

Validation and Testing

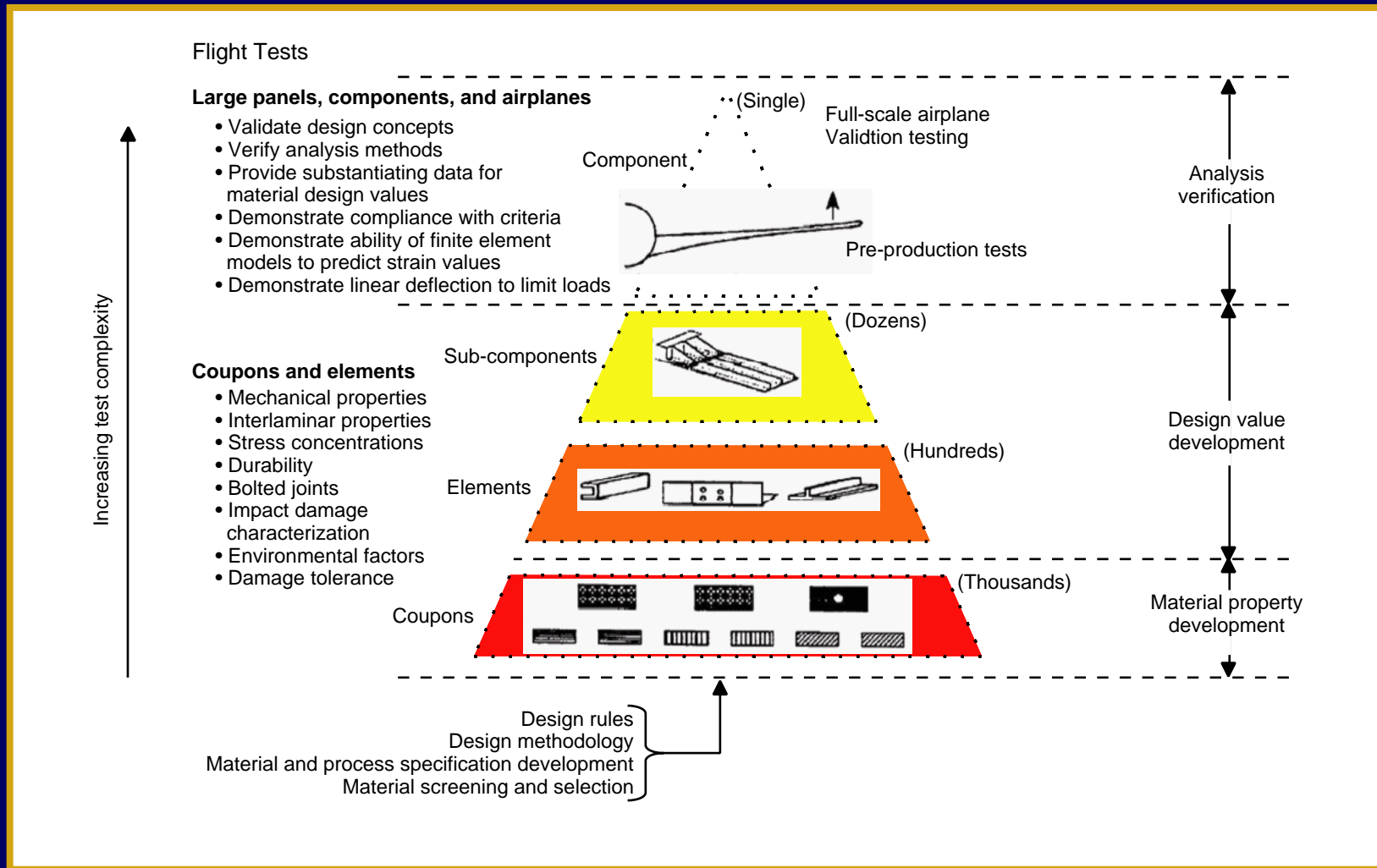
Aerospace Testing Expo 2005

November 8-10, 2005
Long Beach, CA

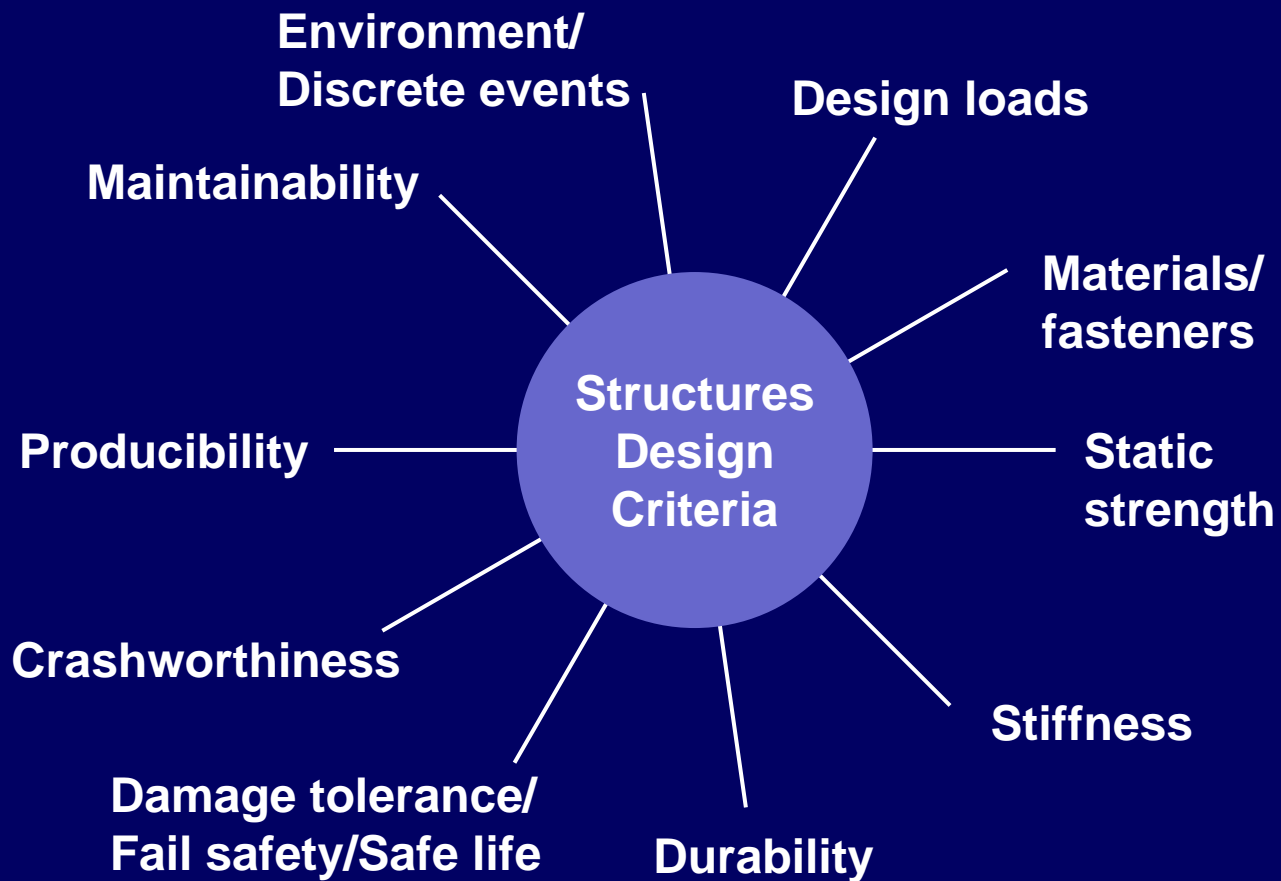
Michael Mohaghegh
Boeing Commercial Airplanes



