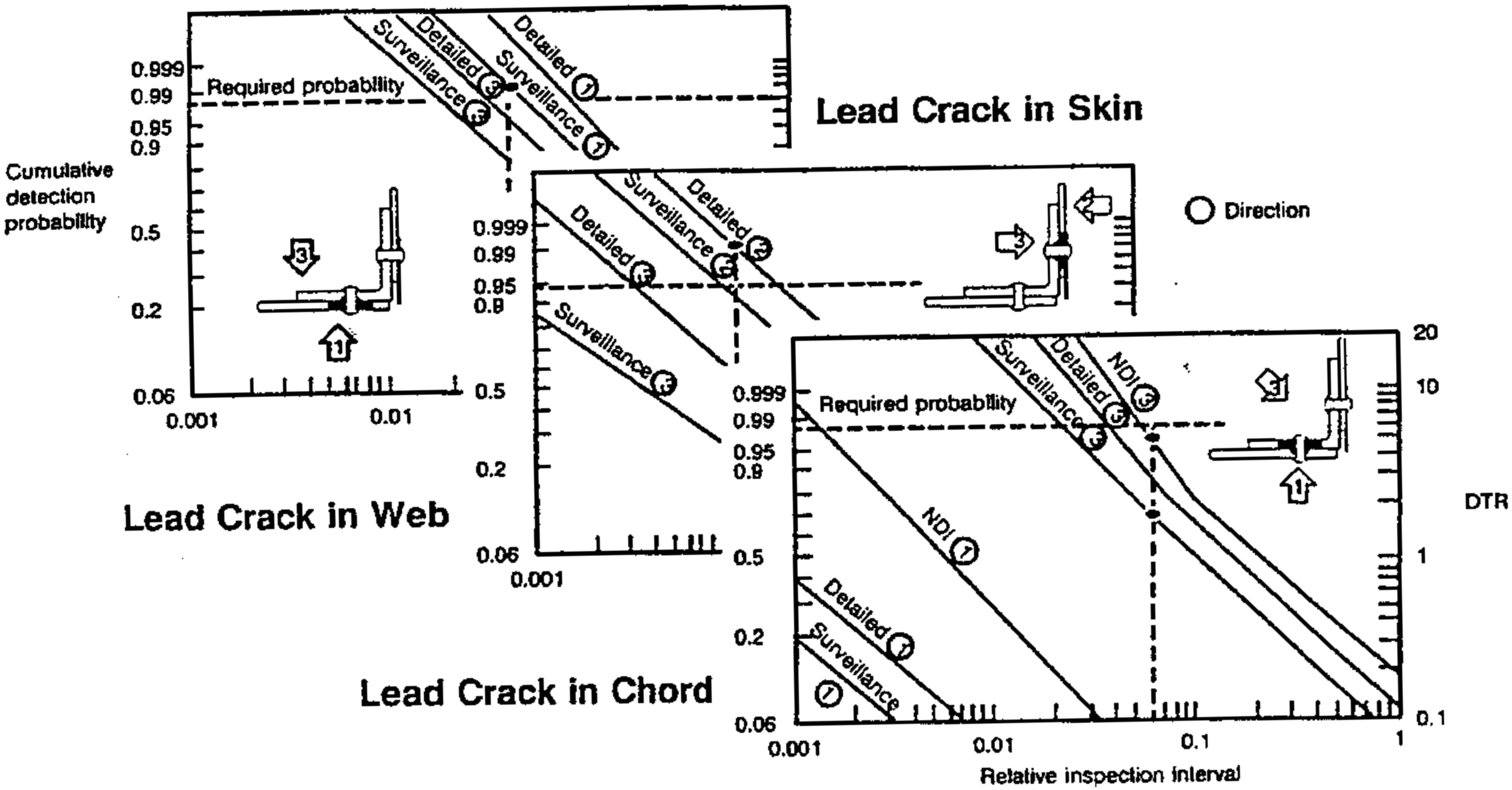
Cumulative Detection Probability
Inspection Interval Selection

- Cracking pattern/inspection direction combinations





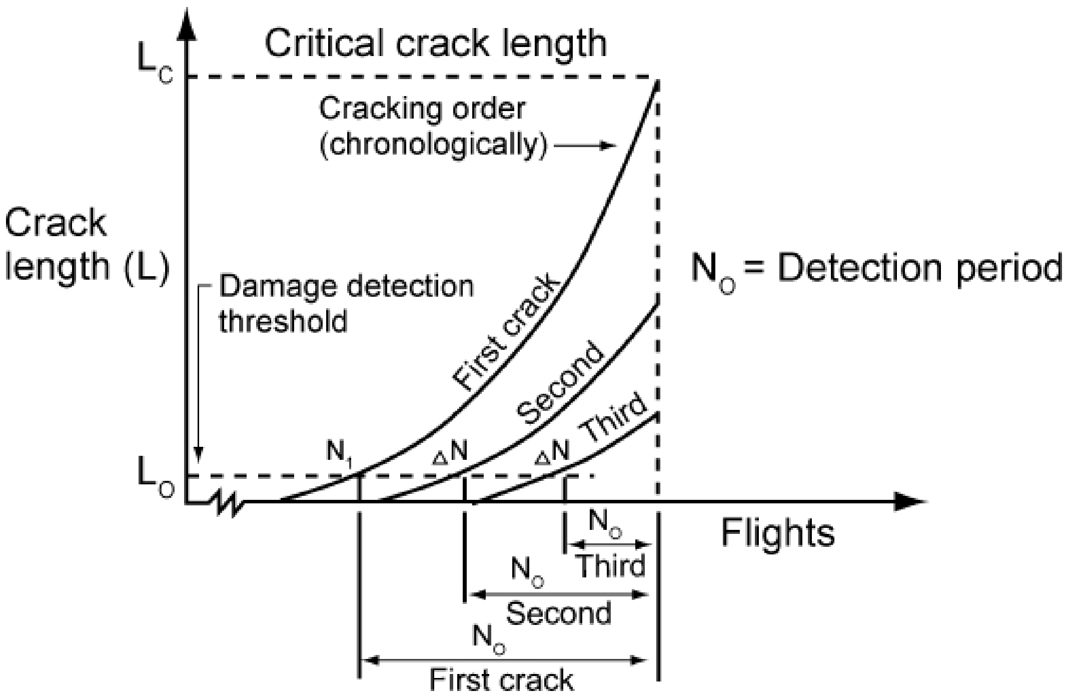
Cumulative Detection Probability



Structural Maintenance Considerations

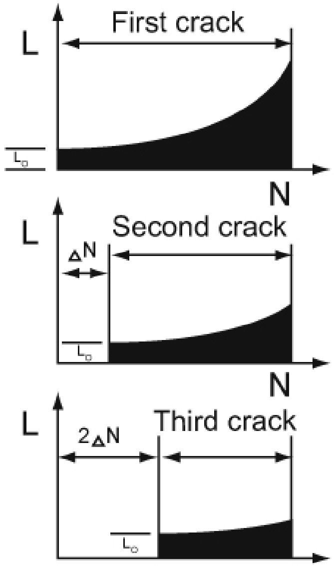
- Inspection thresholds
- Fleet Sampling Options
- Inspection Intervals
- Damage Detection Considerations
- **Multiple Inspections**

Multiple Aircraft Cracking in the Fleet



Cumulative detection probability

- Multiple fleet cracking contributions to damage protection

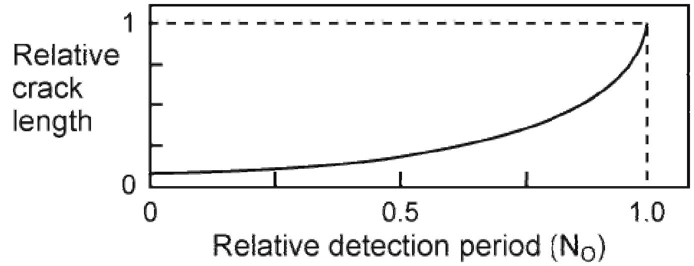


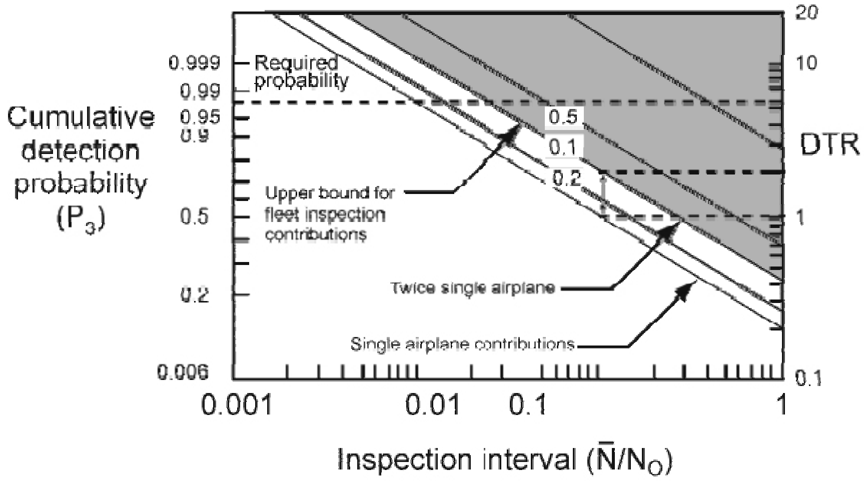
Number of flights available for detection of:

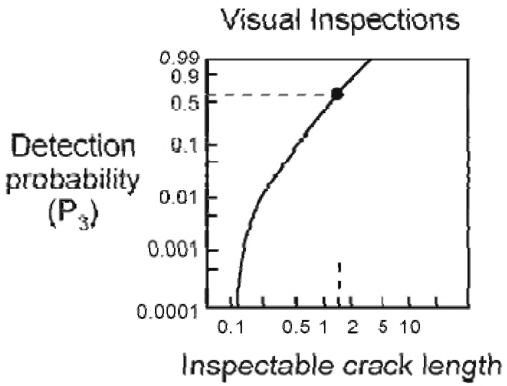
- **First crack in the fleet = N_o**
- **Second crack in the fleet = $N_o - \Delta N$**
- **Third crack in the fleet = $N_o - (2\Delta N)$**

Cumulative Detection Probability

- Fleet inspection detection contributions limited to 50% of total





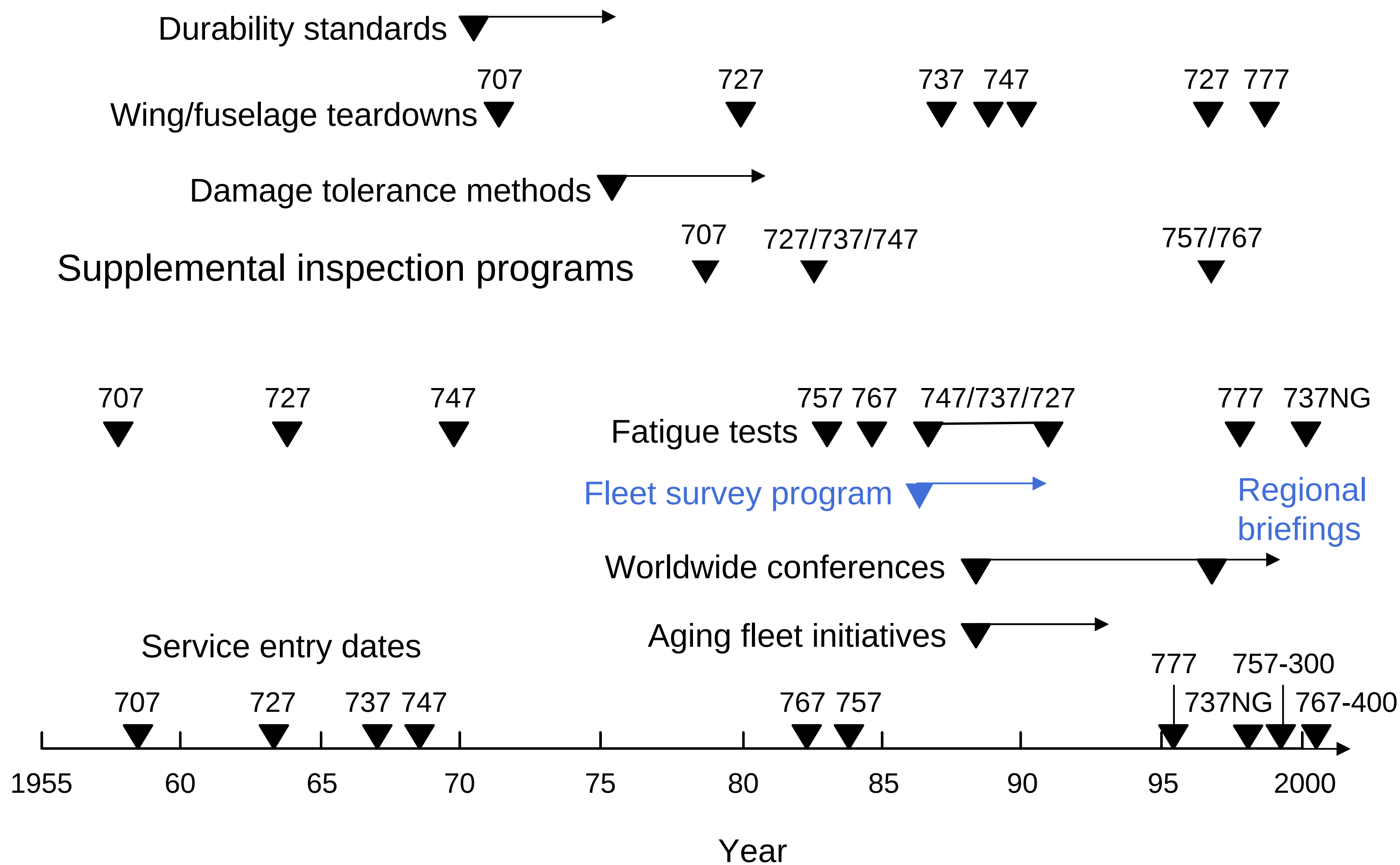


Damage Tolerance – Facts and Fiction

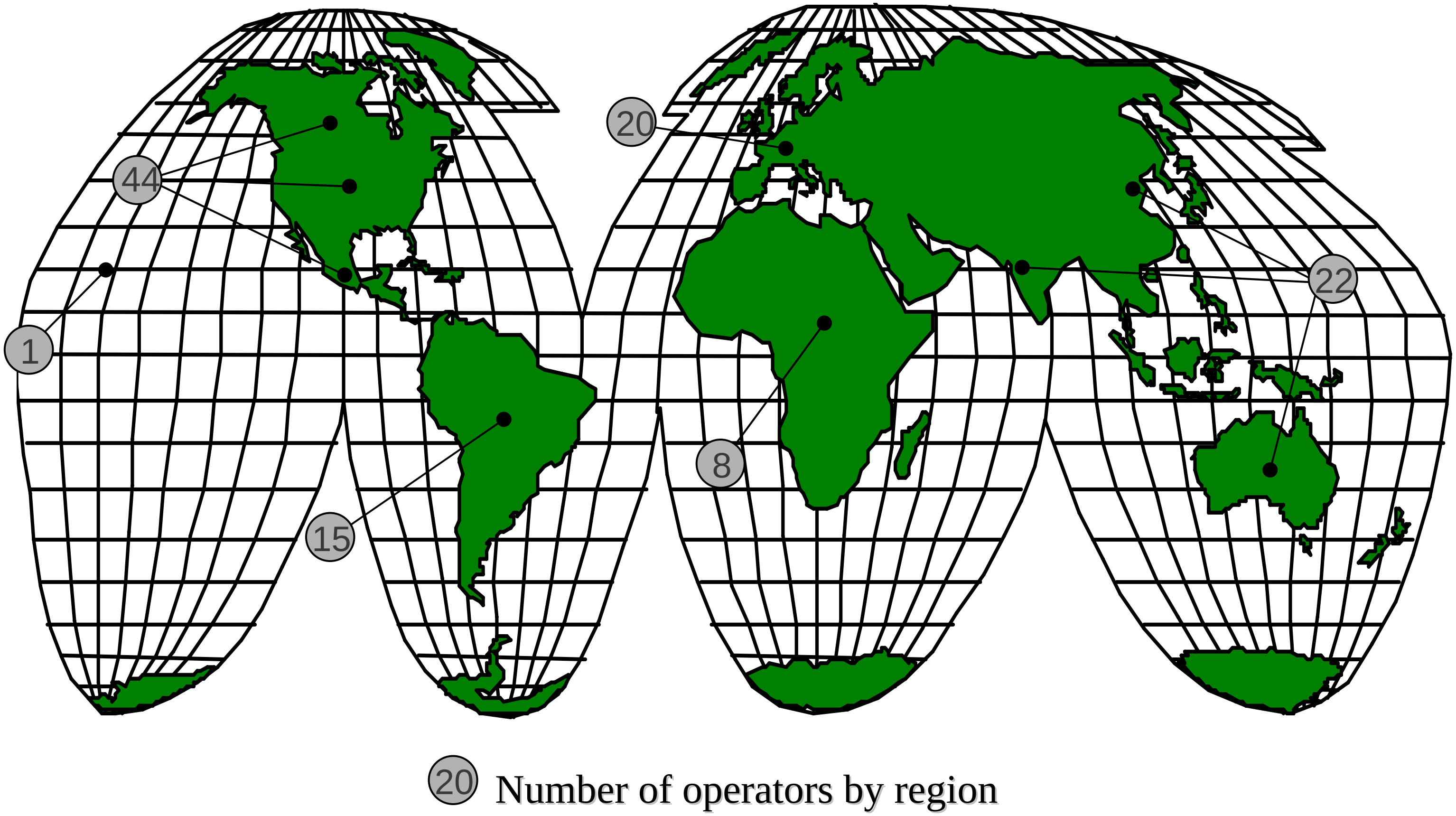
- Overview
- Elements of Damage Tolerance
- Structural Maintenance Considerations
- **Continuing Airworthiness Challenges**
- Summary

Boeing Fleet Support Actions

Fleet Survey Program

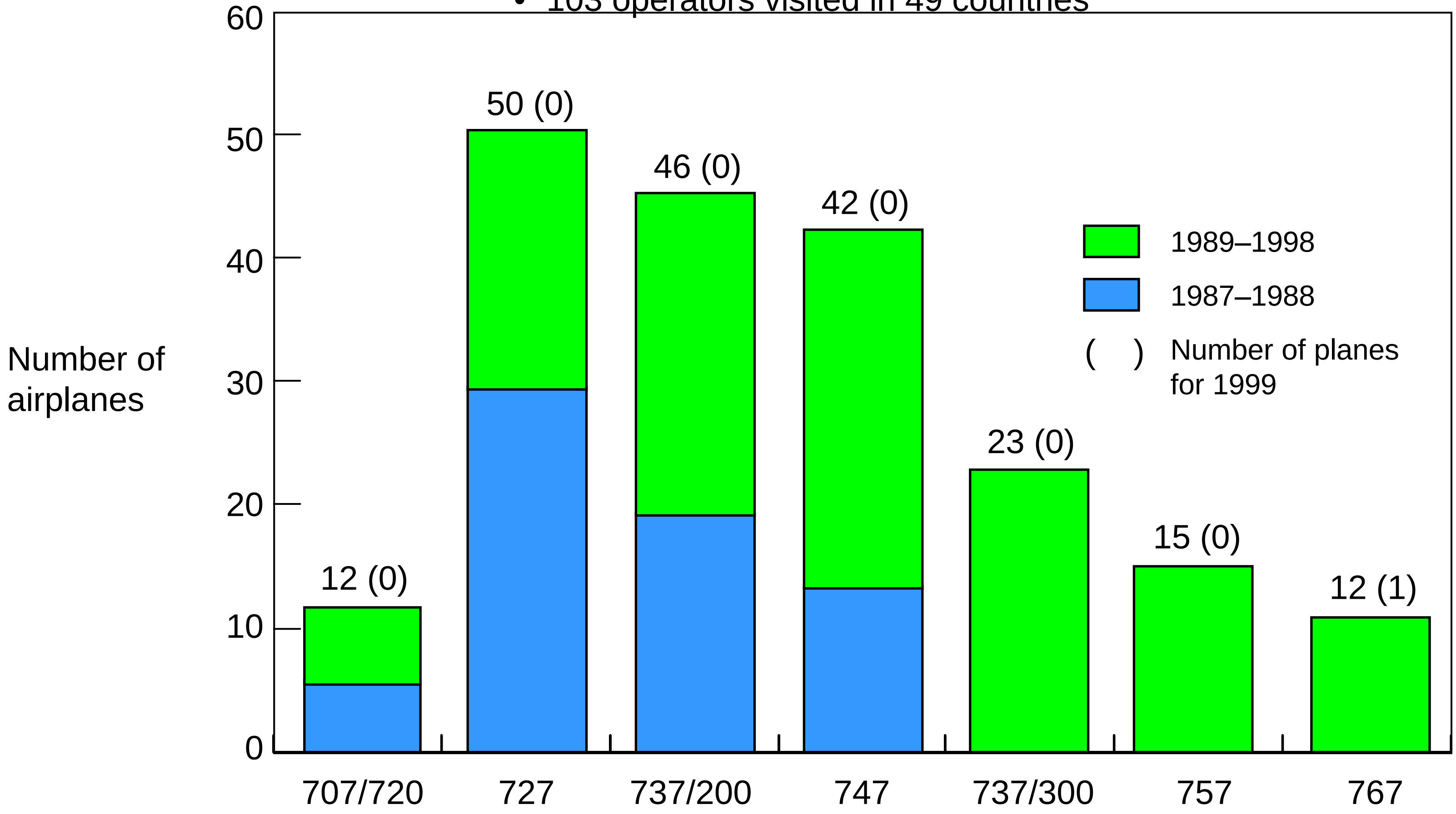


Boeing Fleet Survey Program
Initiated 1987



Boeing Fleet Surveys
200 Airplanes; 103 Operators; 49 Countries

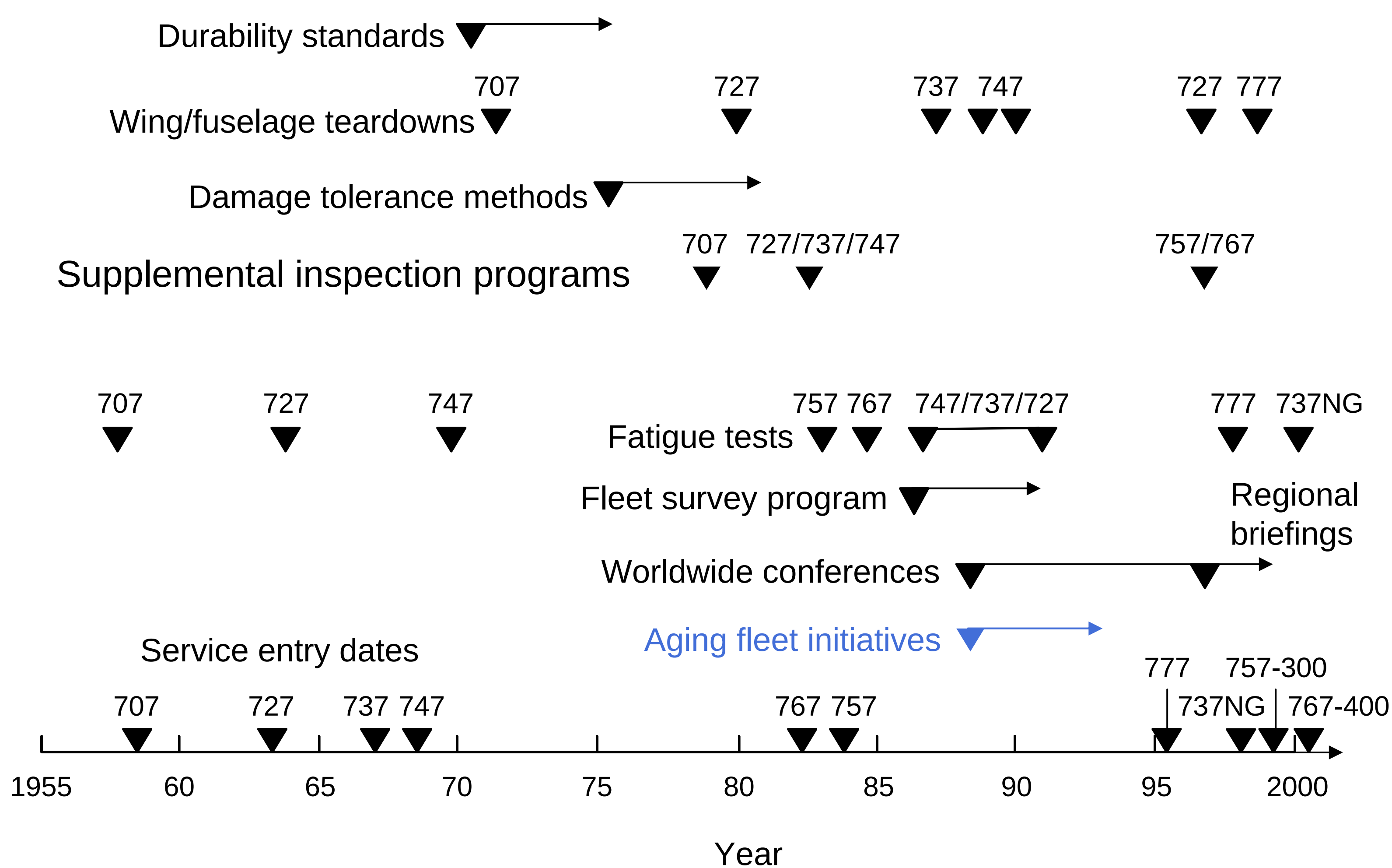
- September 1999
- 200 airplanes surveyed
- 103 operators visited in 49 countries



