Incorporation Of Buffet Into The F-35 Full Scale Durability Tests Spectra

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F-35 – ASIP
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F-35 Spectrum Development Criteria

- **The F-35 Program Has Three Variants**
  - CTOL; Conventional Takeoff and Landing
  - STOVL; Short Takeoff, Vertical Landing
  - CV; Carrier Version

- **A Flight-by-flight Spectrum And A Dedicated Full Scale Airframe Durability Test Are Required For Each Variant**

- **Spectrum Development Criteria**
  - CTOL Has A Mission Usage Based Spectrum
    - *USAF Criteria*
  - STOVL and CV Have A CPITS Based Spectrum
    - *Critical Point In The Sky*
    - *US Navy Criteria*

F-35 Spectrum Development

- **Flight-by-flight Spectrum Contains Operational Loads**
  - ***Flight Plus Ground Conditions***
    - Contract Driven Requirement
      - *Production And Development Schedule Results in Full Scale Tests Completion Before Flight Test Data Is Available*
    - Design And Test Based On Predicted Buffet Loads
      - *Wind Tunnel, Water Tunnel And Limited Flight Data*
    - Normal Operations Contain Significant Time In Buffet-prone Environments

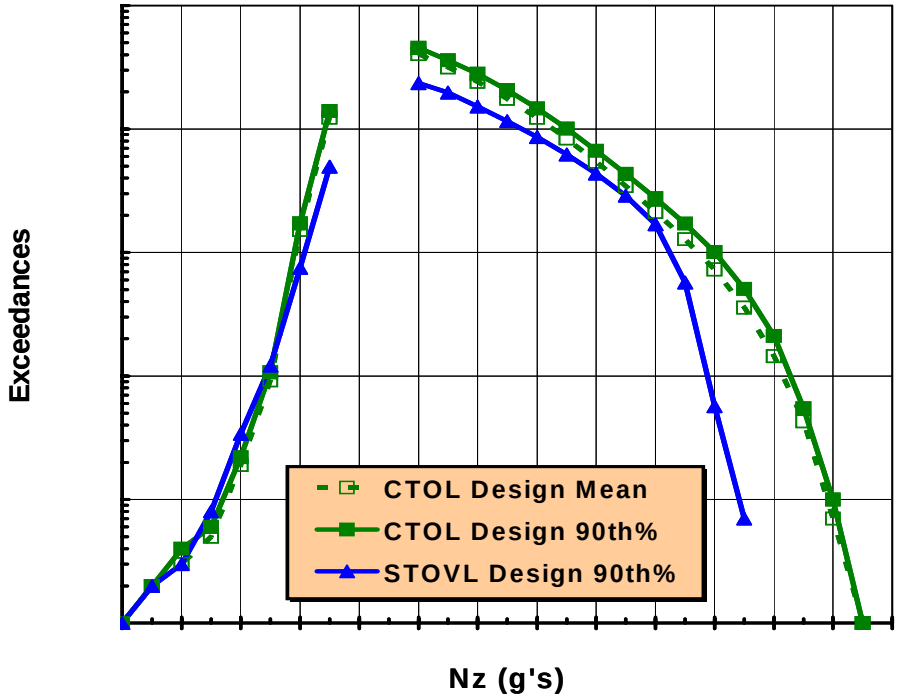
- **"Test What We Design"**
  - ***Loads Used For Design Are Applied To The Structure Being Tested***
    - *M. E. Jackson, Lockheed Martin Technical Fellow*

F-35 Spectrum Development

Spectrum Content

7000 Unique Service Load Conditions
Reference Limit Condition Set
Component Load Exceedances
Flight Maneuvers
Speed-brake Operations
Weapons Bay Door Cycling
Control Surface Movements
Landing & Ground Events
Store Ejection