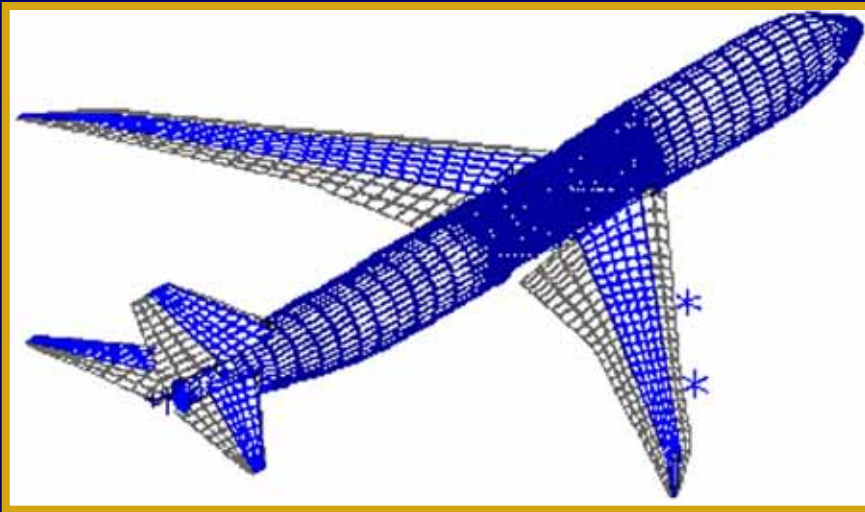
Building Block Approach



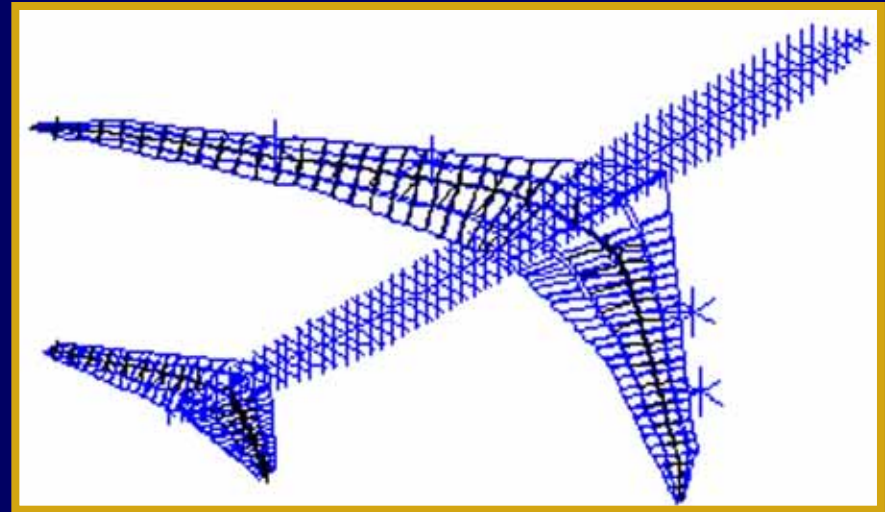
Principal Structural Design Requirements



External Loads Model

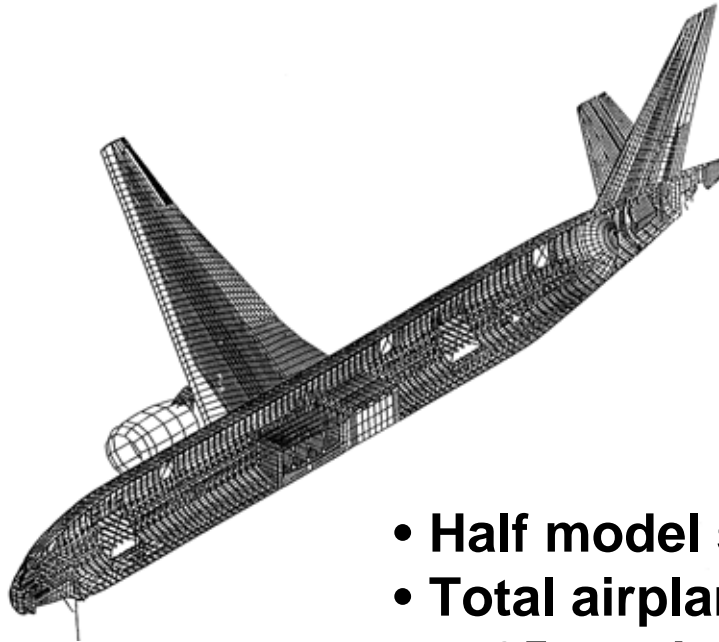


(a) FEM Model



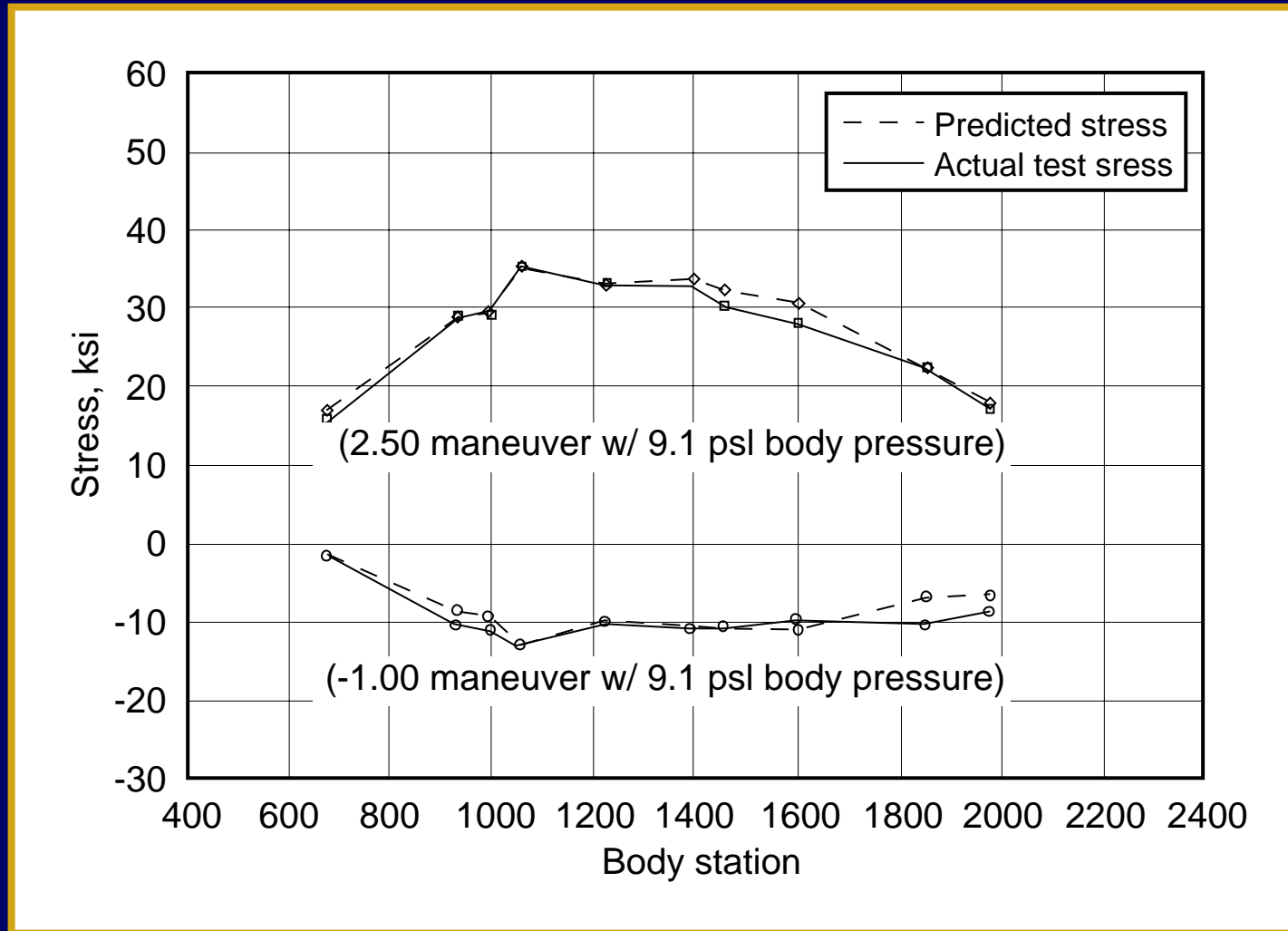
(b) Beam Model

FEM Model



- Half model shown
- Total airplane model
 - 35 meshes (substructures)
 - 60,000 nodes
 - 150,000 elements
 - 225,000 degrees of freedom

