

COMMERCIAL TRANSPORT AIRCRAFT

COMPOSITE STRUCTURES

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This presentation will take a look at the role that analysis plays in the development, production, and substantiation of aircraft structures; the types, elements, and applications of failure that are used and needed; the current application of analysis methods to commercial aircraft advanced composite structures, along with a projection of future needs; and some personal thoughts on analysis development goals and the elements of an approach to analysis development.

INTRODUCTION

ANALYSIS ROLE

ANALYSIS ELEMENTS

COMPONENT ANALYSIS

ANALYSIS DEVELOPMENT

SUMMARY

The analysis of structure is the only truly feasible means of substantiating the strength, fatigue life, and damage tolerance of a majority of commercial aircraft structures. This is true simply because only a minimum number of critical locations on the aircraft can be validated by full-scale testing. Test data at the coupon, detail, structural element, and subcomponent levels provide half of the information required to establish the critical margin of safety. The other half is obtained by structural analysis. Therefore, the confidence and credibility of the analysis tools used are very critical to the acceptance of analysis as the prime means of structural substantiation of commercial aircraft structure.

AREAS OF DISCUSSION

FAILURE ANALYSIS

FAILURE MECHANISMS

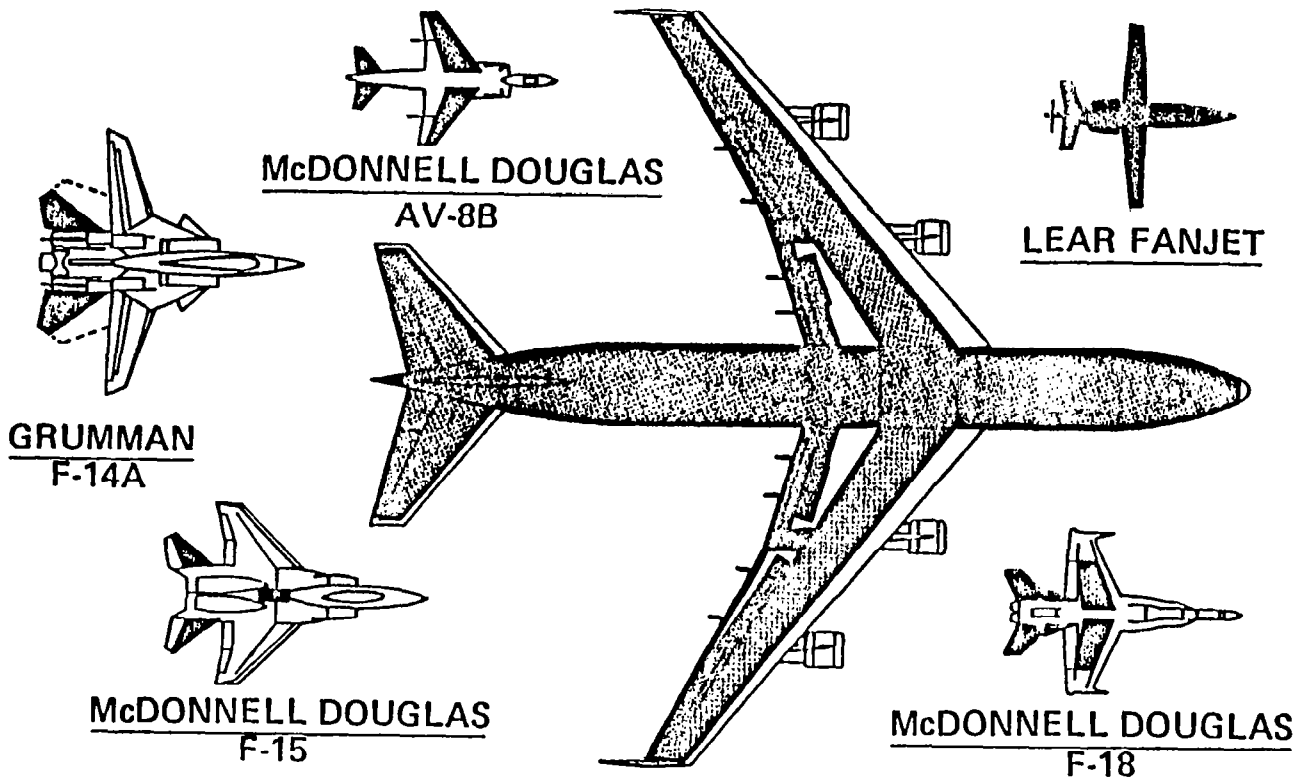
ANALYSIS ROLE FOR COMMERCIAL AIRCRAFT:

"THE PRIMARY MEANS OF STRUCTURAL SUBSTANTIATION FOR CERTIFICATION OF COMMERCIAL AIRCRAFT IS BY ANALYSIS. IT IS EXPECTED THAT THE ANALYSIS WILL BE SUPPORTED BY THE APPROPRIATE TEST EVIDENCE"

This figure dramatizes the idea of why the analysis is really the only means of fully substantiating the structure of large aircraft. This in no way implies that the same is not true for small aircraft. The large number of structural details that must be reviewed in producing any aircraft requires that all information required by both halves of the margins of safety equations be available.

Transport Aircraft Composite Structures

- Large primary structure composite development



The Federal Aviation Regulations (FAR 25) (ref. 1) established the requirements for structural certification of commercial aircraft. The list of numbered paragraphs shows those most pertinent to this discussion on advanced composite applications. In addition to the FAR 25, the FAA has issued an advisory circular for composite structure (ref. 2). The advisory circular provides guidance to both industry and the FAA as to the acceptable means of compliance with the FAR 25 for advanced composites.

CURRENT REGULATIONS
INVOLVED IN COMPOSITE
CERTIFICATION

MATERIAL AND PROCESS SPECIFICATIONS	{ 25.603 25.605	MATERIALS FABRICATION METHODS
MATERIAL PROPERTIES	{ 25.613 25.615 25.619	MATERIAL STRENGTH PROPERTIES AND DESIGN VALUES DESIGN PROPERTIES SPECIAL FACTORS
PROOF STRENGTH	{ 25.305 25.307	STRENGTH AND DEFORMATION PROOF OF STRUCTURE
DAMAGE TOLERANCE	25.571	FATIGUE EVALUATION OF FLIGHT STRUCTURE

ADVISORY CIRCULAR AC NO. 20-107 DATED 7/10/78
SUBJECT: COMPOSITE AIRCRAFT STRUCTURE

These lines selected from FAR 25 (ref. 1) and the advanced composite advisory circular (ref. 2) illustrate FAA's recognition of the major role that structural analysis plays in the substantiation of the strength and damage tolerance of a commercial aircraft structure. Both the regulations and the guidelines recognize the relationship of the types of material, experience with material, and structural configuration and concepts, as well as the supportive contribution of test data.

FAR 25 & ANALYSIS

FAR 25.307... "STRUCTURAL ANALYSIS MAY BE USED ONLY IF THE STRUCTURE CONFORMS TO THOSE FOR WHICH EXPERIENCE HAS SHOWN THIS METHOD TO BE RELIABLE..."

FAR 25.571(b) DAMAGE-TOLERANCE (FAIL-SAFE) EVALUATION... "THE DETERMINATION MUST BE BY ANALYSIS SUPPORTED BY TEST EVIDENCE AND (IF AVAILABLE) SERVICE EXPERIENCE..."

ADVISORY CIRCULAR & ANALYSIS

AC NO. 20-107

3b... "THE EXTENT OF TESTING AND/OR ANALYSIS AND THE DEGREE OF ENVIRONMENTAL ACCOUNTABILITY REQUIRED WILL DIFFER FOR EACH STRUCTURE DEPENDING UPON THE EXPECTED SERVICE USAGE, THE MATERIAL SELECTED, THE DESIGN MARGINS, THE DATA BASE AND EXPERIENCE WITH SIMILAR STRUCTURE AND ON OTHER FACTORS AFFECTING A PARTICULAR STRUCTURE."

5... "THE STATIC STRENGTH OF COMPOSITE DESIGN SHOULD BE DEMONSTRATED THROUGH A PROGRAM OF COMPONENT ULTIMATE LOAD TESTS IN THE APPROPRIATE ENVIRONMENT, UNLESS EXPERIENCE WITH SIMILAR DESIGNS, MATERIAL SYSTEMS AND LOADINGS IS AVAILABLE TO DEMONSTRATE THE ADEQUACY OF THE ANALYSIS SUPPORTED BY SUBCOMPONENT TEST."

This particular statement should be of interest to the workshop attendees since several of the presentations relate to the idea of material system allowables.

ADVISORY CIRCULAR & ANALYSIS

4b. "THE MATERIAL SYSTEM ALLOWABLES SHOULD BE ESTABLISHED ON THE LAMINATE LEVEL BY EITHER TEST OF THE LAMINATE OR BY TEST OF THE LAMINA IN CONJUNCTION WITH A TEST VALIDATED ANALYTICAL METHOD"

An understanding of which analysis tools relate to commercial aircraft safety and which to lifecycle economics is required to form a proper perspective of the analysis substantiation requirements. This chart attempts to provide a view of this idea. The confidence required for safety is attained by conservative application of simple analysis methods supported by extensive testing, or realistic application of a variety of analysis tools of varying sophistication supported by appropriate levels of test evidence.