Buffet Loads

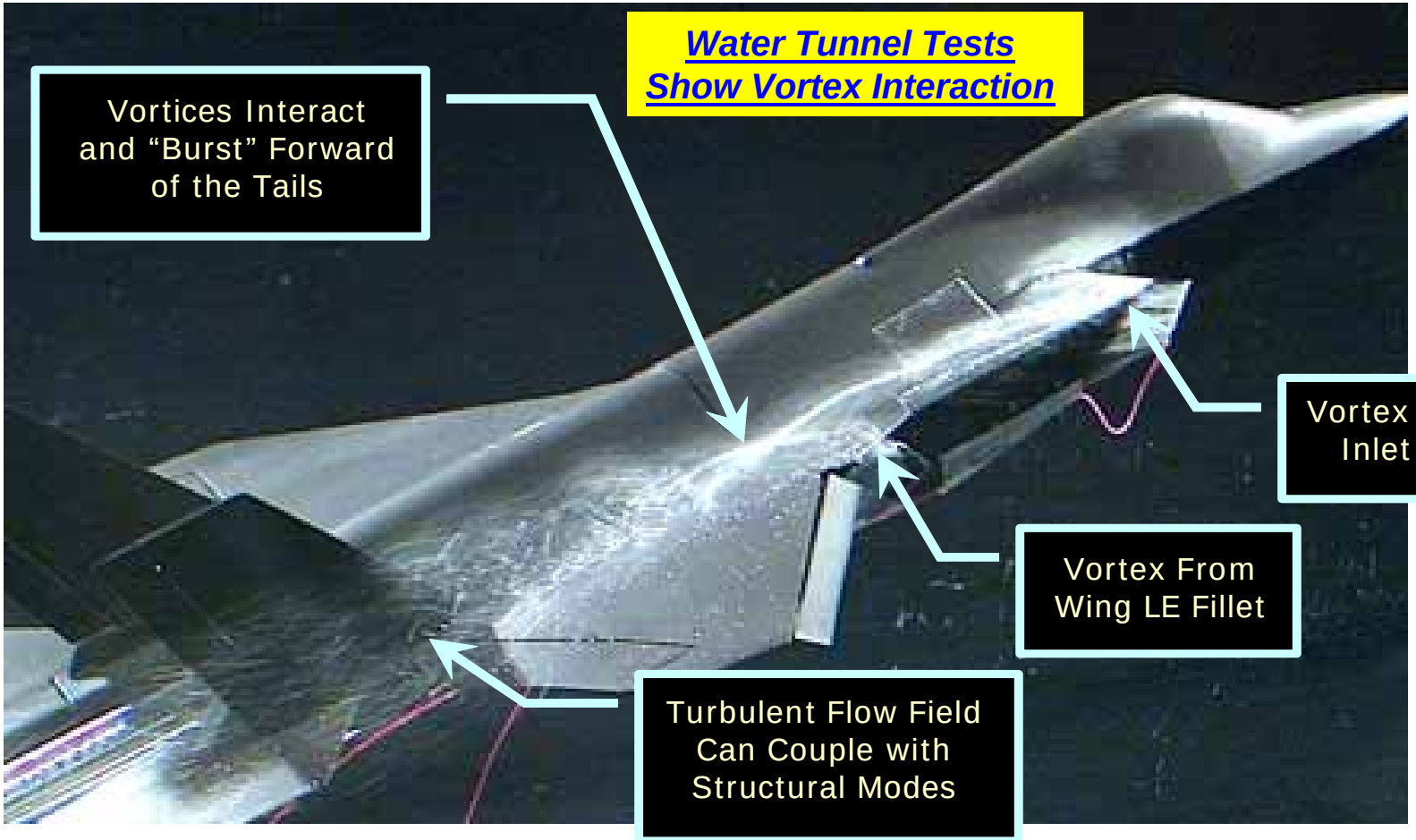


This Paper Outlines The Incorporation of Buffet Loads Into The Full Scale Durability Tests Spectra

Steps To Incorporate Buffet

1. Buffet Loads Development and Implementation
   Methodology & Background
2. Assess Scope
   Delimiting Structural Zones Life-Affected by Buffet
3. Define Modes
   Selection Of Buffet Induced Modes by Structural Mechanism
4. Evaluate Damage By Mode
   Impact of Individual Modes On Fatigue Related Damage
5. Reduce Modal Cycle Count
   Reduction of Content to Meet Schedule and Budget
6. Define Modes Required For Full Scale Durability Tests
   Reduced Set Of Modes
7. Configuration Of Full Scale Durability Tests
   Airframe and Stand-Alone Components

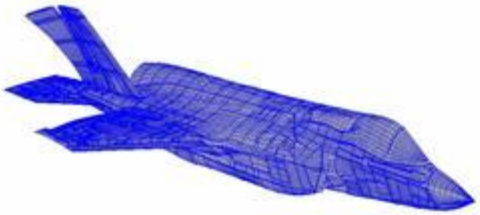
Buffet Loads Development

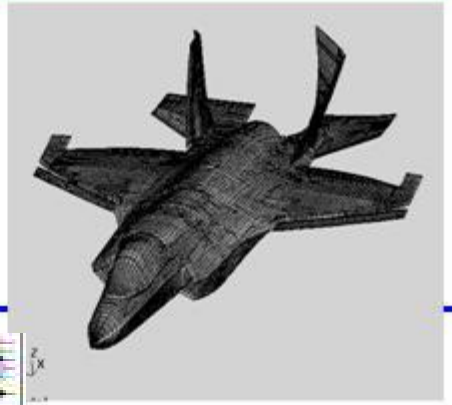


Buffet Loads Development

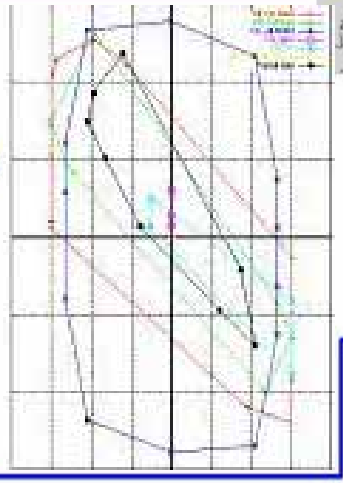
Dynamics Group develops grid point forces to achieve buffet mode shapes

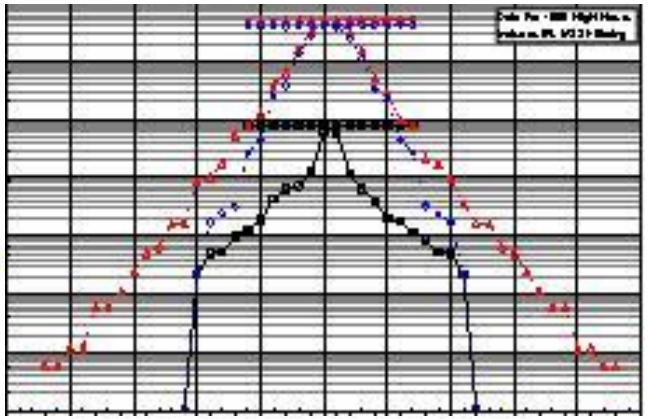
Grid point forces mapped to the Air Vehicle FEM to get internal loads.