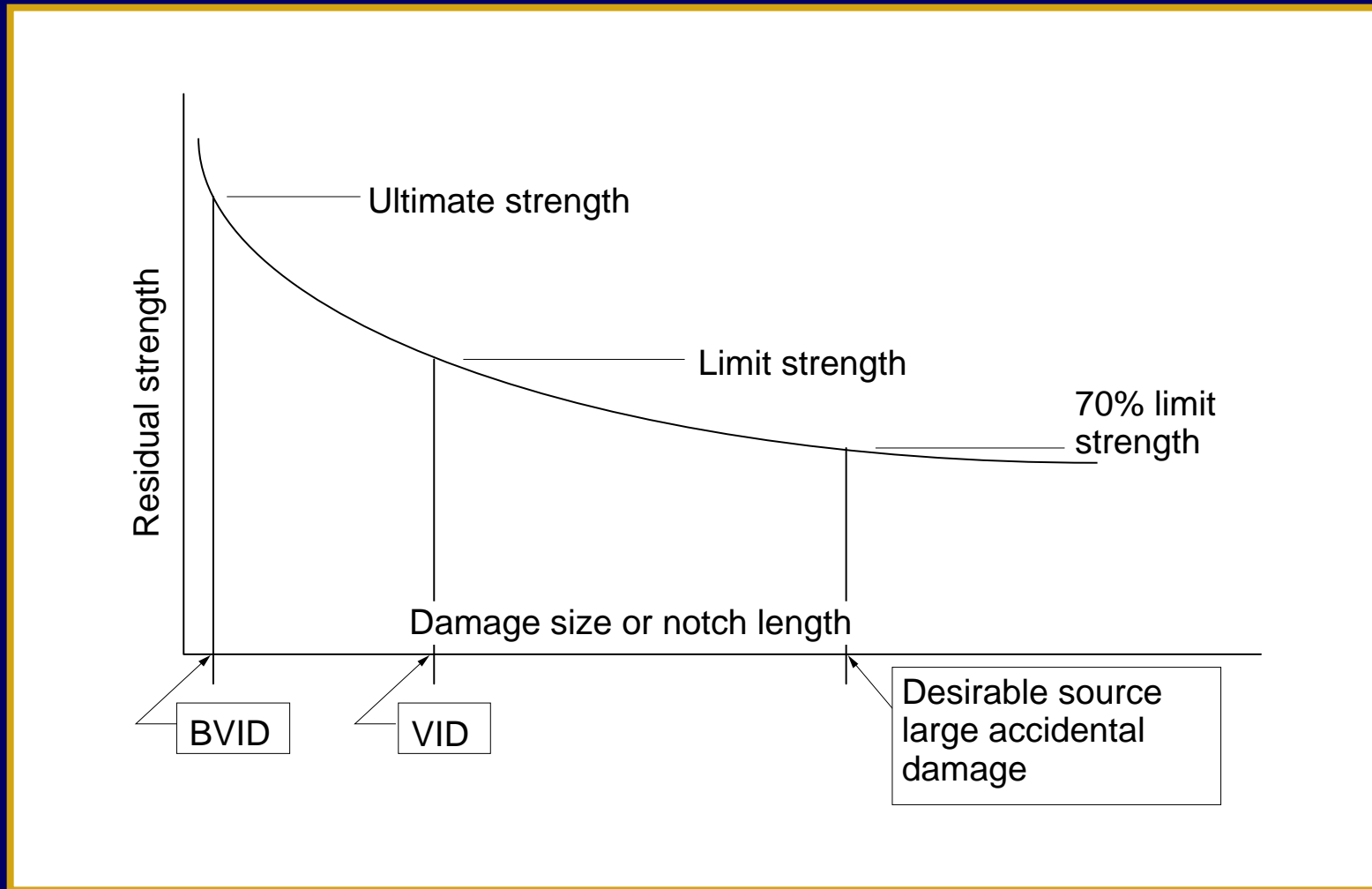
Crown Stringer Stress Distribution



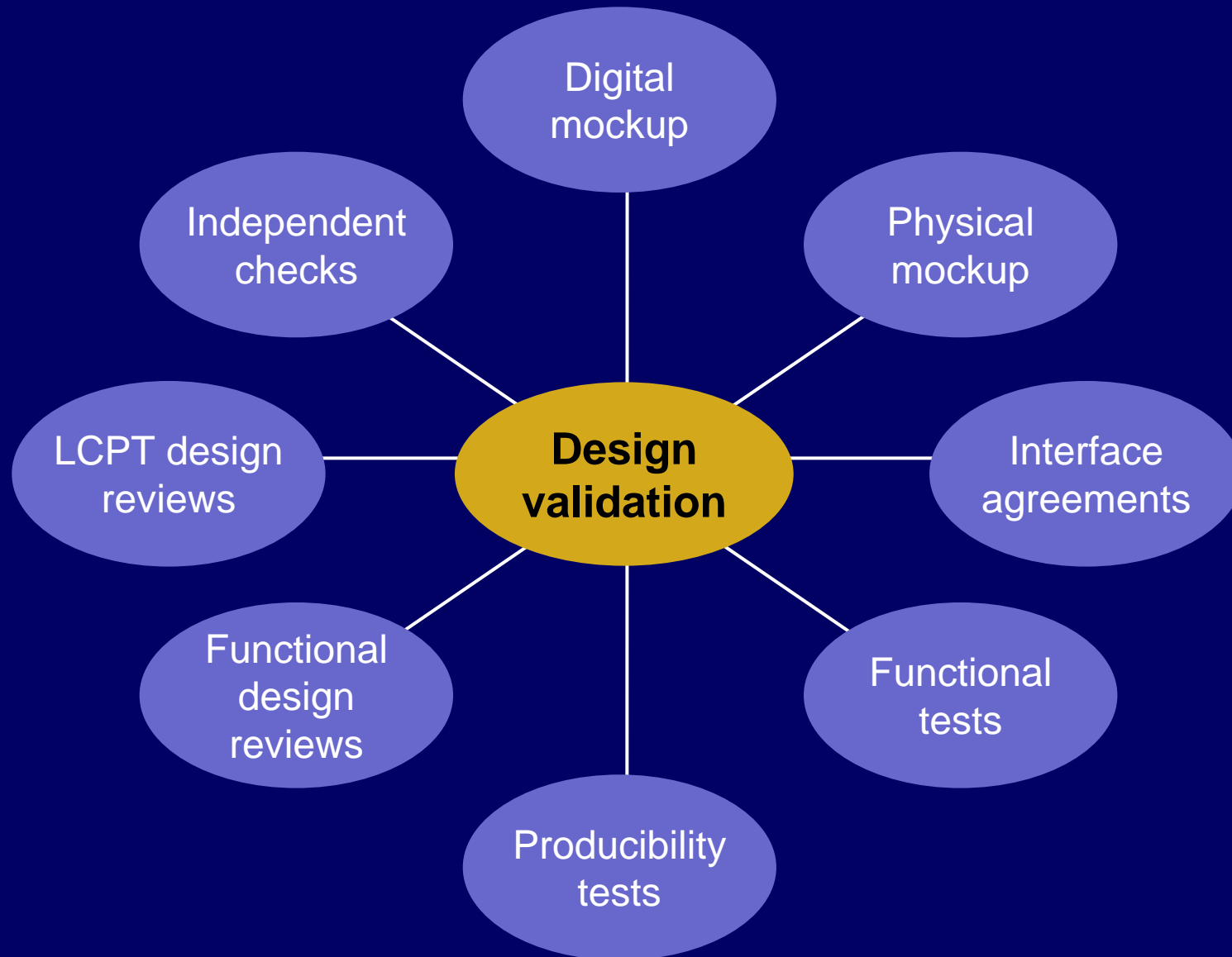
FAR 25.571 Amendments Related to Fail Safety and Damage Tolerance

Amendment level and date	Title	Summary of changes to FAR 25.571
25-0 (12/24/64)	Fatigue evaluation of flight structure	(c) Fail safe strength. “It must be shown by analysis, tests, or both, that catastrophic failure or excessive deformation, that could adversely affect the flight characteristics of the airplane, are not probable after fatigue or obvious partial failure of a single PSE.”
25-45 (12/1/78)	Damage-tolerance and fatigue evaluation of structure	(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 residual strength evaluation must show that the remaining structure is able to withstand loads corresponding to ...”
25-96 (4/30/98)	Damage-tolerance and fatigue evaluation of structure for WFD.	(b) Damage-tolerance evaluation, for WFD Initial flaw of maximum probable size from manufacturing defect or service induced damage used to set inspection thresholds; sufficient full scale fatigue test evidence must demonstrate that WFD will not occur within DSO (no airplane may be operated beyond cycles equal to ½ the cycles on fatigue test article until testing is completed).