Fleet Survey Findings

Fleet Survey Findings

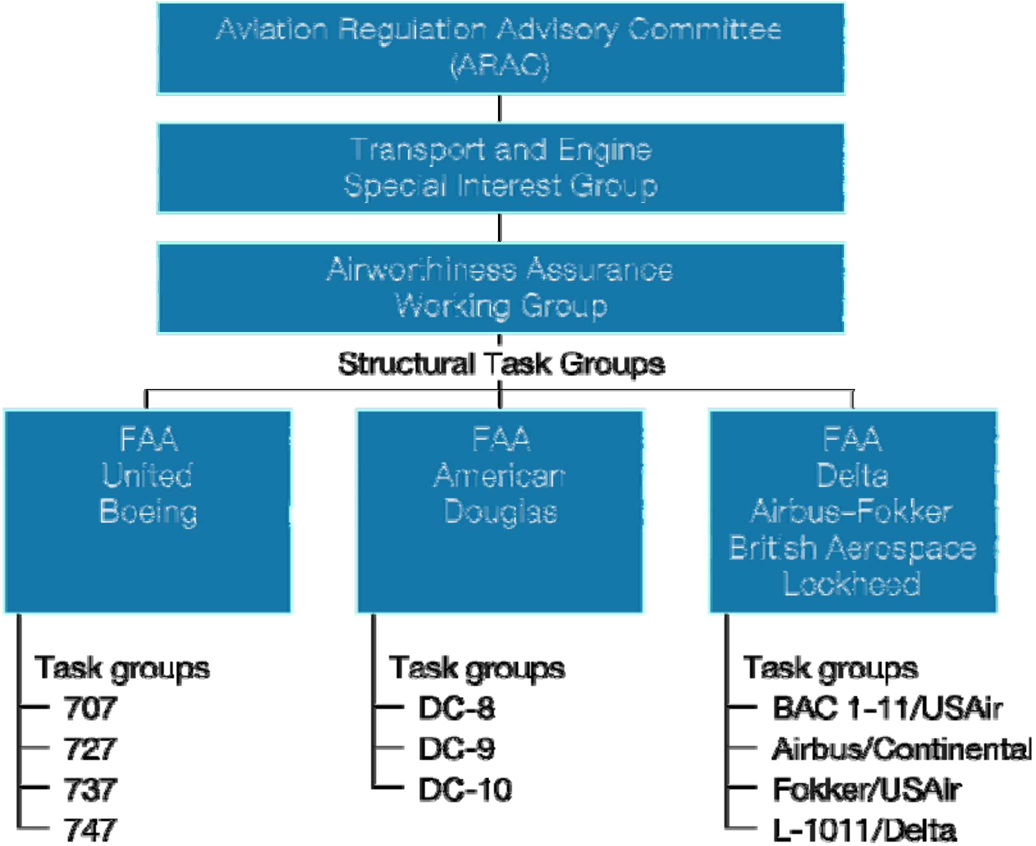
Boeing Fleet Support Actions
Aging Fleet Initiatives



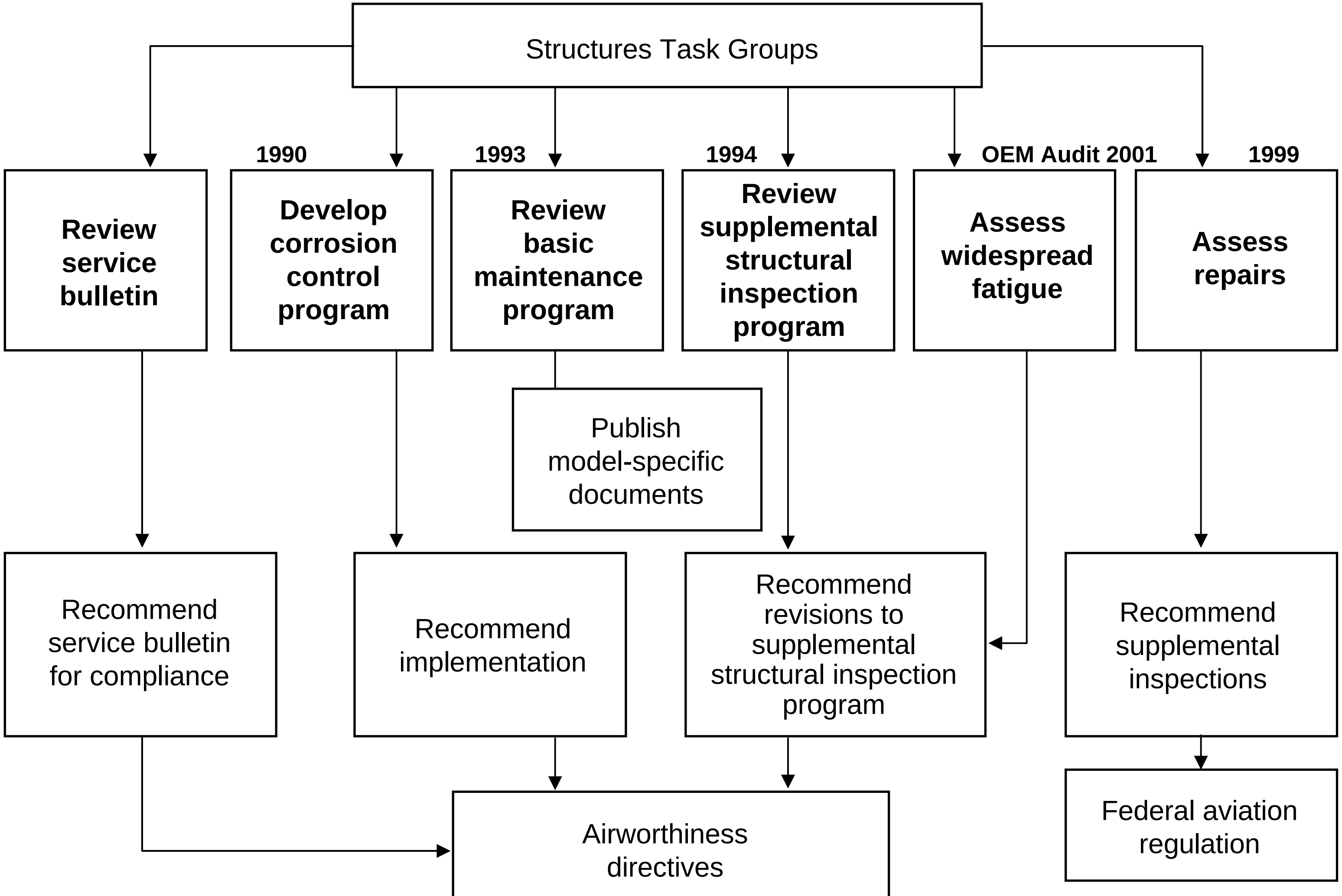
Aloha Airlines 737
1988 Explosive Decompression

- 1988

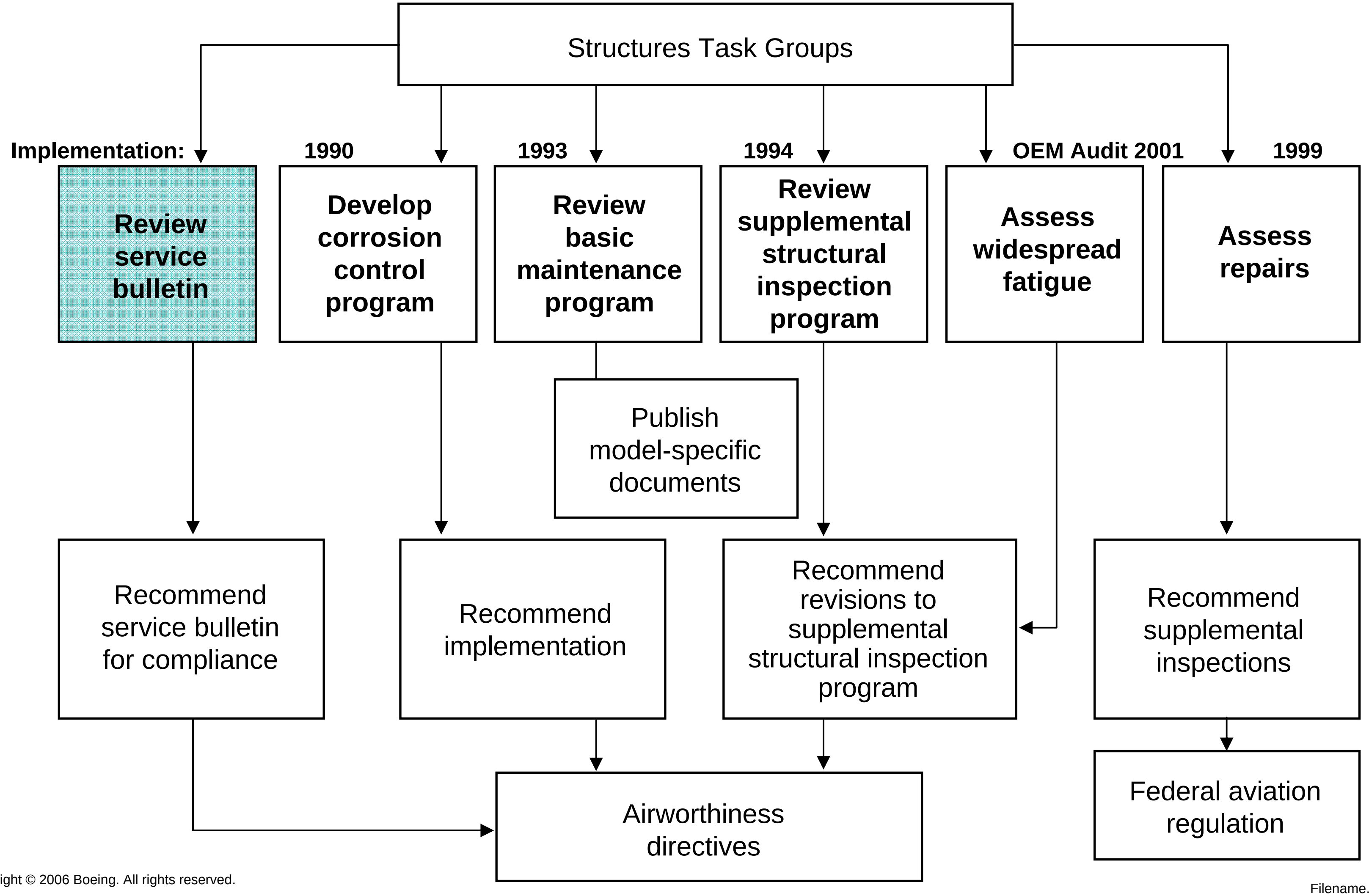
Government and Industry Task Groups



Continued Airworthiness –
Industry Initiatives



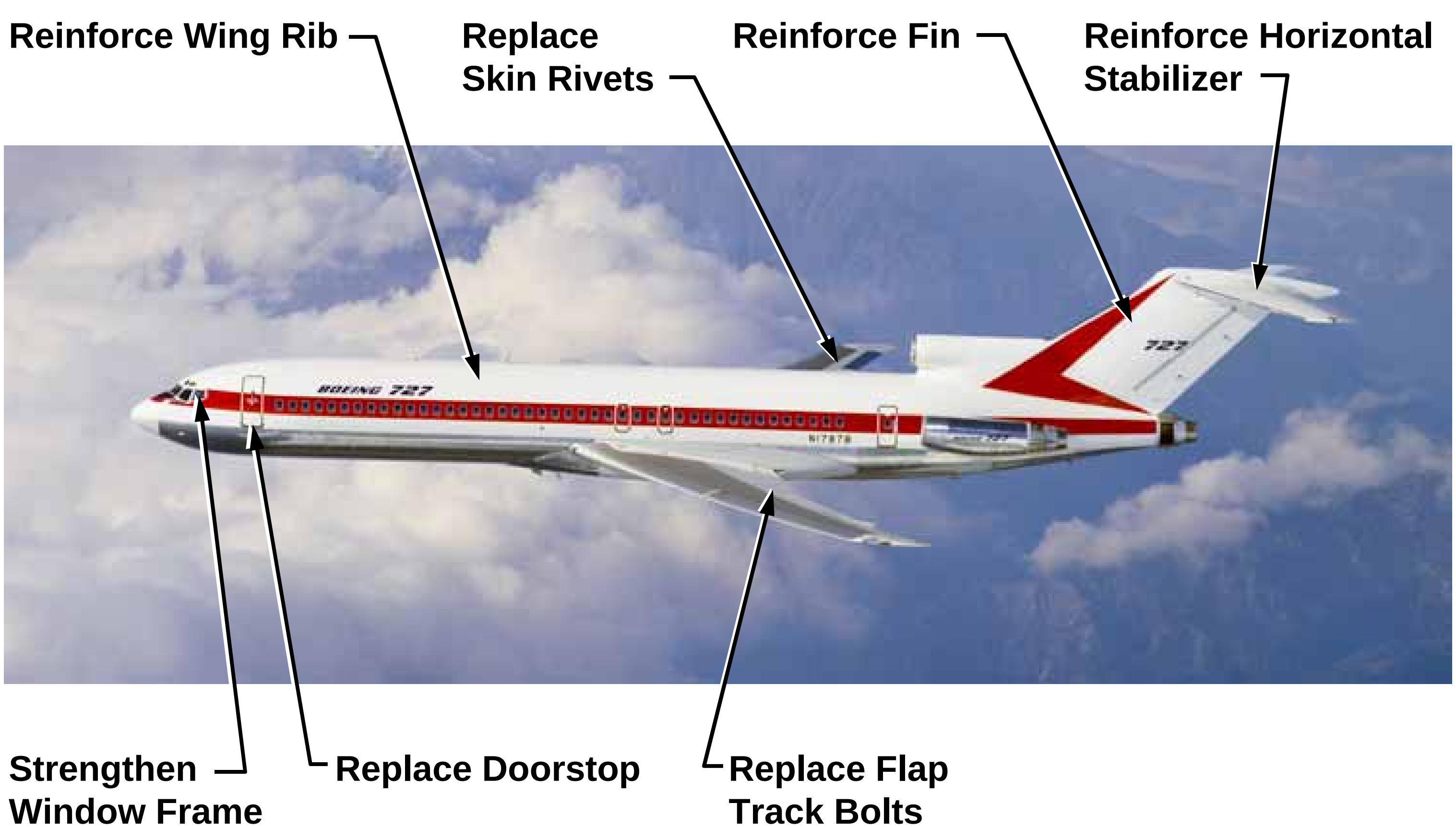
Continued Airworthiness- Industry Initiatives



Continuing Airworthiness Challenges

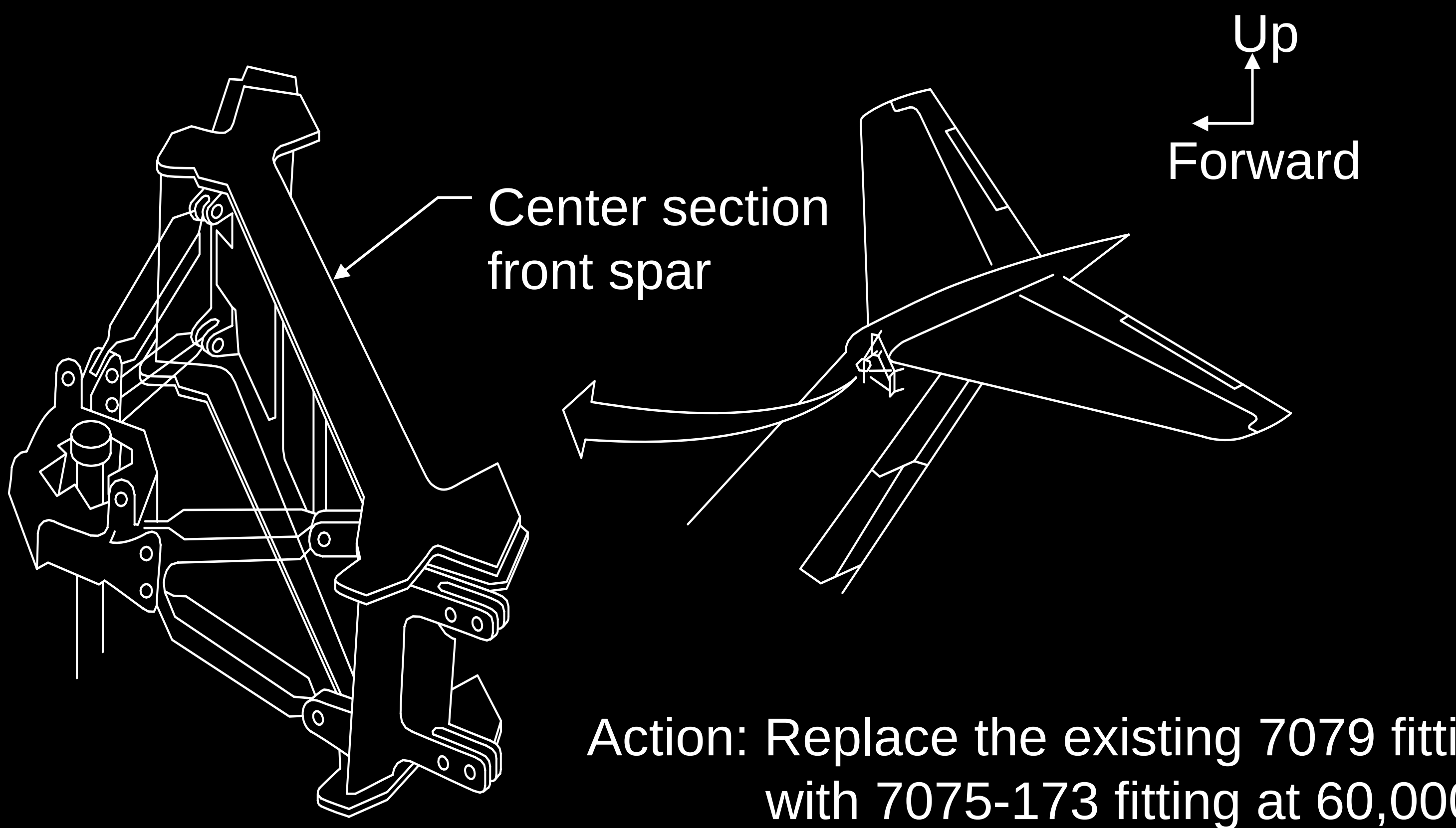
- **Mandatory Service Bulletin Modifications**

Typical 727 High-Time Modifications



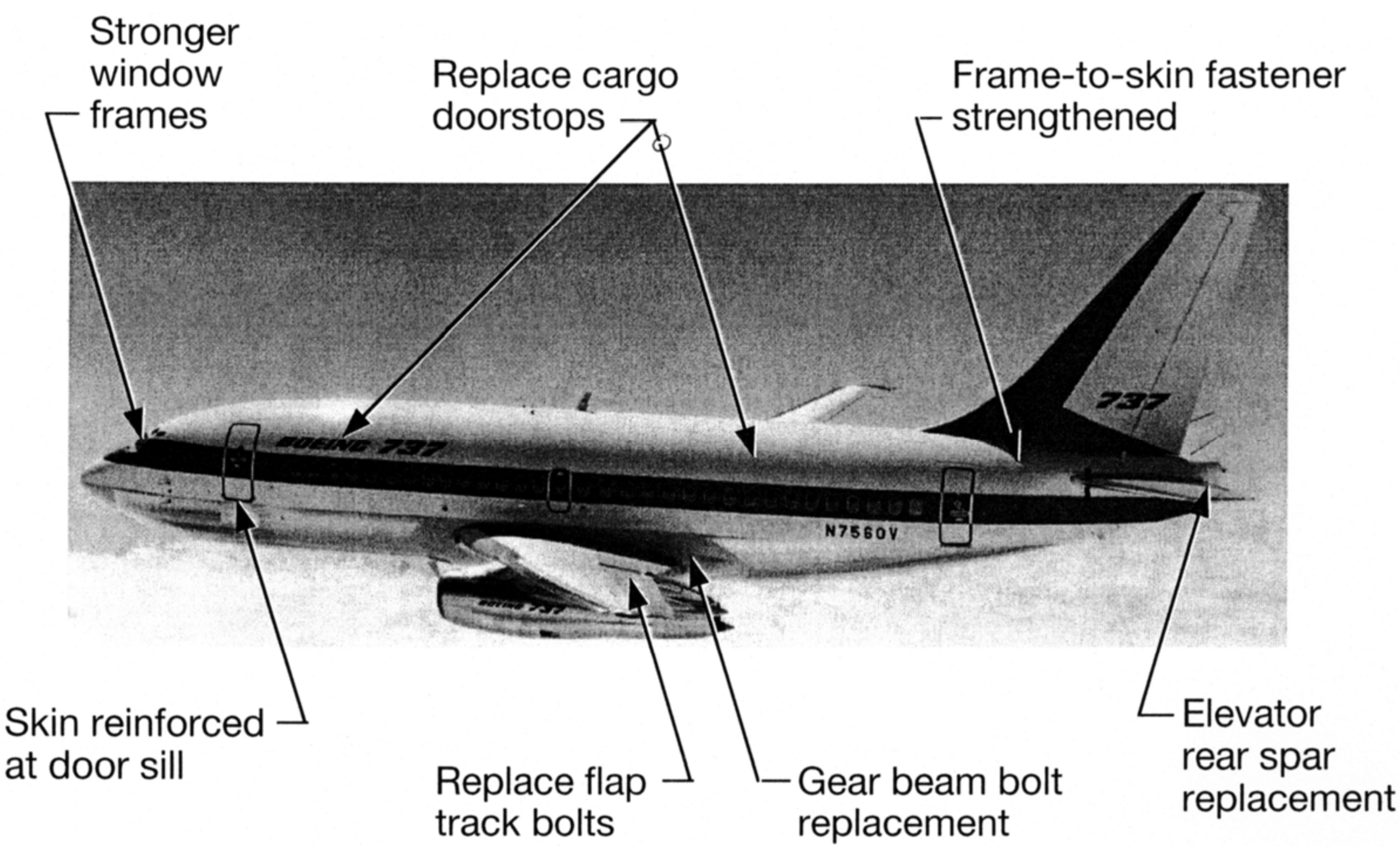
Mandatory Service Bulletin Modifications