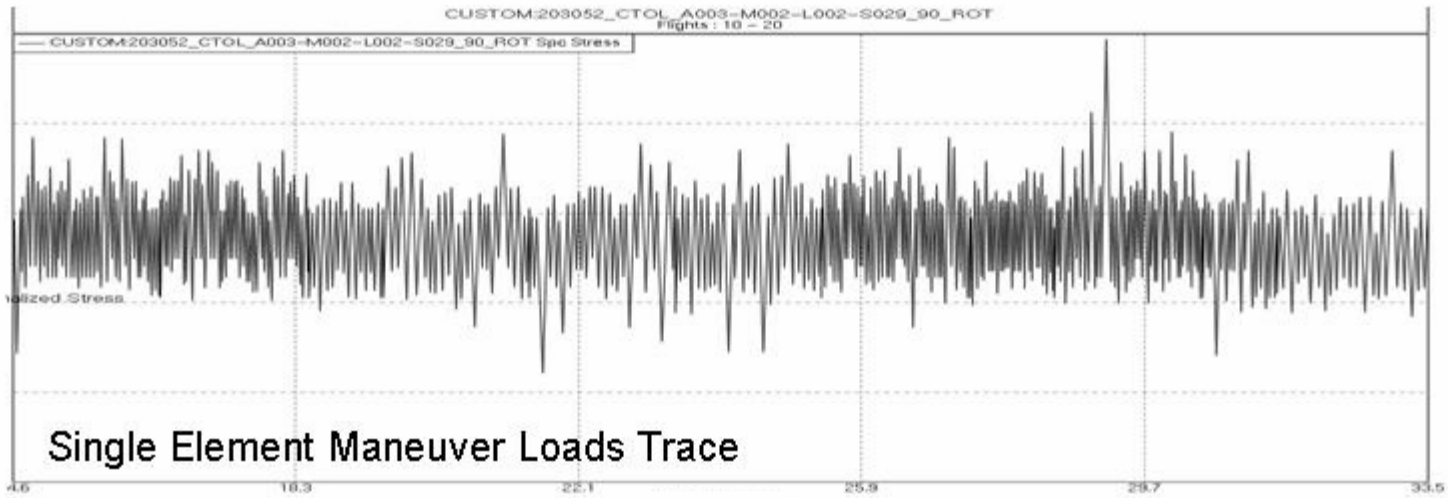


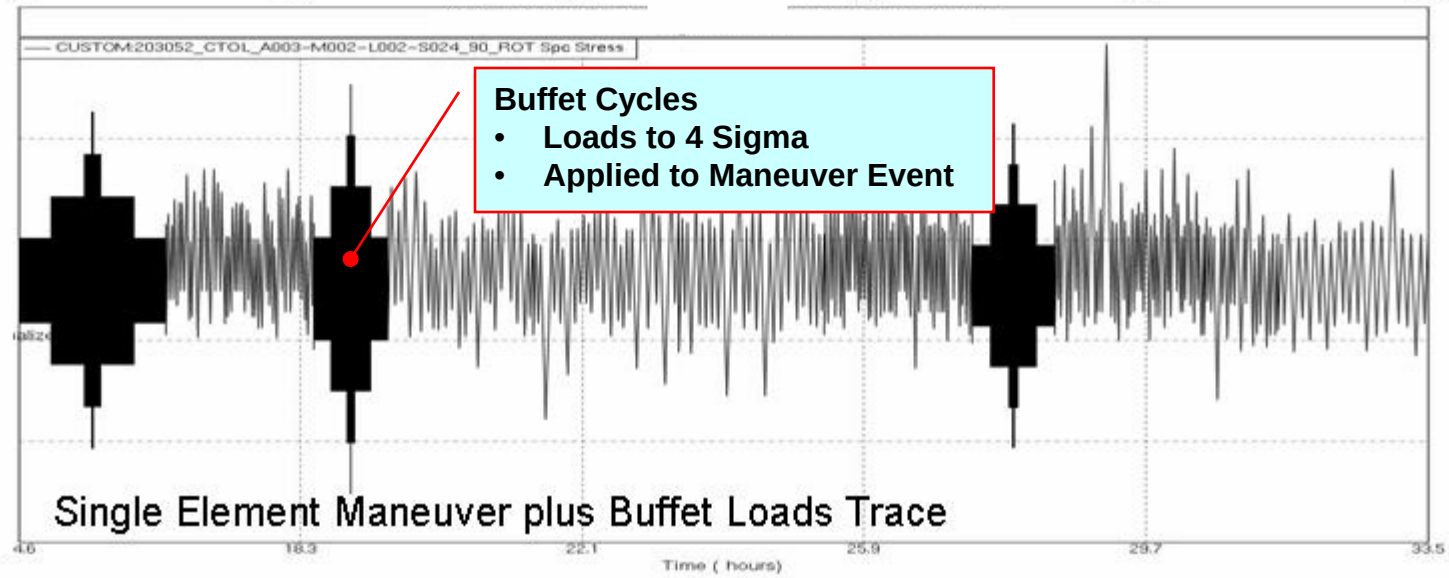
Incremental internal buffet loads added to corresponding static loads yielding strength, service loads.