DESIGN/ANALYSIS AND CERTIFICATION ELEMENTS

SAFETY	}	STATIC STRENGTH	EXTERNAL LOADS ANALYSIS <u>MAT'L & STR. ALLOWABLES</u> <u>FAILURE CRITERIA & ANALYSIS</u>
		DAMAGE TOLERANCE	<u>FLAW GROWTH ANALYSIS</u> <u>RESIDUAL STRENGTH ANALYSIS</u> INSPECTION REQUIREMENTS
		FLUTTER MARGIN	STIFFNESS REQUIREMENTS FLUTTER ANALYSIS
ECONOMICS	}	MAINTENANCE COST	<u>DURABILITY - FATIGUE ANALYSIS</u> INSPECTION COST REPAIR COST
		PRODUCTION COST	MAT'L COST DESIGNED-IN COST MANUFACTURING METHODS & COST INSPECTION METHODS & COST

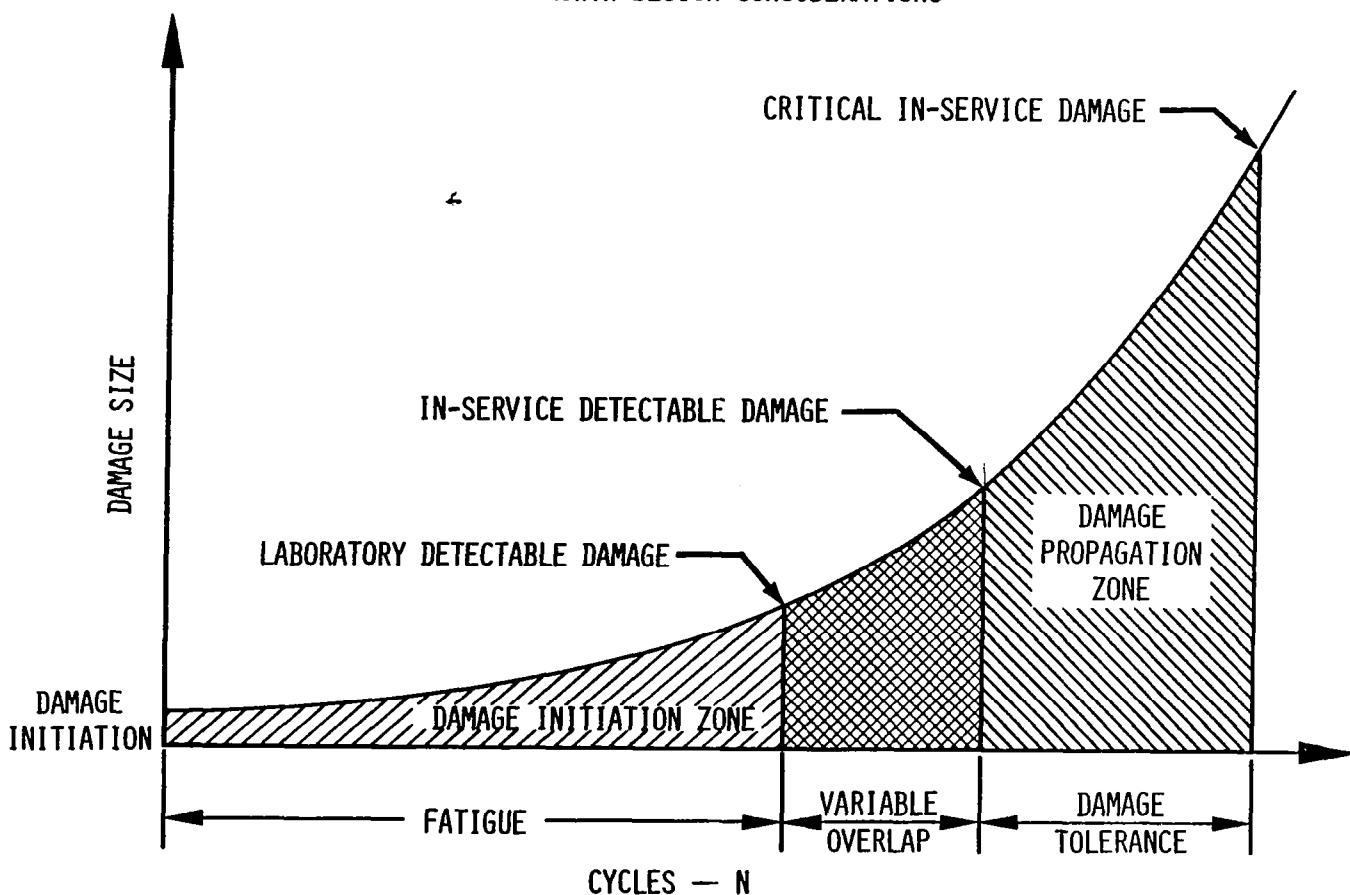
To better describe the requirements of damage-tolerant concepts, two charts are presented with the following statements. (1) The anticipated damage that may arise from normal aircraft operations can include fatigue damage, manufacturing and/or maintenance flaws, or errors in undetected accidental damage. (2) The damage tolerance design structure must also provide a very substantial means of protecting against accidental damage sustained in flight as a result of such things as engine breakup, hail, and bird or other types of impact damage. In these particular cases it is expected that the damage will be found upon completion of the flight.

DAMAGE TOLERANCE

"THE STRUCTURE MUST BE DESIGNED IN SUCH A WAY THAT ANY DAMAGE INCURRED FROM NORMAL OPERATION IS DETECTABLE BEFORE THE STRENGTH OR STIFFNESS OF THE STRUCTURE FALLS TO AN UNACCEPTABLE LEVEL."

In order to establish for this discussion the separation of the fatigue aspect of analysis from that of damage tolerance analysis, this chart gives a graphical representation of this separation. Simply stated, damage-tolerant considerations must include the idea of damage detectability. Therefore, the idea acts to provide a real design and application separation. Once detectable, the time to grow to critical is the area needing the damage tolerance growth analysis.

DISCIPLINED ANALYSIS APPROACH TO DURABILITY/DAMAGE
GROWTH DESIGN CONSIDERATIONS



This chart presents a breakdown by category of some of the detailed aspects of the requirements of damage tolerance analysis. Categories 2 and 3 are the analysis areas of concern in this discussion. However, Category 1 was the means of meeting the damage tolerance requirements for the Boeing 727 advanced composite elevator.

DAMAGE TOLERANCE ANALYSIS REQUIREMENTS

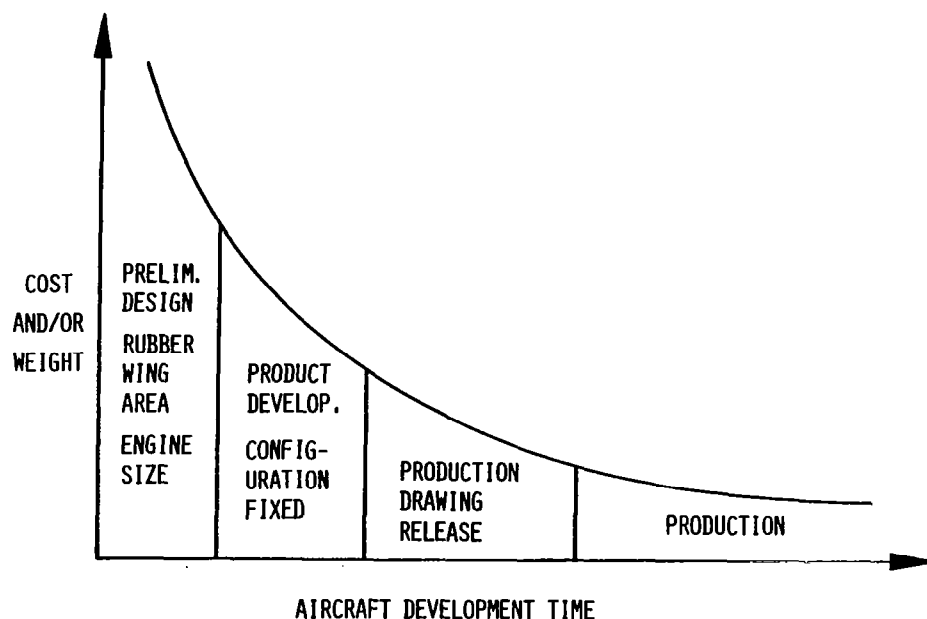
STRUCTURAL CATEGORY		TECHNIQUE OF ASSURING SAFETY	TECHNOLOGY CONTROL METHOD
SECONDARY STRUCTURE	① SECONDARY STRUCTURE	DESIGN FOR LOSS OF COMPONENT OR SAFE SEPARATION	<ul style="list-style-type: none"> ● CONTINUED SAFE FLIGHT
PRIMARY STRUCTURE	DAMAGE TOLERANCE DESIGN	② DAMAGE OBVIOUS OR MALFUNCTION EVIDENT	<ul style="list-style-type: none"> ● RESIDUAL STRENGTH
	③ DAMAGE DETECTION BY PLANNED INSPECTION PROGRAM	INSPECTION PROGRAM MATCHED TO STRUCTURAL CHARACTERISTICS	<ul style="list-style-type: none"> ● RESIDUAL STRENGTH ● CRACK GROWTH ● INSPECTION PROGRAM
	SAFE-LIFE DESIGN	④ SAFE-LIFE	CONSERVATIVE FATIGUE LIFE

The ability to configure a new aircraft is based on the state of the art of the available analysis tools. The structure configuration, structural concept, and material selection are all evaluated analytically. The payoff of this analytical effort is the future successful production and operation of new aircraft. The ability to change and improve the aircraft is reduced with this advancement through the development, production, and operational cycle. The state of the art and the ease of application of the analysis of tools applied early in the design cycle are significant factors in developing a successful aircraft.

DESIGN/ANALYSIS ROLE IN STRUCTURAL AIRFRAME DEVELOPMENT

- RESEARCH & DEVELOPMENT
 - IDENTIFY NEW STRUCTURAL PAYOFFS
 - EVALUATE MATERIALS & STRUCTURAL CONCEPTS
 - GUIDE THE TEST PLANNING & DATA ANALYSIS
- PRELIMINARY DESIGN & PRODUCT DEVELOPMENT
 - TRADES - WEIGHT & COST
 - CONFIGURATION & CONCEPTS
- AIRCRAFT PROGRAM
 - STRUCTURAL SIZING
 - DRAWING RELEASE
 - FORMAL ANALYSIS - FOR CERTIFICATION
 - MARGINS OF SAFETY
 - TEST/ANALYSIS CORRELATION

ANALYSIS SUPPORTED DECISION EFFECT ON COST AND/OR WEIGHT



An element in utilizing any analytical capability is the fact that in a large design program there must be a discipline to the tools used. Each company publishes design manuals, stress manuals, and analysis programs in various forms to ensure some uniformity in analysis procedures. The key then is the disciplined procedures that provide the benefits shown on this chart.