727 Horizontal Stabilizer Front Spar - Stress Corrosion Problems

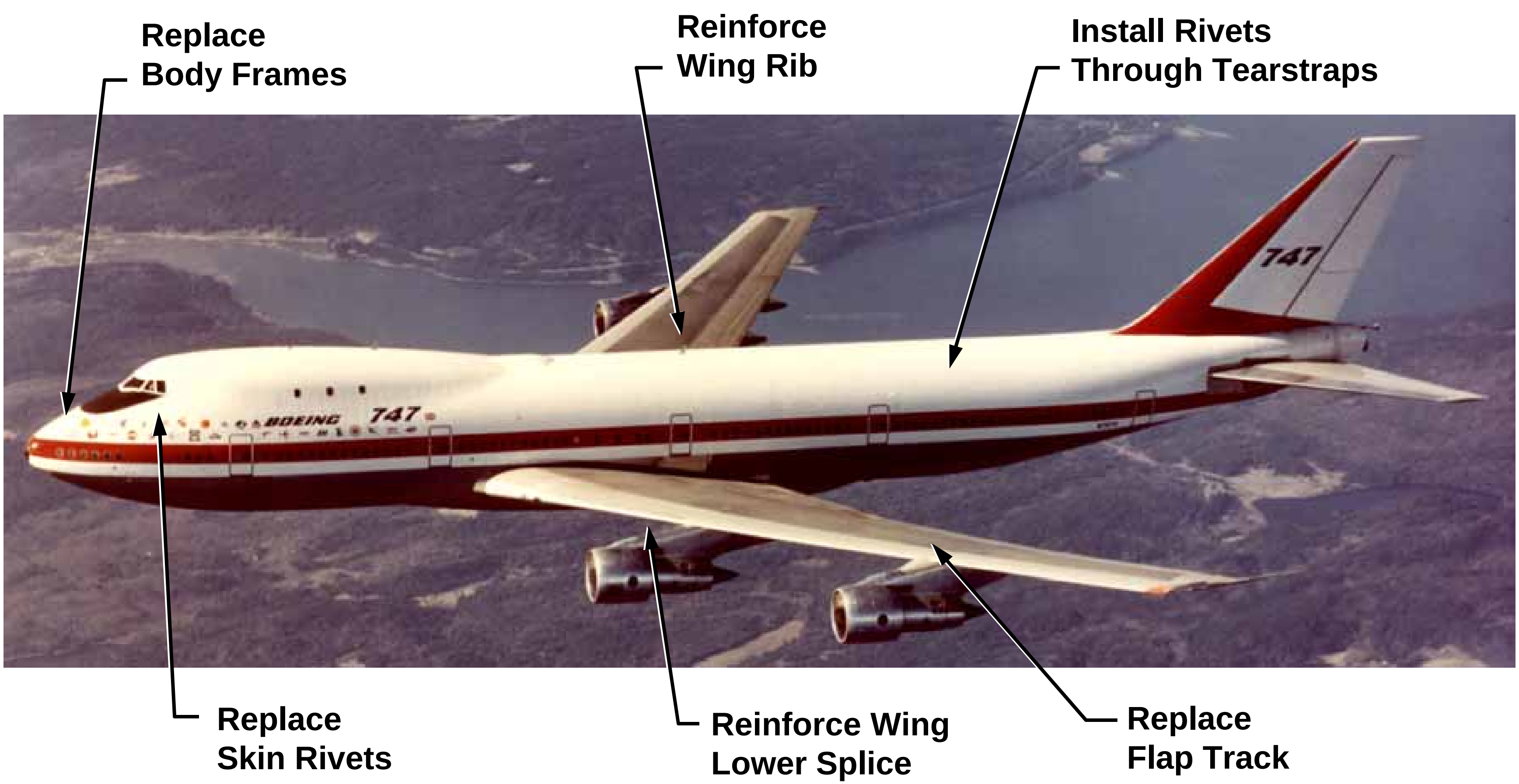


Action: Replace the existing 7079 fitting with 7075-173 fitting at 60,000 flight cycles or 20 years, whichever occurs first.

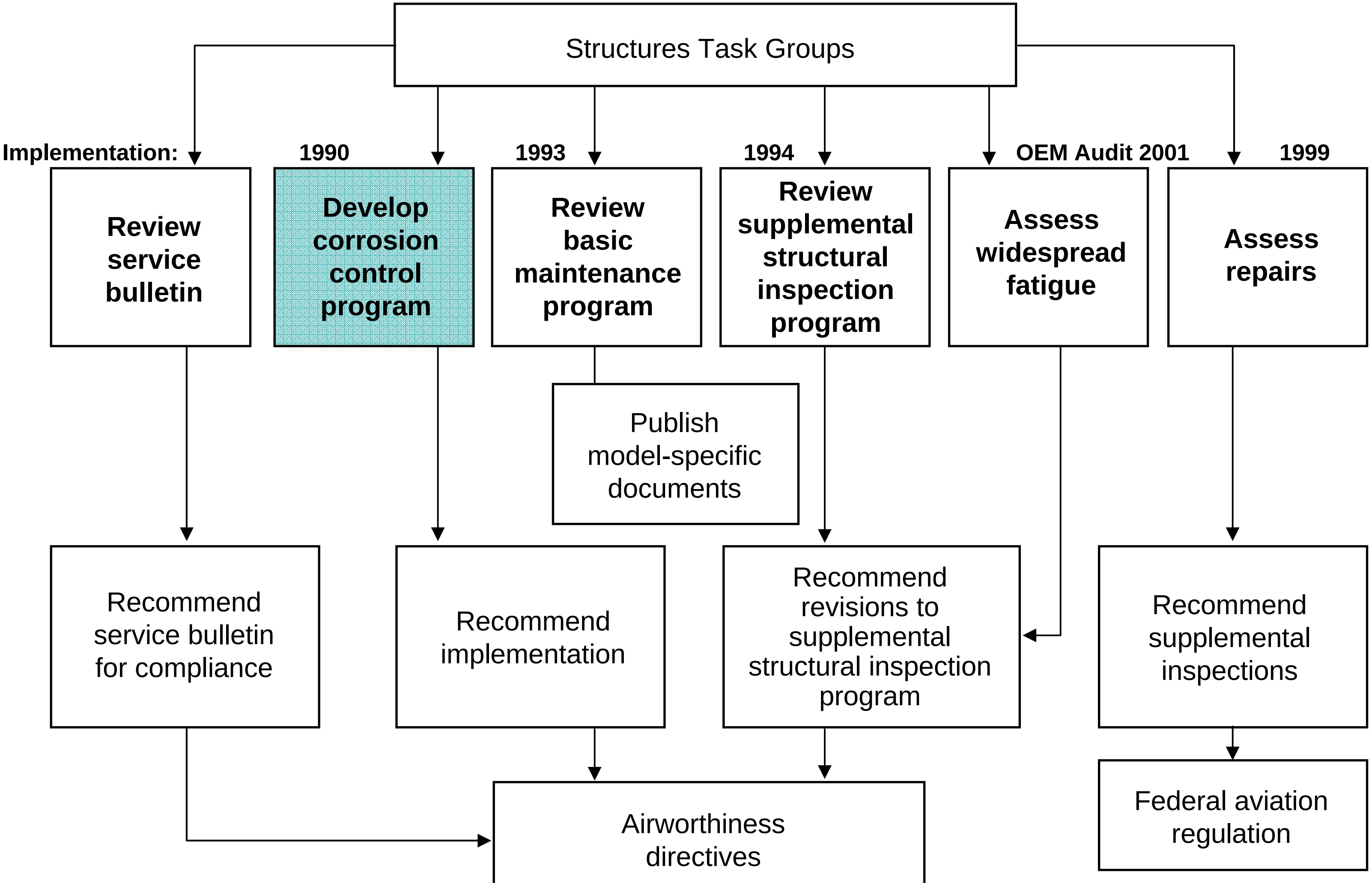
Typical 737 High-Time Modifications



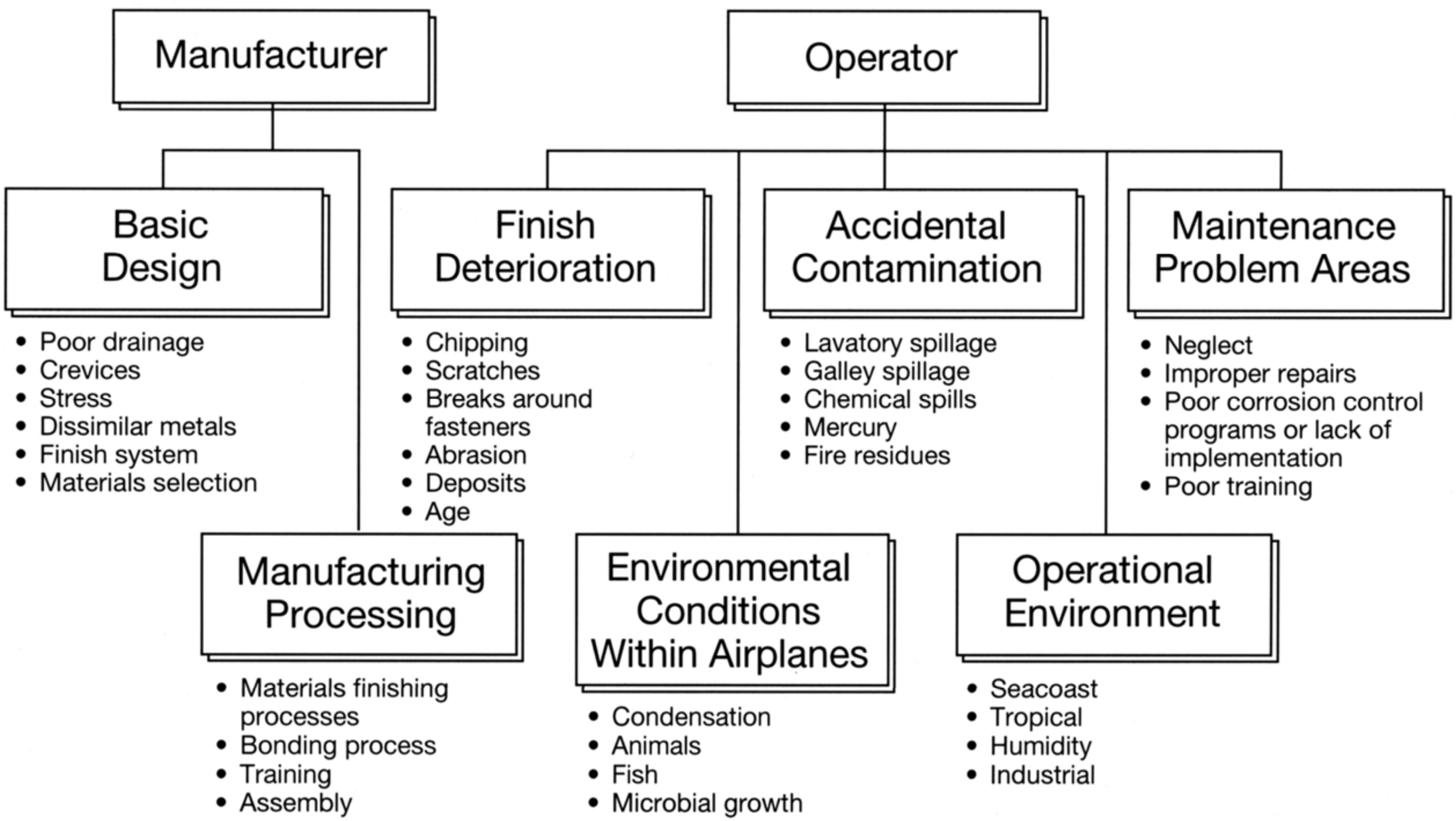
Typical 747 High-Time Modifications



Continued Airworthiness
Industry Initiatives



Contributing Causes of Corrosion



Corrosion Program Areas

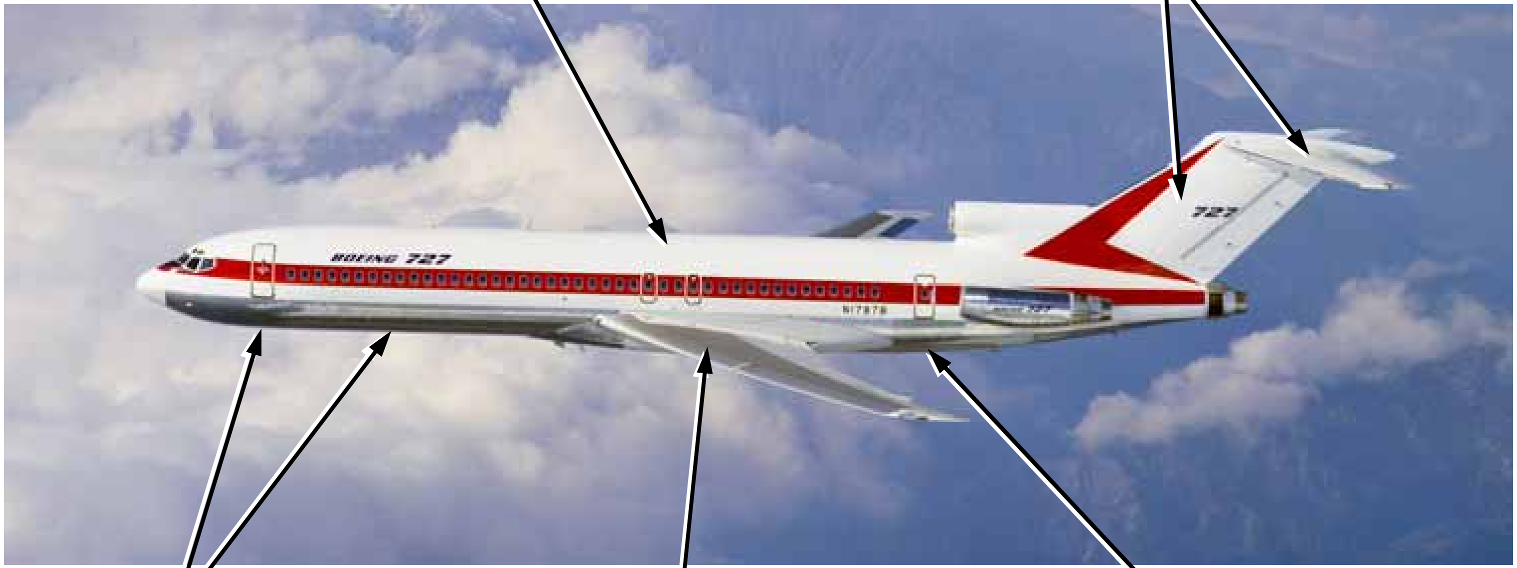
Airplane

- **Wing**
  - Exterior surface
  - Leading-edge cavity
  - Main box
  - Trailing-edge cavity
  - Center section
- **Fuselage**
  - Exterior surface
  - Flightcrew compartment
  - Upper/lower lobe
  - Bilge
  - Under fairings
- **Empennage**
  - Exterior surface
  - Leading-edge cavity
  - Main box
  - Trailing-edge cavity
  - Horizontal stabilizer center section
- **Landing gear and strut**
  - Nose landing gear
  - Main landing gear
  - Powerplants and struts

AAWG Status

- On June 29, 2001, the AAWG submitted a Proposed Operational Rule to ARAC on the Control and Prevention of Widespread Fatigue Damage (WFD) in the Commercial Transport Fleet.
  - Once finalized the rule will require the use of maintenance programs that address the potential occurrence of WFD as the airplanes age.
  - Operation of the airplane will be prohibited beyond the stated Limits of Validity (LOV) of the Maintenance Program unless an approved amendment is incorporated to address any WFD concerns.
- The issuance of the rule will represents closure of all issues resulting from the April 1988 Aloha Accident.
- The AAWG is now focusing on supplemental type certificates (STC)

The 727 Corrosion Prevention Program



Fuselage Upper Lobe Interior 10yr/8yr*

Fin and Horizontal Stabilizer Interiors 10yr/8yr*

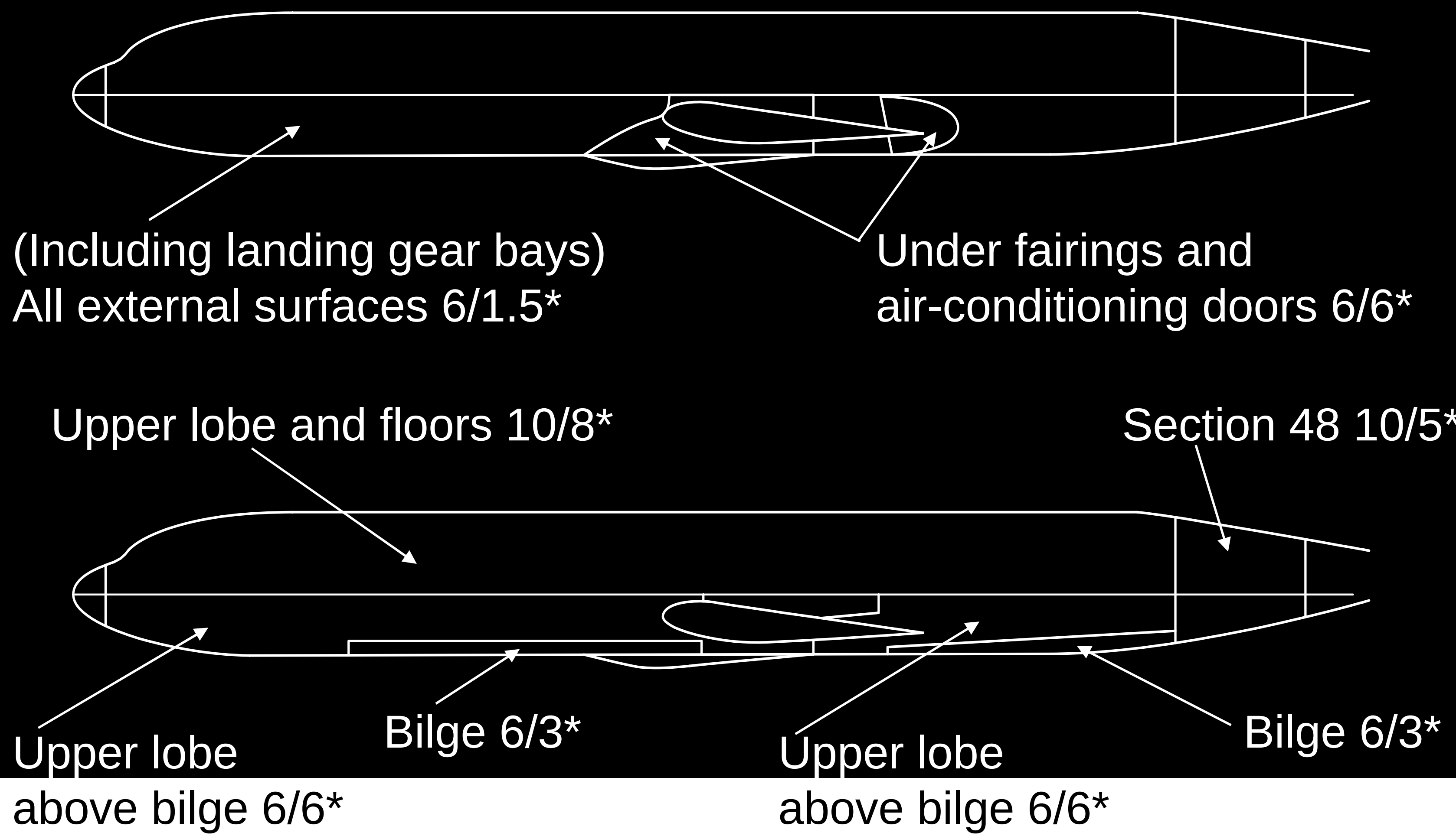
External Doors and Landing Gear Bay 6yr/1.5yr*

Outboard Main Wingbox Interior 10yr/10yr*

Bilge 6yr/3yr*

*** Initial Implementation/Repeat Interval in Years.**

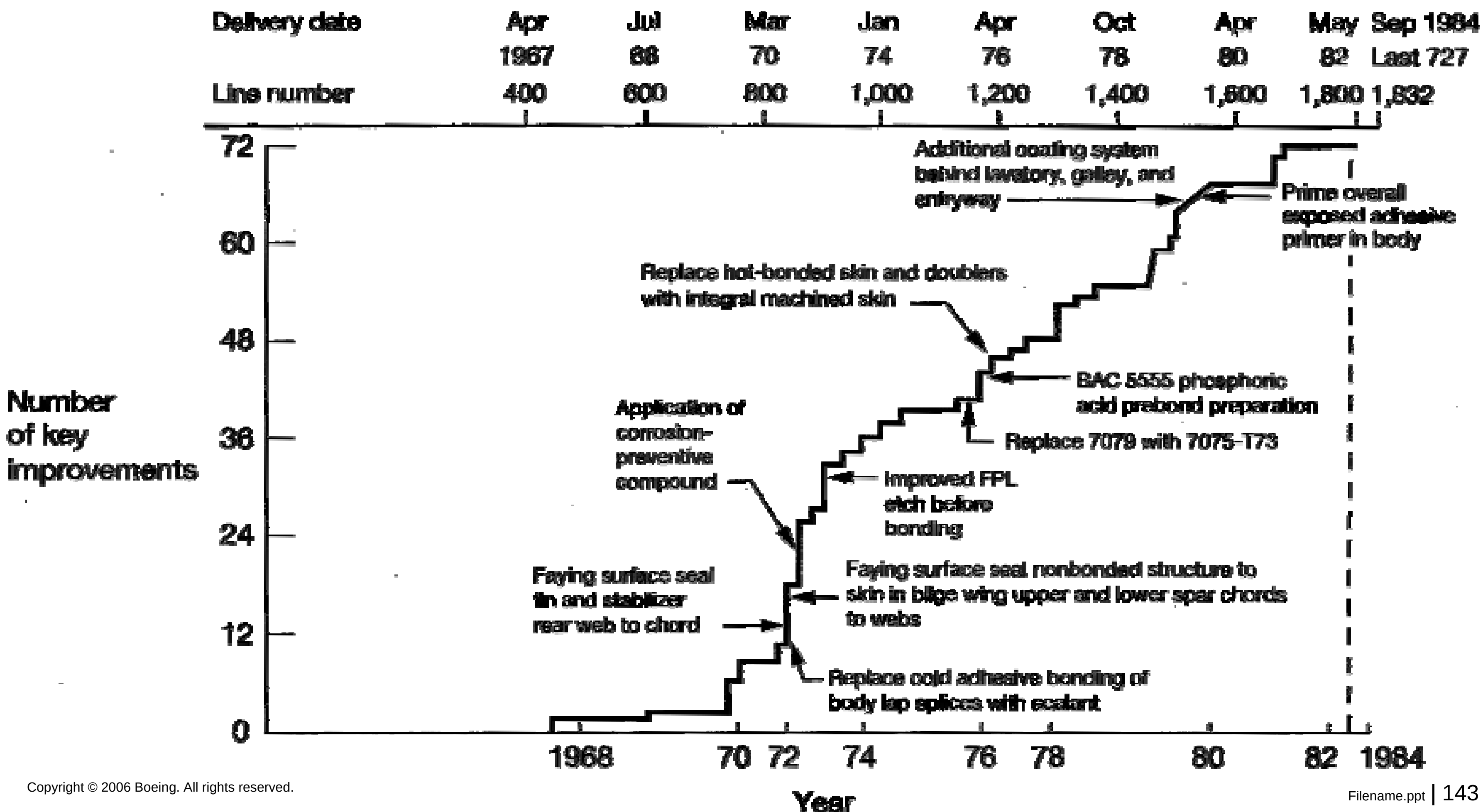
727 Corrosion Control Program
Fuselage Structure Example