Buffet Implementation

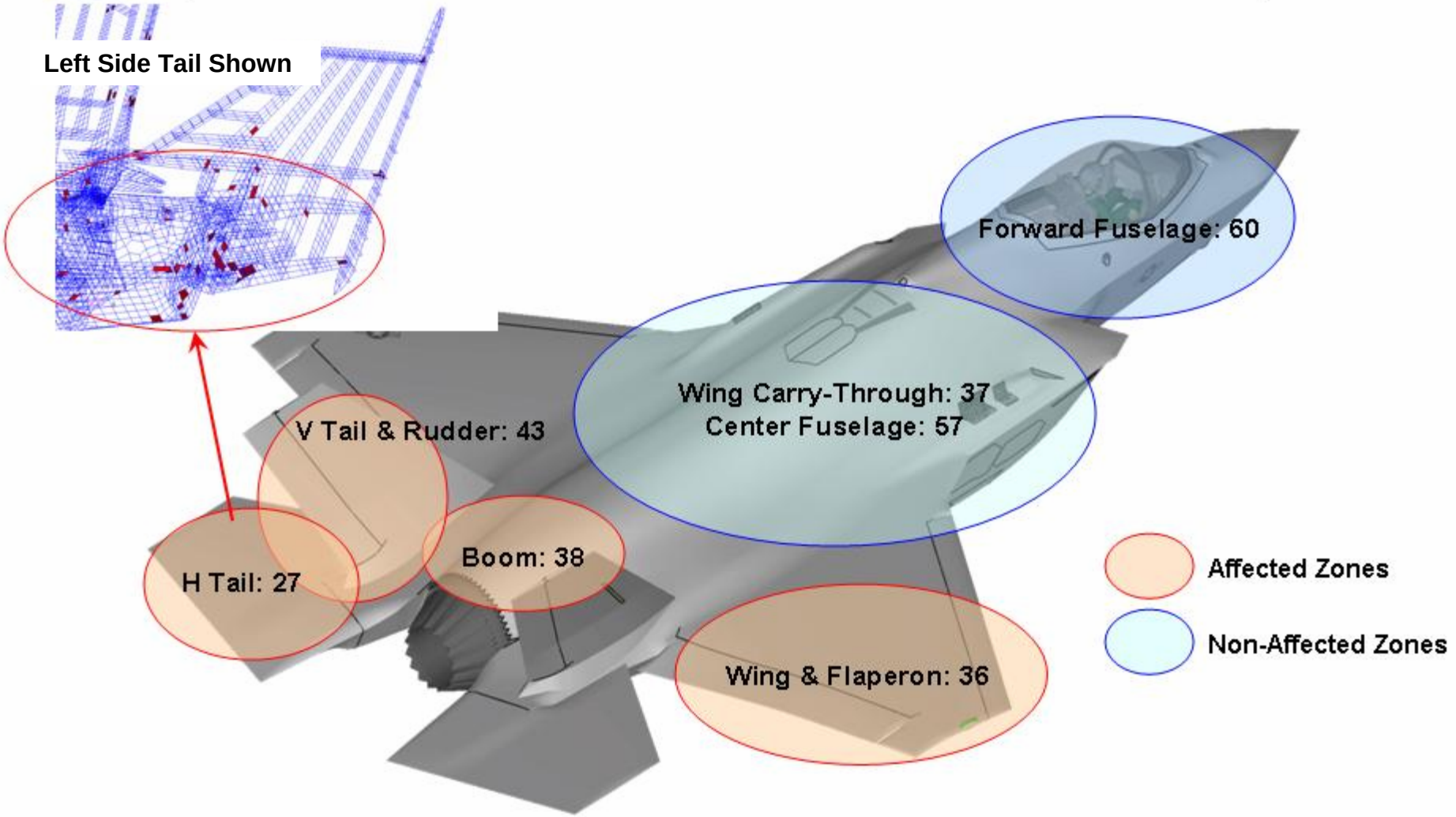




Determine Structural Zones Affected by Buffet

- Evaluate Structural Zones With Predicted Buffet Content
  - Survey Airframe Dynamic FEM under Buffet Loading - 144 Primary Structure Survey Points based on Mid Point Element Strains
    - » Wing Box and Tip: 29 Survey Points
    - » Flaperon and Hinges: 7 Survey Points
    - » Boom, Keel and Frames: 38 Survey Points
    - » Vertical Tail and Rudder and Fittings: 43 Survey Points
    - » Horizontal Tail and Fittings: 27 Survey Points
- Confirm Buffet Extent Outside Predicted Buffet Zones
  - Survey Airframe Design - 154 Primary Structure Survey Points
    - » Wing Carry Through, Longitudinal Structure; 18 Survey Points
    - » Wing Carry Through, Lateral Structure; 19 Survey Points
    - » Center Fuselage, Longitudinal; 57 Survey Points
    - » Forward Fuselage, Longitudinal; 60 Survey Points
- Surveys Damage Analyses Based On Relative Crack Growth Life
  - Constant Model Geometry
    - » Location- dependent Material and Spectrum

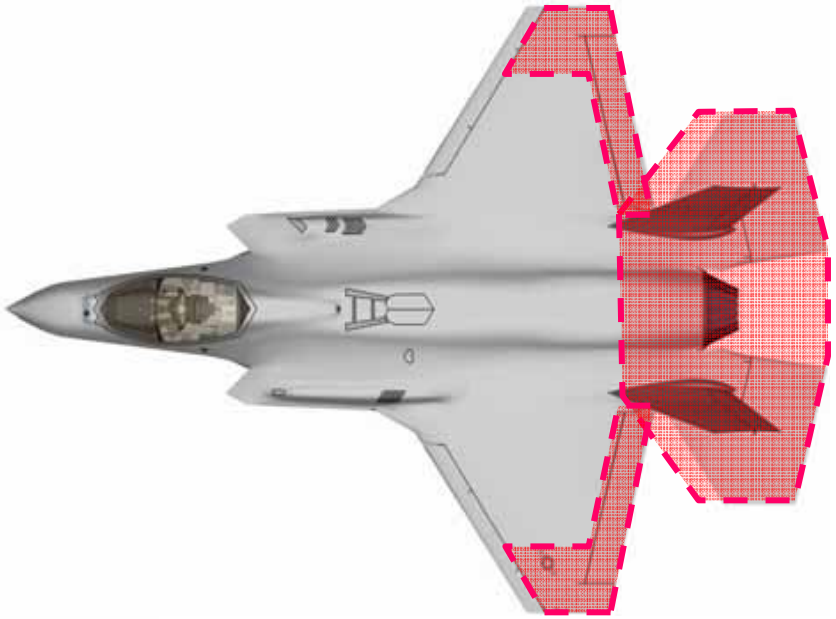
Structural Zones Affected by Buffet

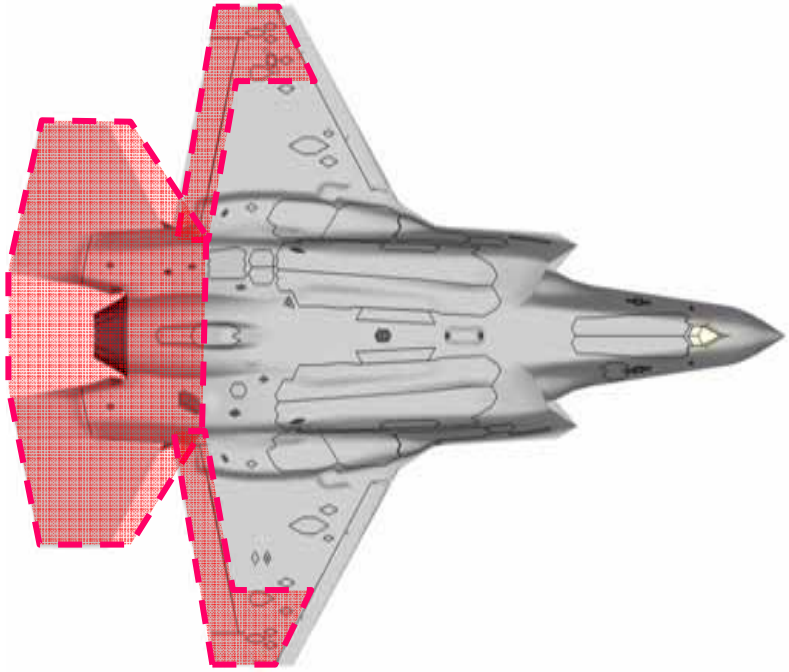


Structural Zones Affected by Buffet

Studies And Legacy Experience Indicated That Major Affected Structure Would Be:

- Wing Tips
- Flaperons
- Vertical Tails
- Horizontal Tails
- Aft Fuselage





Results Of Surveys Confirm The Affected Zones

Buffet Load Cases – Define Individual Modes

The Primary Goal In Selecting Buffet Load Cases Was To Capture The Predominant Buffet Load Mechanisms For Each AOA Range.

Case	AOA Range	Predominant Mechanism
1.	1	Flaperon Rotation – Wing Torsion
2.	1	Wing Aft Tip Acceleration - Wing Tip Bending/Torsion
3.	2	H Tail Aft Tip Acceleration – H Tail Bending/Torsion
4.	2	Rudder Aft Tip Acceleration – Rudder Rotation
5.	3	H Tail Fwd Tip Acceleration – H Tail Bending/Torsion
6.	3	H Tail Actuator - H Tail Bending & Pitch
7.	4	Rudder Actuator – V T Box Torsion
8.	4	V Tail Aft tip Acceleration – Root Bending & Torsion
9.	5	Rudder Aft Tip Acceleration
10.	5	V Tail Root and Mid Bending
11.	6	V Tail Root Bending