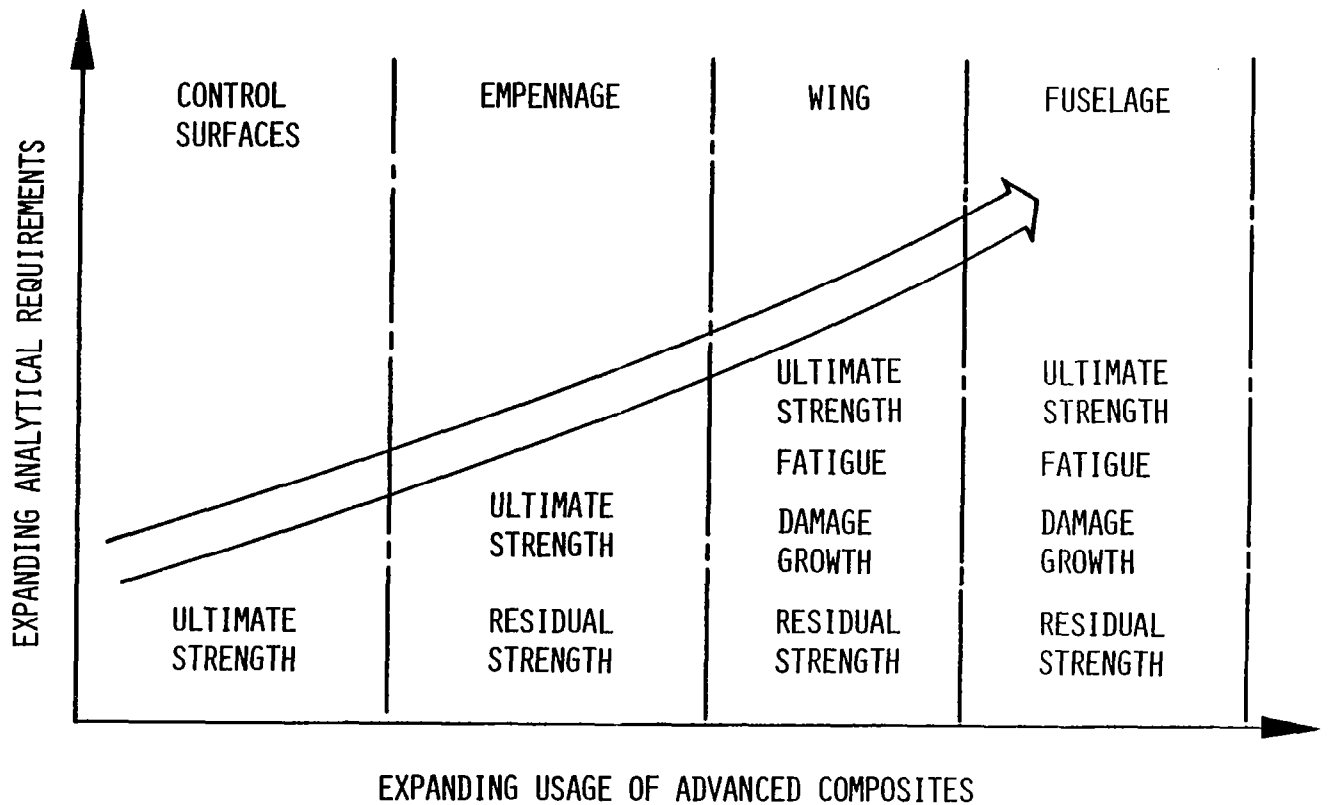
ANALYSIS SUPPORT OF AIRCRAFT PROGRAMS

KEY - DISCIPLINED PROCEDURES

PROVIDES ACCEPTABLE TOOLS AT ALL LEVELS
USABLE BY LARGE NUMBERS OF NON-SPECIALISTS
CAUSES ATTENTION TO BE FOCUSED ON CRITICAL PARAMETERS
PROVIDES COMMON QUANTIFIABLE BASE FOR DECISION MAKING
CORRELATES FLEET AND TEST EXPERIENCE
ESTABLISHES BASE FOR AIRFRAME SUSTAINING

This list will be familiar to all those in the structures technical community. The application of analysis of tools in each of these levels of structural significance will be discussed. These analysis classifications have been separated for discussion purposes into the areas of requirements analysis and capability analysis. The idea is that the structure is required to perform a set of structural functions or requirements, and the structure has been designed to provide a level of capability to meet those performance requirements.

ANALYSIS PROCEDURE NEEDS



A collection of analytical tools across all the analysis disciplines (strength, fatigue, and damage tolerance) provides a means of quantifying the structures capability margin (margins of safety) in each area. This and the following charts are aimed to illustrate the disciplined approach in production analysis of structures.

DESIGNED & REQUIRED STRUCTURAL PERFORMANCE

PERFORMANCE EVALUATION:

$$\text{MARGIN OF SAFETY} = \frac{\text{CAPABILITY OF STRUCTURE}}{\text{STRUCTURAL REQUIREMENTS}} - 1 = \underline{\quad}\%$$

A discipline analysis procedure can be used not only to establish the margins of safety but also as a means of quantifying structural performance against weight and cost. The analytical tools should end up clearly defining both the requirements of the structure and the capability of the structure being designed.

**COMMON APPROACH TO STATIC, FATIGUE, DAMAGE GROWTH
AND RESIDUAL STRENGTH DESIGN**

ANALYSIS	ULTIMATE STRENGTH	FATIGUE STRENGTH	DAMAGE GROWTH	RESIDUAL STRENGTH
REQUIREMENT	f_{tu}	$FQ_{REQUIRED}$	$DTR_{REQUIRED}$	f_{RS}
CAPABILITY	F_{tu}	FQ_{DETAIL}	DTR_{DETAIL}	F_{RS}
MARGIN	$\frac{F_{tu}}{f_{tu}} - 1$	$\frac{FQ_{DETAIL}}{FQ_{REQUIRED}} - 1$	$\frac{DTR_{DETAIL}}{DTR_{REQUIRED}} - 1$	$\frac{F_{RS}}{f_{RS}} - 1$

The idea of an analysis model being part of the requirements analysis does not imply a single model, but refers rather to all the analysis tools required to establish the requirements half of the margins of safety equation. The analysis model for structure can include the following: finite element, interlaminar stresses, laminate stress analysis at the detailed stress analysis level, fatigue damage model, damage growth model, and fracture mechanics analysis.

ANALYSIS PROCEDURE

REQUIREMENTS ANALYSIS	ULTIMATE STRENGTH	FATIGUE DURABILITY	FLAW GROWTH	RESIDUAL STRENGTH
● AIRCRAFT	FLIGHT ENVELOPE	SERVICE LIFE	INSPECTION INTERVALS	FLAW DETECTABILITY
● LOADING	STATIC 1.5 x LIMIT	REPEATED SPECTRUM	REPEATED SPECTRUM	STATIC LIMIT
● ENVIRONMENT	MAX CRITICAL	NORMAL USAGE	NORMAL USAGE	MAX. CRITICAL
● ANALYSIS MODEL	MAX STRAIN (ETC.)	ACCUMULATIVE DAMAGE	FLAW GROWTH	STRESS INTENSITY (ETC)
● REQUIRED CAPABILITY	CRITICAL STRAIN	MAX CYCLIC STRAIN	GROWTH INTERVAL REG.	CRITICAL FLAW SIZE

The capabilities analysis recognizes that the structural form, the type of applied load, the material used, and the expected failure mechanism or mechanisms must be part of any evaluation. The material properties can be as simple as test data to develop the properties, i.e., tension, compression, or shear, or they can be established by analysis procedures, such as in a simple column analysis. Because of the intrinsic variability of material properties, a reliability analysis of the test data must be part of any procedure. These forms of capability analysis and the requirement analysis are only an example.

ANALYSIS PROCEDURE

CAPABILITY ANALYSIS	ULTIMATE STRENGTH	FATIGUE DURABILITY	FLAW GROWTH	RESIDUAL STRENGTH
● GROSS CONFIGURATION	————— TYPE OF STRUCTURE —————			
● DETAIL CONFIGURATION	————— TYPE OF STRUCTURAL ELEMENT —————			
● MATERIAL PROPERTIES	STATIC ALLOWABLE	FATIGUE DATA	FLAW GROWTH DATA	FRACTURE TOUGHNESS
— RELIABILITY 1	●	●	●	●
— ENVIRONMENT 2 FACTORS	●	●	●	●
● DETAIL CAPABILITY	ALLOWABLE STRAIN	MAX FATIGUE STRAIN	$\frac{dA}{dN}$ RATE	K_I ALLOWABLE

1 25.613 (a) & (b) (ref. 1)

2 25.613 (c) (ref. 1)

This section of the discussion will look at where we are in the development cycle of commercial aircraft advanced composite structure. I will try to express two ideas: (1) the application of the appropriate analysis tools to the component and recognition of the background that has been established to date, and (2) a projection of future needs.

