International Committee on Aeronautical Fatigue (ICAF) 2009
Rotterdam, the Netherlands
20 – 25 May, 2009

DEVELOPMENT OF A "LOW STRESS CRITERION" THAT ELIMINATE A LARGE PORTION OF THE AIRCRAFT FROM DAMAGE TOLERANCE BASED MAINTENANCE PROGRAM FOR STRUCTURAL REPAIRS REQUIRED BY THE NEW PART 26 FEDERAL REGULATIONS

Dr. Girindra Das
Technical Fellow
Dr. Matthew Miller
Manager
Structural Damage Technology
Boeing Commercial Airplanes
Seattle, Washington, USA

BOEING

Contents

- Background
- Part 26 regulations
- Criteria development for Part 26
- Low Stress Criterion
  - Based on Fatigue
  - Based on Crack growth
- Summary and Conclusions

CFR ~ Code of Federal Regulation

Title 14: Aeronautics and Space

Chapter 1
Federal Aviation Administration
Department of Transportation

SUBCHAPTER C - AIRCRAFT

PART 25
AIRWORTHINESS STANDARDS:
TRANSPORT CATEGORY AIRPLANES

Subpart C - Structure ~ Fatigue Evaluation

§ 25.571
Damage-tolerance and fatigue evaluation of structure

§ 25.571

- Damage Tolerance and Fatigue Regulation for Design and Certification for Commercial Transport for past 43 years

Requires:

- An evaluation of the strength, detail design, and fabrication that must show that catastrophic failure due to fatigue, corrosion, manufacturing defects, or accidental damage, will be avoided throughout the operational life of the airplane.
- This evaluation must be conducted --- for each part of the structure that could contribute to a catastrophic failure (such as wing, empennage, control surfaces and their systems, the fuselage, engine mounting, landing gear, and their related primary attachments).
- Based on the evaluations, inspections or other procedures must be established to prevent catastrophic failure

CFR ~ Code of Federal Regulation

Title 14: Aeronautics and Space

Chapter 1
Federal Aviation Administration
Department of Transportation

SUBCHAPTER C - AIRCRAFT

PART 25

AIRWORTHINESS STANDARDS FORTRANSPORT CATEGORY AIRPLANES

Subpart C
– Structure
~ Fatigue Evaluation

§ 25.571
Damage-tolerance and fatigue evaluation of structure

PART 26

CONTINUED AIRWORTHINESS AND SAFETY IMPROVEMENTS FOR TRANSPORT CATEGORY AIRPLANES

Subpart E~
Aging Airplane Safety Damage Tolerance Data for Repairs and Alterations

§ 26.41 Definitions. § 26.43 Holders of and applicants for type certificates-Repairs. § 26.45 Holders of type certificates -Alterations and repairs to alterations. § 26.47 Holders of and applicants for a supplemental type certificate -Alterations and repairs to alterations. § 26.49 Compliance plan.

Introduction

- New Part 26 rule and Advisory Circular (AC) published in the Federal Register on December 12, 2007 and becomes effective January 11, 2008 that directs Type Certificate Holders (TCH) to support operator compliance to the 14 CFR 121.1109 and 129.109 operational rules.
- TCH support constitutes providing necessary data to develop a DT based maintenance program for all structural repairs and alterations
- This rule affects all past, present and future commercial transports and includes airplanes in-certification, in-production & out-of-production

Title 14 CFR 121.1109 ~ Supplemental inspections

- (a) *Applicability.* This section applies to transport category, turbine powered airplanes with a type certificate issued after January 1, 1958, that as a result of original type certification or later increase in capacity have :
  - (1) A maximum type certificated passenger seating

    capacity of 30 or more; or
  - (2) A maximum payload capacity of 7,500 pounds or more.

14 CFR 121.1109 Supplemental inspections (Cont.)

(c) *General requirements.* After December 20, 2010, a certificate holder may not operate an airplane under this part unless the following requirements have been met:

(1) *Baseline Structure.* The certificate holder's maintenance program for the airplane includes FAA-approved damage-tolerance-based inspections and procedures for airplane structure susceptible to fatigue cracking that could contribute to a catastrophic failure. For the purpose of this section, this structure is termed "fatigue critical structure."

14 CFR 121.1109 Supplemental inspections (Cont.)

- (2) *Adverse effects of repairs, alterations, and modifications.* The maintenance program for the airplane includes a means for addressing the adverse effects repairs, alterations, and modifications may have on fatigue critical structure and on required inspections. The means for addressing these adverse effects must be approved by the FAA Oversight Office.