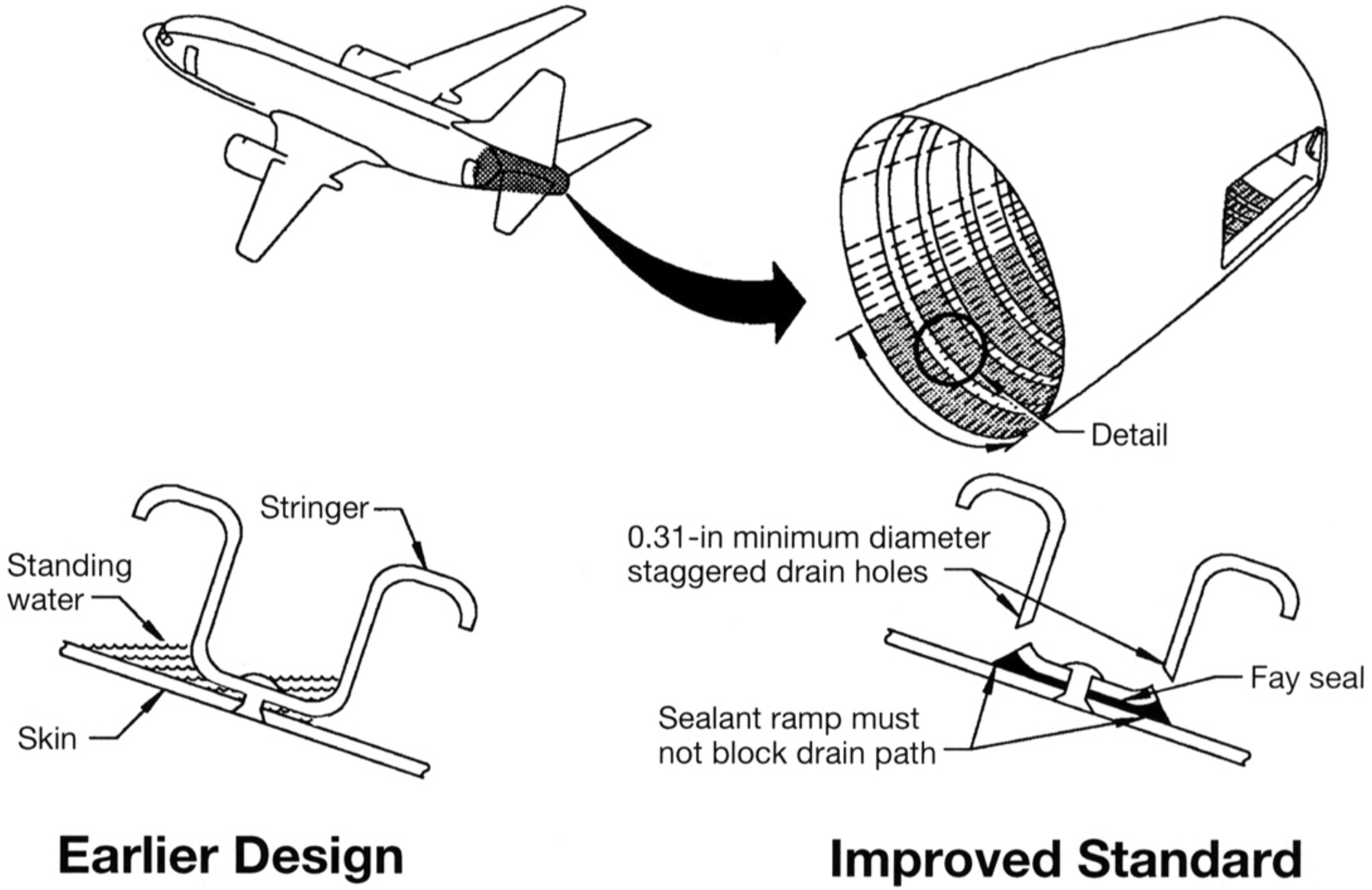
*Threshold interval (years)

Corrosion Control Improvements

- 727 Airplane

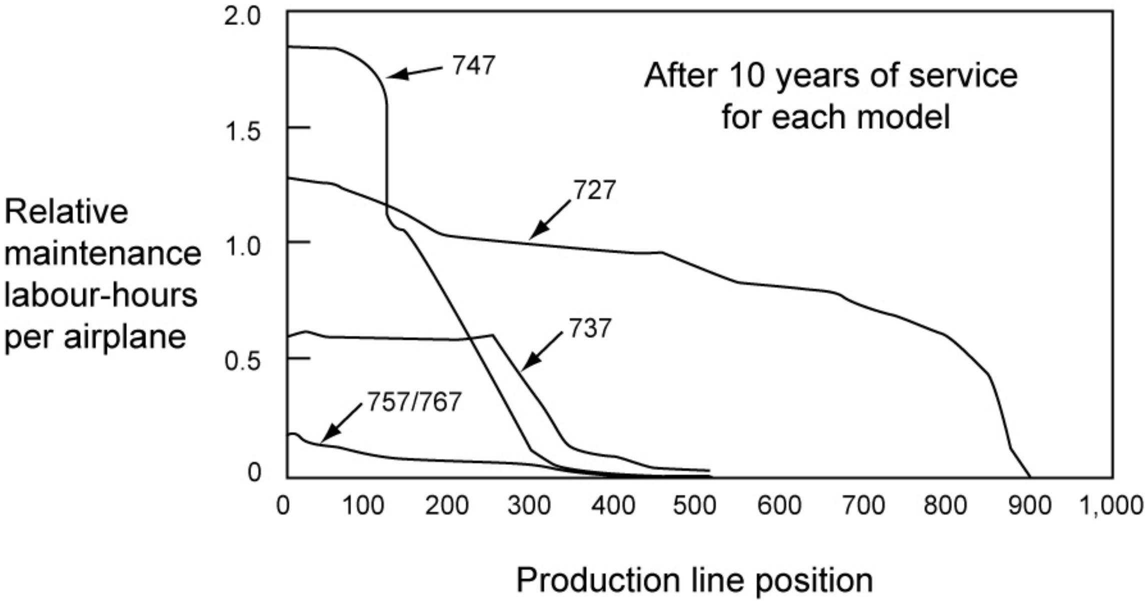


Stringer Drainage and Sealing - Lower Lobe

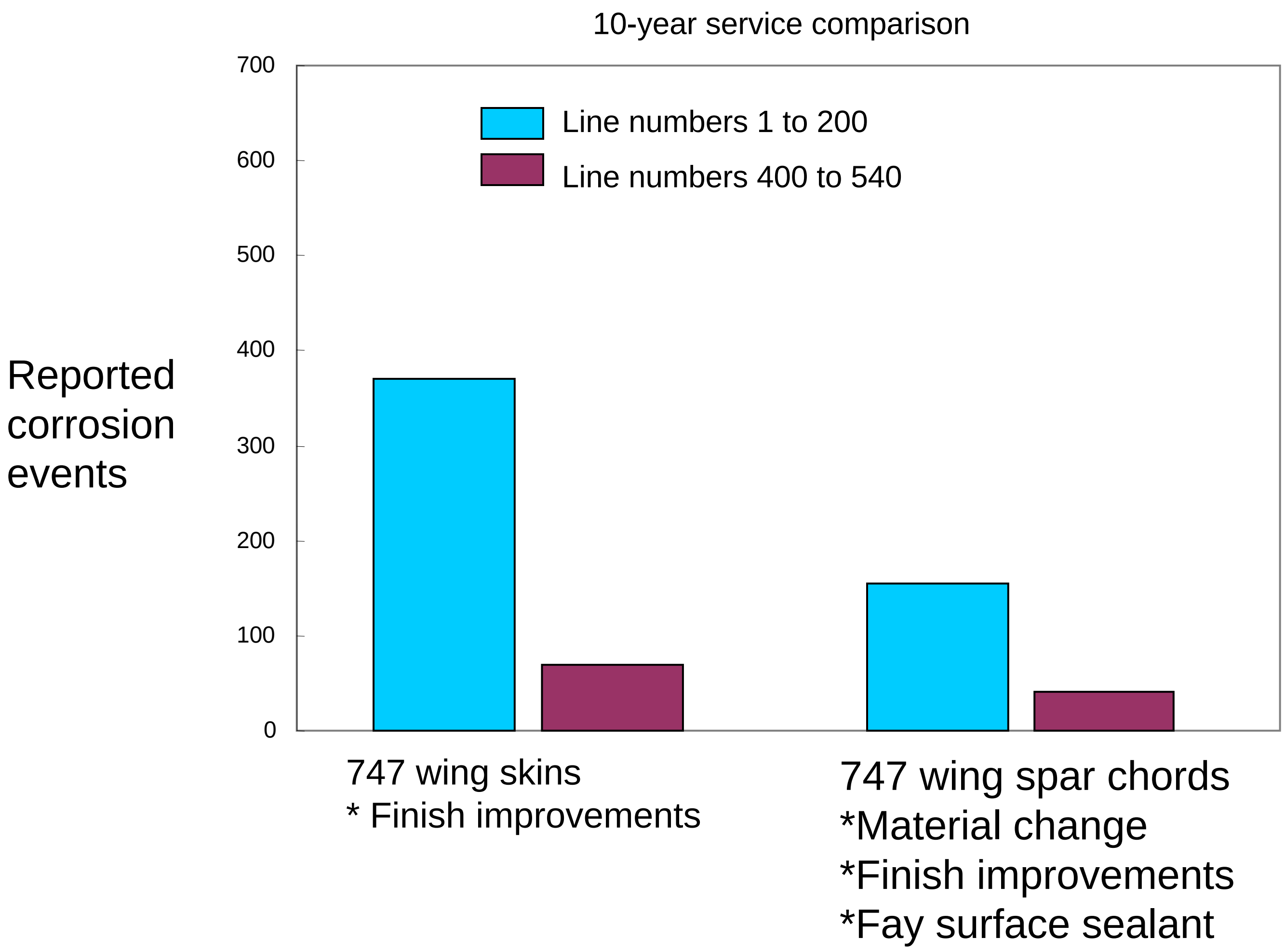


Service Bulletin Modifications - Labor-Hours

Corrosion and Fatigue

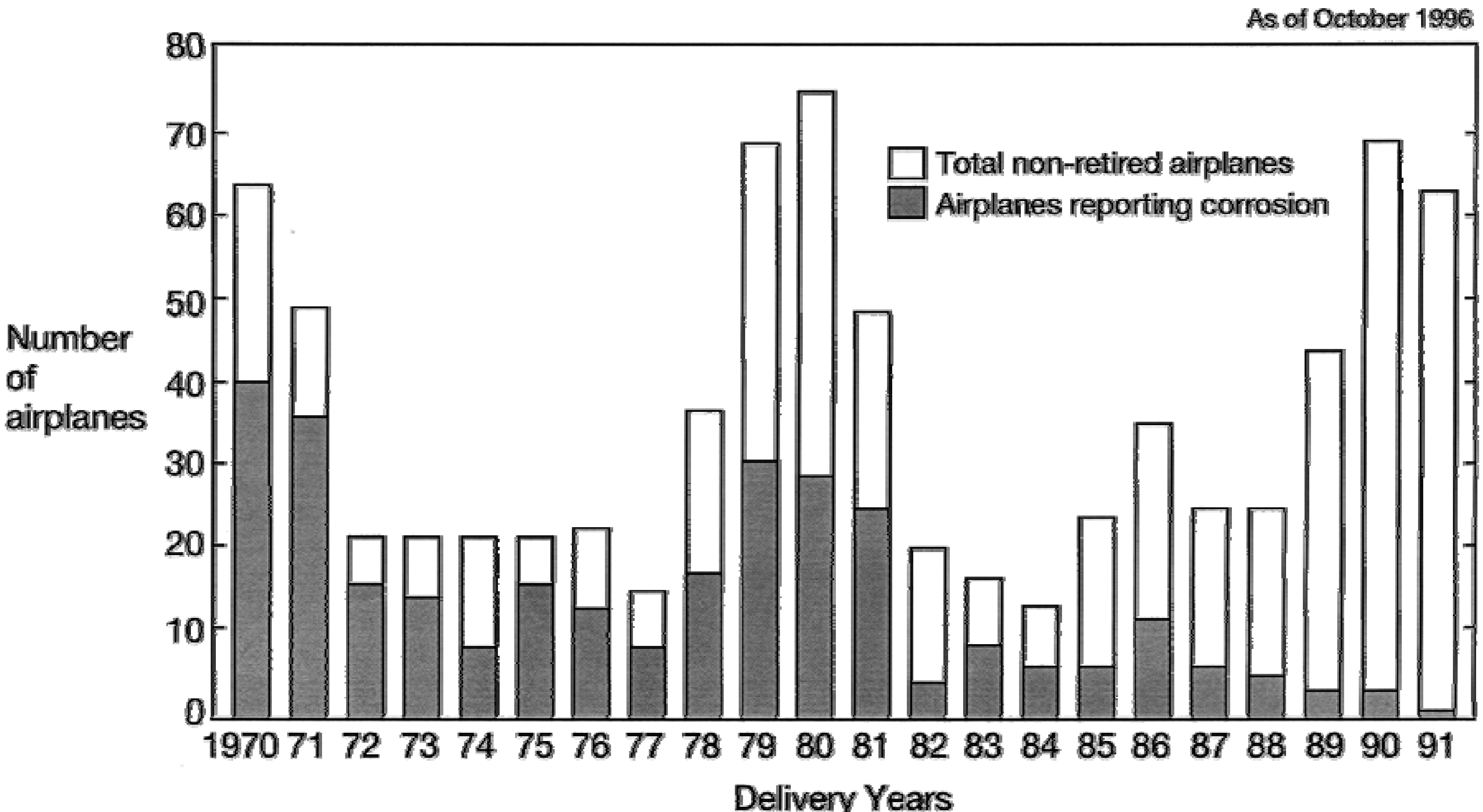


Effects of Corrosion Control Improvements on the 747



Test Versus Service

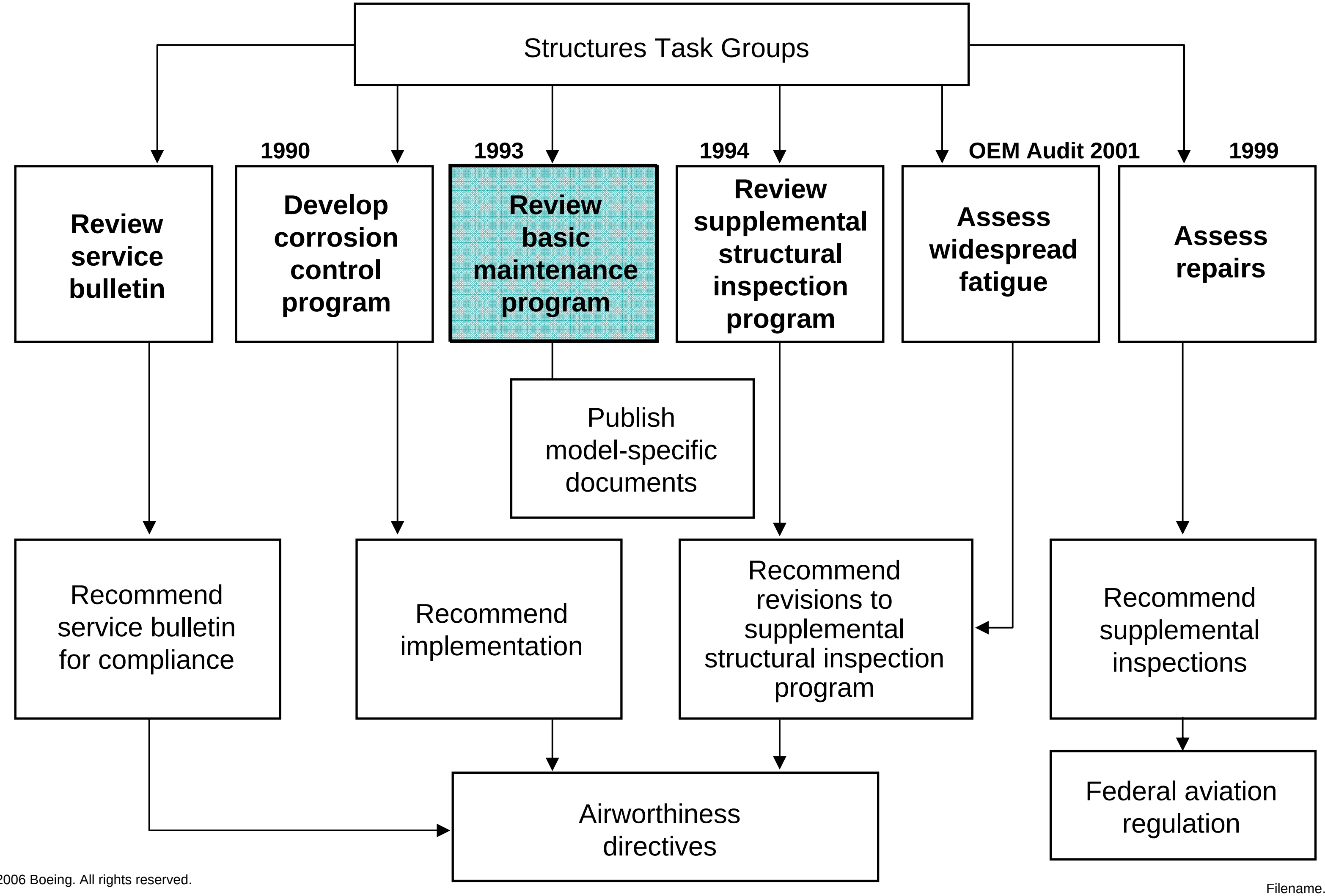
- -100/-200/-300/-400/SP/SR



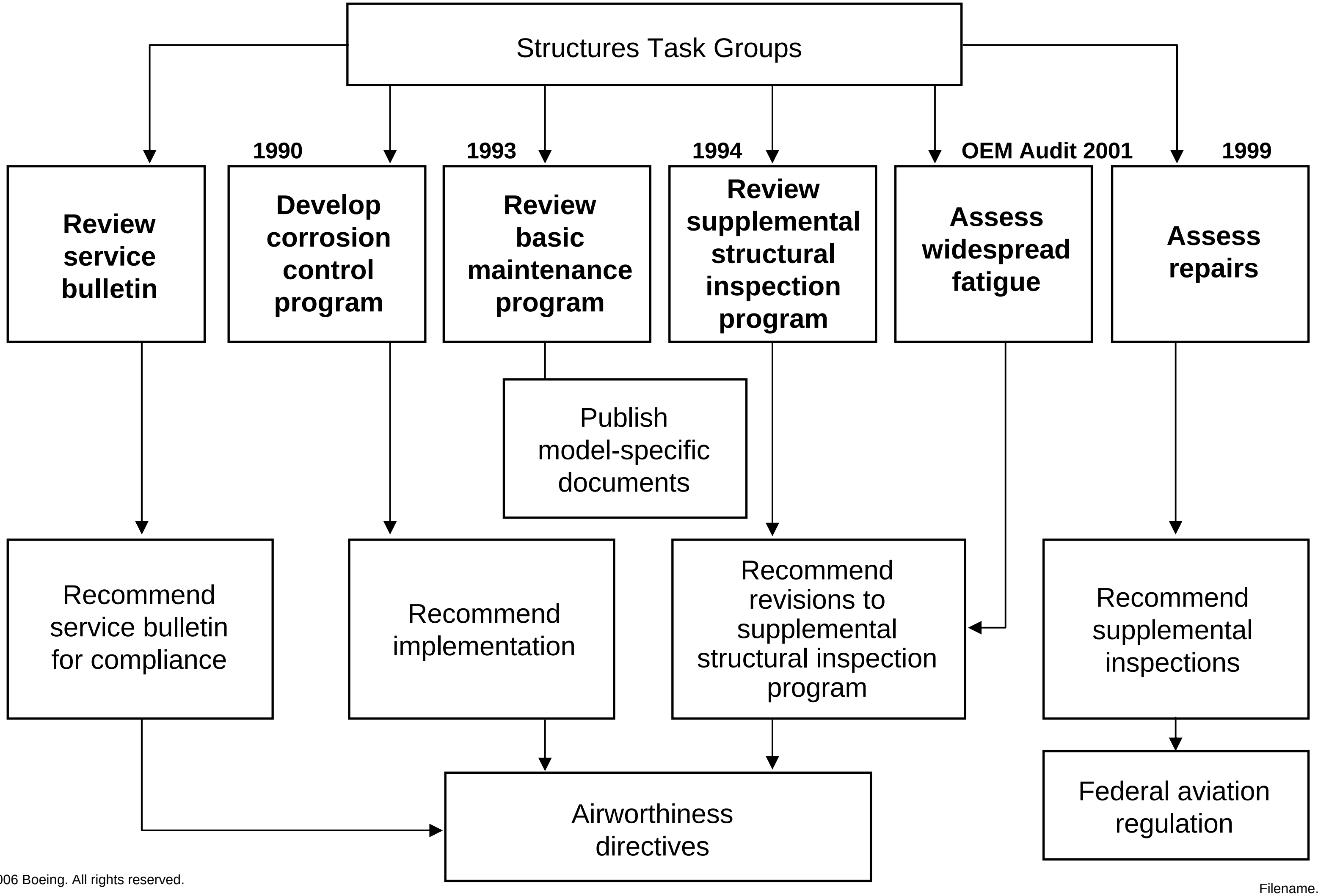
Continuing Airworthiness Challenges

- Mandatory Service Bulletin Modifications
- Corrosion Prevention and Control Programs
- **Maintenance Programs**

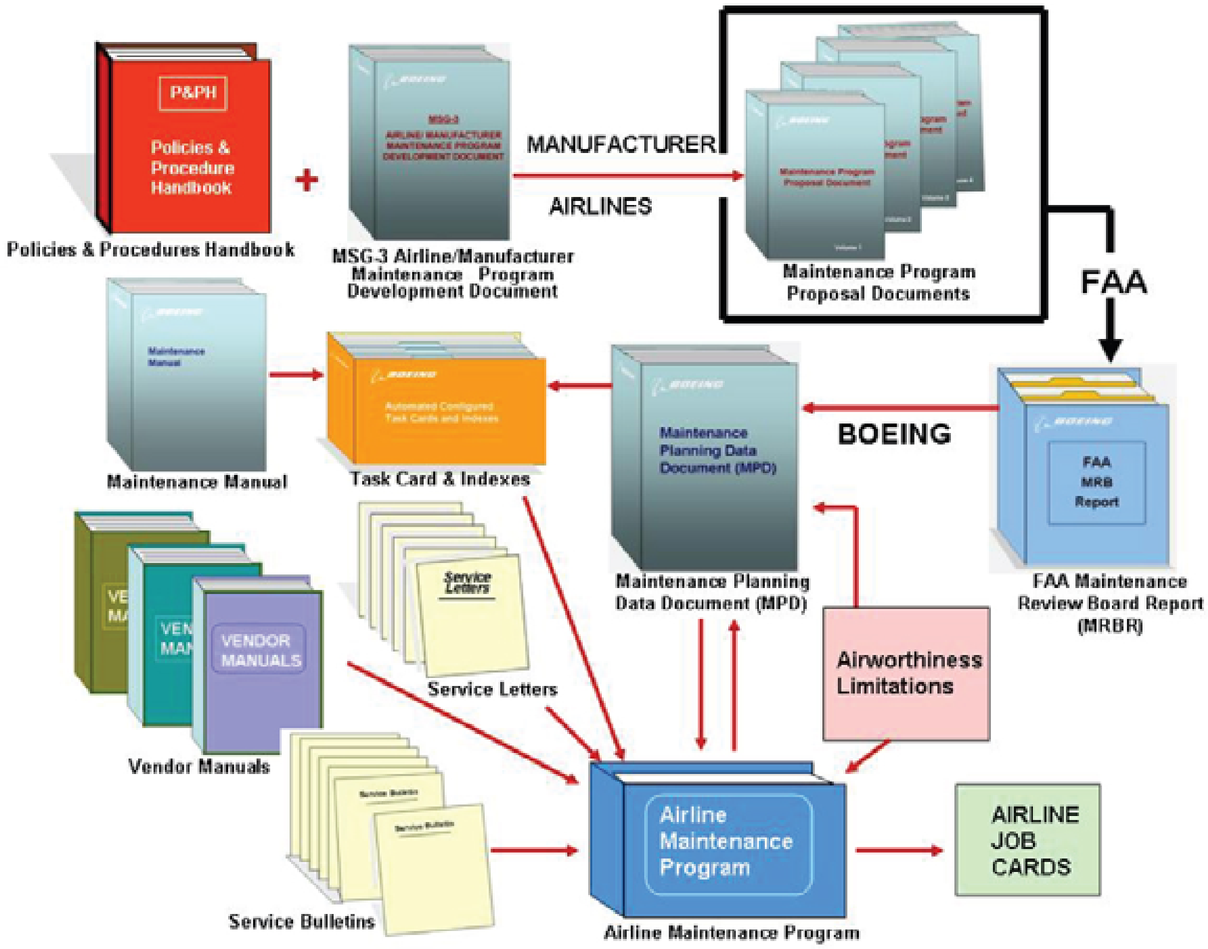
Continued Airworthiness Industry Initiatives