Residual Strength Versus Damage Size or Notch Length



Design Validation Methods



Probabilistic Life Cycle Management

Design (\$\$)

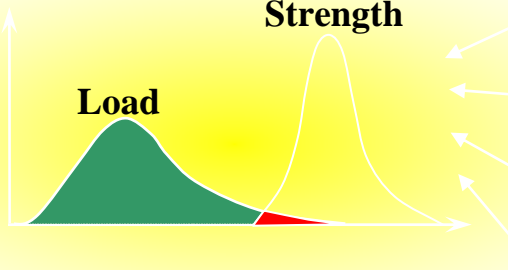
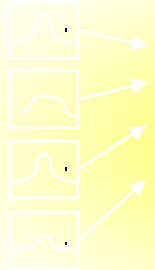


- Static/Ultimate Strength
- Durability/Safe Life
- Fail Safety/Damage Tolerance

Probabilistic Risk Assessment



Maneuver
Gust
Thermal
Payload
Environment
Fit-up stress
Sensors
Etc.



Modulus
Ult. strength
Toughness
S-N/DaDT
Corrosion
Damage
Tolerance, Shimming
Etc.

• Certification

• Statistical Quality Control

• Initial Defects Quantification

Manufacturing (\$\$)



Fleet Readiness



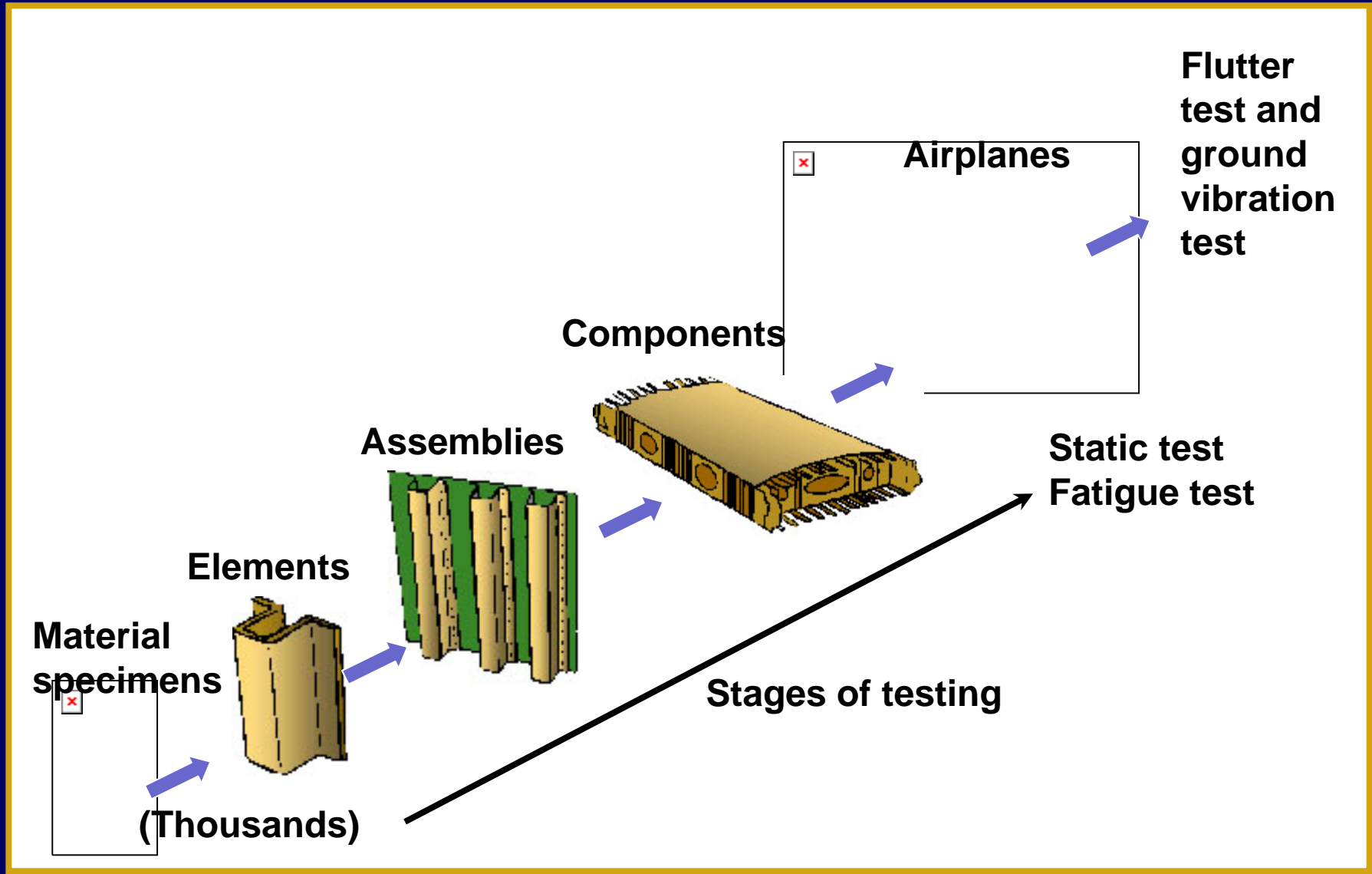
• Inspection and Repair

• Health Monitoring

Operation/
Maintenance (\$\$)



Levels of Structural Testing



Design Allowables Descriptions

Basis	Description	Typical Use
A	A value which 99% of the measured values will exceed associated with a 95% confidence level	Single loadpath structures
B	A value which 90% of the measured values will exceed associated with a 95% confidence level	Multiple loadpath structures
C	A value associated with specification acceptance values. No statistical significance may be assumed.	

Airplane Static Test



Full Scale Airplane Static Test Results

Airplane model	707 (KC135)	727	737	747	767	757	777
% wing ultimate design load at failure	110%	110%	106%	115%	99.4% ①	111%	103%
Failure location	Lower panel	Upper panel	Upper panel	Upper panel	No wing failure	Upper F/S chord	Upper panel

① No wing failure, test terminated due to failure of non-representative body.