14 CFR PART 129 ~ Operations: Foreign Air Carriers And Foreign Operators Of U.S.-Registered Aircraft Engaged In Common Carriage

- § 129.109 Supplemental inspections for U.S.-registered aircraft.

New 14 CFR Part 26 rules :

Require:

- New Criteria and Method for DT Analysis of Repairs, Alterations and Modifications in addition to those for the Basic Airplane

- Boeing Structural Damage Technology (SDT) group heavily engaged in developing these, focusing on reducing scope of program without compromising safety.

Some Examples of Methods and Criteria being developed:

- Develop new SIFs for repair configurations
- Develop Fatigue Critical Baseline Structure (FCBS) for all commercial models. Only repairs on FCBS need DT evaluation and inspection
- Widespread Fatigue Damage of repairs
- Define Industry Standard repairs
- Method to determine Flight Length Sensitive items and hour cutoff for DT inspections for repairs on them
- Low stress criterion which reduces scope of the program significantly without compromising safety

- Type Certificate Holders (Boeing, Airbus), Supplemental Type Certificate Holders (Repair Stations, Mod Centers other than Original Equipment Manufacturers), Operators, and Lessees will be significantly impacted by new requirements for *Damage Tolerance based maintenance program* for Repairs, Alterations and Modifications.

“Low Stress Criteria” for structural repairs.

- Criterion defines the stress levels below which no damage tolerance evaluations and damage tolerance inspections for structural repairs to FCBS need to be carried out to satisfy the requirements of 14 CFR Part 26 Subpart E ~ “Damage Tolerance Data for Repairs and Alterations”.

“Low Stress” Criteria

- Based on Fatigue (Crack Initiation)
  - very high fatigue life
- Based on Damage Tolerance (Crack propagation)
  - very long inspection intervals
- Analyses based on Boeing recommended typical repair configurations detailed in Service Repair Manuals (SRM) provided to the Airlines
- Large number of repairs evaluated to develop Criteria