Continued Airworthiness Industry Initiatives



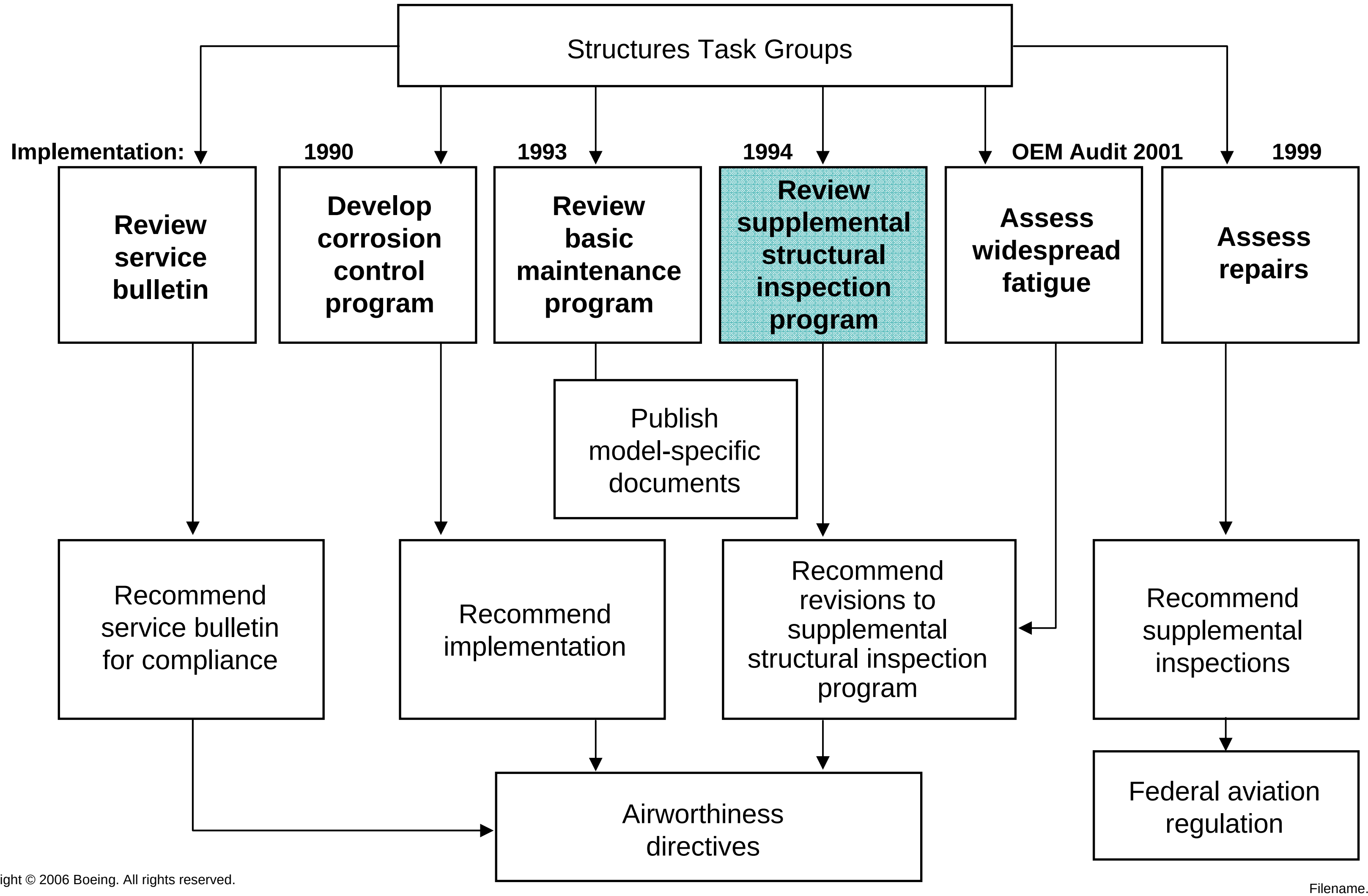
Maintenance Planning Process



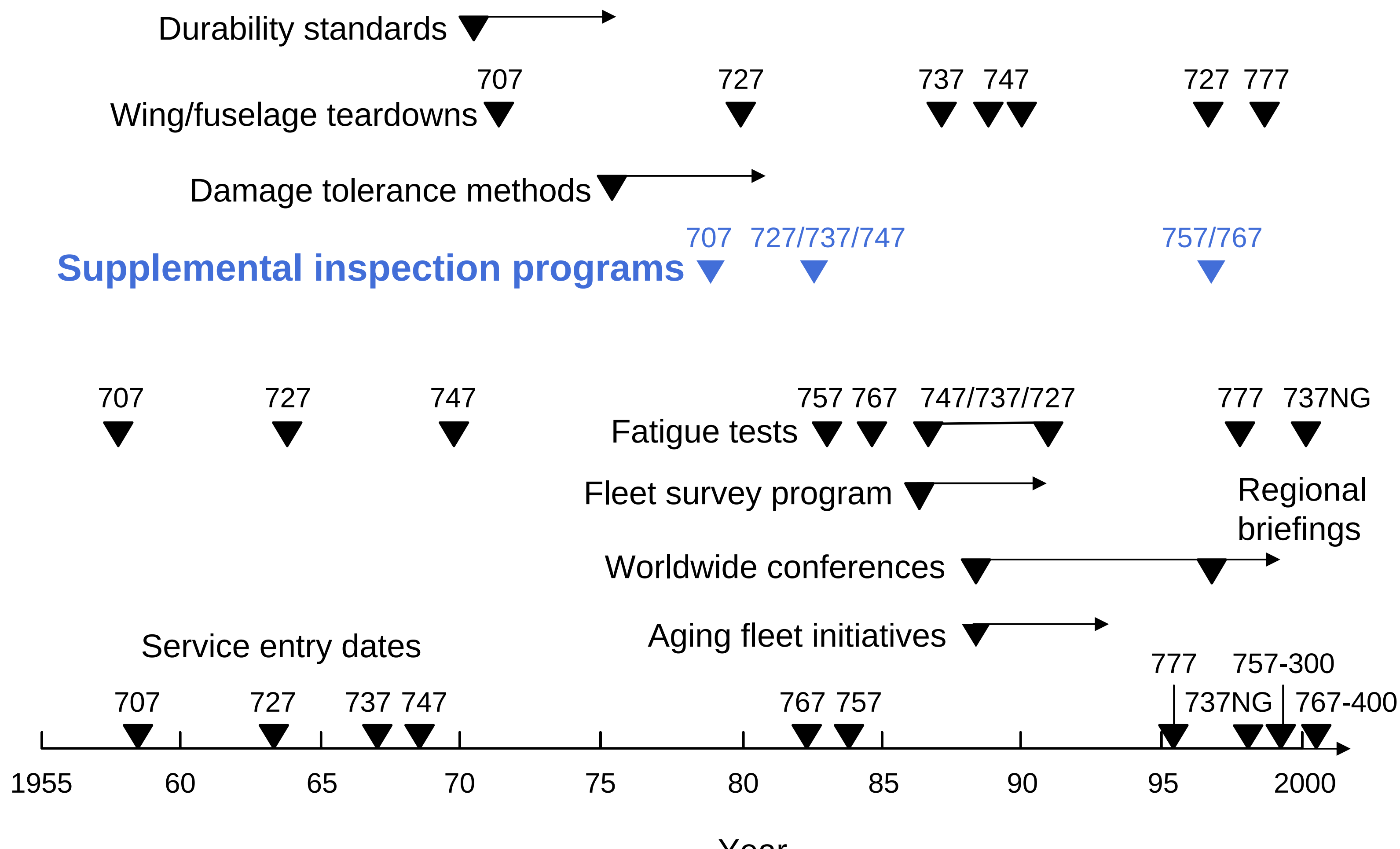
Continuing Airworthiness Challenges

- Mandatory Service Bulletin Modifications
- Corrosion Prevention and Control Programs
- Maintenance Programs
- **Supplemental Inspection Programs**

Continued Airworthiness
Industry Initiatives



Boeing Fleet Support Actions

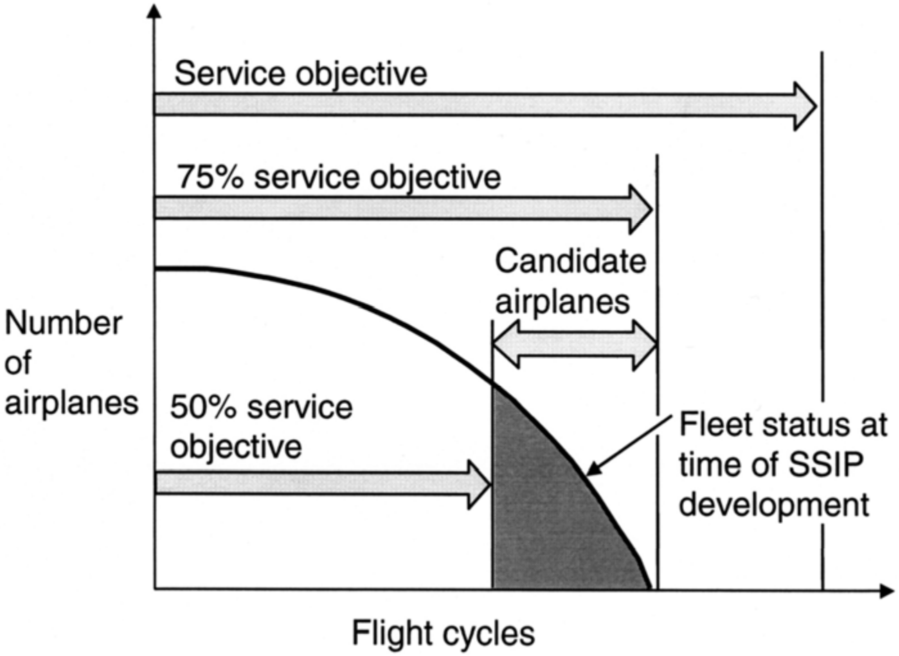


Continuing Airworthiness Challenges

- Mandatory Service Bulletin Modifications
- Corrosion Prevention and Control Programs
- **Supplemental Inspection Program Reviews**

Supplemental Inspections - Airplane Selection
Candidate Fleet v.s Inspection Threshold

- 1999 Status



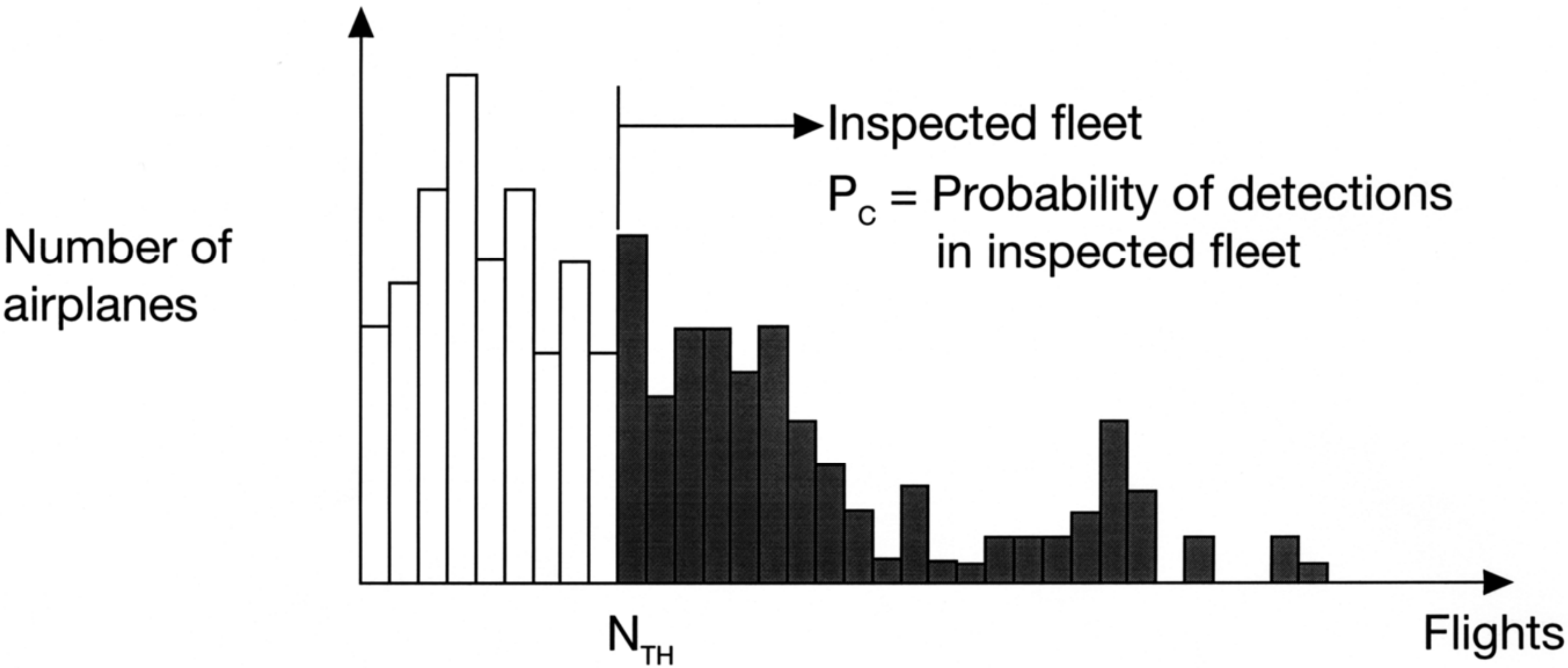
Airplane		Original candidate airplanes	1999 candidate fleet
Model	Series		
707/720	All	100*	58
727	100/200	389	207
	100C	72	68
737	100/200	124	90
747	100/100F/200B	117	91

* Specific 707 inspection thresholds used

Supplemental Inspection Threshold

- Fleet Utilization Distribution

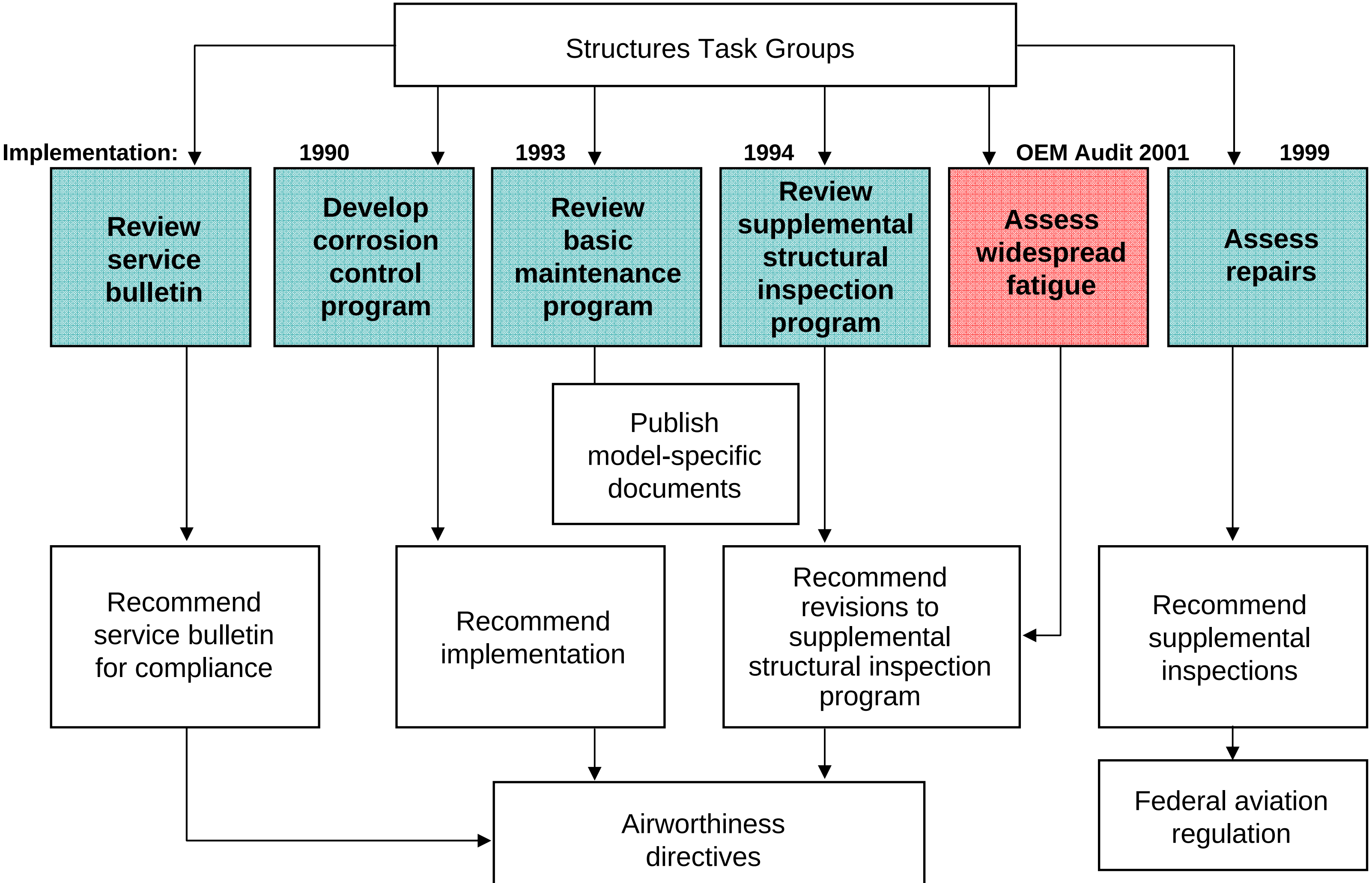
N_T selected to minimize risk of having cracks in airplanes below N_{TH}



Continuing Airworthiness Challenges

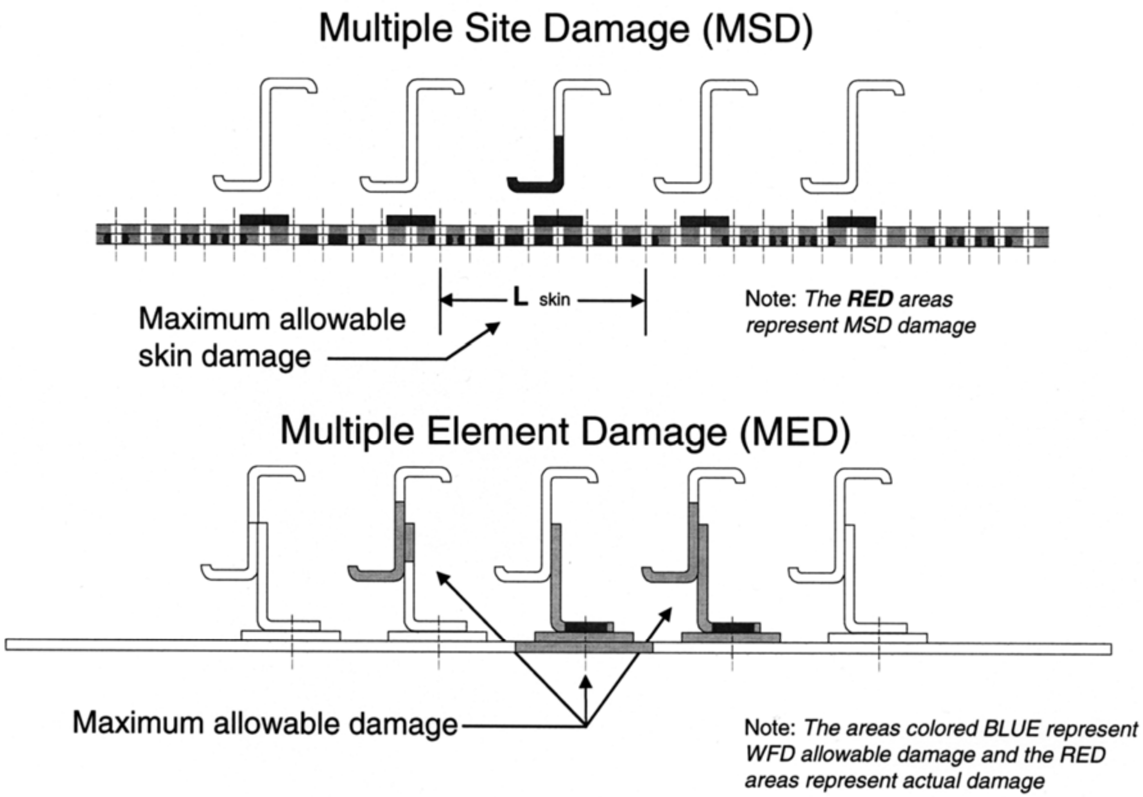
- Mandatory Service Bulletin Modifications
- Corrosion Prevention and Control Programs
- Maintenance Programs
- Supplemental Inspection Programs
- **Widespread Fatigue Damage**

Continued Airworthiness – Industry Initiatives

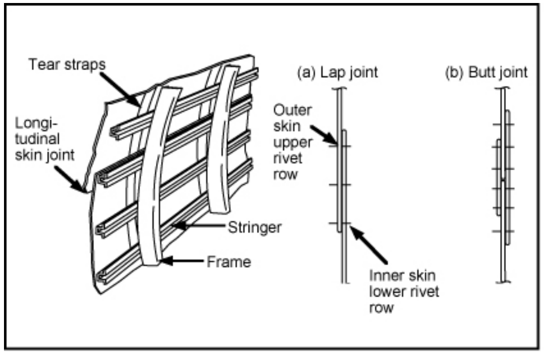


Widespread Damage

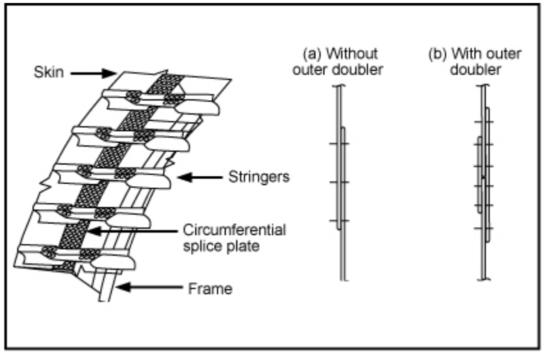
- Widespread Similar Details
- Similar Stresses
- Structural interaction with reduced allowable damage



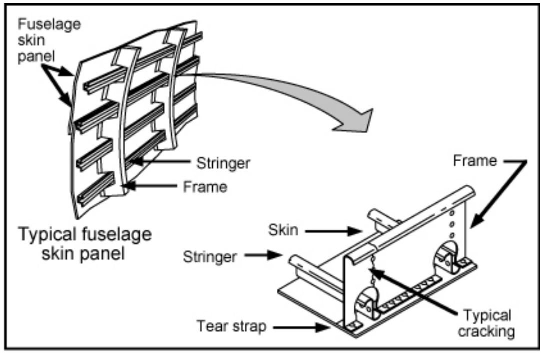
Structure Susceptible to WF
Typical Examples