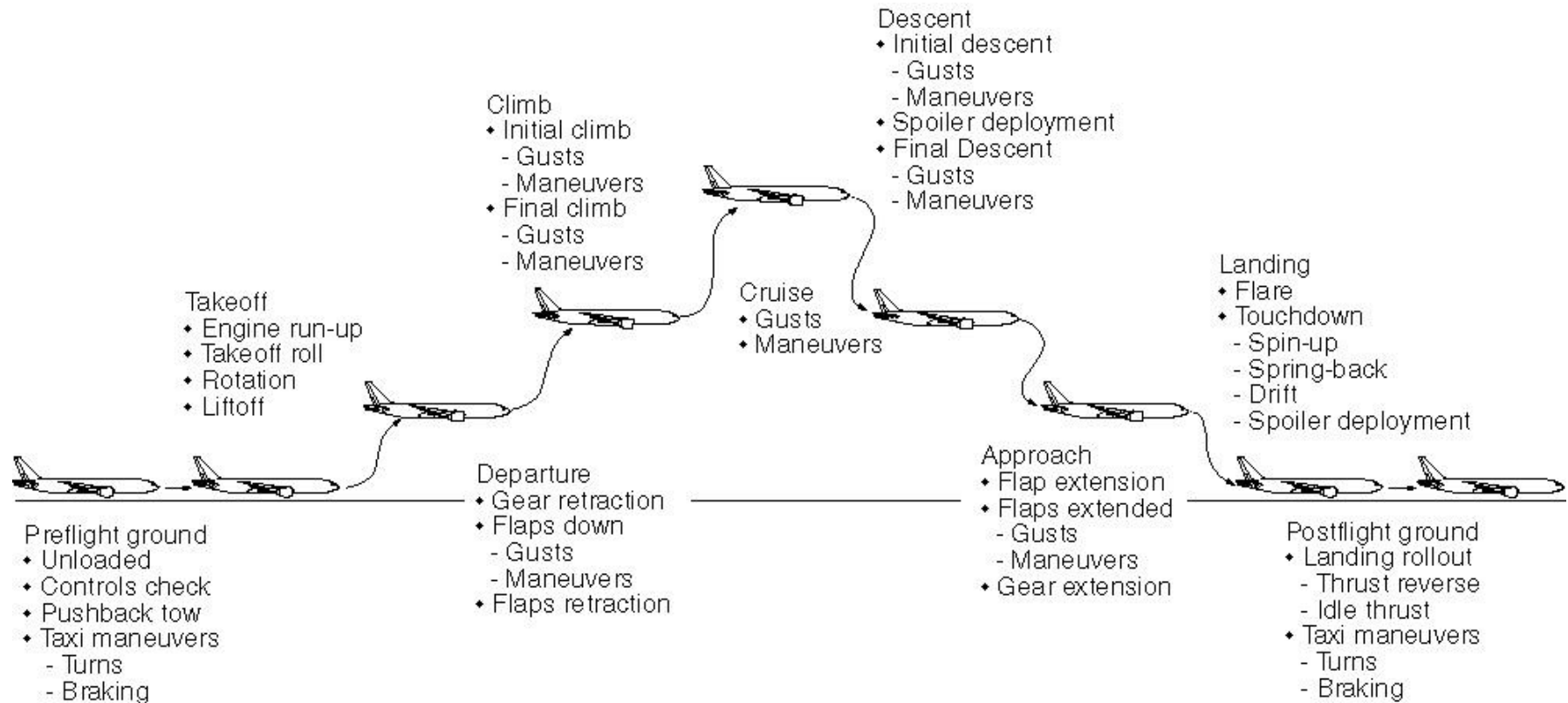
Airplane Fatigue Test



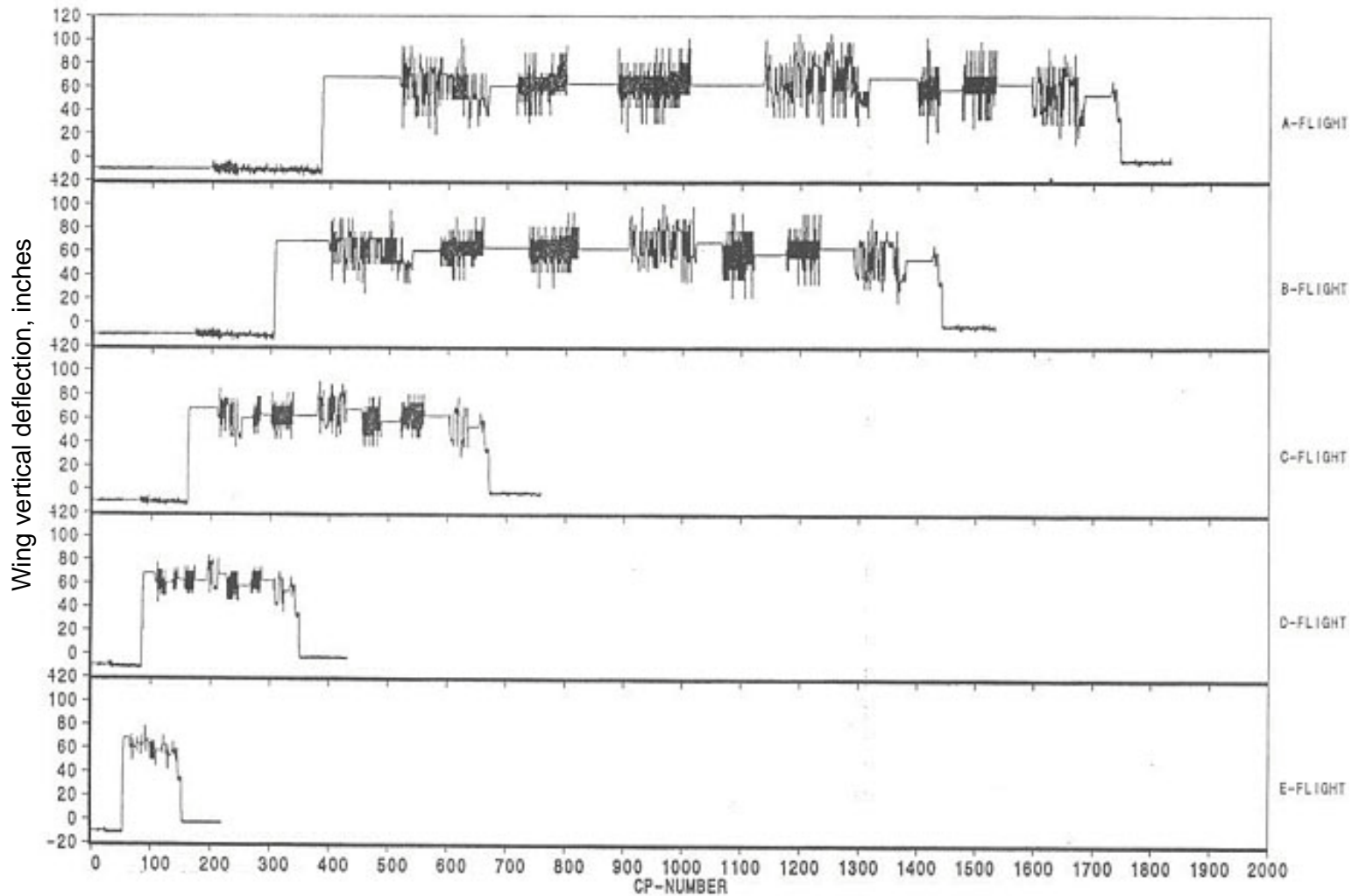
Airplanes are Fatigue Tested Far Beyond Their Design Service Objectives

Airplane	Minimum design service objectives	Fatigue test cycles	Remarks
707	20,000	50,000	Fuselage Hydro-fatigue test
727	60,000	a. 60,000 b. 170,000	Complete airframe Complete fuselage 47,000 cycles in service, plus 123,000 pressure test cycles
737	75,000	a. 150,000 b. 129,000	Fuselage section/pressure and shear Complete aft fuselage 59,000 cycles in service, plus 70,000 pressure test cycles
747	20,000	a. 20,000 b. 40,000 c. 60,000	Complete airframe Complete airframe 20,000 cycles in service, plus 20,000 pressure test cycles 747-400 sections 41 and 42 pressure test cycles
757	50,000	100,000	Complete airframe
767	50,000	100,000	Complete airframe
777	44,000	120,000 plus 20,000 pressure cycles	Complete wing and fuselage airframe test in progress for early 1997 completion