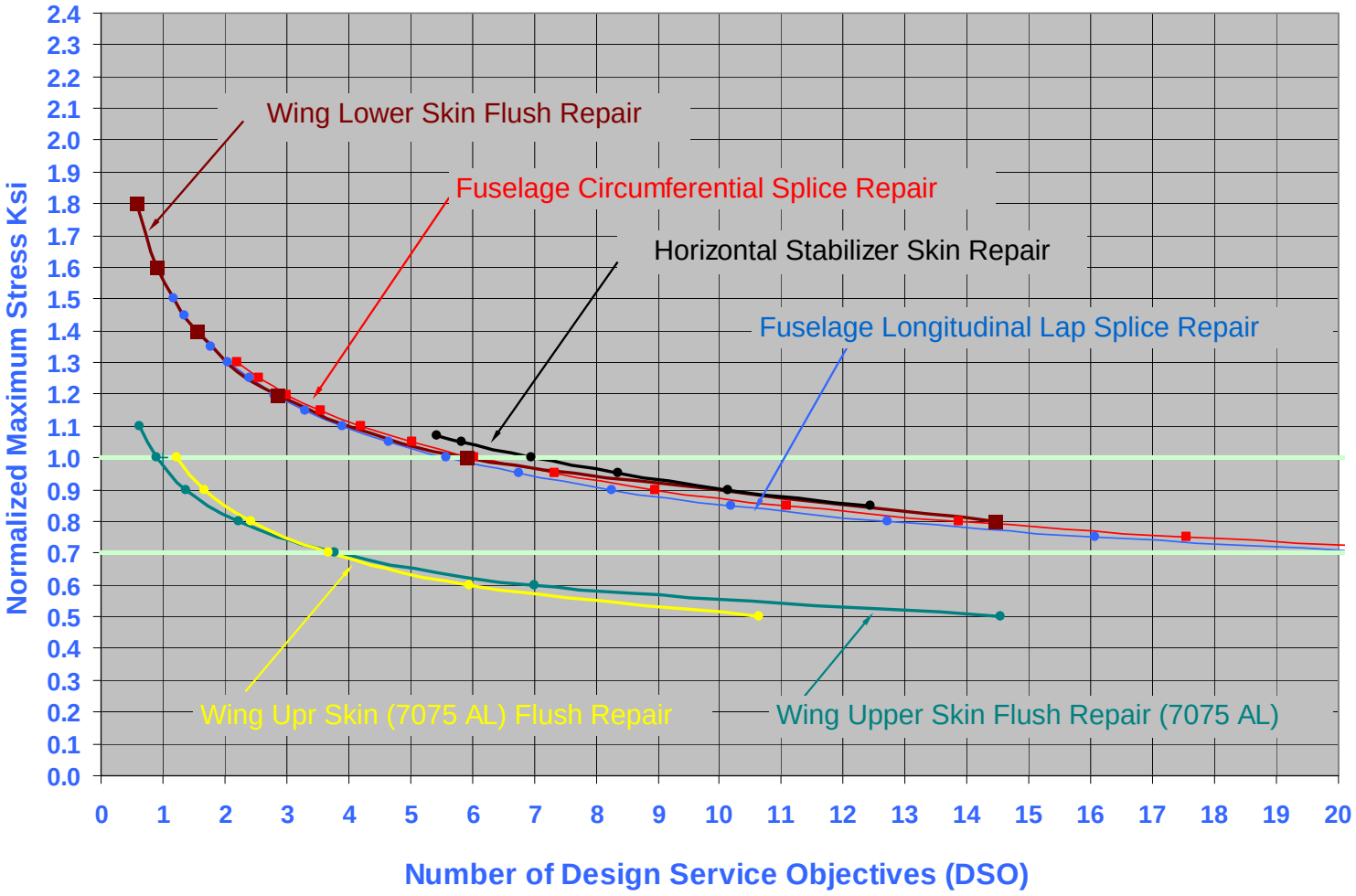
“Low Stress” based on Fatigue

- Besides maximum stress other parameters considered that provide fatigue life
  - Stress Ratio
  - DFR ~Quality parameter related to local increase in stress, manufacturing quality etc
  - Ground Air Ground (GAG) Damage Ratio
- $N_{95/95}$ Fatigue Life (95% reliability & 95% confidence) calculated using standard methods for typical repairs from SRM using actual operating loads

“Low Stress” based on Fatigue

- Keeping all other parameters same Fmax is gradually reduced and $N_{95/95}$ Fatigue Life calculated for these reduces stress levels.
- $N_{95/95}$ Fatigue Lives normalized in terms of Design Service Objectives (DSO)
  - DSO is the number of flights all critical structure is designed to, during which practically no fatigue crack will initiate
- $N_{95/95}$ Fatigue Life plotted in terms of multiple of DSO against normalized maximum stress

Normalized Maximum Stress Vs DSO



Analysis of Results:

- The figures show fatigue life lower for 7000 Aluminum
- For 7000 alloys (wing upper skin repairs) chosen stress level gives fatigue life more than 3 to 4 times DSOs.
- For rest of the items analyzed chosen stress level gives fatigue life more than 5 DSOs.
- Pressure critical structure did not show any specific reduction in fatigue life compared to other items

“Low Stress” based on Crack Growth

- Parameters influencing crack growth:
  - Effective Stress Rating “S” that includes effect of spectrum loading
  - Material crack growth parameter
  - Configuration dependent Geometric Modification Factors that determine SIFs
- Complete DT analysis conducted using current method for typical repairs (from SRM) using actual loads for these repairs (same items that was used in fatigue analysis)

“Low Stress” based on Crack Growth

- DT analysis involved
  - Determining critical crack length using Residual Strength analysis
  - Calculating detectable to critical crack growth using crack growth parameters specific to repair analyzed
  - Using routine inspections normally conducted by world airlines like “D” or “4C” Surveillance as reference
  - Using Boeing developed DTR method for intervals
  - Developing DTR forms for each repair
    - Forms provide DTR for various intervals for a specific type of inspection
    - Inspection interval must provide DTR that exceeds required DTR set by regulatory requirements