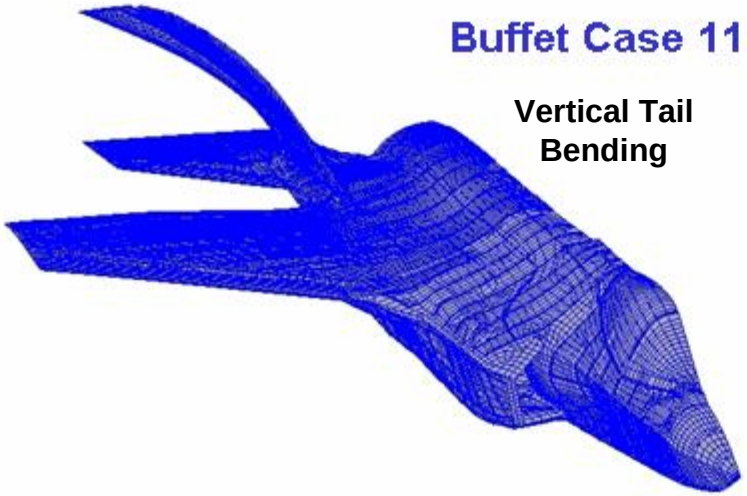
AoA	Degrees
Bin	Range
Ref Q	psf
Ref RMS	Value
Selection Basis	VT Root Bending
Characteristic Frequency	Hz

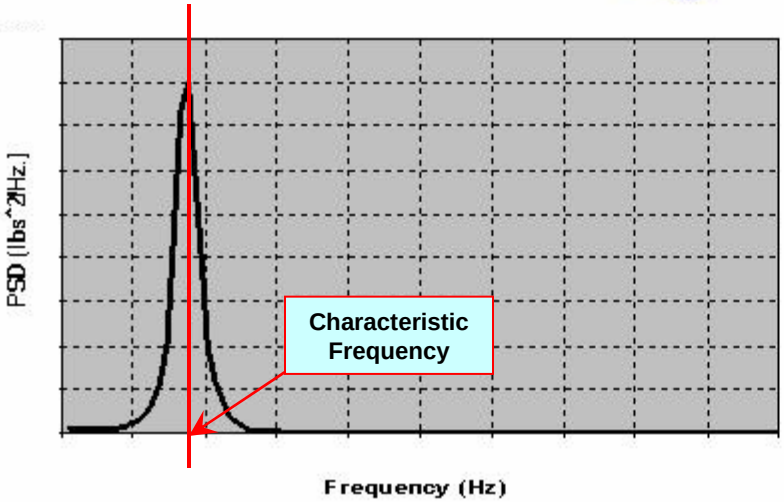
A Time Hack Is Chosen From Each Dynamic Load Case To Become The Static Representation Of That Case, With A Characteristic Frequency

Buffet Load Cases –2 Individual Modes

Buffet Case 11

Vertical Tail Bending

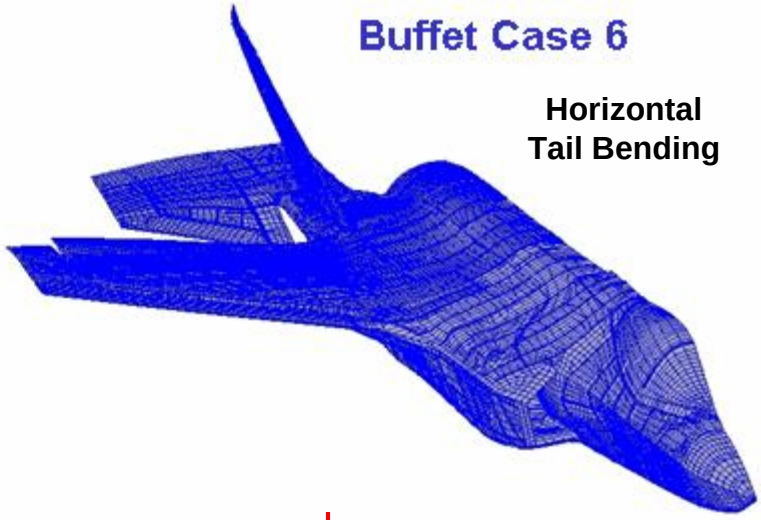


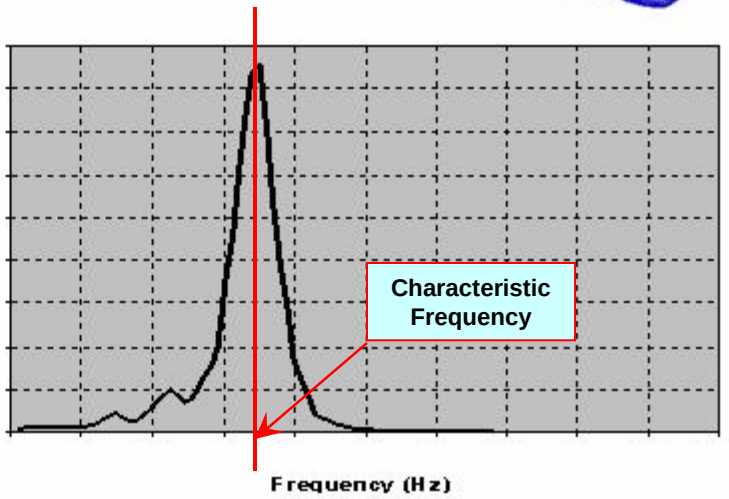


This VT Bending Buffet Load Case is selected for VT Root Bending.

Buffet Case 6

Horizontal Tail Bending





The HT Rotation Buffet Load Case is selected for HT Actuator Force

Evaluate Mode Damage By Zones

- **11 Separate Buffet Modes; Impractical For The Airframe Full Scale Durability Tests**
  - ***Establish Damage Caused by Individual Modes***
  - ***Fatigue Related Damage is Caused by Limited Number Of Modes***
    - Treat Each Structural Zone Independently
  - ***Eliminate Individual Modes That Do Not Contribute***
  - ***Buffet Zone Survey Points Were Used***
    - Crack Growth Life Selected As The Damage Criterion
      - *Constant Geometry, Correct Material, As For The Content Survey*
      - *Strain Life was Also Evaluated, But Proved Less Sensitive*
  - ***Each Survey Point Was Evaluated For:***
    - Maneuver Spectrum With Buffet; All Modes Included
    - Maneuver Spectrum Without Buffet
    - Maneuver Spectrum Combined With Each 11 Individual Buffet Modes