COMMERCIAL AIRCRAFT DEVELOPMENT OF COMPOSITE STRUCTURE

CURRENT

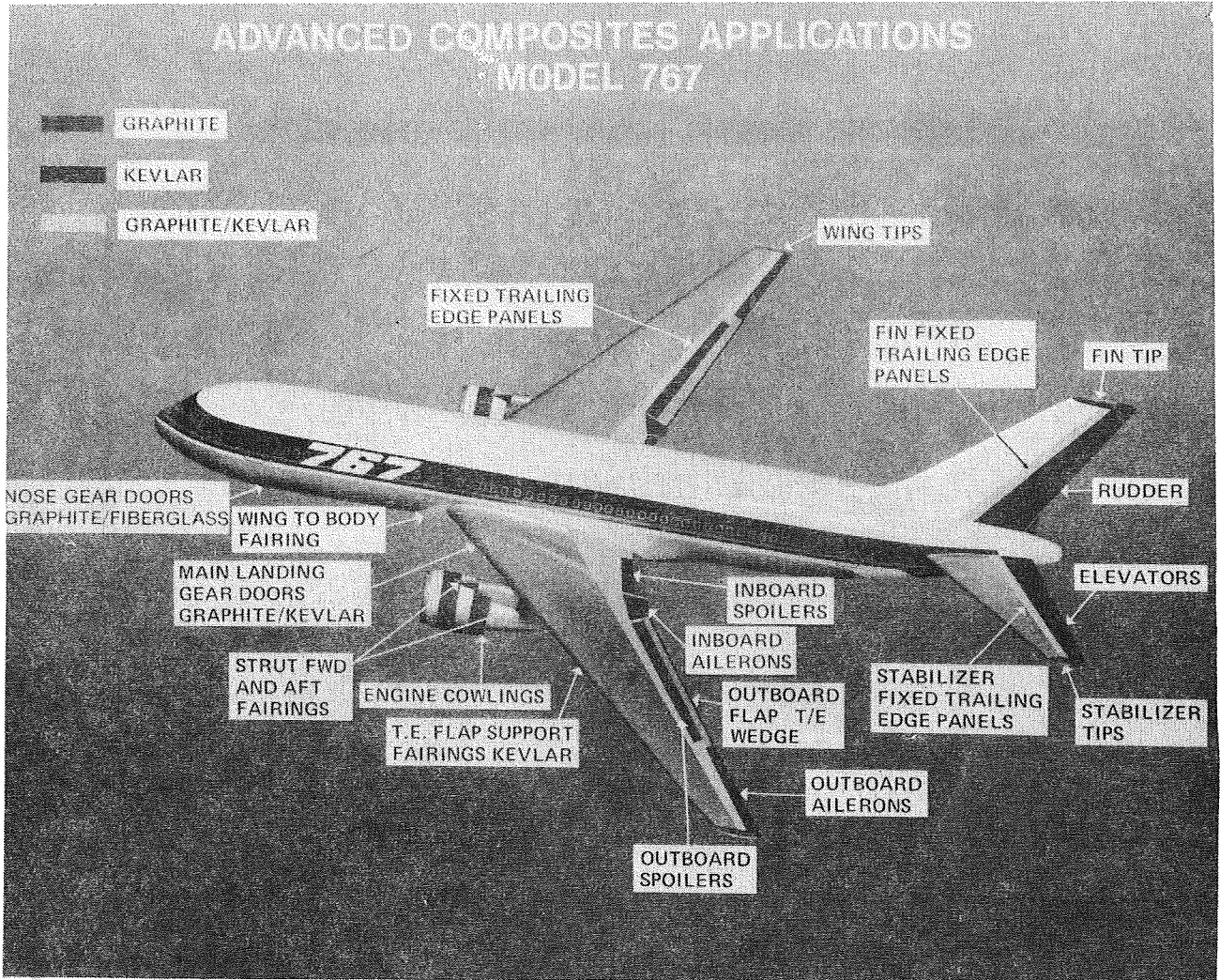
- CONTROL SURFACES
- EMPENNAGES

FUTURE

WINGS

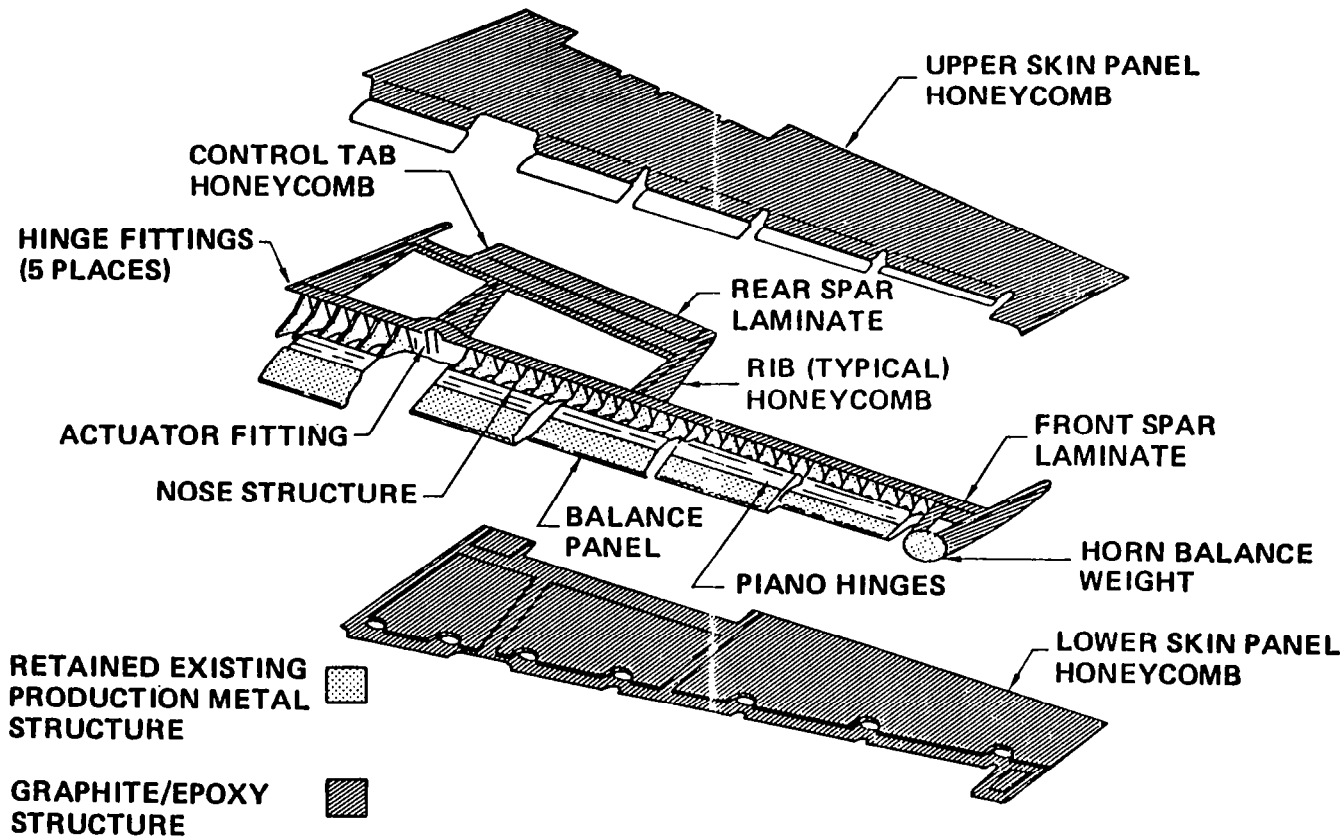
BODY

This figure is shown here to establish the current production status of advanced composites on commercial aircraft. The primary control surfaces, of graphite/epoxy, have been designed and certified using analysis tools available to date. An example of the level of this analysis is illustrated in the discussion that follows on the 727 advanced composite elevator.



The 727 elevator, which is illustrated in the figure, shows an upper and lower skin of honeycomb design consisting of one ply of cloth at $\pm 45^\circ$ and a chordwise 0° tape direction. The spars are laminate with $\pm 45^\circ$ dominant webs and with 0° dominant in the chords. The few ribs noted are primarily $\pm 45^\circ$ with some 0° in the chords and honeycomb webs. This design has been fully certified by the FAA.

Elevator Structural Arrangement



The following lists of analysis considerations are to direct attention not to the detailed analysis but to those facts that were considered in the interplay between this structure and current analysis capability or the analysis capability available at the time of the development and certification of the 727 elevator. The analysis used was just at the level required to meet those certification and design requirements. Since, as noted on the chart, only ultimate strength certification requirements were needed, this is all that is addressed by the analysis tools available.

727 ELEVATOR - ANALYSIS CONSIDERATIONS

DESIGN CRITERIA

SIMILAR STIFFNESS TO ALUMINUM ELEVATOR

DAMAGE TOLERANCE CATEGORY #1

TEMPERATURE RANGE -75°F TO 180°F

MOISTURE CONTENT 1% ± .1% BY WEIGHT

RESULTS OF CRITERIA ON DESIGN

LOW ULTIMATE DESIGN STRAIN

NO FATIGUE CONSIDERATIONS

NO DAMAGE TOLERANCE REQUIREMENTS

CERTIFICATION CONSIDERATIONS

1ST OF A TYPE MUST TEST TO ULTIMATE

WITH ACCOUNTABILITY FOR MOISTURE & TEMPERATURE

ULTIMATE STRENGTH ONLY

The tools used in the analysis of the 727 elevator were those that have been used in the past on some large control surfaces, i.e., on the Boeing 747. Most Boeing control surfaces are currently analyzed by hand. The 727, being the first generic of its type at Boeing, incorporated the use of the finite element method. The Boeing 767 control surfaces were primarily analyzed by hand. For the reasons noted, other than the first generic, the finite element method was used on this 727 elevator. The other analysis concerned the stability and the ultimate strength of both the surface panels and the web of the front spar. Simplified analysis was used to adequately establish the buckling capability of these honeycomb panels. The ultimate strains were simply the strains associated with the maximum strain in the most critical direction compared to point design allowables of the specific layup developed by test.

727 ELEVATOR ANALYSIS REQUIREMENTS

FINITE ELEMENT ANALYSIS

- NO RIBS BACKING UP HINGE FITTINGS
- METHOD OF ACCOUNTING FOR MOISTURE/TEMPERATURE
- CHECK STIFFNESS SIMILARITY

DETAIL ELEMENT ANALYSIS (STRENGTH CHECK)

SURFACE PANELS

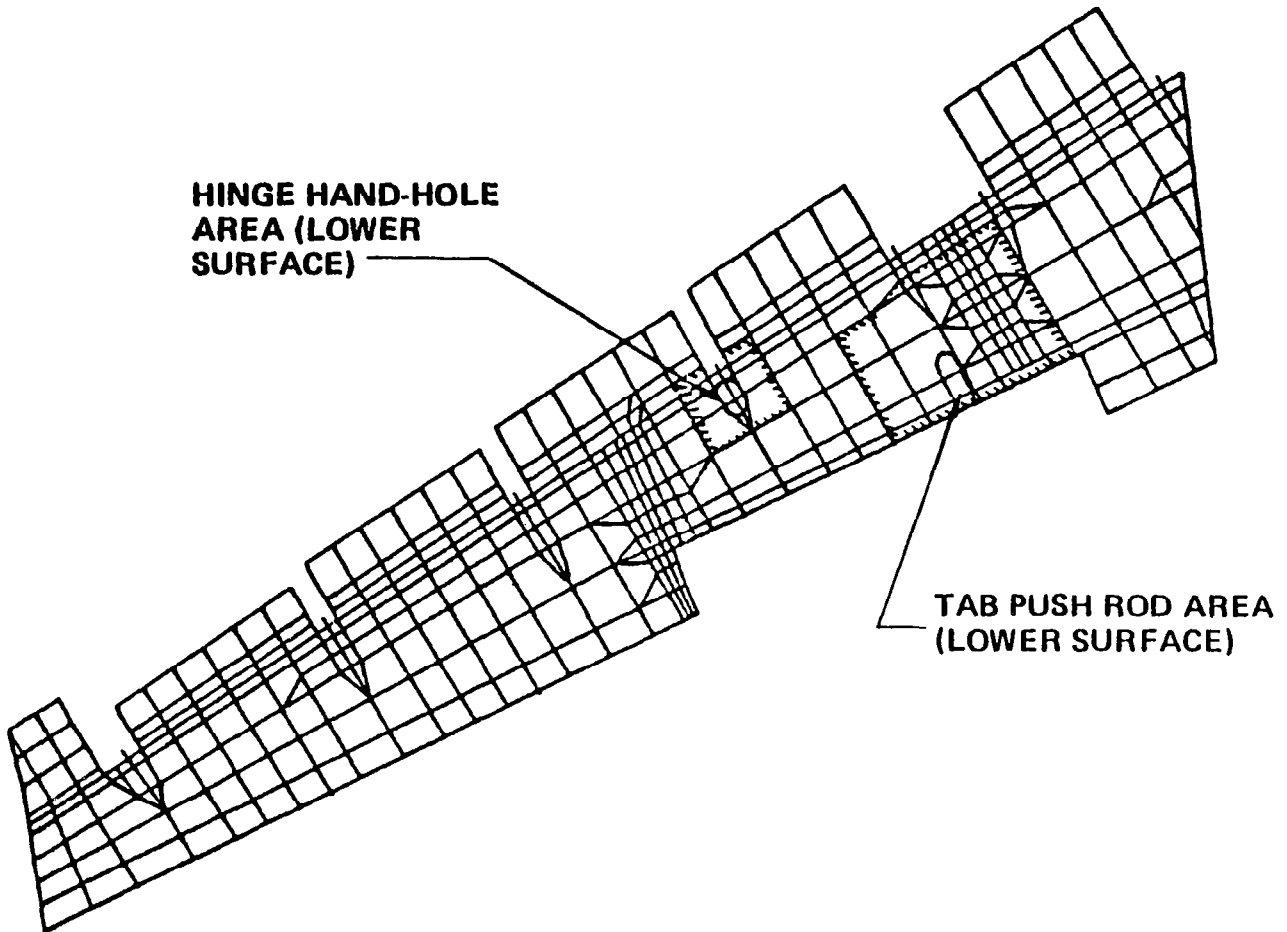
- STABILITY - MODIFIED ALUMINUM METHOD
- ULTIMATE STRAIN - MAX. PRINCIPAL

FRONT SPAR

- WEB SHEAR STABILITY - MODIFIED AL. METHOD
- ULTIMATE STRAIN IN SHEAR
- CHORD STRAINS - ULTIMATE STRAINS T & C
- JOINT STRENGTH BEARING, TENSION