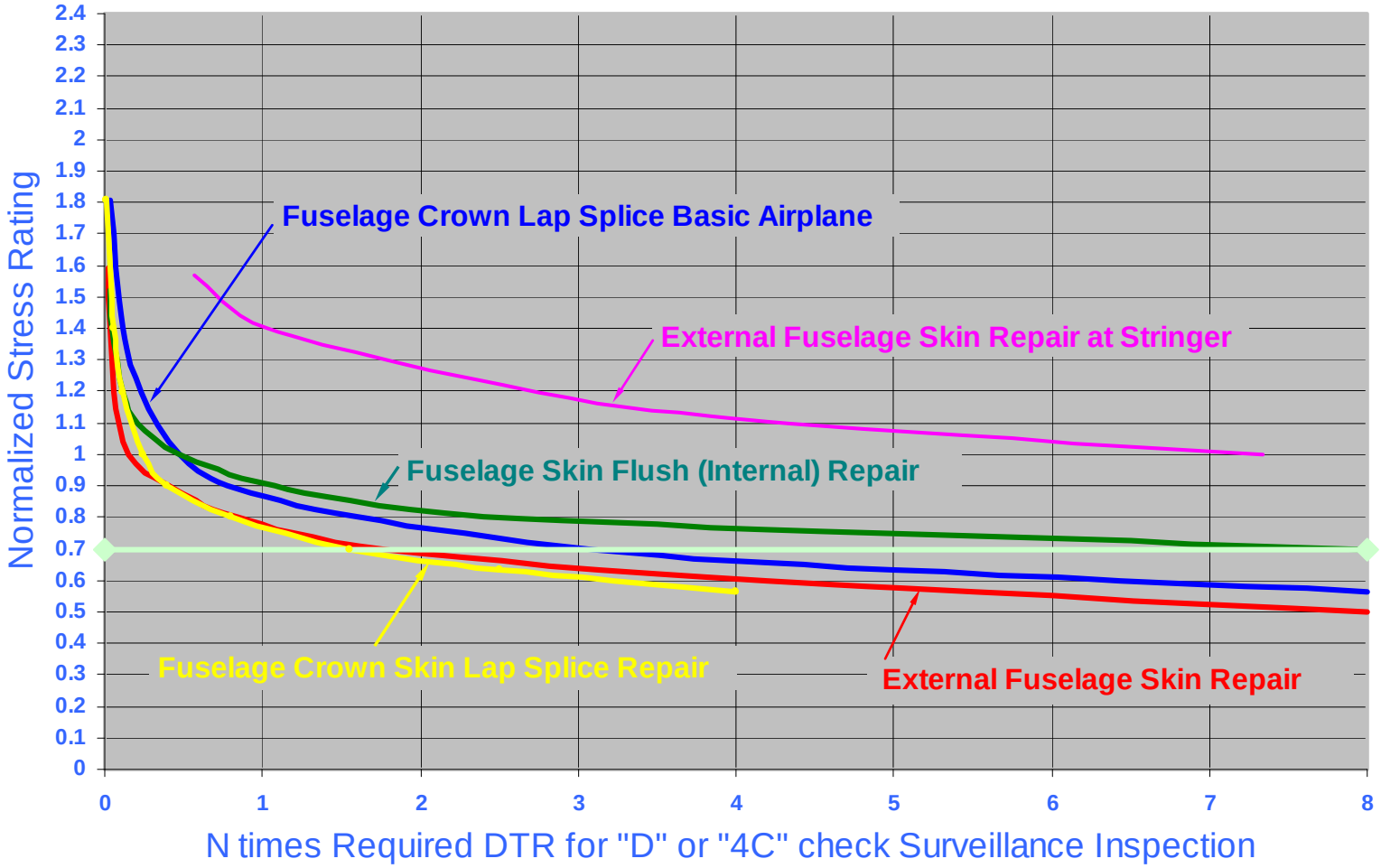
“Low Stress” based on Crack Growth

- Keeping all other parameters same, “S” is gradually reduced and DTR form developed for each of these reduced Stress Ratings.
- Using routine inspections like “D” or “4C” Surveillance DTR values obtained for each level of “S” for each repair.
- DTR values for each level of “S” normalized in terms of Required DTR for the structure