Evaluate Mode Damage By Zones

Normalized Baseline Life from Complete Maneuver plus Buffet Spectrum

Relative Life from Individual Modes

Single Mode Life Ratio for Mode 6, Highest Buffet Contribution

Single Mode Life Ratio for Mode 7 Buffet contribution = 0

Relative Life from Maneuver – Only Spectrum

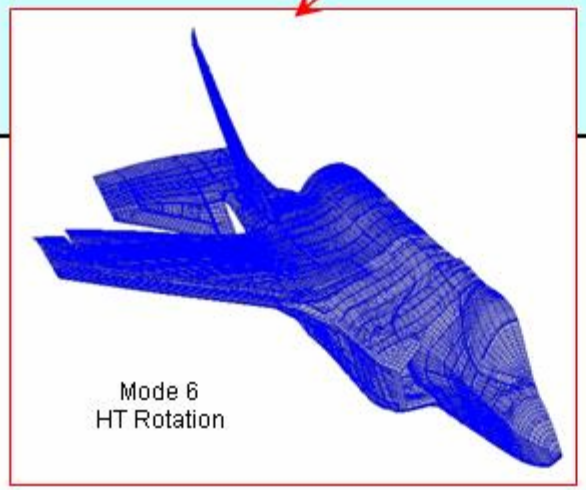
Element ID	All Modes	1	2	3	4	5	6	7	8	9	10	11	Maneuver
1	1.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	2.3	**1.3**	3.9
2	1.0	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.1	**1.2**	2.9
3	1.0	**1.4**	**1.4**	**1.4**	**1.3**	**1.3**	**1.2**	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**	1.4
4	1.0	31.5	31.5	31.5	31.5	2.8	**1.6**	31.5	31.5	31.5	31.5	31.5	31.5
5	1.0	31.2	31.2	31.2	31.2	3.0	**1.6**	31.2	31.2	31.2	31.2	31.2	31.2
6	1.0	31.7	31.7	31.7	31.7	2.6	**1.7**	31.7	31.7	31.7	31.7	31.7	31.7
7	1.0	6.5	6.5	6.5	6.5	6.5	6.2	6.4	6.5	6.5	2.5	**1.3**	6.5
8	1.0	13.3	13.3	13.3	13.3	2.7	**1.8**	13.3	13.2	13.3	13.2	13.3	13.3
9	1.0	31.6	31.6	31.6	31.6	3.1	**1.7**	31.6	31.6	31.6	31.6	31.6	31.6
10	1.0	**1.7**	**1.7**	**1.6**	**1.6**	**1.4**	**1.2**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	1.7
11	1.0	30.7	30.7	30.7	30.7	2.3	**1.8**	30.7	30.7	30.7	30.7	30.7	30.7
12	1.0	30.8	30.8	30.8	30.8	3.8	2.3	8.8	30.8	7.8	30.8	23.7	30.8
13	1.0	**1.3**	**1.3**	**1.3**	**1.3**	**1.2**	**1.1**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	1.3
14	1.0	31.7	31.7	31.7	31.7	3.7	**1.5**	31.7	31.7	31.7	31.7	31.7	31.7
15	1.0	31.6	31.6	31.6	31.6	6.4	5.6	4.0	31.6	3.3	31.6	10.6	31.6
16	1.0	**1.2**	**1.2**	**1.2**	**1.2**	**1.1**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	1.2
17	1.0	30.9	30.9	30.9									
18	1.0	31.3	31.3	3									
19	1.0	31.8	31.8	3									

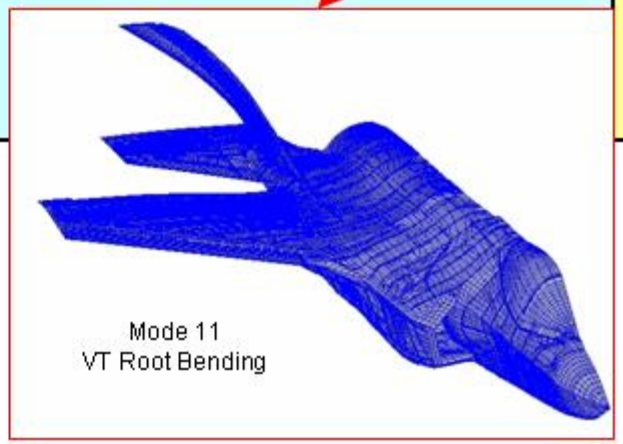
- Mode Filters
  - **Subject to a 4 Life Limit**
    - **Single Modes Lives Greater than 4 are Eliminated.**
      - ***A value in the table of 2.0 = 4 lives***
  - **Within 20% of the 'Maneuver' Total**
    - **Single Modes with Limited Buffet effect are Eliminated**

Evaluate Damage By Zones And Modes

Element ID	All Modes	1	2	3	4	5	6	7	8	9	10	11	Maneuver
1	1.0											1.3	3.9
2	1.0											1.2	2.9
3	1.0						1.2						1.4
4	1.0						1.6						31.5
5	1.0						1.6						31.2
6	1.0						1.7						31.7
7	1.0											1.3	6.5
8	1.0						1.8						13.3
9	1.0						1.7						31.6
10	1.0						1.2						1.7
11	1.0						1.8						30.7
12	1.0												30.8
13	1.0						1.1						1.3
14	1.0						1.5						31.7
15	1.0												31.6
16	1.0												1.2
17	1.0												30.9
18	1.0												31.3
19	1.0												31.8

Filters Identify Significant SP/Mode Combinations





Damaging Modes – Complete Airframe

- Process Was Repeated For All Affected Zones
- Structural Zones Are Affected By A Limited Number Of Modes, Typically Two Modes Per Zone

Component/Mode	1	2	3	4	5	6	7	8	9	10	11
Boom and Aft Fuselage						■					■
Wing	■	■									
Flaperon	■										
Horizontal Tail			■			■					
Vertical Tail and Rudder							■				■

Affected: ■ **Not Significantly Affected:** □

Reduce Mode-Related Cycle Count

- **Reduction Of Buffet Modes Reduces End Point Count**
  - ***Example For The Boom Structure***

    - All Modes Total ~ 100% (Several Million Cycles)
    - The Two Identified Modes Are 6 And 11
      - *Mode 6 Has ~ 10.6% Cycles*
      - *Mode 11 Has ~ 1.9% Cycles*
      - *Total Modes 6 + 11 ~ 12.5% Cycles*

    - Eliminating the Non-Damaging Modes Reduces the Spectrum Size to 12.5%
    - Maneuver-Only Part of The Spectrum Has 0.9% Cycles