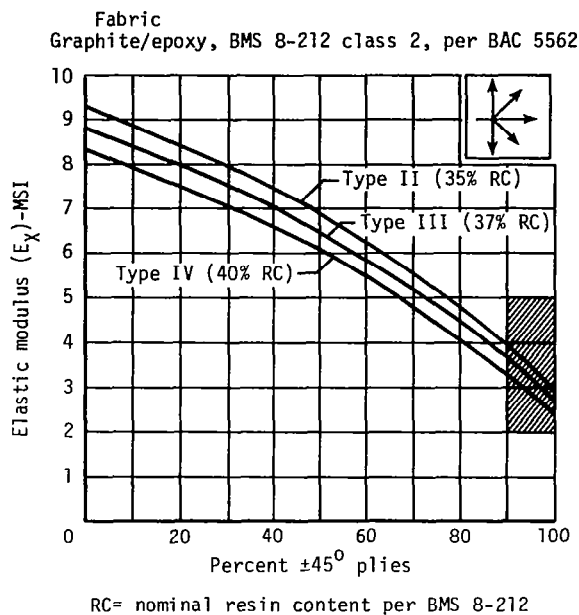
This figure simply illustrates the finite element model used. Note the grid refinement aft of the hinge locations. The extra attention in this area was due to the fact that this was the first Boeing design that did not use a backup rib at each hinge location. The local load redistribution from the hinges was of particular interest.

Elevator Finite Element Model

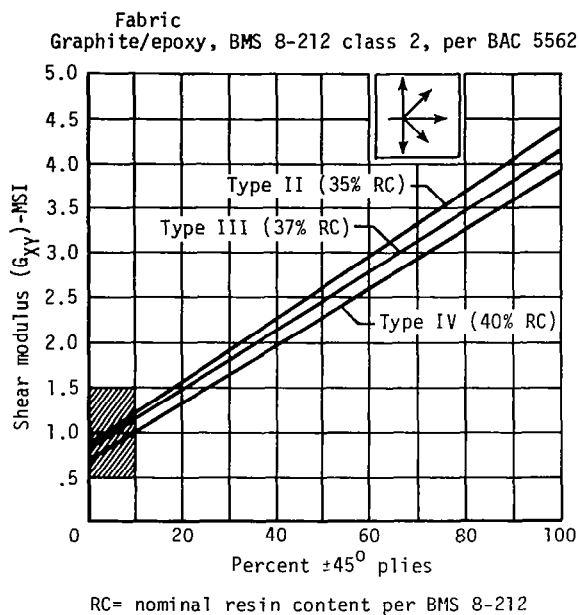


This figure and the next one illustrate the simplicity of the data available for basic analysis. These strain cutoffs and modulus charts, along with some bearing allowables and the laminate testing that was part of the ancillary test program of the 727 elevator, are all that was provided for both the preliminary design as well as the formal analysis.

ELASTIC MODULUS AND ALLOWABLE STRAINS



IN-PLANE SHEAR MODULUS AND ALLOWABLE STRAINS



Limit and ultimate strain (in/in)	Limit strain	Ultimate strain	
		"A" basis	"B" basis
Laminate tension ϵ_t	.0035	.0059	.0064
Laminate compression ϵ_c	.0027	.0054	.0059
Sandwich tension ϵ_t	①	.0043	.0046
Sandwich compression ϵ_c	①	.0035	.0038

① Ultimate strain = 1.5

Caution: Properties in the cross-hatched region may be adversely affected by temperature and humidity

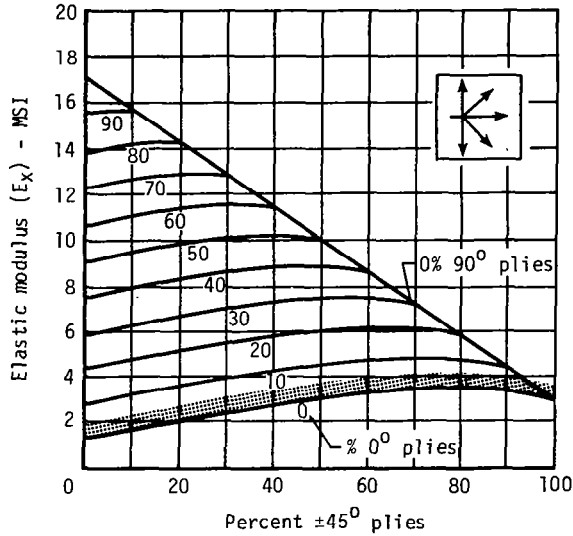
Limit and ultimate strain (in/in)	Limit strain	Ultimate strain	
		"A" basis	"B" basis
Laminate shear ϵ_{xy}	.0053	.0108	.0117
Sandwich shear ϵ_{xy}	①	.0070	.0076

① Ultimate strain = 1.5

Caution: Properties in the cross-hatched region may be adversely affected by temperature and humidity.

ELASTIC MODULUS AND ALLOWABLE STRAINS

Tape
Graphite/epoxy, BMS 8-212 Type III Class 1, per BAC 5562

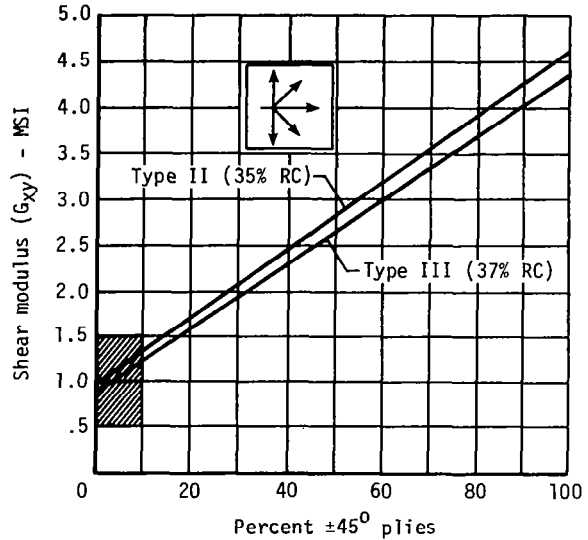


Limit & ultimate strain (in/in)	Ultimate strain		
	Limit strain	"A" basis	"B" basis
Tension ϵ_t	.0035	.0082	.0090
Compression ϵ_c	.0027	.0067	.0072

Caution: Properties in the cross-hatched region may be adversely affected by temperature and humidity.

IN-PLANE SHEAR MODULUS AND ALLOWABLE STRAINS

Tape
Graphite/epoxy, BMS 8-212 Class 1, per BAC 5562



RC-nominal resin content per BMS 8-212

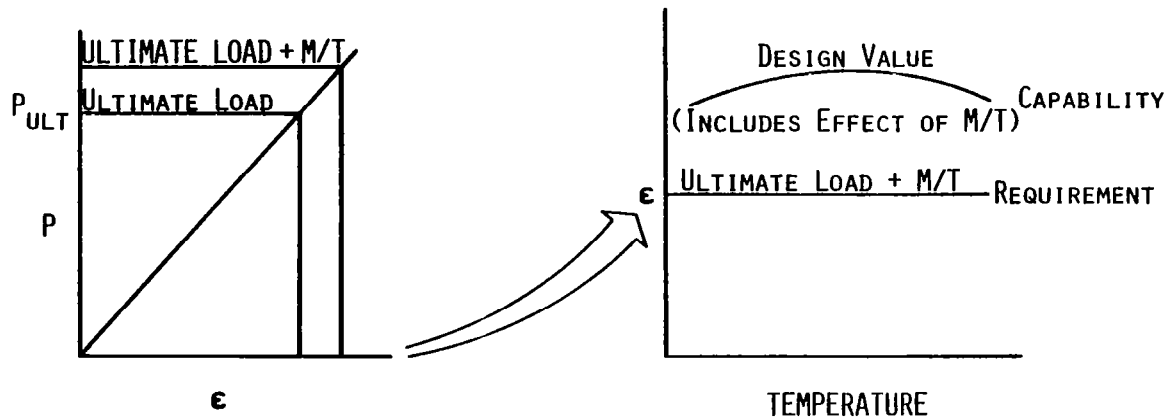
Limit & ultimate strain (in/in)	Ultimate strain		
	Limit strain	"A" basis	"B" basis
Shear ϵ_{xy}	.0053	.0133	.0144

Caution: Properties in the cross-hatched region may be adversely affected by temperature and humidity.

One of the unique considerations of the analysis model was the use of the characteristics of the material, the finite element analysis, and the validation by full-scale ultimate load test of the strain distribution to establish a means of analytically accounting for the effects of moisture and temperature in the ultimate load test results. Since material acts in a linear manner and the response to both load-induced strains and moisture- and temperature-induced strains is also linear in response in fiber-dominated structure, the two can algebraically be added to establish accurate strain in the material at all locations by analysis. The distribution for the loads analysis is verified by the full-scale test. By comparing this analysis strain level to those established by laminate level testing, a margin of safety can be adequately described.