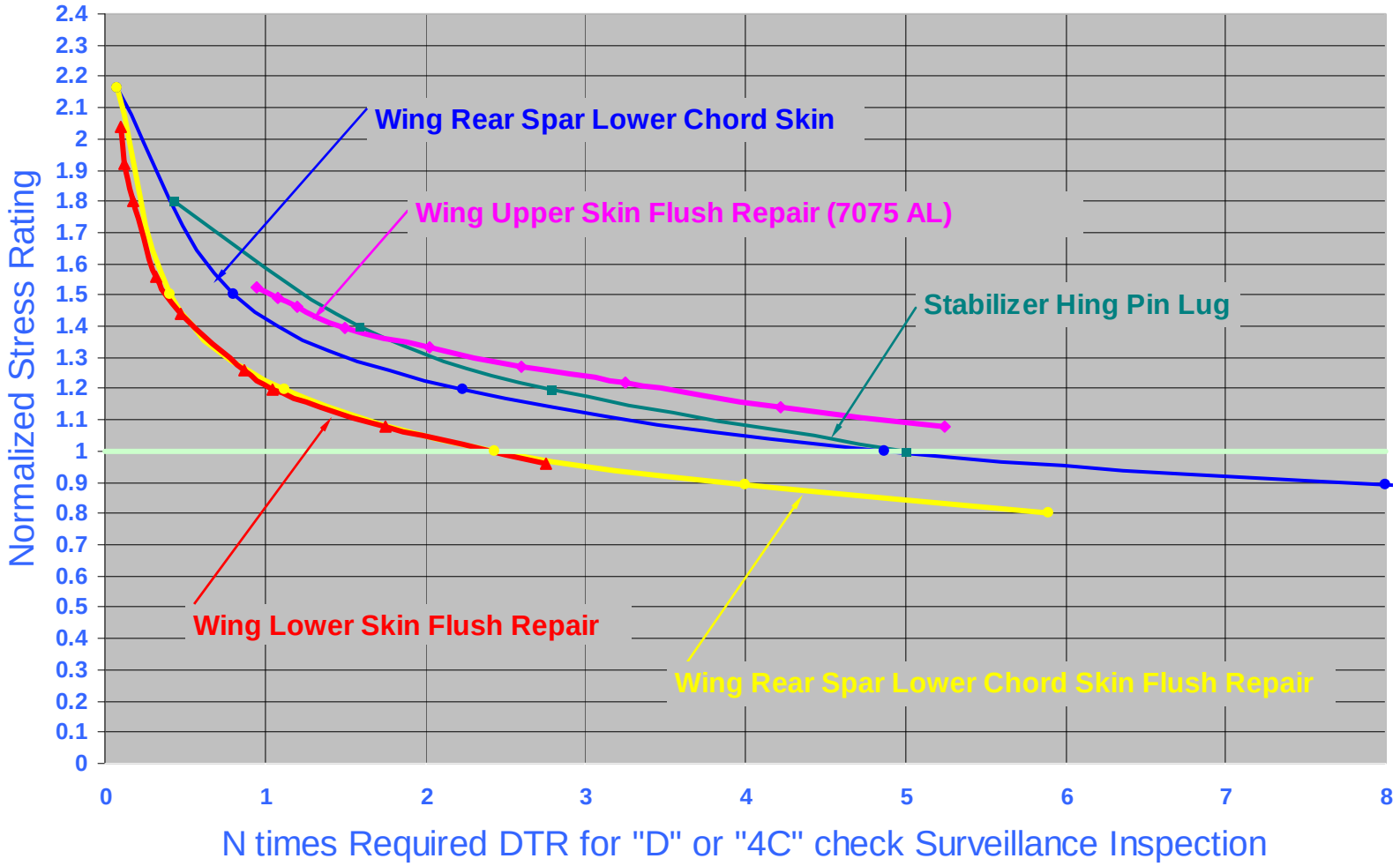
“Low Stress” based on Crack Growth

- Stress Rating levels are plotted against DTR for routine inspections like “4C” or “D” Check Surveillance normalized as a fraction of Required DTR
- Low Stress criterion is based on
  - Stress levels that provide many times the required DTR by routine inspections like “D” or “4C” Checks Surveillance that is regularly conducted by the airlines

Normalized Stress Rating Vs Relative Required DTR for "D" or "4C" Surveillance for Pressure Critical Structure



Normalized Stress Rating Vs Relative Required DTR for "D" or "4C" Surveillance for Non Pressure Critical Structure



Analysis of Results:

- The figures show Pressure Critical Structure more critical than other structure for repeat inspections
- From DT perspective 7000 alloys did not show any significant reduction
- For pressure critical structure chosen level gave 2 to 3 times the required DTR
- For rest of structure “S” level chosen gave 2 to 3 times the required DTR

SUMMARY

- A method has been developed to obtain a stress level below which no analysis or inspection needs to be done by the operators
- Methods based on both fatigue (initiation) and crack growth (propagation)
- Analyzed for both and lower of the two is used
- Will apply to Industry Standard Repair

Benefit to the industry

- Criterion will save industry significant resources without compromising safety
- Large area of airplane will be exempt from
  - (a) required analysis to be done by Original Equipment Manufacturer and
  - (b) required inspections to be carried out by operators
- Attention and resources could be focused on more critical structure defined by this criterion