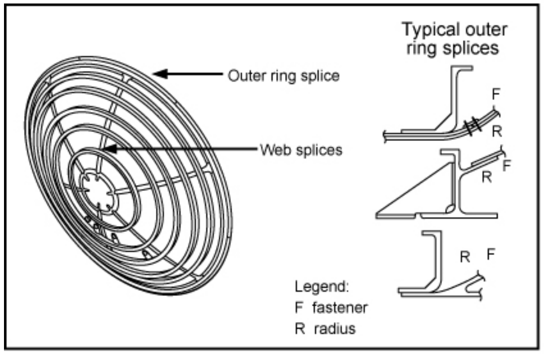
Longitudinal Skin Joints, Frames, and Tear Straps (MSD, MED)



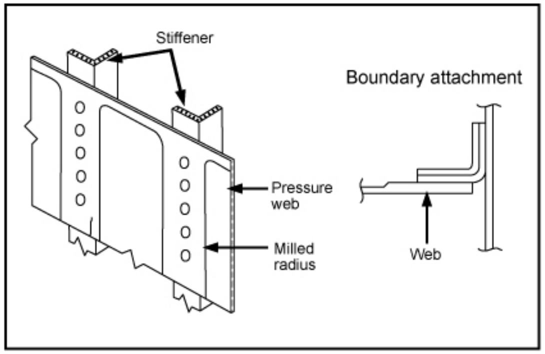
Circumferential Joints and Stringers (MSD, MED)



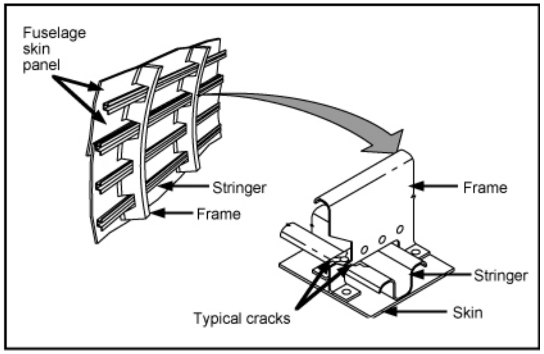
Fuselage Frames (MED)



Aft Pressure Dome Outer Ring and Dome Web Splices (MSD, MED)

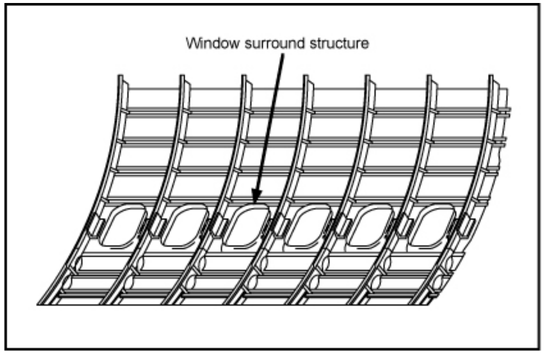


Other Pressure Bulkheads Attachment to Skin—Web Attachments to Stiffener and Pressure Decks (MSD, MED)

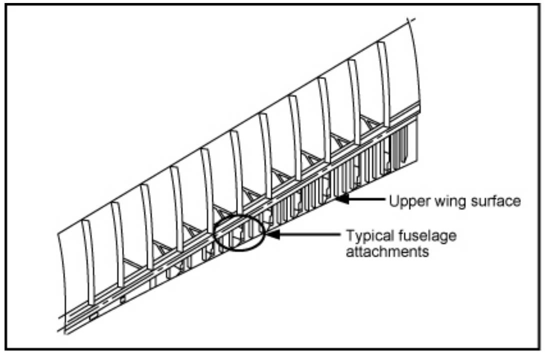


Stringer-to-Frame Attachments

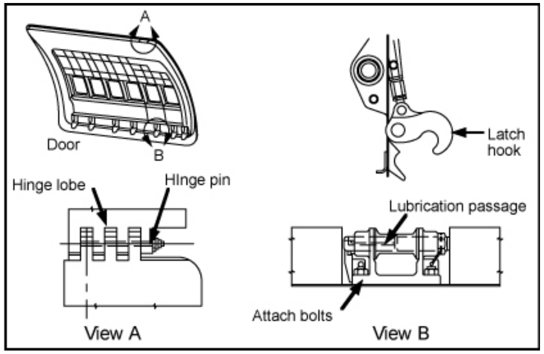
Structure Susceptible to WFD Cont'd



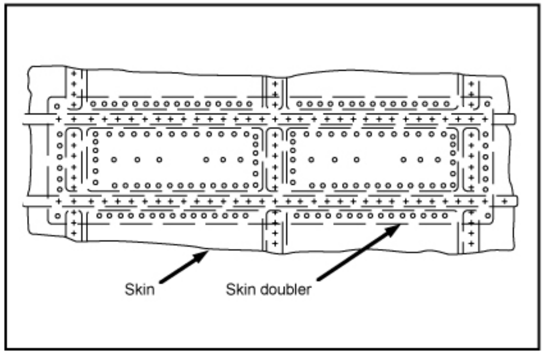
Window Surround Structure
(MSD, MED)



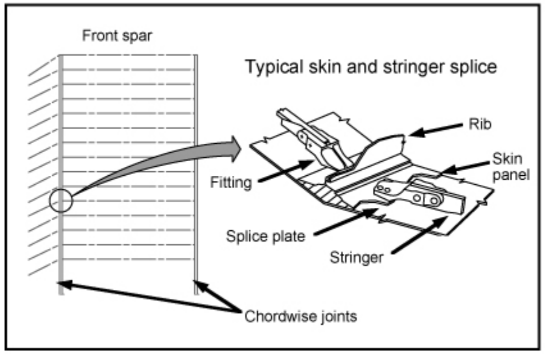
Overwing Fuselage Attachments
(MED)



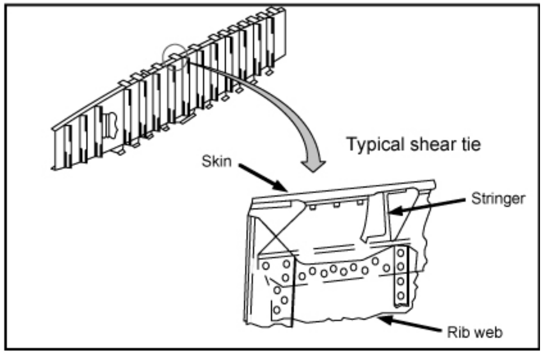
Latches and Hinges of Nonplug
Doors (MSD, MED)



Skin at Runout of Large Doubler (MSD)—
Fuselage, Wing, or Empennage

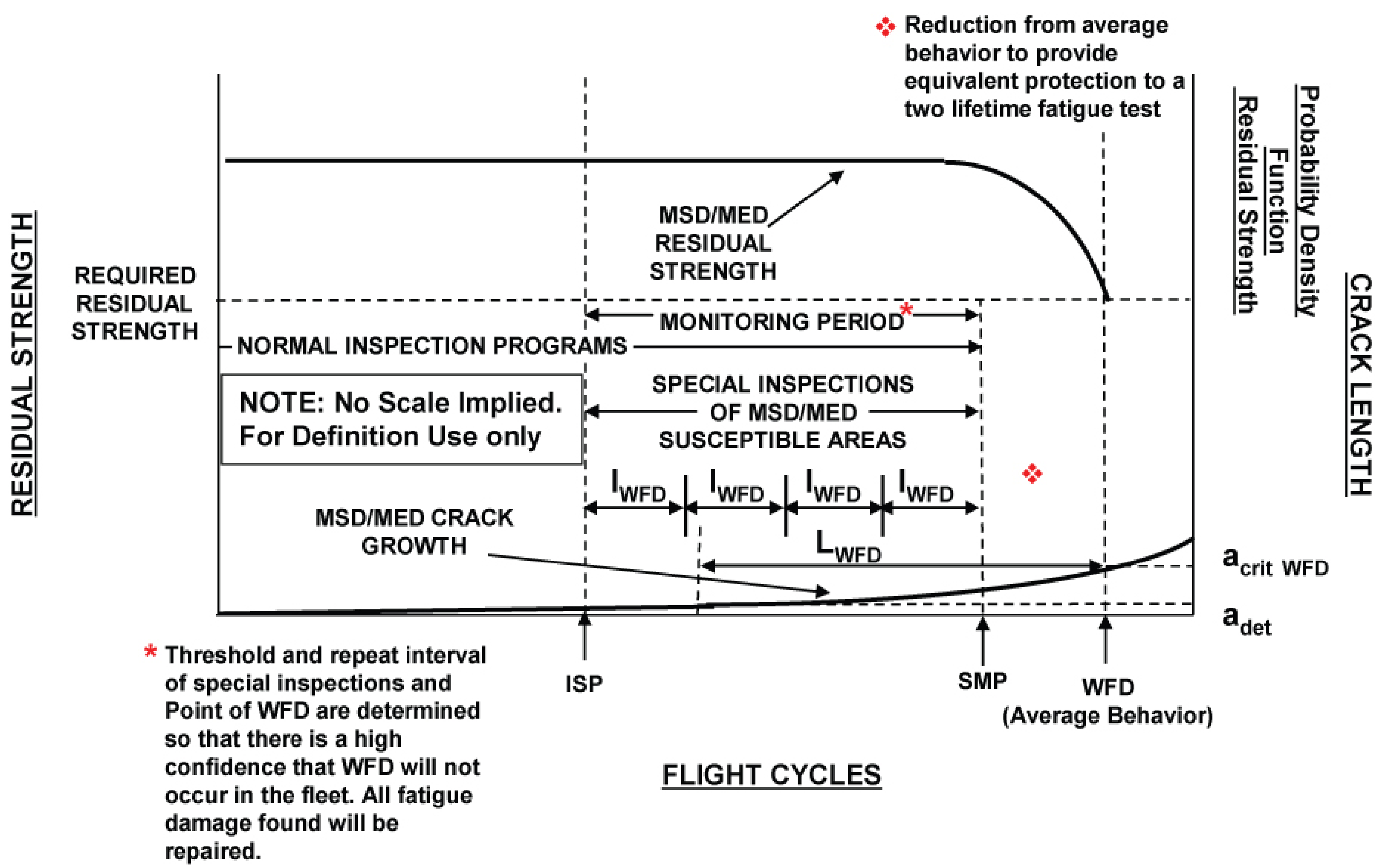


Chordwise Splices (MSD, MED)

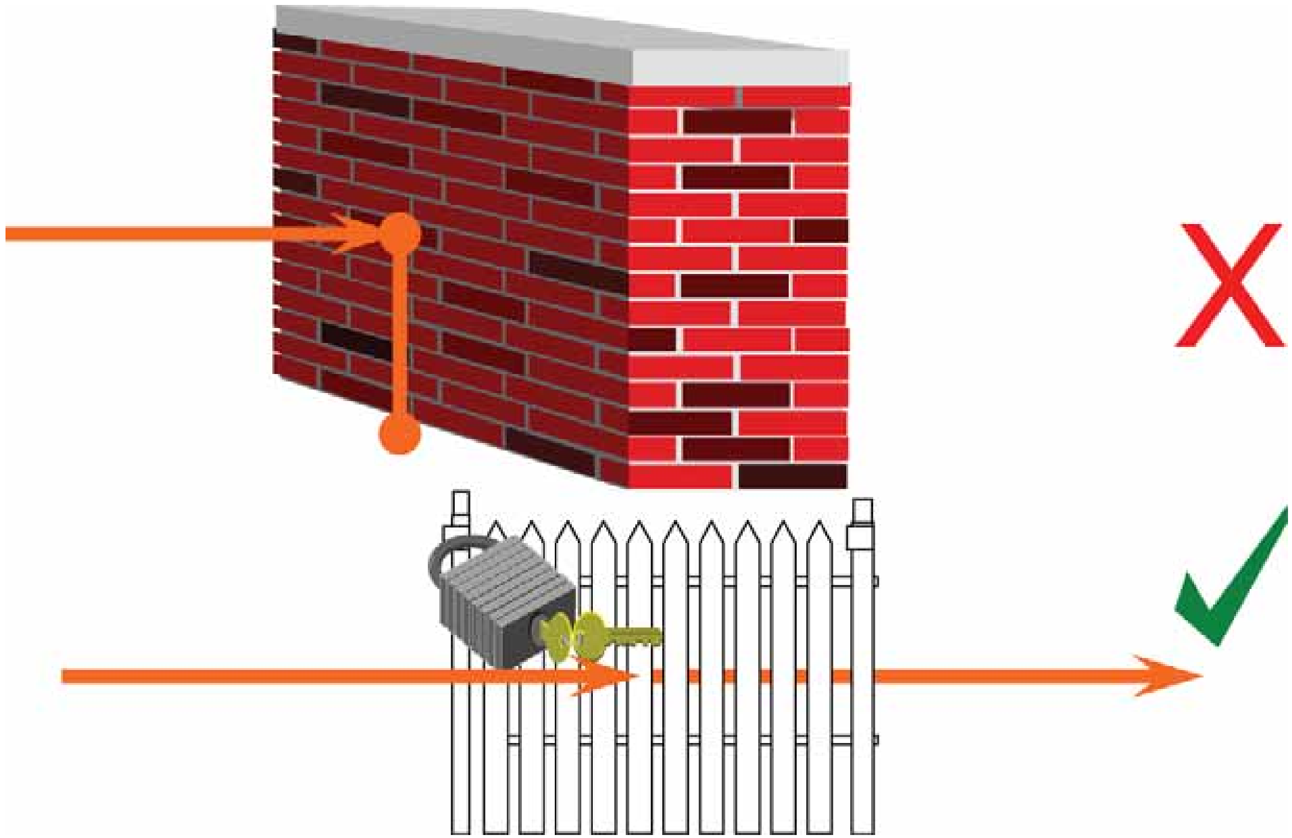


Rib-to-Skin Attachments
(MSD, MED)

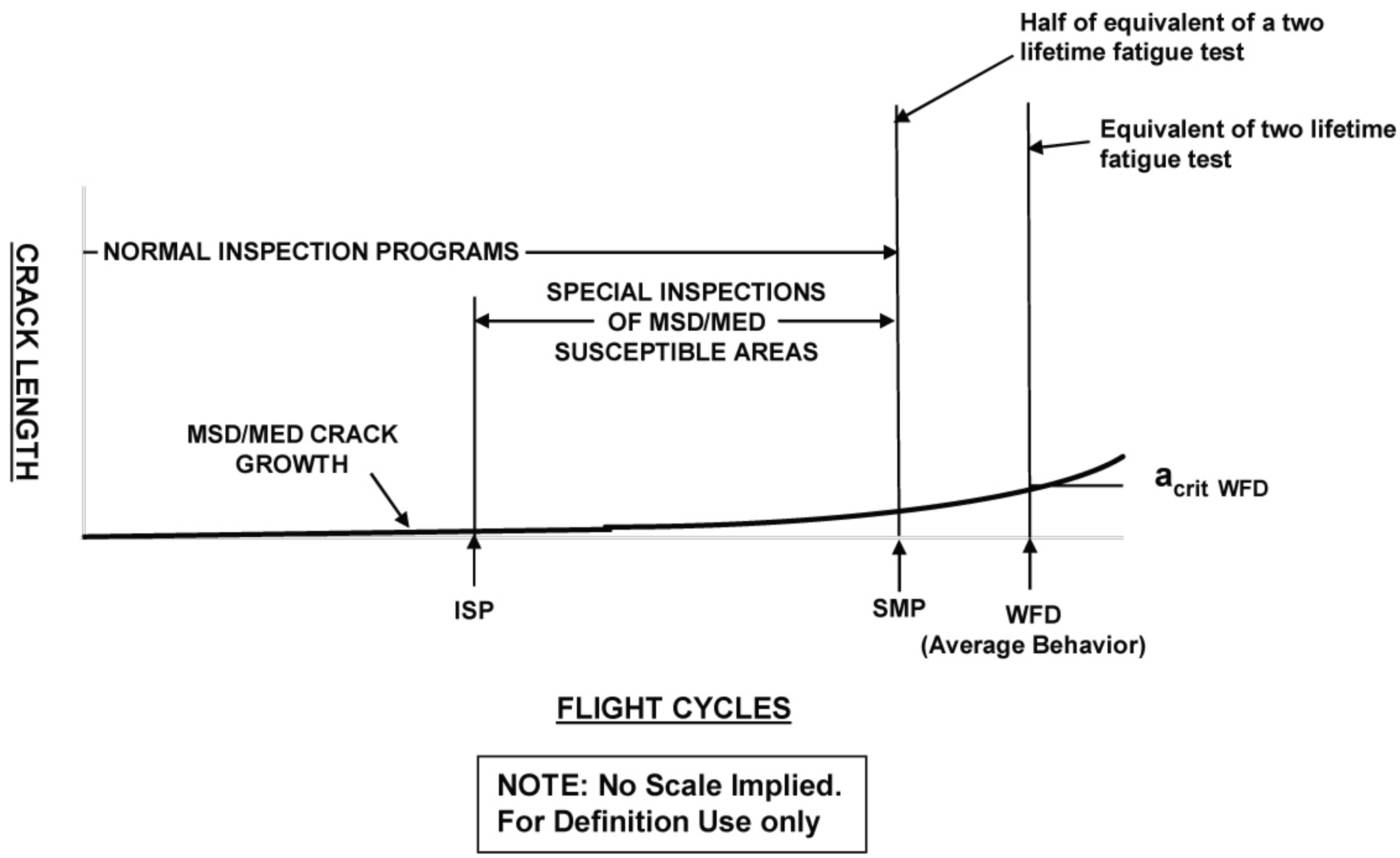
WFD Graphical Representation



Limit of Validity



ISP and SMP Graphic Representation



Preliminary LOVs

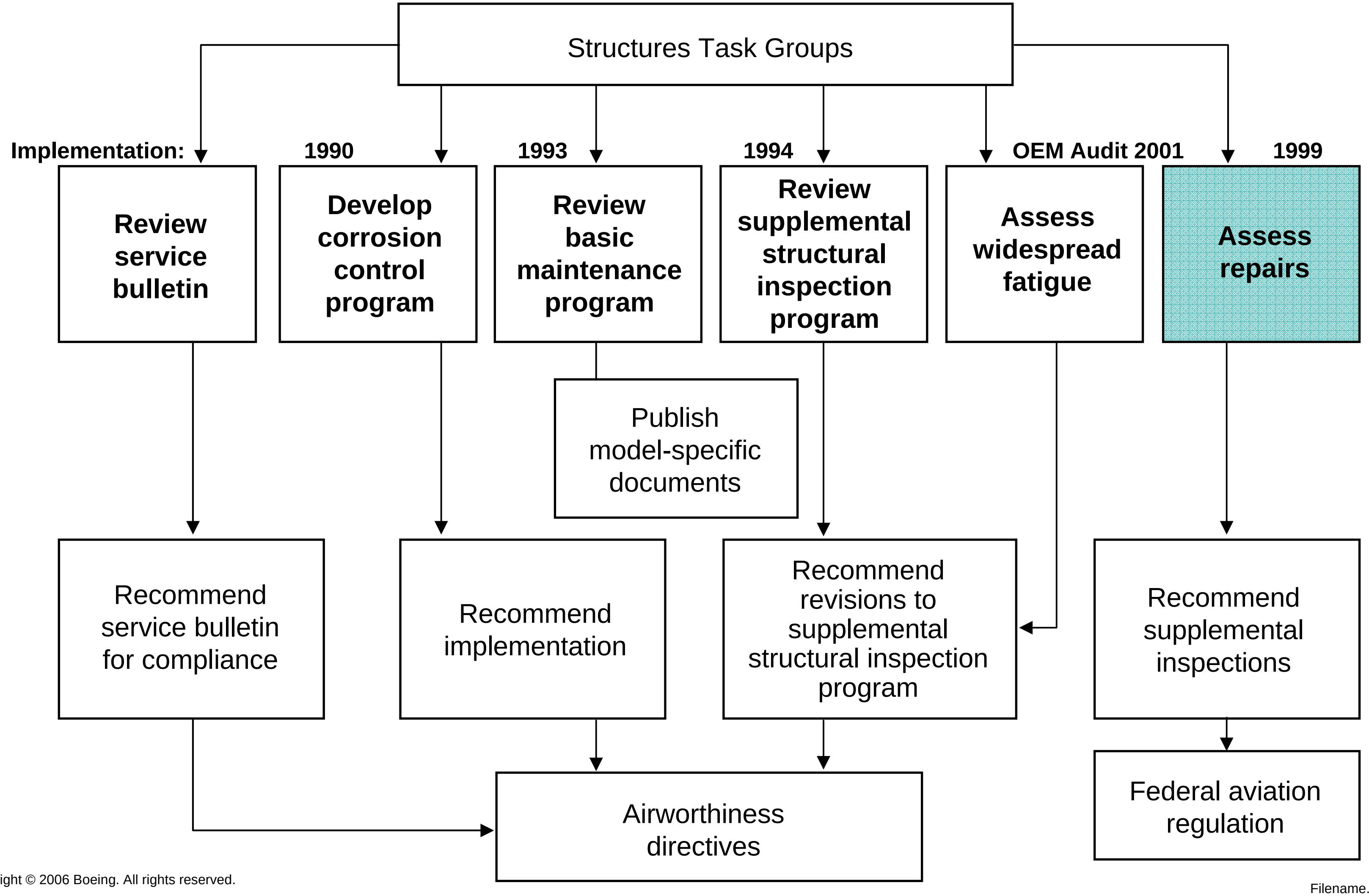
Model	Preliminary LOV*	Airplanes above LOV	Projected above LOV in 2011
707	40,000 f/c	0	0
727	100,000 f/c	0	0
737	100,000 f/c	0	10
747 Classic	30,000 f/c 115,000 hours 35,000 $\text{f/c}_{\text{extended}}$ 135,000 $\text{hours}_{\text{extended}}$	40 5 9 0	59 47 28 5
747-400	35,000 f/c 165,000 hours	0 0	0 0