**727 ELEVATOR ANALYSIS CONSIDERATION
ULTIMATE LOAD TEST MOISTURE AND TEMPERATURE ACCOUNTABILITY**

- MATERIAL RESPONSE
- FINITE ELEMENT ANALYSIS
- STRAIN DISTRIBUTION VALIDATION
- LINEAR STRAIN RESPONSE
- FIBER DOMINATED AND MAJOR LOAD PATH DESIGN



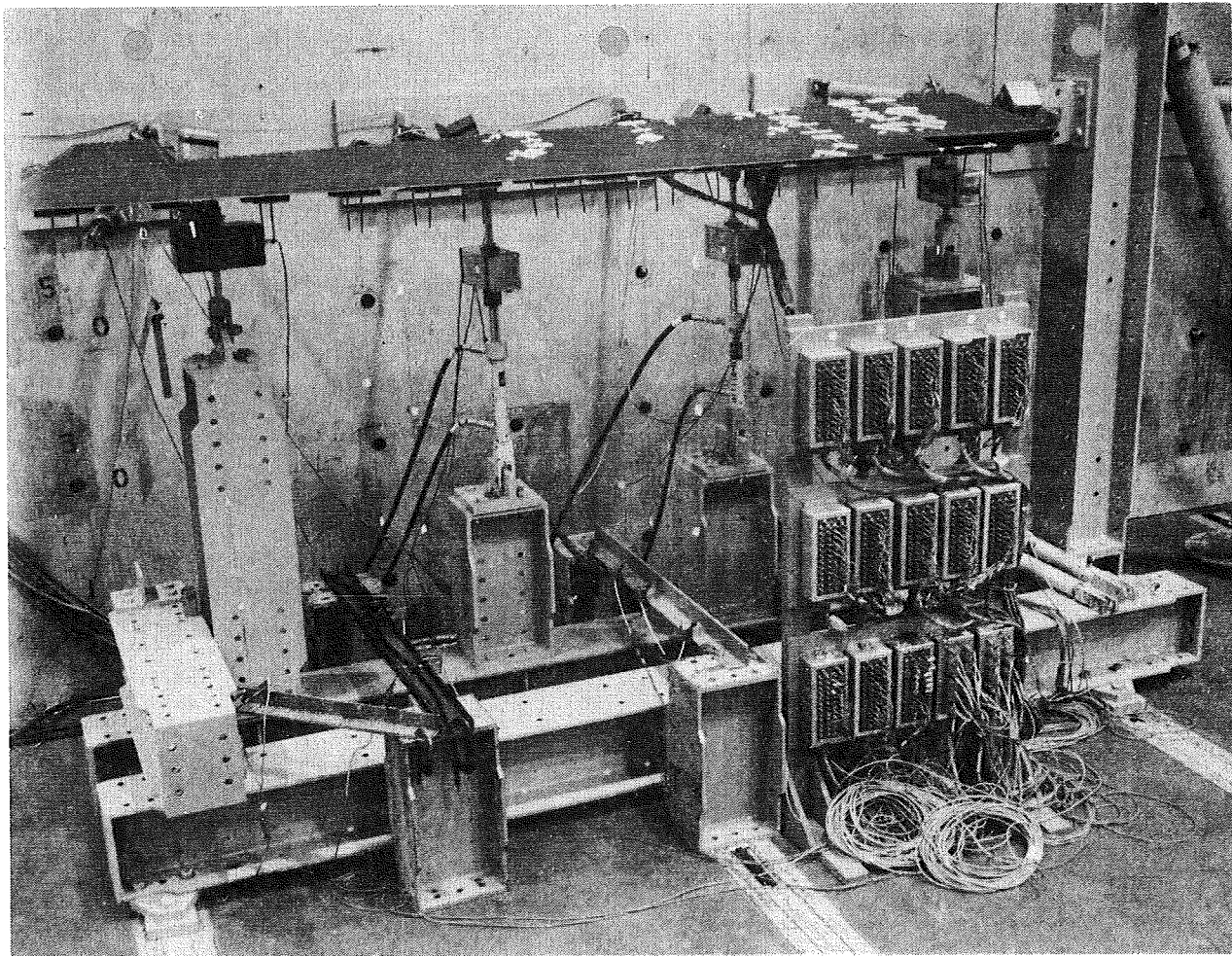
This table illustrates the result of including the effects of moisture and temperature in the requirements part of the margin of safety calculation.

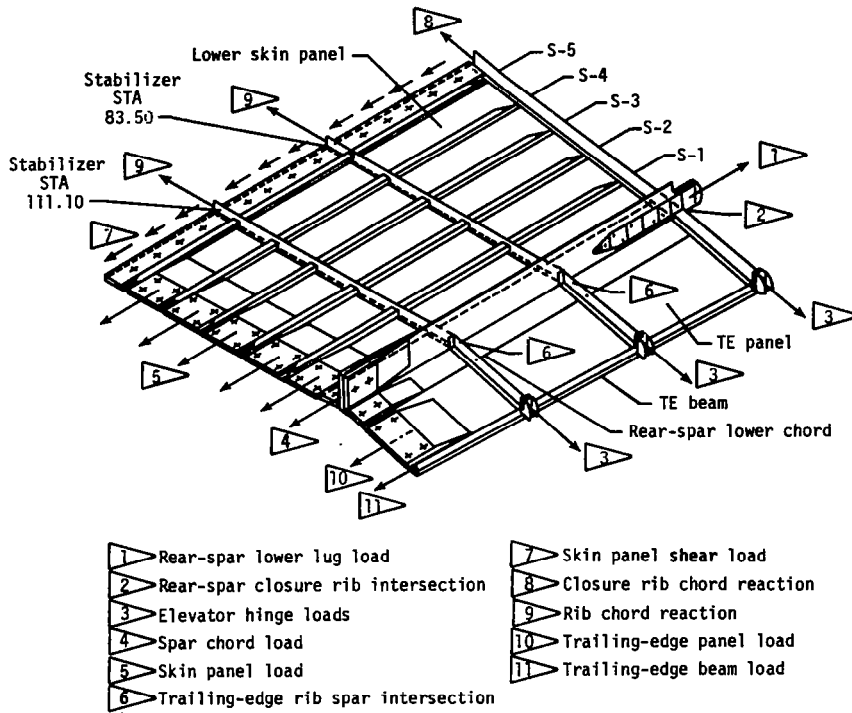
PRINCIPAL STRAINS, ALLOWABLES, AND MARGINS OF SAFETY - ATLAS PANEL 1135, LOAD CASE 125

PANEL SURFACE	ENVIRONMENTAL CONDITION	PRINCIPAL STRAINS*			ALLOWABLE PRINC. STRAINS*			MARGINS OF SAFETY		
		ϵ_{MAX}	ϵ_{MIN}	γ_{MAX}	ϵ_{MAX}	ϵ_{MIN}	γ_{MAX}	ϵ_{MAX}	ϵ_{MIN}	γ_{MAX}
EXTERIOR	70° DRY	1989	-2404	4393	5310	-4930	8499	1.67	1.05	.93
	70° WET	1545	-2294	3840	4260	-4410	6690	1.76	.92	.74
	-75° DRY	1754	-2073	3826	7060	-5670	8156	3.03	1.74	1.13
	-75° WET	1463	-2116	3579	5850	-5790	6422	3.00	1.74	.79
	140° DRY	2406	-2833	5239	4450	-4600	8800	.85	.62	.68
	140° WET	1938	-2700	4638	3600	-3900	6755	.86	.44	.46
	180° DRY	2693	-3127	5821	3980	-4400	8608	.48	.41	.48
	180° WET	2221	-2990	5211	3260	-3650	6770	.47	.22	.30
INTERIOR	70° DRY	1502	-1629	3132	4930	-5310	8499	2.28	2.26	1.71
	70° WET	1006	-1451	2456	4410	-4260	6690	3.38	1.94	1.72
	-75° DRY	560	-1098	1657	5670	-7060	8156	9.13	5.43	3.92
	-75° WET	327	-1183	1509	5790	-5850	6422	16.71	3.95	3.26
	140° DRY	2185	-2087	4273	4600	-4450	8800	1.11	1.13	1.06
	140° WET	1679	-1898	3577	3900	-3600	6755	1.32	.90	.89
	180° DRY	2591	-2364	4956	4400	-3980	8608	.70	.68	.74
	180° WET	2084	-2175	4259	3650	-3260	6770	.75	.50	.59

* MICROSTRAIN

The following figures represent two of the test articles that were used (1) to demonstrate the analysis of the structure for the load strains and for the thermal and moisture strains and (2) to show that the analysis gave good correlation in fiber-dominated structure. The results of these two tests are illustrated on the three graphs. In addition to the 727 and the 737 tests, I have shown the similar compatibility of the linear strain effect previously discussed. These tests, along with the test data at the coupon structural element and subcomponent levels, which included the effects of moisture and temperature, formed the basis both for demonstrating the requirements of capability analysis validity and for providing the capability data to form the margins of safety used in the certification of both the 727 and 737 advanced composite components.

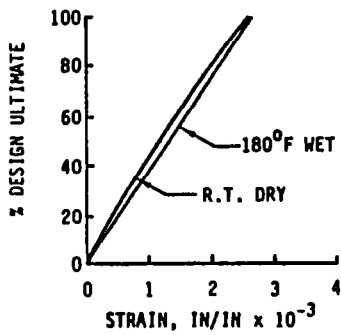




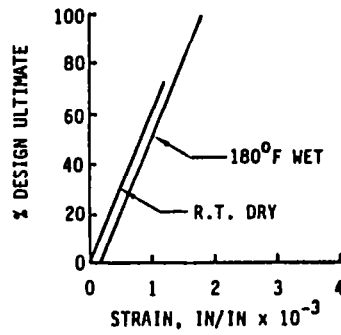
Stabilizer rear-spar lower chord and skin panel environmental test panel (test 33)