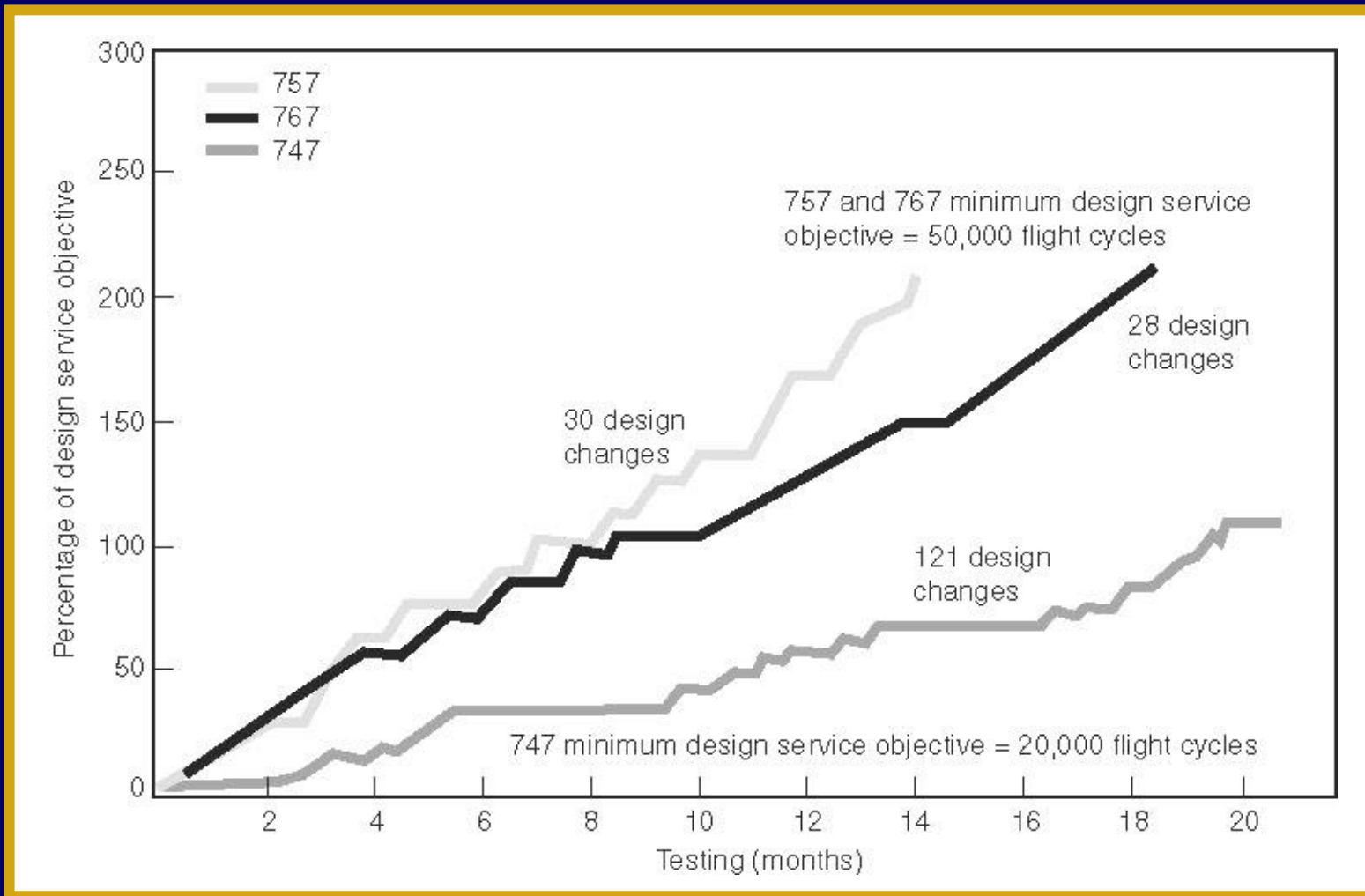
Aircraft Fatigue Loads Overview



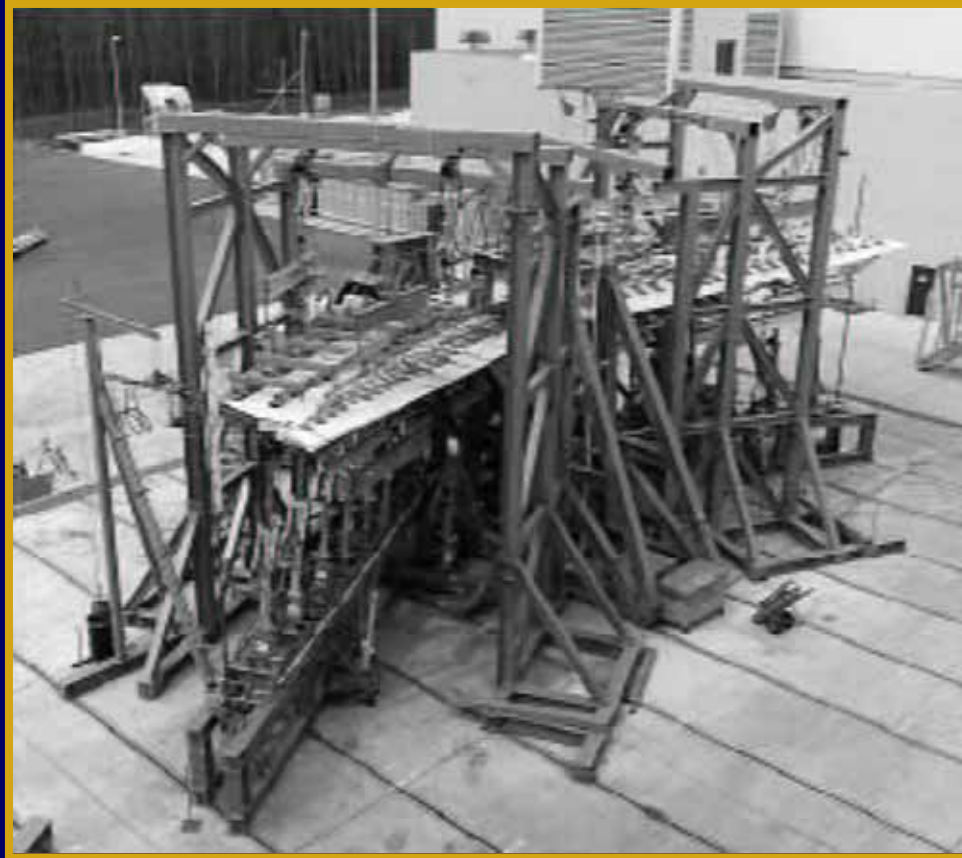
Fatigue Test Deflections



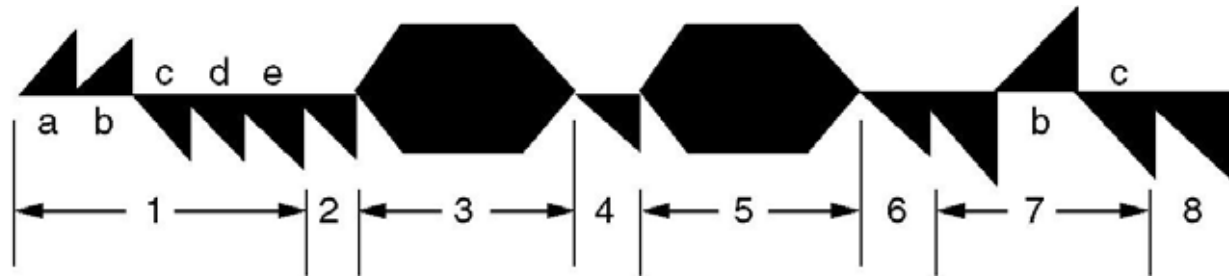
Design Changes During full-Scale Fatigue Testing