*** Subject to FAA approval**

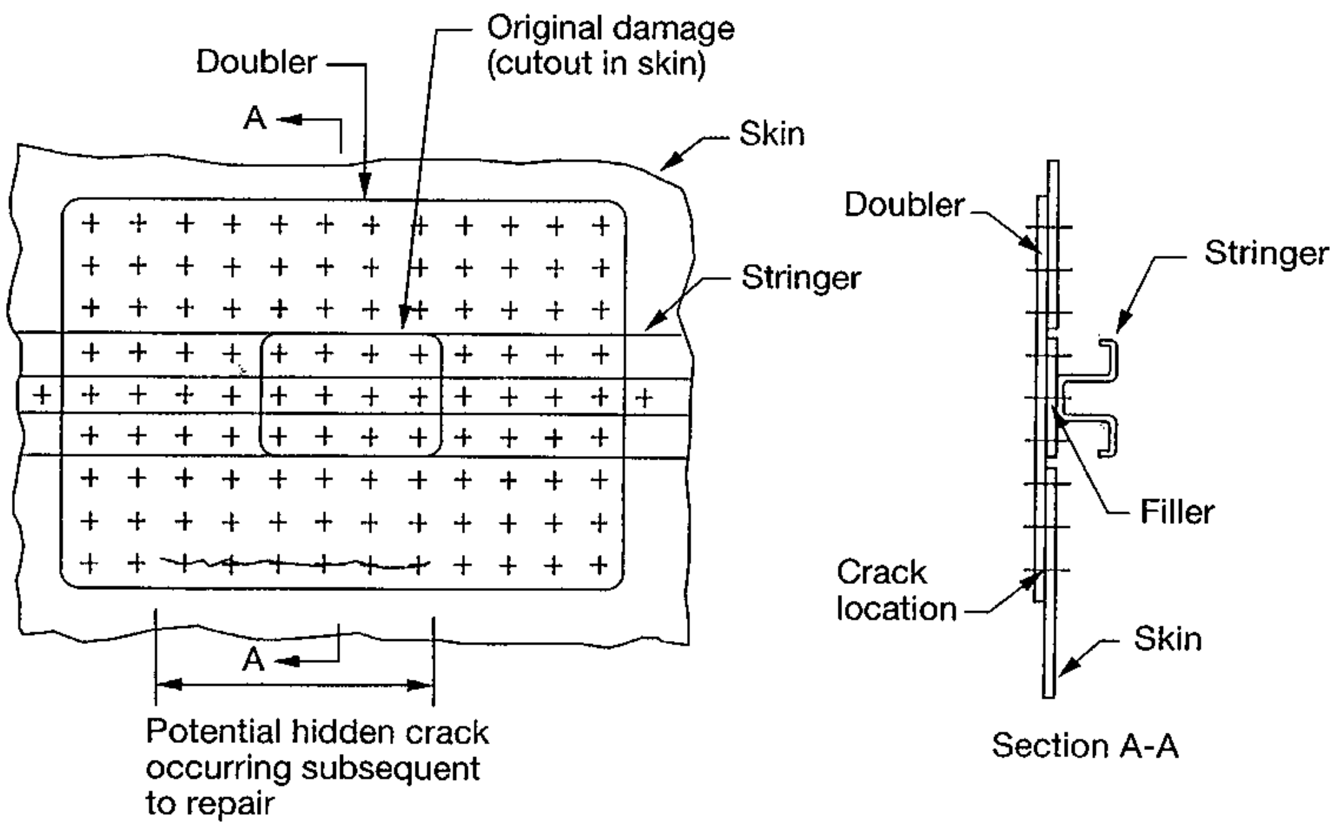
Continuing Airworthiness Challenges

- Mandatory Service Bulletin Modifications
- Corrosion Prevention and Control Programs
- Supplemental Inspection Program Reviews
- Widespread Fatigue Damage
- **Structural Repair Assessments**

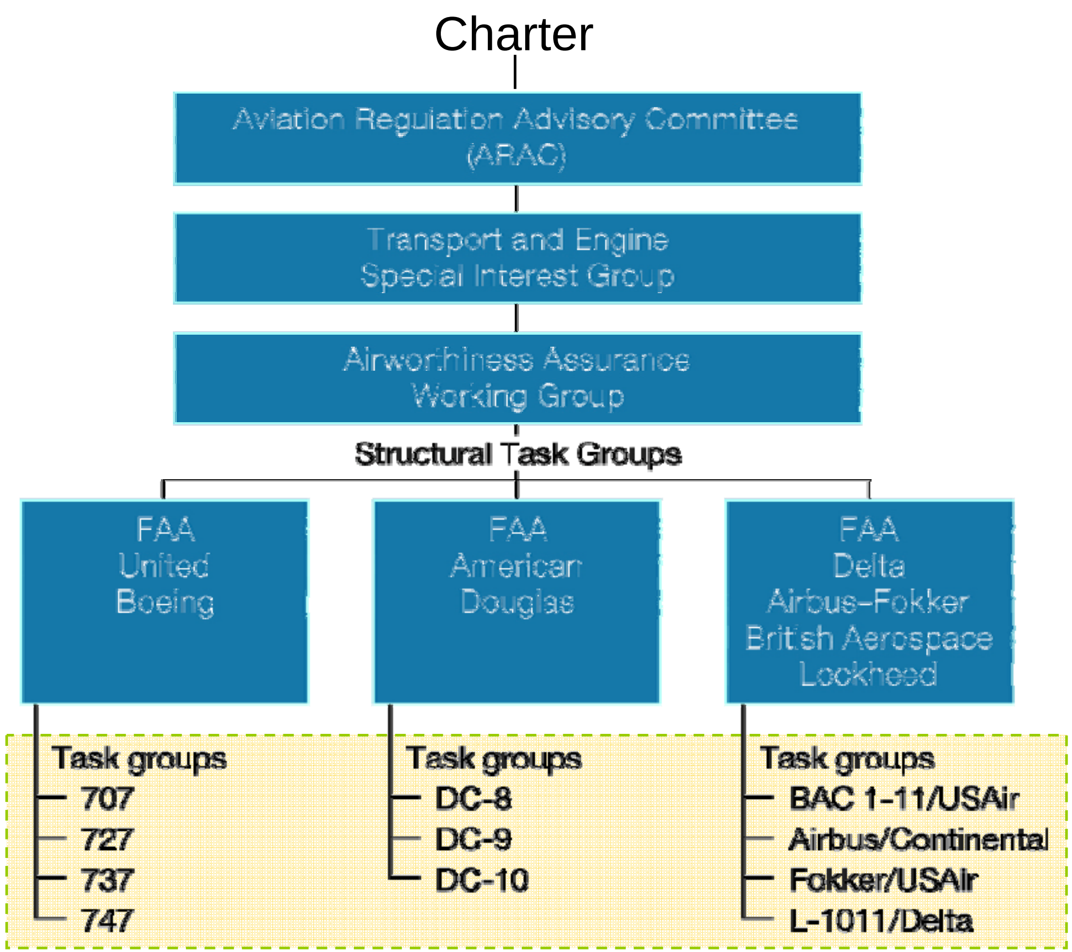
Continued Airworthiness – Industry Initiatives



Typical Fuselage External Skin Repair

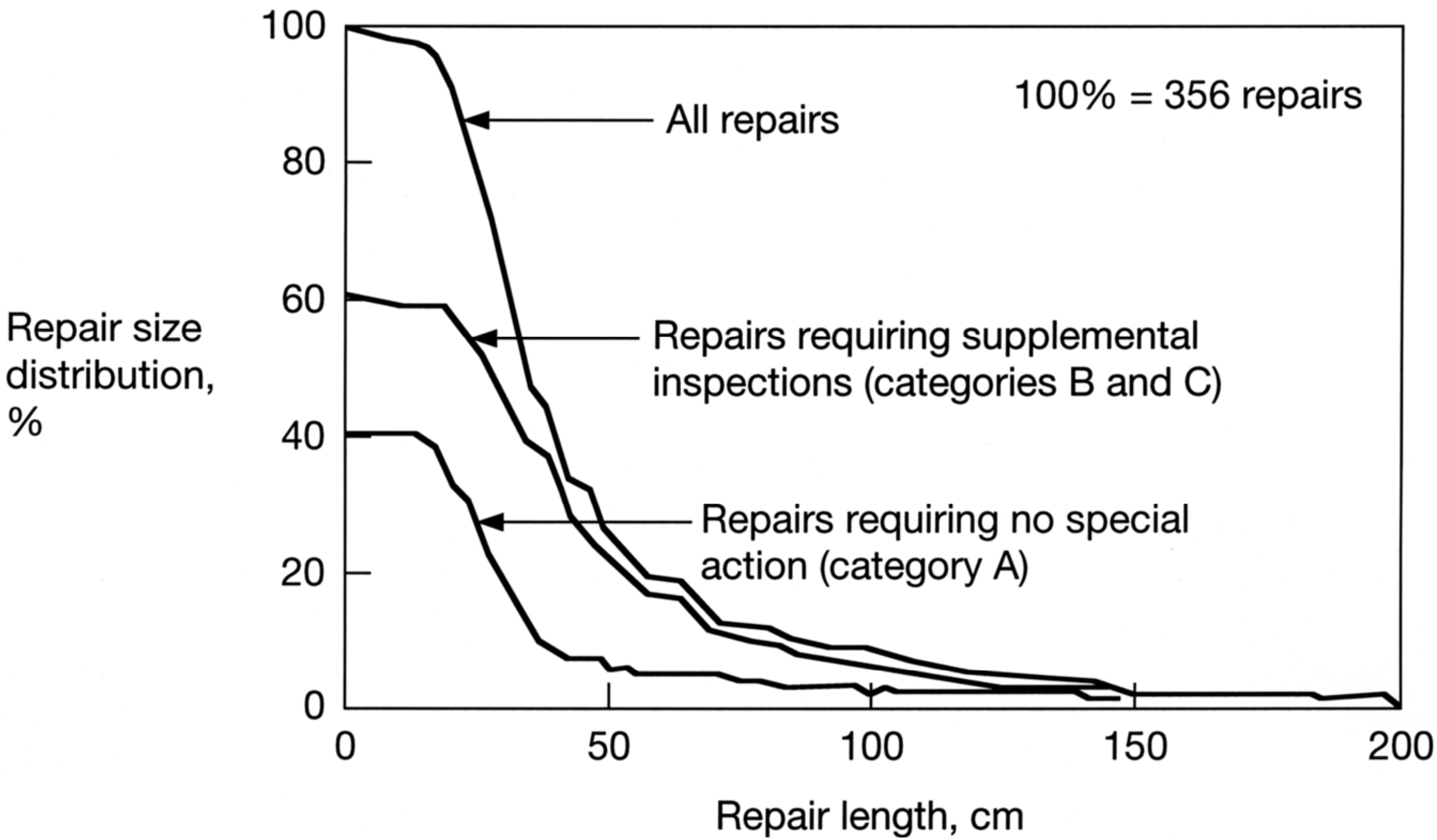


Repair Assessment Task Group

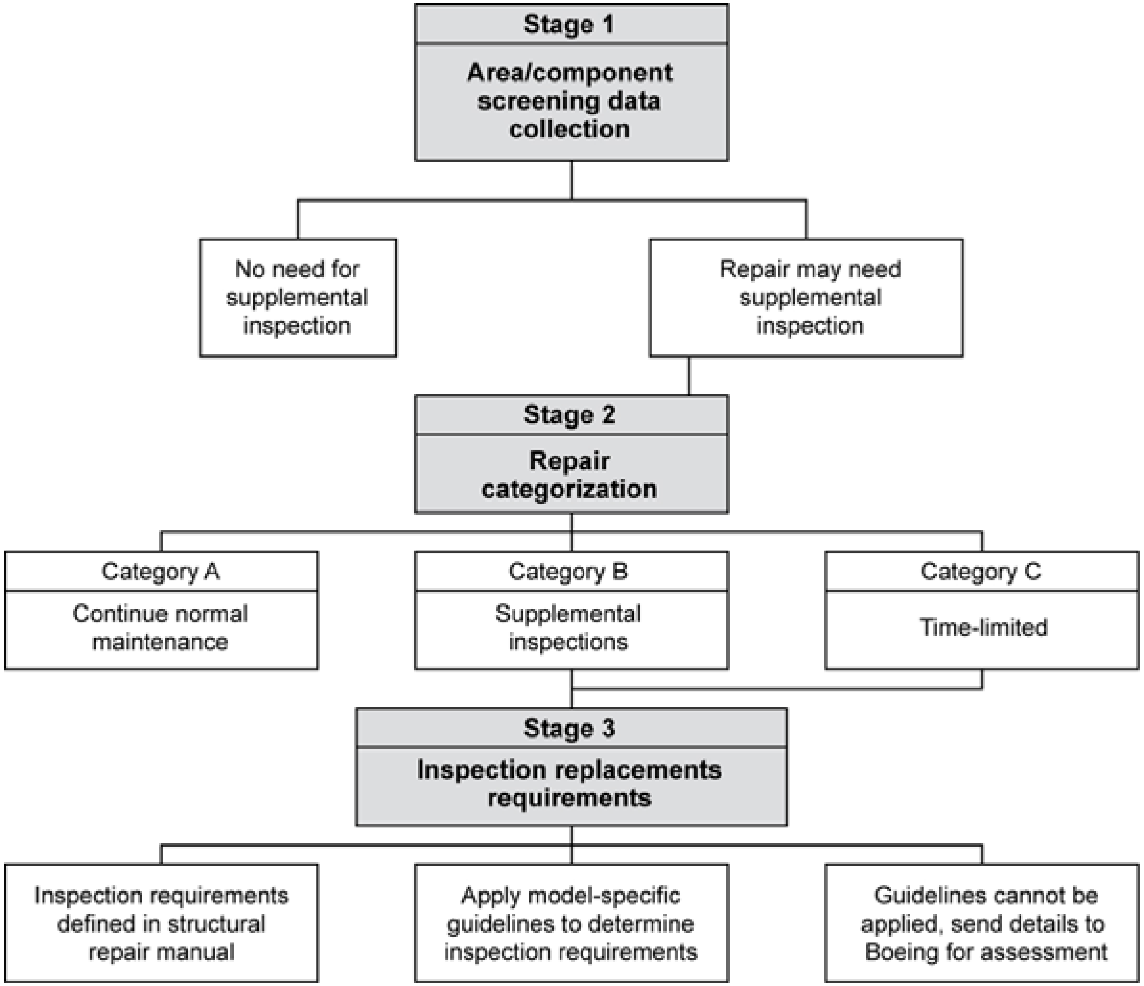


Repair Assessment Task Group

Fuselage Repair Size Distributions

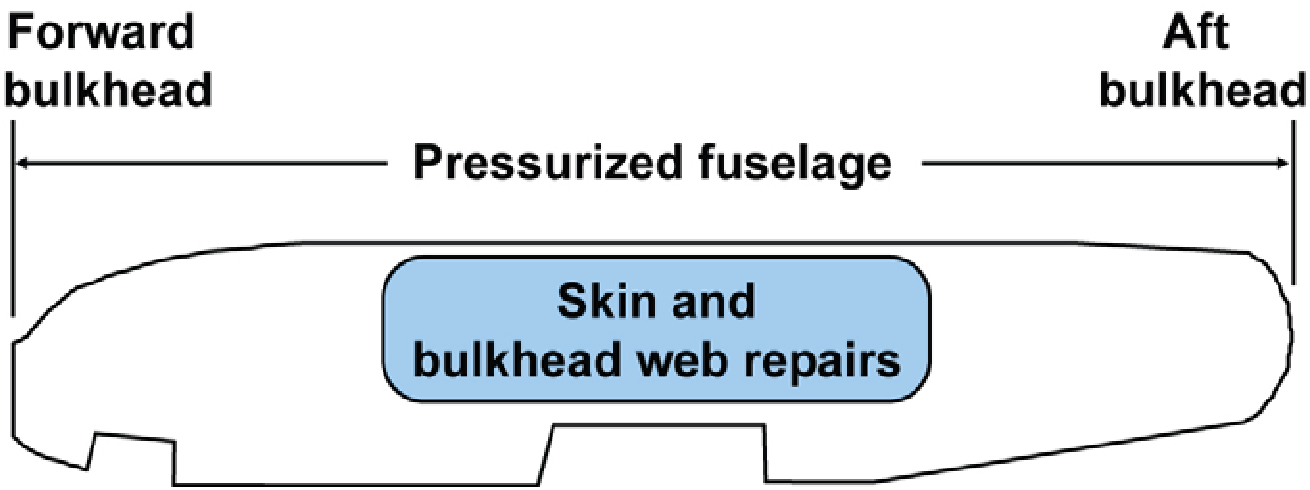


Repair Assessment Stages



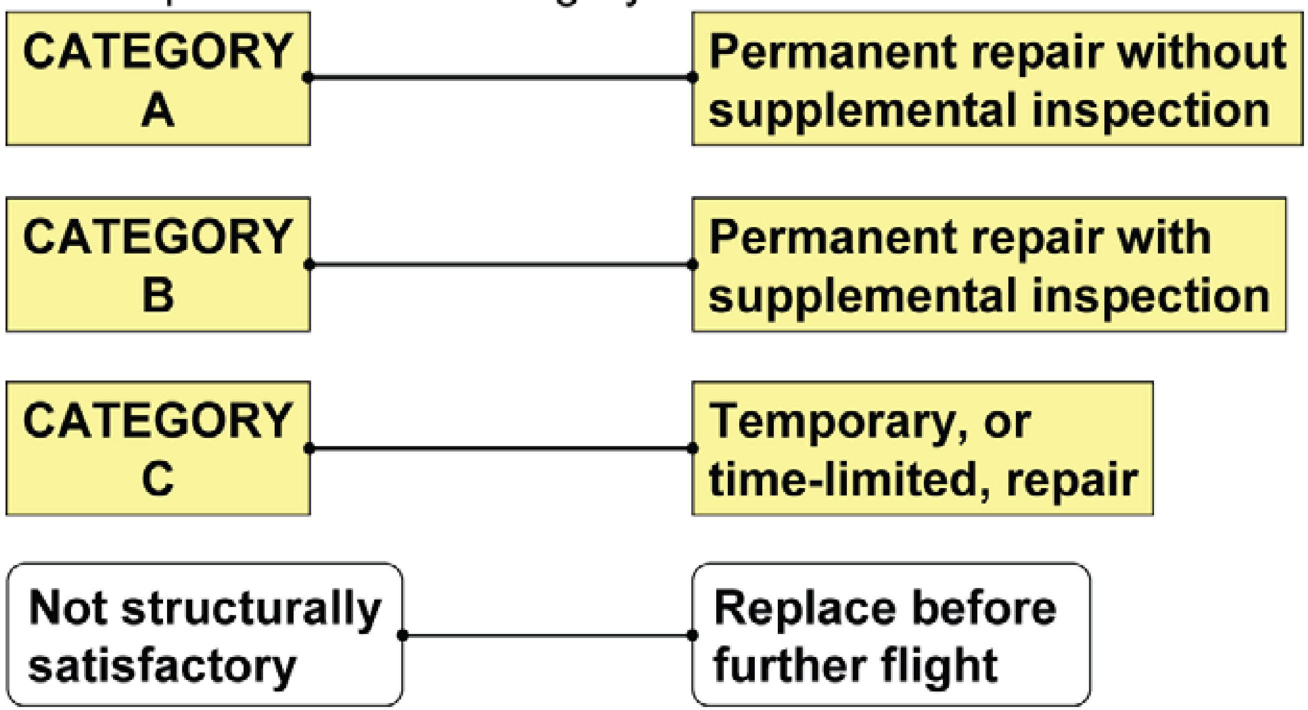
Stage 1 - Assessment Area

- Only fuselage pressure boundary repairs need to be assessed



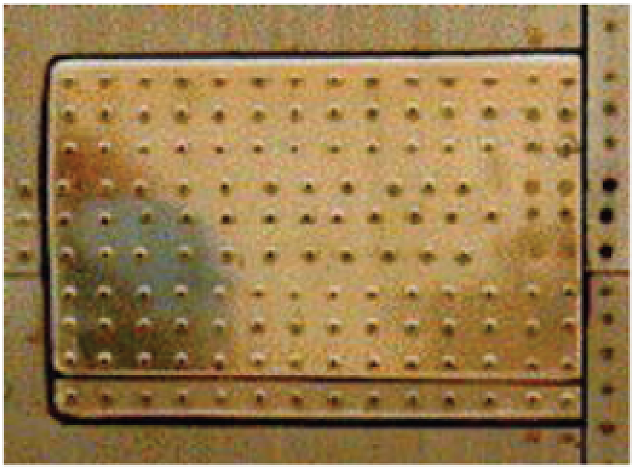
Stage 2 - Repair Categorization

- All repairs fit into a category



Category C Repair Examples

- External repairs with
  - Blind rivets
  - Damage continuing from previous repair
  - Two rows of fasteners around damage cutout
  - Fastener spacing not within 3 to 8 fastener diameters



External Blind Rivet Repair

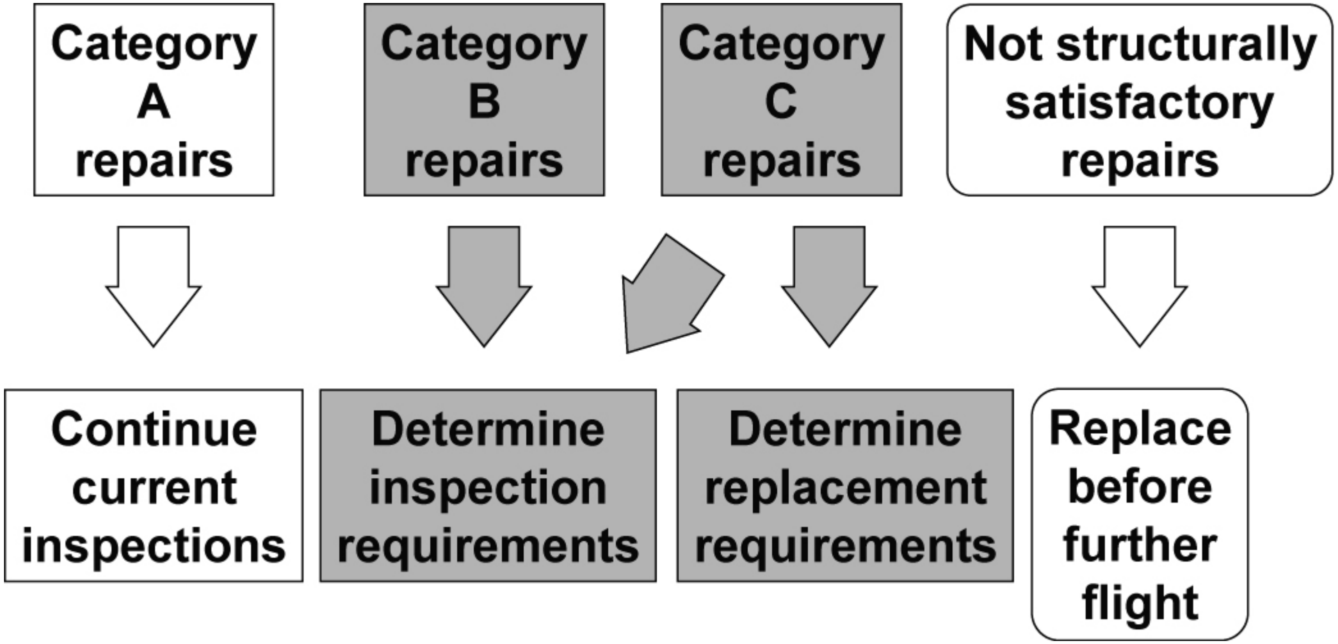
Structurally Not Satisfactory Repair Examples

- Single row of fasteners
- Cracking or corrosion
- Missing fasteners

Single-row Repair

- Use standard maintenance practices
- RAP does not add new requirements

Stage 3 - Supplemental Inspections



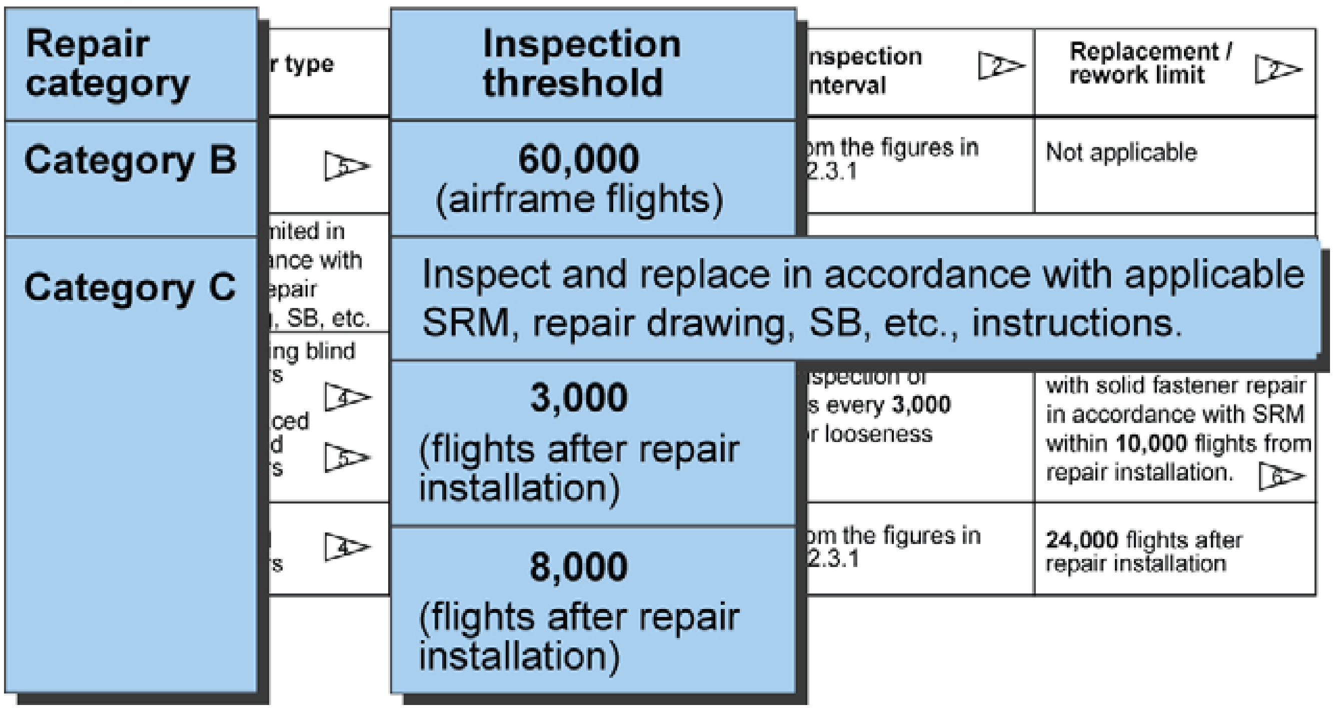
Repair Assessment Thresholds
Manufacturer Recommendations

Manufacturer	Model	Threshold [1] (flights)
Airbus	A-300-B2	32,000
British Aerospace	BAC 1-11	60,000
Boeing	707 727 737 747	15,000 45,000 60,000 15,000
McDonnell Douglas	DC-8 DC-9/MD-80 DC-10	30,000 60,000 30,000
Fokker	F-28	60,000
Lockheed	L-1011	27,000

[1] Assessment of existing repairs recommended at next major (D-check equivalent) check or threshold, whichever is later.