737 HORIZONTAL STABILIZER

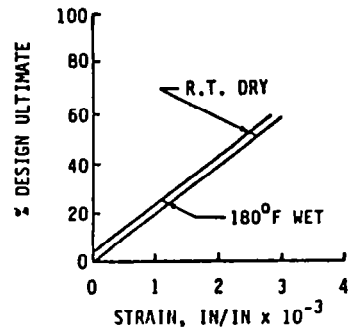
FAA ENVIRONMENTAL PANELS COMPARATIVE TEST RESULTS



727



737



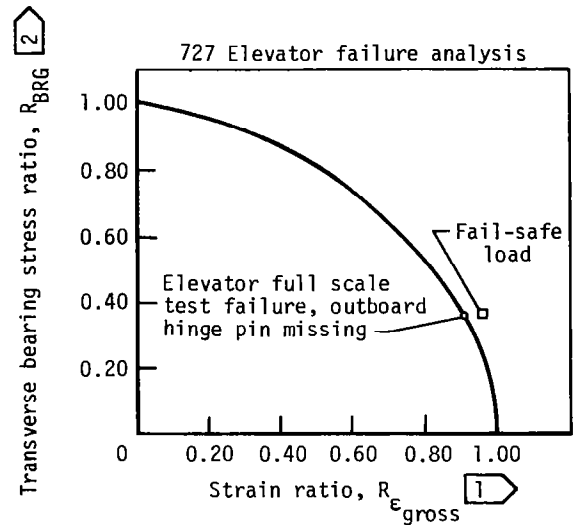
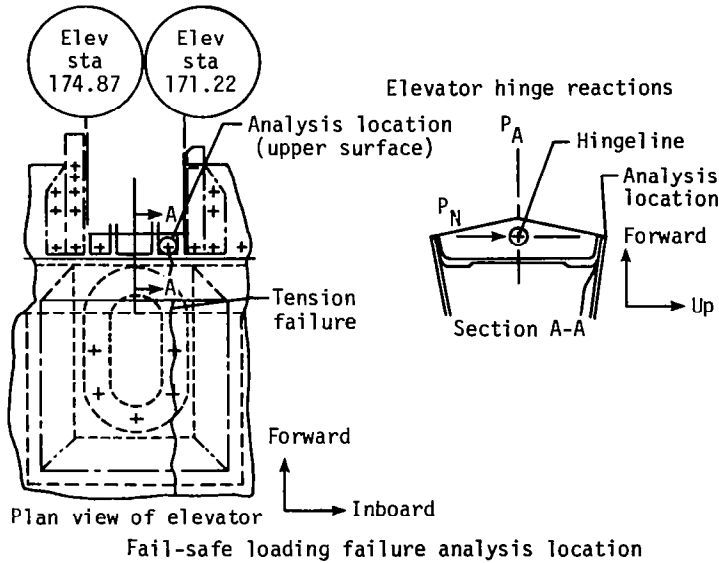
DC-10

The failure of the front spar of the 727 elevator during test was for a Boeing design condition, not an FAA required condition. The failure occurred in a combined load area of the upper chord of the spar at the hinge fitting. The combined load in the fastener area was demonstrated to be the reason for this failure. A simple interaction curve showed that the failure should have occurred. Good correlation between (1) the stress analysis at both the finite element level and the detailed hand analysis level and (2) the test data and interaction curve shown gave a very good correlation with the failure noted.

727 Elevator Failure Analysis

Combined load on front spar chord hinge fitting attachment

Failure of front spar in a Boeing fail-safe test

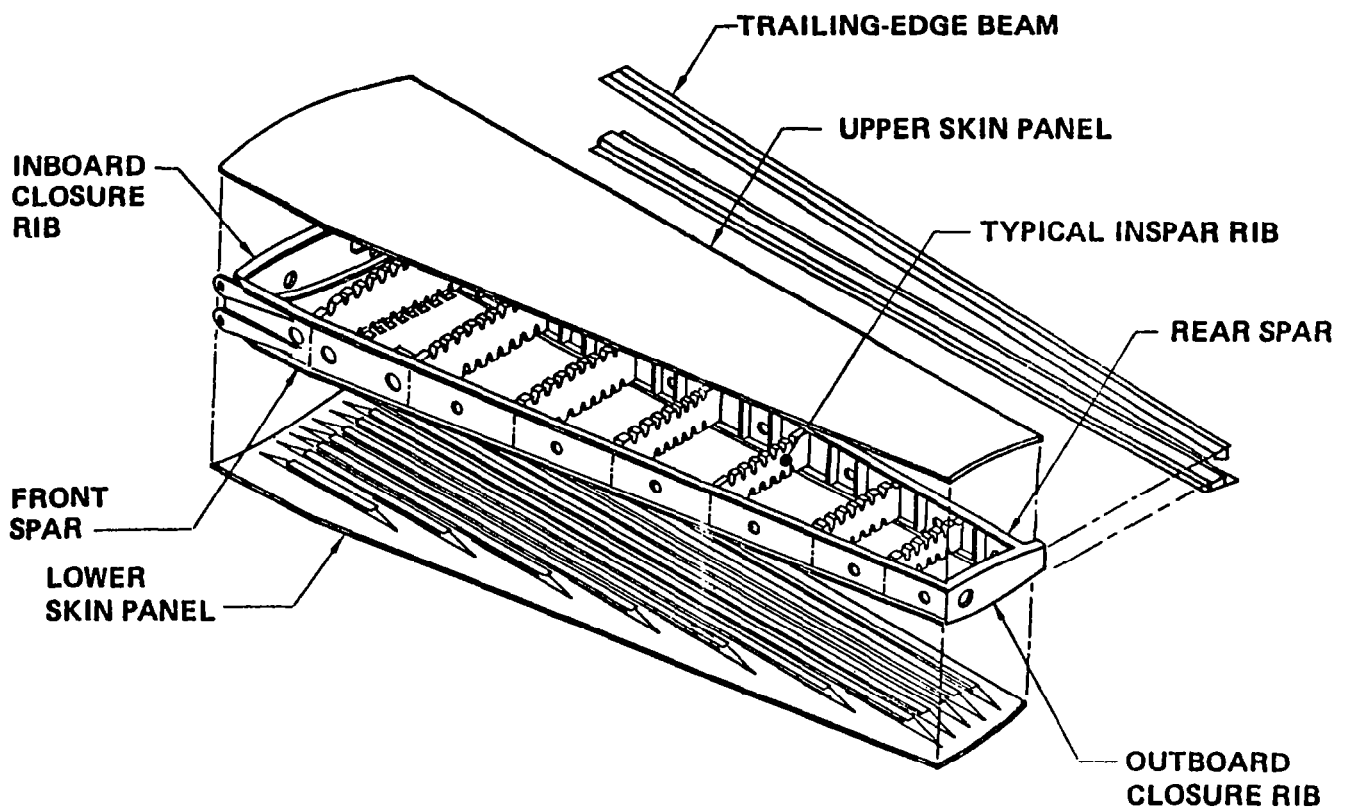


- 1 $R_{\epsilon_{gross}}$ of 1.00 based on $\epsilon_{gross} = 0.0046 \text{ mm/mm, (in/in)}$, from room temperature, dry test specimens (fig 71)
- 2 R_{BRG} of 1.00 based on $f_{BRG} = 709 \text{ MPa (102 800 lbf/in}^2)$ from room temperature, dry test specimens (fig 68)

Interaction Curve Bearing versus Tension Bypass Strain

A look at the 737 structure will give some insight into the levels of information and analysis capability that were required for this structure. Again, simple tools could be used since the structure is primarily designed by stiffness. This shows a breakdown of the structural elements of the 737 horizontal stabilizer, which consists of cover panels (co-cured I-stiffened panels), laminate front and rear spars, and honeycomb composite ribs.

Stabilizer Inspar Structural Arrangement



The 737 analysis considerations look at the design criteria impact, and here again stiffness design dominated and therefore produced low strain levels. The damage tolerance requirements are shown to be category 2. This requires that the horizontal stabilizer be designed for large detectable damage with no growth. The same moisture/temperature characteristics and analysis procedure were established as were used for the elevator. Therefore, the 737 requires certification for both damage tolerance and ultimate strain. Again, a finite element analysis was applied to the horizontal stabilizer primarily because of the design, which carries only the two spars through the center section. Therefore, a very significant shear lag and load distribution problem needs careful analysis. Also, by using finite elements and cutting or removing structure to simulate damage tolerance requirements, the analysis procedure was easier to perform.

737 STABILIZER - ANALYSIS CONSIDERATIONS

DESIGN CRITERIA

- SIMILAR STIFFNESS TO AL. STABILIZER
- DAMAGE TOLERANCE CATEGORY #2
- CONTROL STRAIN TO ELIMINATE DAMAGE GROWTH
(I.E., CATEGORY #3)
- TEMPERATURE/MOISTURE (SAME AS ELEVATOR)

RESULTS OF CRITERIA ON DESIGN

- LOW ULTIMATE DESIGN STRAINS
- NO FATIGUE CONSIDERATIONS
- NO FLAW GROWTH CONSIDERATIONS
- TOLERANT TO DISCRETE DAMAGE

CERTIFICATION CONSIDERATION

- 1ST OF A TYPE MUST BE TESTED ULTIMATE
WITH ACCOUNTABILITY FOR MOISTURE & TEMPERATURE
- ULTIMATE STRENGTH
- DAMAGE TOLERANCE (CATEGORY #2)

737 HORIZONTAL ANALYSIS REQUIREMENTS

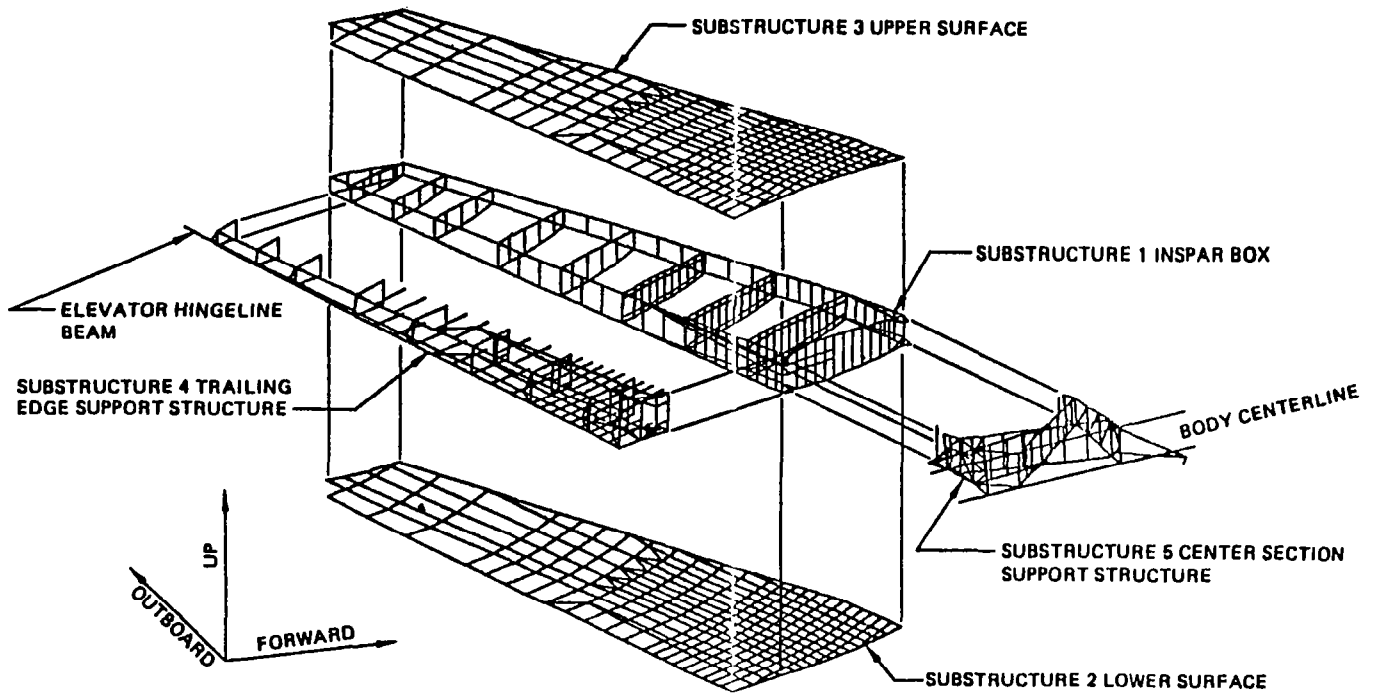
FINITE ELEMENT ANALYSIS

- SPAR CARRY THROUGH TO CENTER SECTION ONLY
- METHOD OF ACCOUNTING FOR MOISTURE/TEMPERATURE
- CHECK STIFFNESS SIMILARITY
- DAMAGE TOLERANCE ANALYSIS
 - MAJOR DAMAGE/FAIL SAFE