Horizontal Stabilizer Test Setup

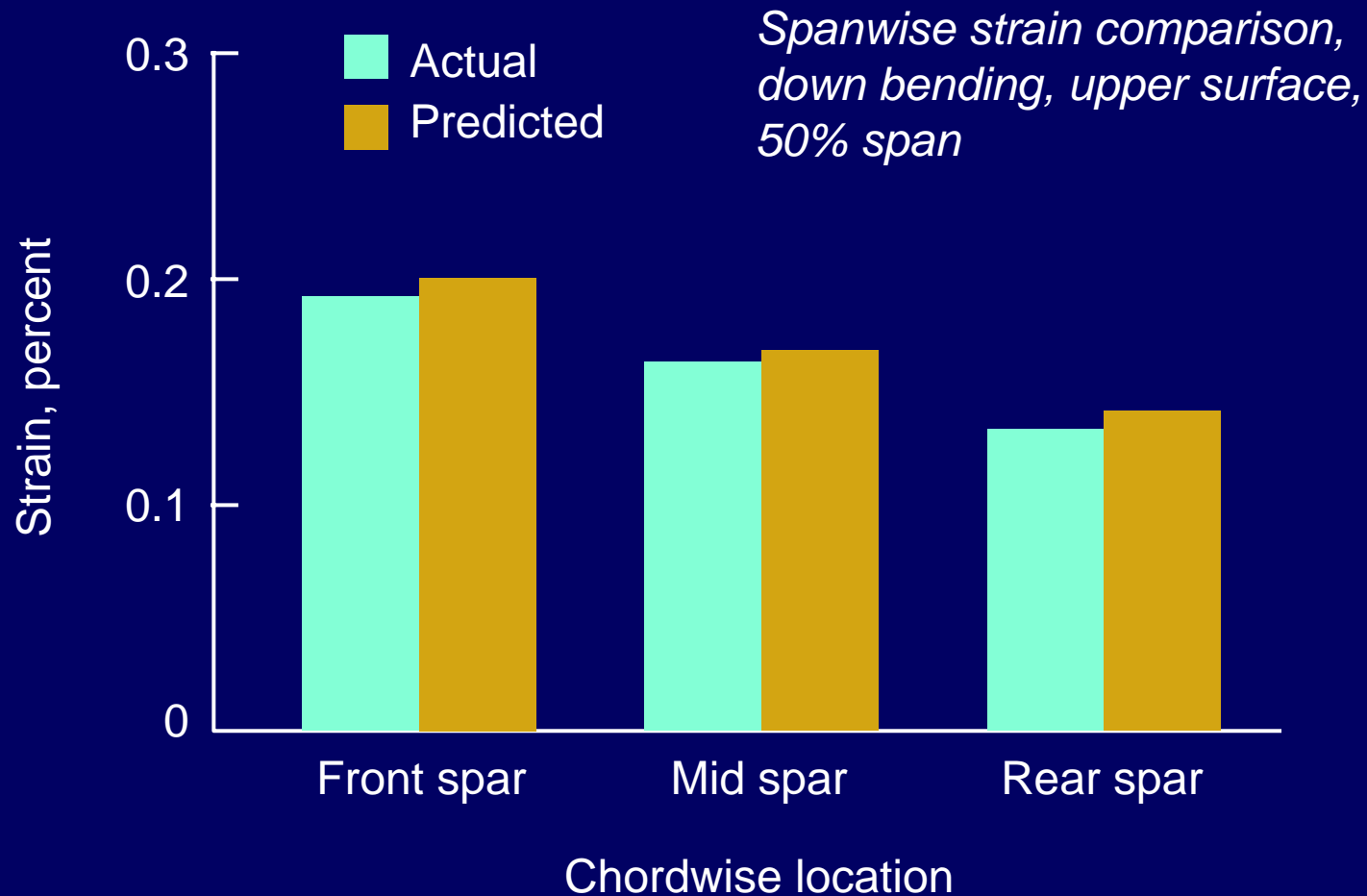


Horizontal Stabilizer Test Sequence

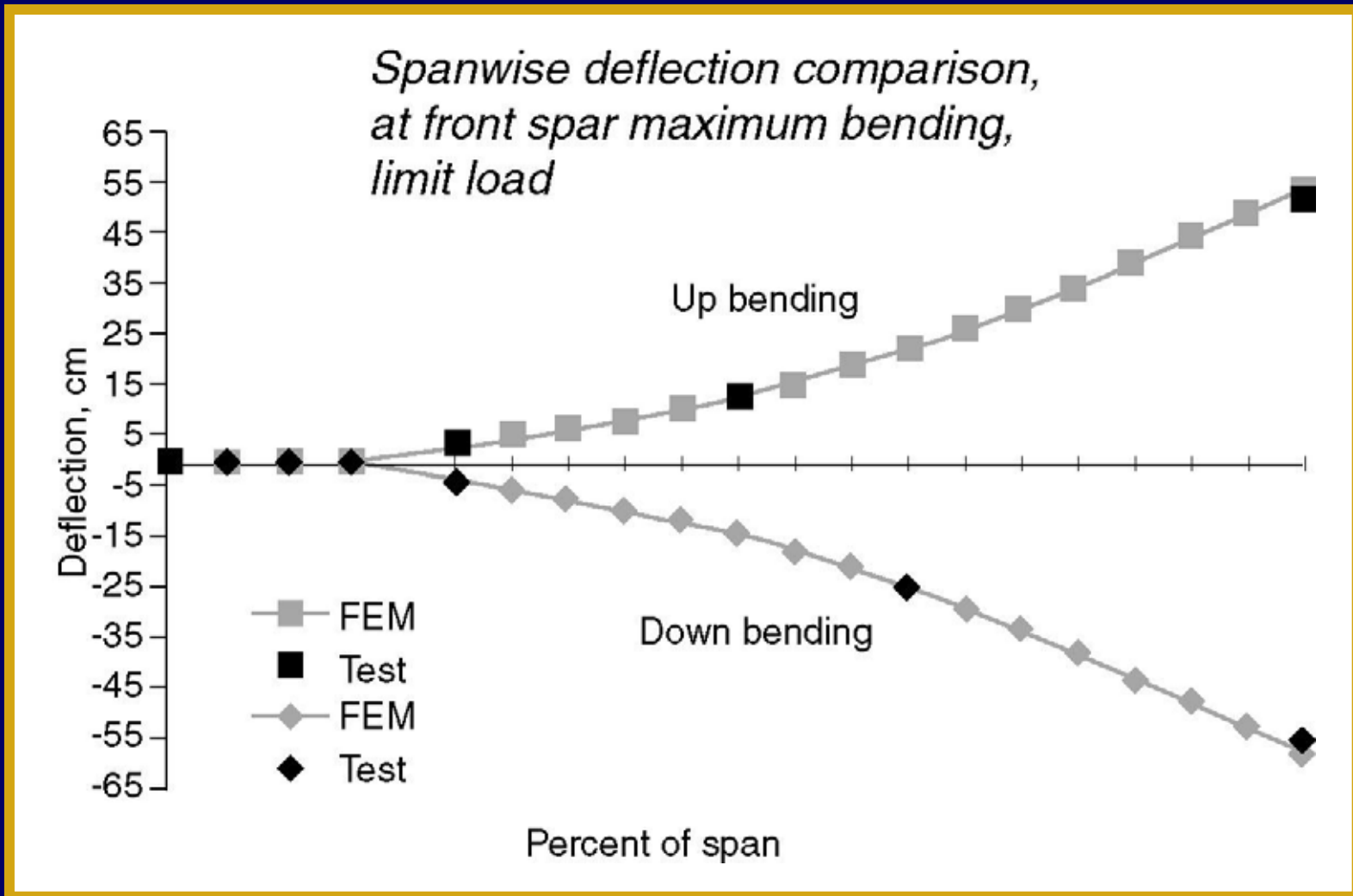


Sequence	Load description	Sequence	Load description
1	Limit proof load a. Up bending b. Up bending/unsymmetric c. Down bending d. Down bending/ unsymmetric e. Stall buffet (unsymmetric)	4	Strain survey
2	Strain survey	5	Fatigue spectrum
3	Fatigue spectrum	6	Strain survey
		7	Ultimate load strain survey a. Stall buffet b. Up bending c. Down bending
		8	Destruction test - down bending