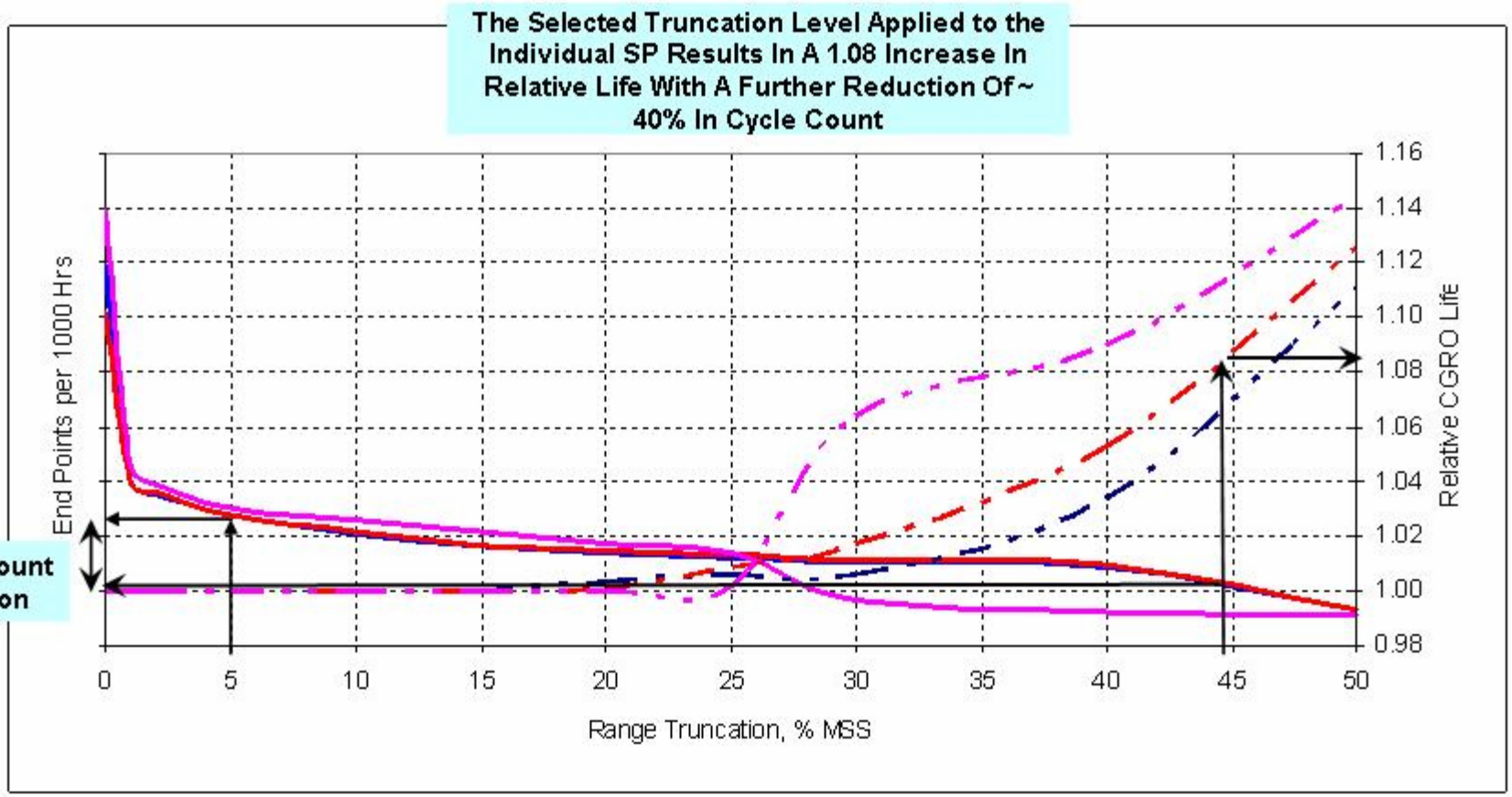
Buffet Truncation

- **Further Cycle Reduction Is Needed For Full Scale Testing**
  - ***Test Duration Has Practical And Economic Considerations***
  - ***Separate Truncation Levels For Buffet And Maneuver***

- **Buffet Truncation**
  - ***20 Boom Locations Were Evaluated To Determine Effects Of Increasing Truncation Greater Than 5%***
    - Determine Cycle Count Reduction
    - Determine Effect On Crack Growth Life
  - ***Highest Count Mode For Each Location Was Used As Reference***

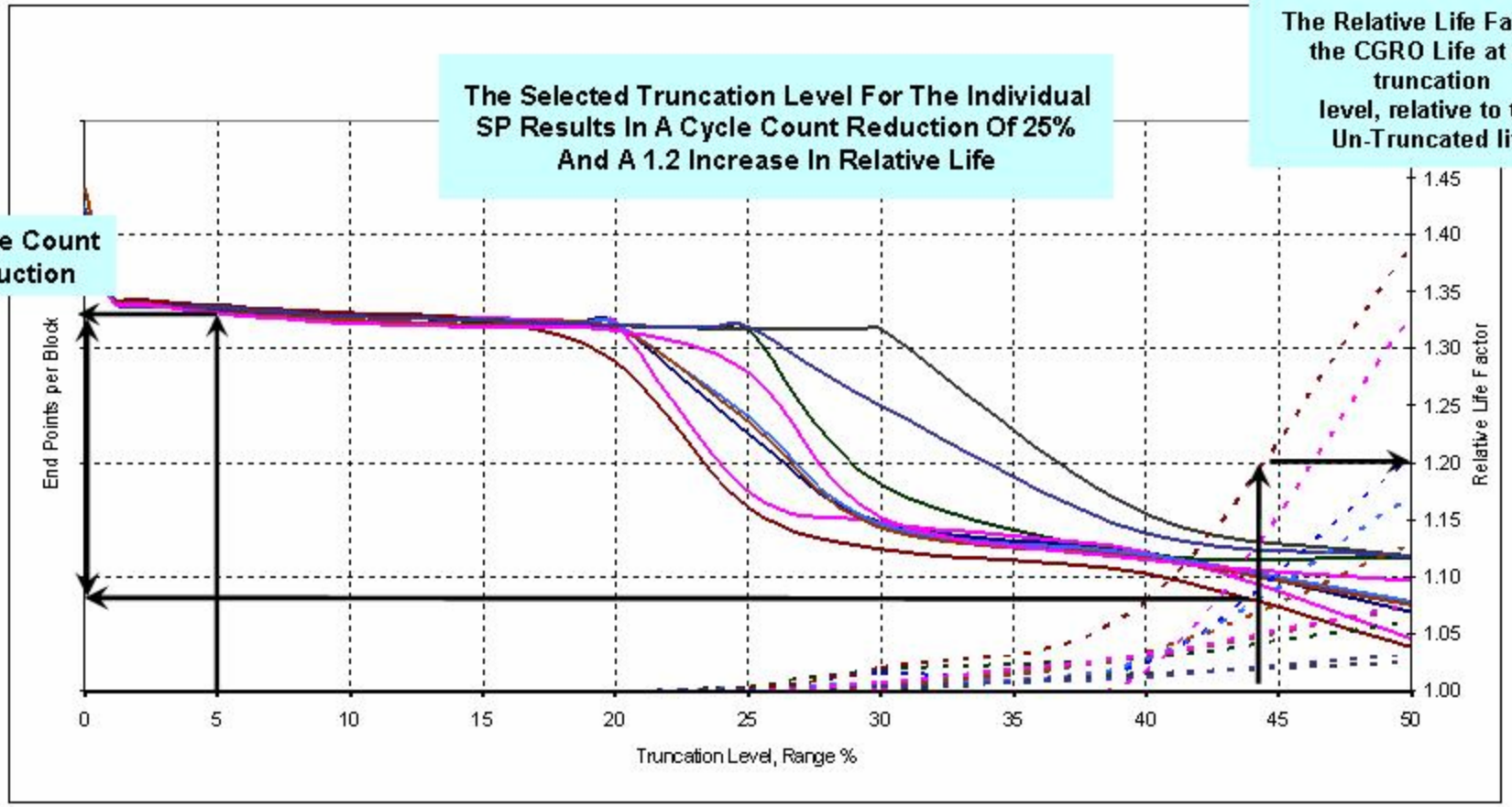
Buffet Truncation – Mode 11 Truncation/Life