Inspection Threshold Requirements

- Figure 2-7 chart, 737 version shown



Assumed Baseline Inspection Intervals 727 Repair Assessments

<table>
<tr><th colspan="3">Structure (surveillance inspection)</th><th>Baseline inspection intervals (flight cycles)</th></tr>
<tr><td rowspan="5">Wing</td><td colspan="2">External</td><td>3,000</td></tr>
<tr><td colspan="2">Leading-edge cavity</td><td>3,000</td></tr>
<tr><td colspan="2">Trailing-edge cavity</td><td>3,000</td></tr>
<tr><td rowspan="2">Wing box (internal)</td><td>Outboard</td><td>15,000</td></tr>
<tr><td>Center section</td><td>20,000</td></tr>
<tr><td rowspan="5">Fuselage</td><td colspan="2">Upper lobe external</td><td>6,000</td></tr>
<tr><td colspan="2">Lower lobe external</td><td>3,000</td></tr>
<tr><td colspan="2">Upper lobe internal</td><td>20,000</td></tr>
<tr><td colspan="2">Lower lobe internal/bilge</td><td>15,000/9,000</td></tr>
<tr><td colspan="2">Section 48 internal</td><td>6,000</td></tr>
<tr><td rowspan="3">Empennage</td><td colspan="2">External</td><td>3,000</td></tr>
<tr><td rowspan="2">Internal</td><td>Vertical stabilizer</td><td>20,000</td></tr>
<tr><td>Horizontal stabilizer</td><td>20,000</td></tr>
<tr><td colspan="3">Strut</td><td>15,000</td></tr>
</table>

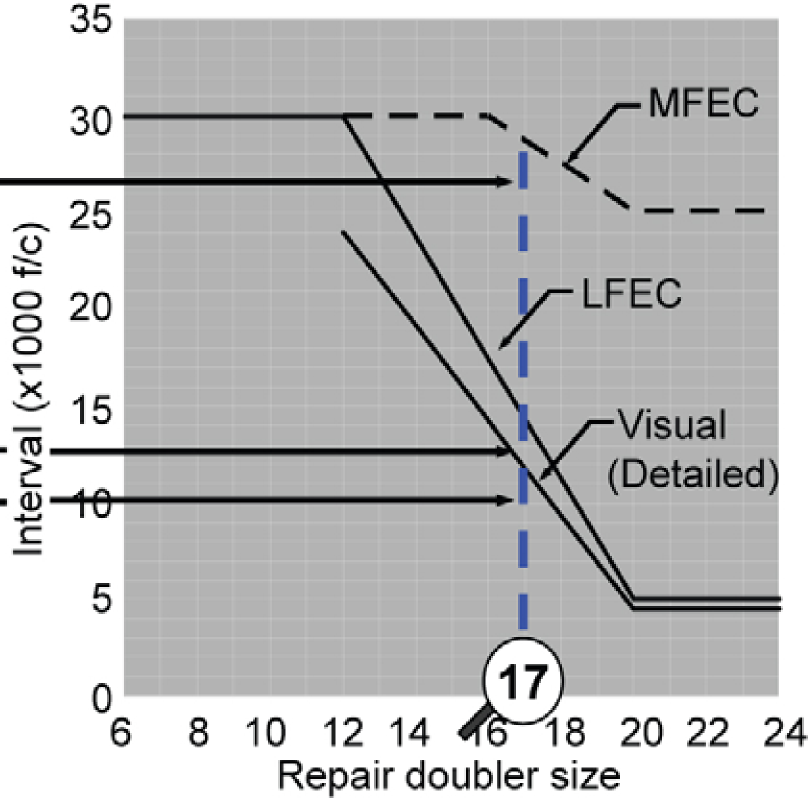
Repair Inspection Options –
Inspection Intervals/Methods

- Choose an inspection option from the chart

MFEC (internal)
28,500 f/c

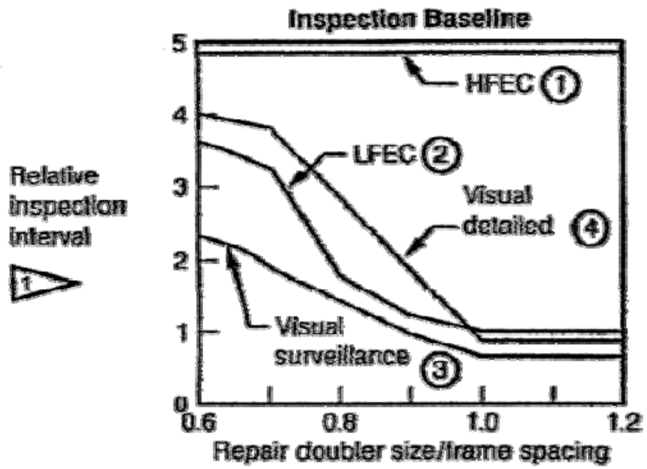
LFEC (external)
14,500 f/c

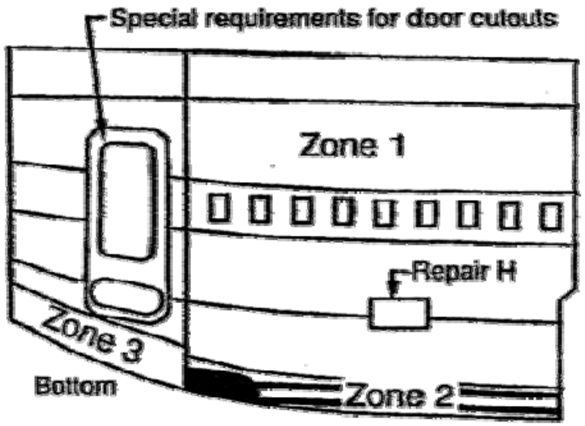
Detailed Visual (internal)
12,000 f/c



Repair Inspection Options –
Inspection Intervals/Methods

- Fatigue Skin Repairs





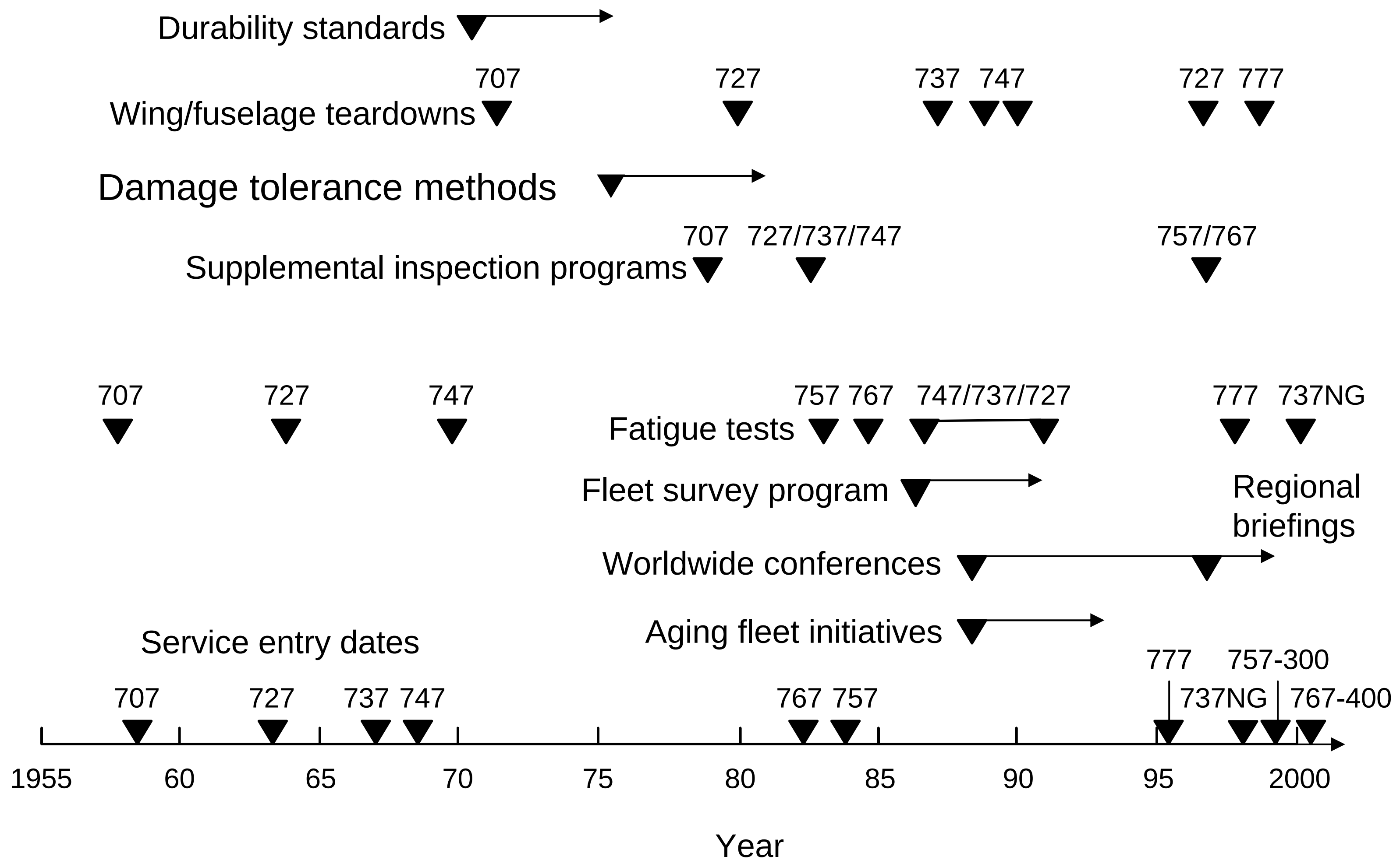
- Option 1: Internal HFEC per curve 1 of skin at all fastener locations on critical row of repair.
- Option 2: For lap splice repairs, external LFEC per cur 2 (if within NDT procedure limits) at all fastener locations on the critical row of repair.
- Option 3: Internal visual surveillance per curve 3 of skin at all fastener locations on the critical row of repair
- Option 4: Internal detailed visual per curve 4 of skin at all fastener locations on critical row of repair.

1 Adjust intervals as required for other zones by appropriate zone factor.

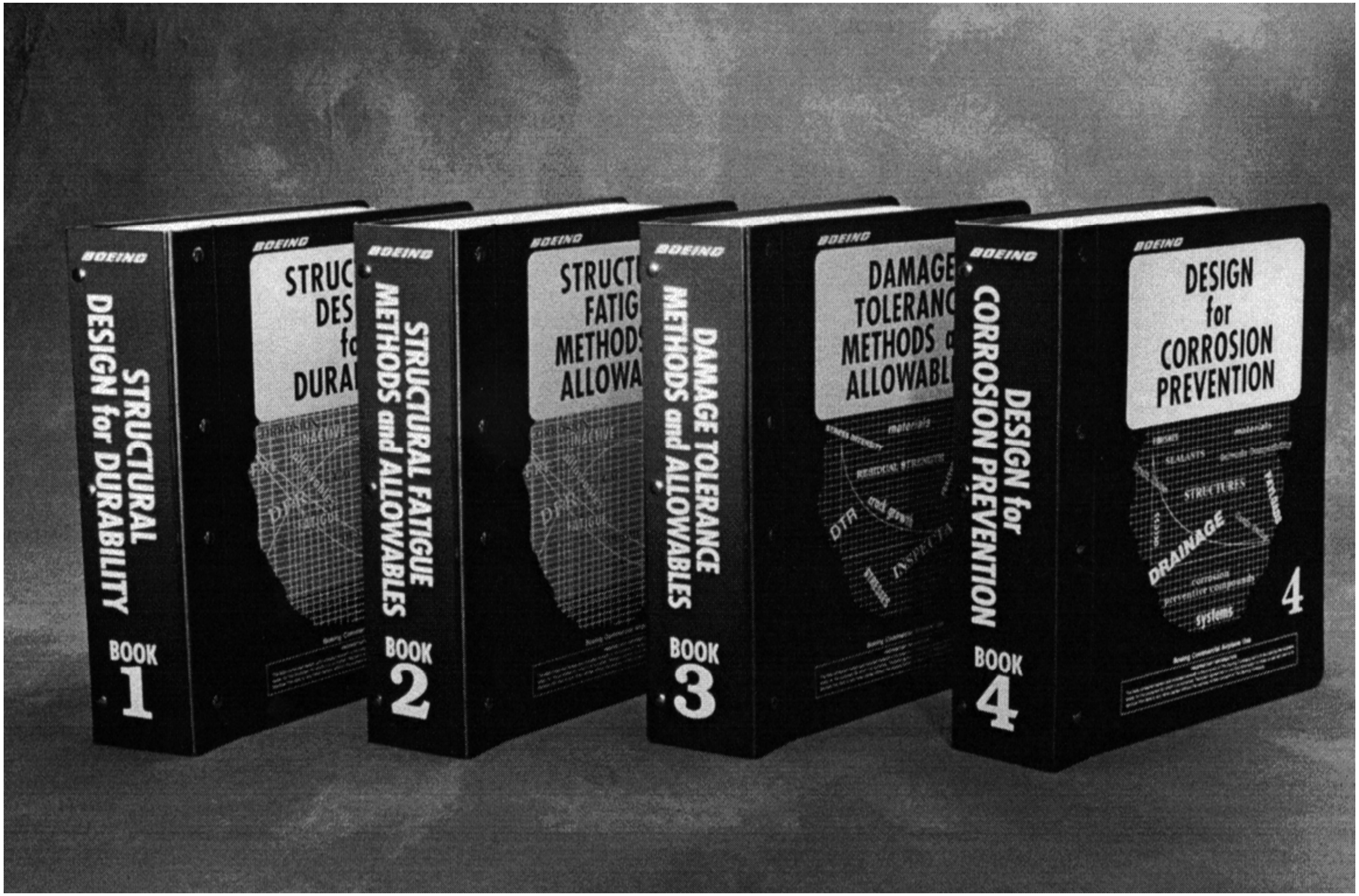
Damage Tolerance – Facts and Fiction

- Overview
- Elements of Damage Tolerance
- Structural Maintenance Considerations
- Continuing Airworthiness Challenges
- **Summary**

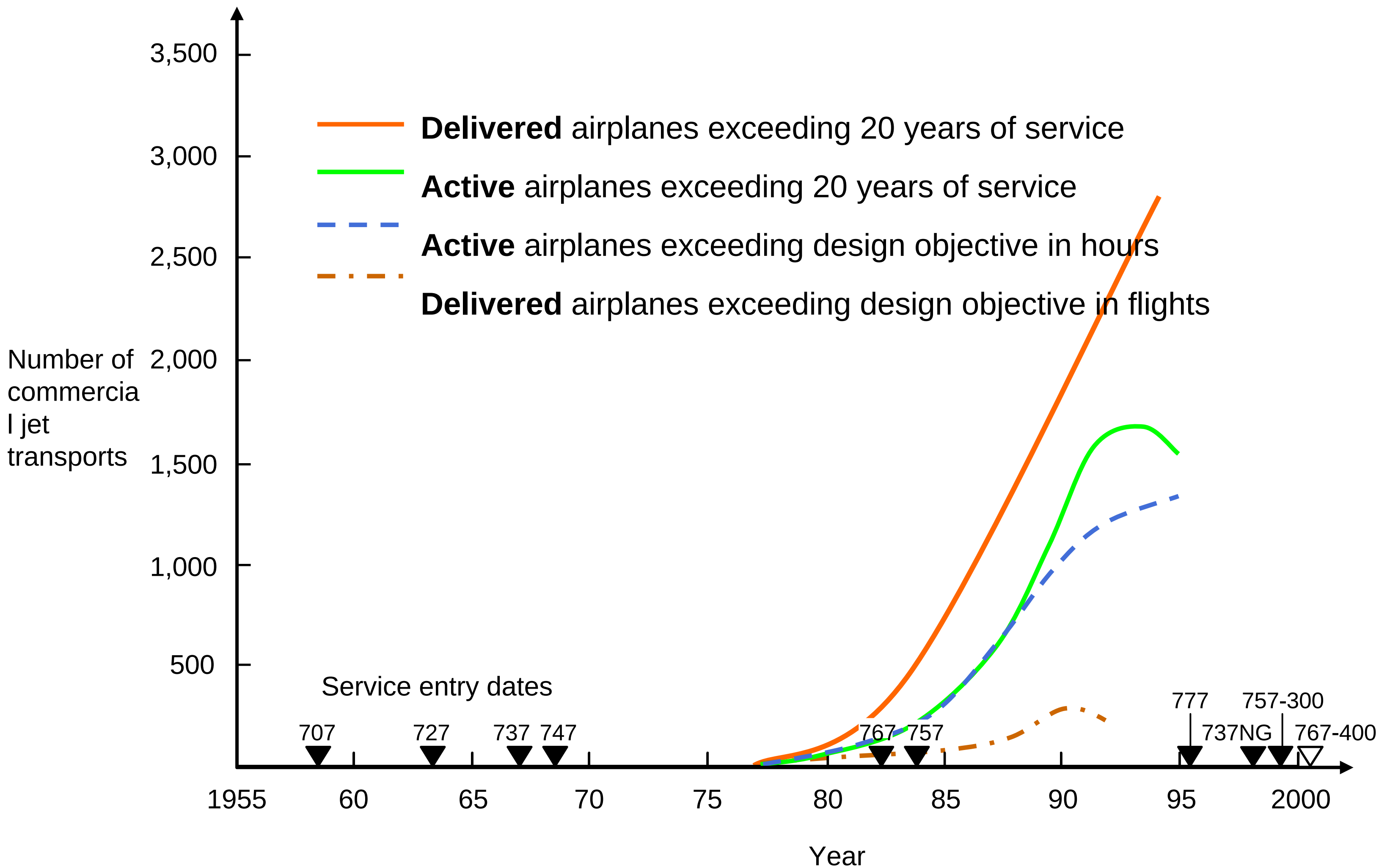
Boeing Fleet Support Actions



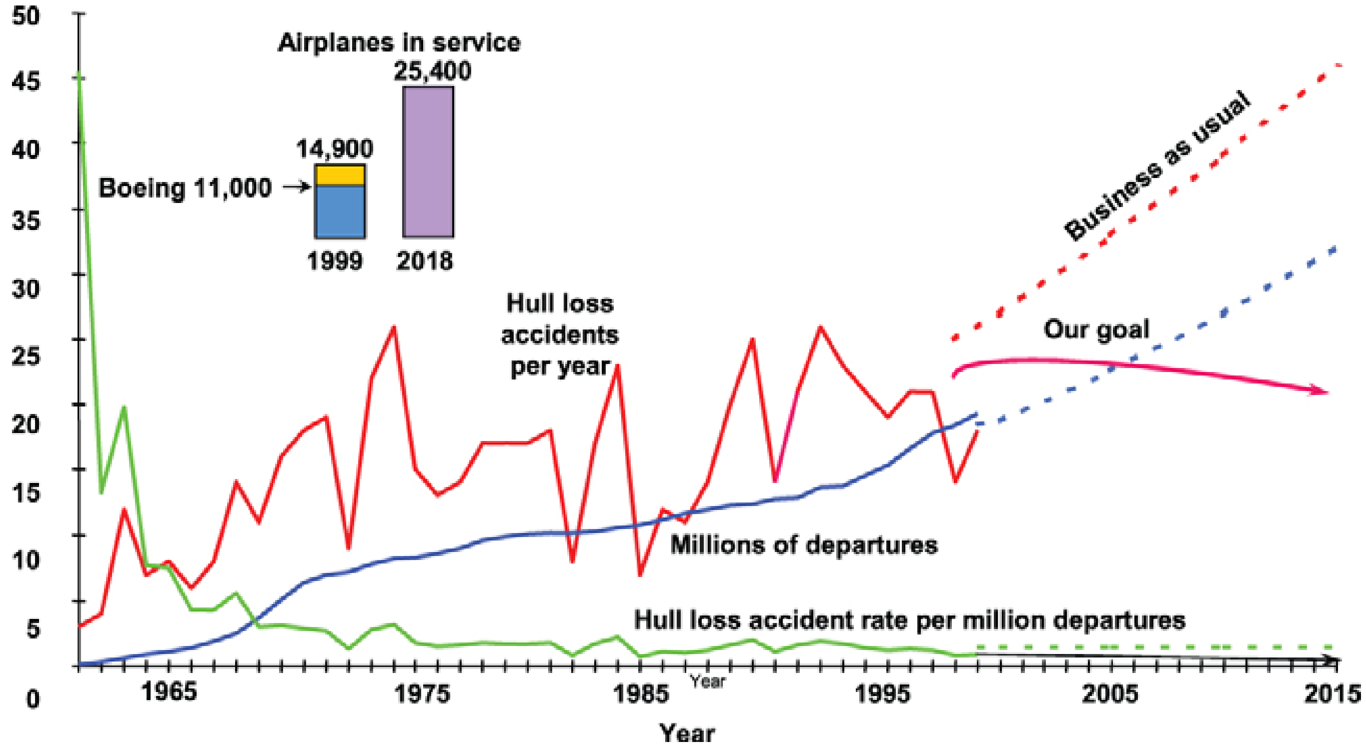
Boeing Structural Design Standards



Boeing Fleet Support Actions



Safety Challenge



Cessna 180 - Single Load Path / Safe Life

60,000 Miles of Bush Flying - Alaska;Canada;Greenland

CESSNA - N6014B - SKYWAGON		
1988 -	JUNEAU, ALASKA	- 3,300 MILES
1989 -	KING SALMON, ALASKA	- 5,600 MILES
1990 -	POINT BARROW, ALASKA	- 6,200 MILES
1991 -	NORTHWEST PASSAGE	- 5,900 MILES
1992 -	NEWFOUNDLAND, CANADA	- 6,900 MILES
1993 -	ILLULISAT, GREENLAND	- 7,600 MILES
1994 -	PROVIDENIYA, RUSSIA	- 5,800 MILES
1995 -	NORTH MAGNETIC POLE	- 4,500 MILES
PILOT - ULF GORANSON - RENTON, WASHINGTON		

Realities of Retirement
E-mail: INGERULF@AOL.COM