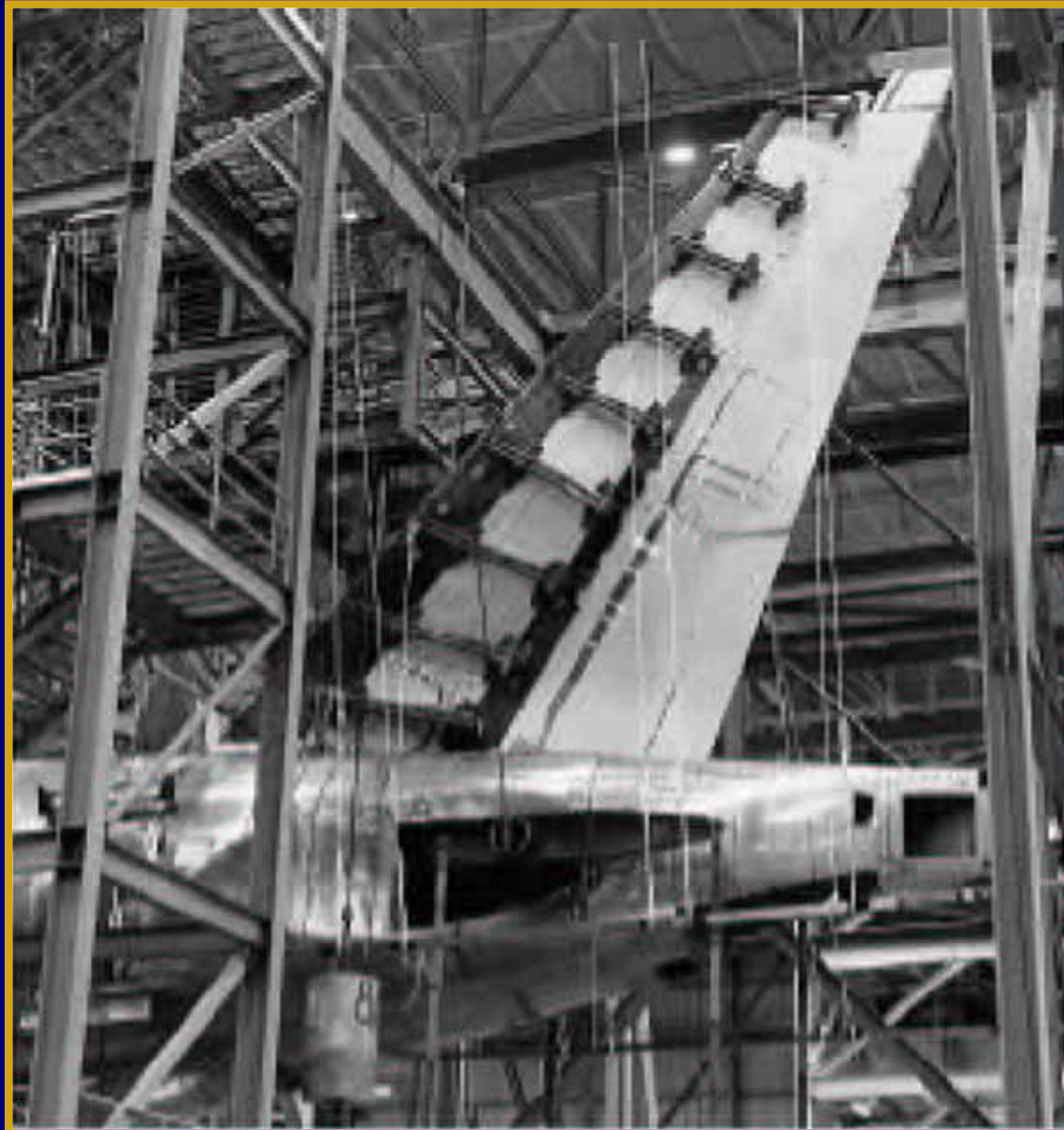
Horizontal Stabilizer Test, Predicted Versus Actual Strains



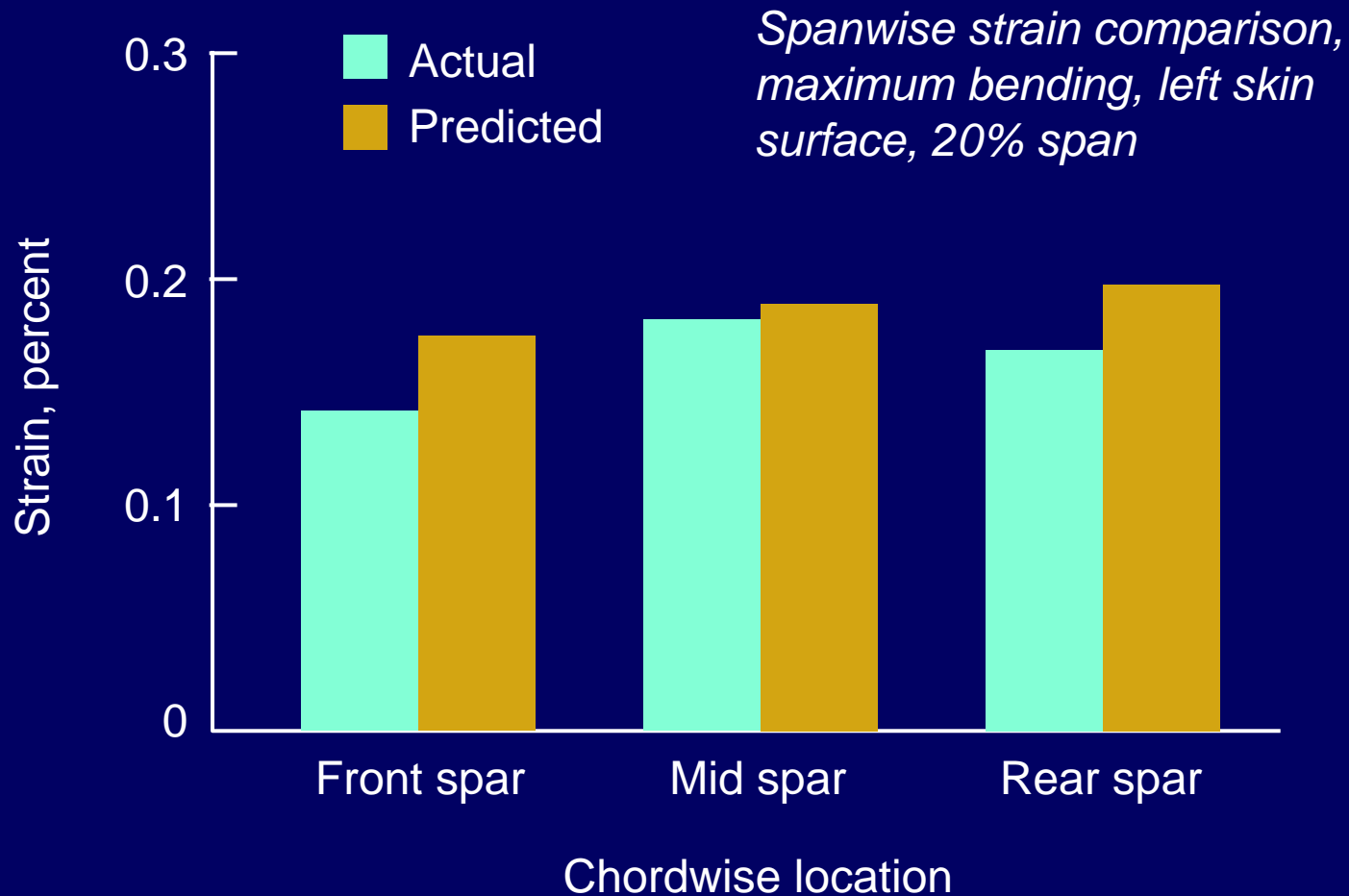
Horizontal Stabilizer Test, Predicted Versus Actual Deflection



Vertical Stabilizer Test Setup



Vertical Stabilizer Test, Predicted Versus Actual Strains



Summary

- Loads, design and analysis of structure must be validated per manufacturer and regulatory requirements.
- All requirements are satisfied by analysis and simulation and sufficient tests are run to validate the analysis of new structure.
- Considerable experience and judgment are required to determine the number and types of tests on a new or derivative program.
- Analytical structural models are validated on correlation with static test strain surveys and flight loads.
- Certification agencies, require that analytical predictions be corroborated by comparison with full scale test and/or flight test results.