Boom – Multiple SP Results

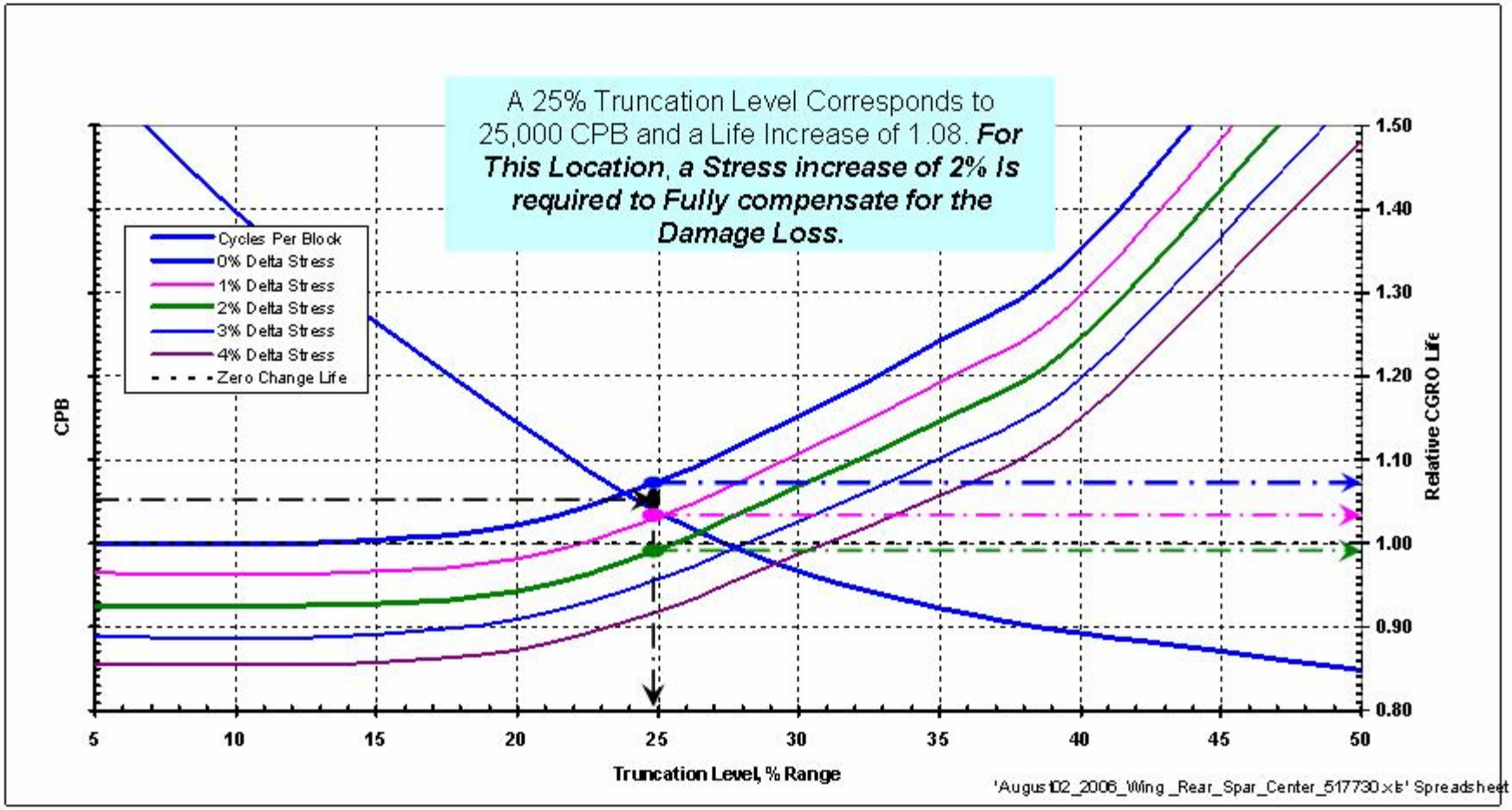


Buffet Truncation – Mode 6 Truncation/Life

Boom – Multiple SP Results



Buffet Truncation – Equivalent Damage



Results

- **Full Scale Durability Test Configuration and Loadings**
  - ***Remove The Vertical and Horizontal Tails from the Test Airframe***
  - ***Add Quasi-Static Buffet Loads to the Remaining Aft Fuselage***
    - High Truncation Levels
    - Equivalent Damage
    - Limited Modal Content
- **Stand-Alone Components**
  - ***Vertical Tails***
    - Shaker Application of Buffet Loads; Limited Modes
    - Maneuver Loads Separately Applied
    - Baseline Truncation
  - ***Horizontal Tails***
    - Shaker Application of Buffet Loads; Limited Modes
    - Maneuver Loads Separately Applied
    - Baseline Truncation

Summary

- **The Contribution Of Buffet To Airframe Damage Has Been Evaluated**
  - Broad Selection Of Structure
  - Range Of Buffet Contribution Established
- **Defined Spectrum Development Methodology To Achieve Program Requirements For Full Scale Durability Tests**
  - Maneuver And Buffet Portions Addressed
  - Modal Contribution Identified And Outlined
- **Next Step – Implementation Of Method On The Full Scale Durability Tests**