DETAIL ELEMENT ANALYSIS (STRENGTH CHECK)

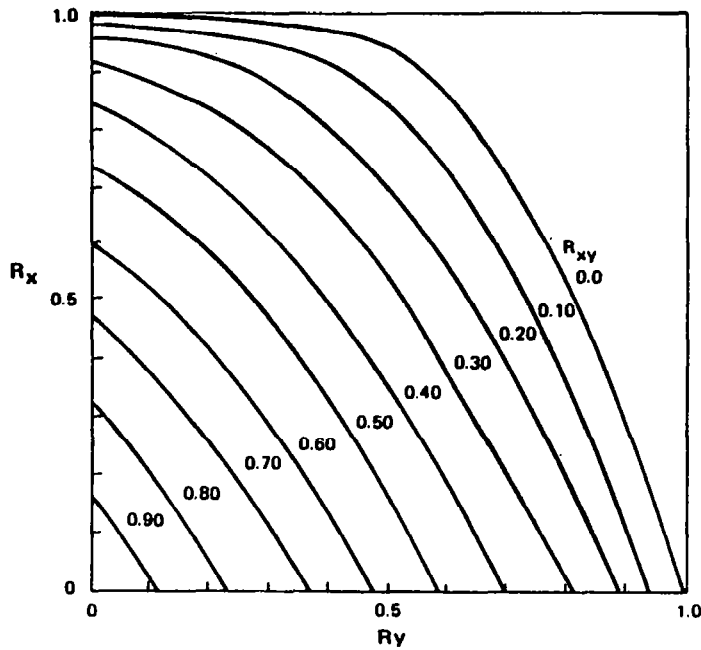
- SURFACE PANEL ANALYSIS
 - STABILITY, STRENGTH & DAMAGE TOLERANCE
- SPARS
 - WEB - STABILITY, STRENGTH & DAMAGE TOLERANCE
 - CHORDS - STABILITY, STRENGTH & DAMAGE TOLERANCE
 - JOINT - STRENGTH
- RIBS
 - STRENGTH & SKIN ATTACHMENT

The breakdown of the finite element model is shown below. Notice the finer grid in the shear lag load distribution region toward the inboard end.

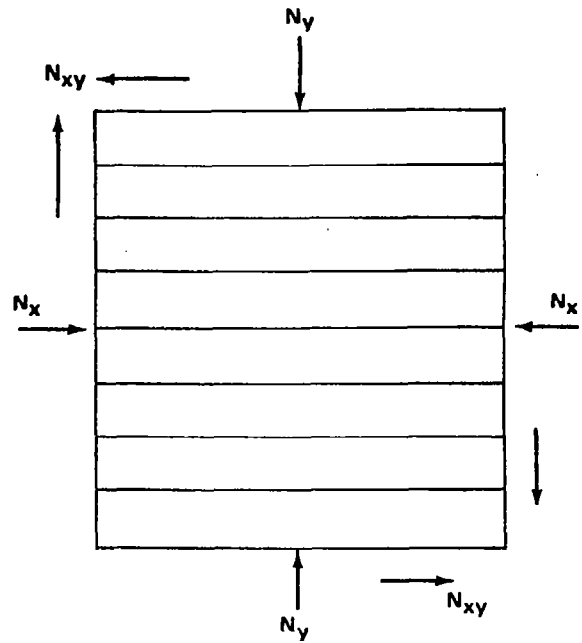


737 Composite Horizontal Stabilizer Finite Element Model Substructure Definition

Buckling Analysis



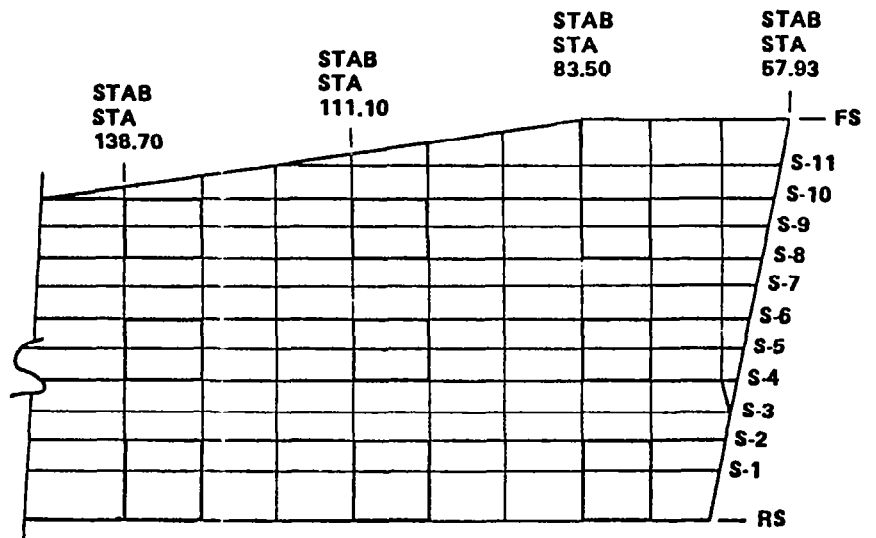
BUCKLING INTERACTION—VIPASA



PANEL 69.9 cm (27.5 in) x 8
STRINGER BAYS

Analysis Approach

- Skin panels buckle at 42% ultimate load
- At ultimate
 - Bending carried by stringers and spar chords
 - Shear carried by skin
- Stiffness matching constraints
- Strain cutoffs



INBOARD SKIN PANEL

The pin removal in the lug in the rear spar simulated a fatigue failure in the aluminum inboard of the graphite structure. The center section is an arrangement of a truss network which carries the torsional loads in the diagonals of the truss and the bending in the front and rear spars of the truss. A failure in this inboard section, particularly at the adjacent lug, would cause a significant load redistribution in the rear spar of the composite structure. This test, therefore, was felt to simulate adequately this type of possible failure mechanism.

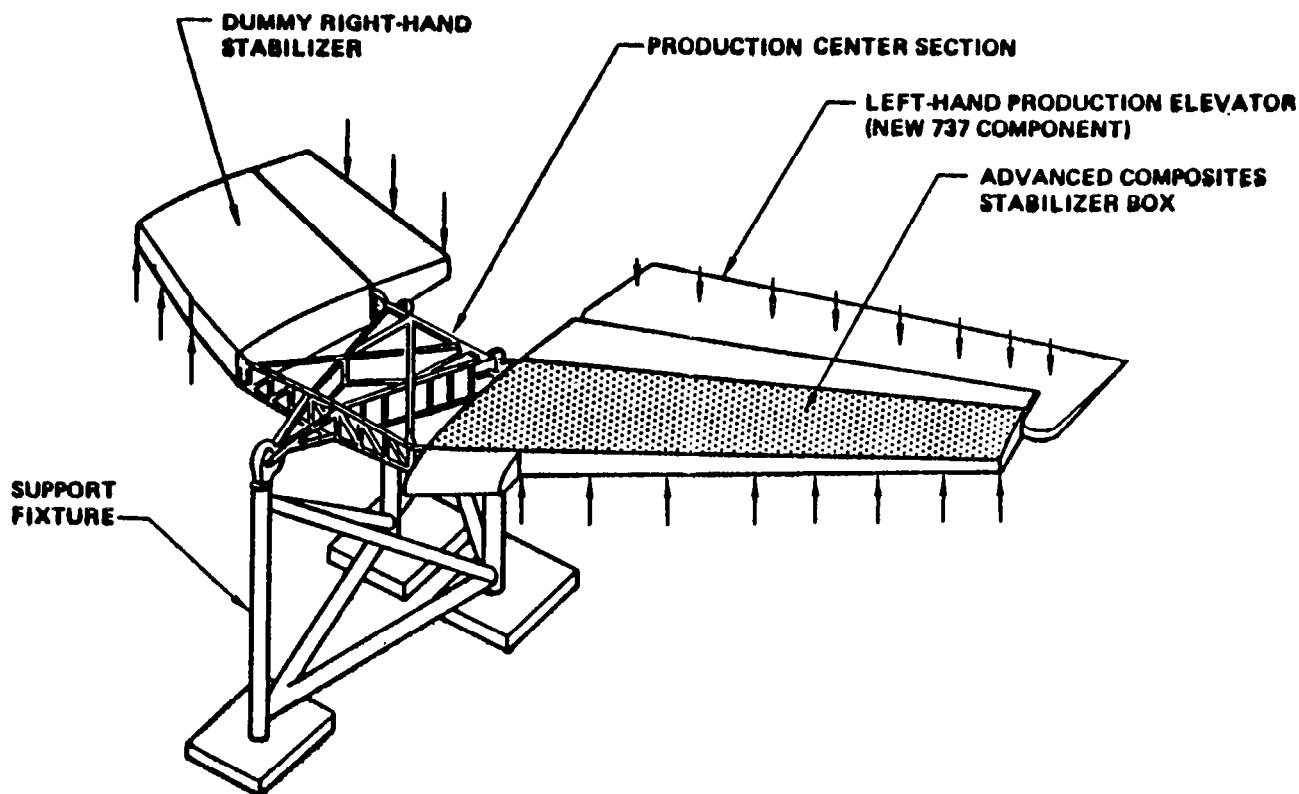
- **Maximum positive bending**
 - **Rear spar lower pin removed**
 - **Front spar lower pin removed**
- **Maximum negative bending**
 - **Front spar upper pin removed**
 - **Rear spar upper pin removed**

Damage Tolerance Test

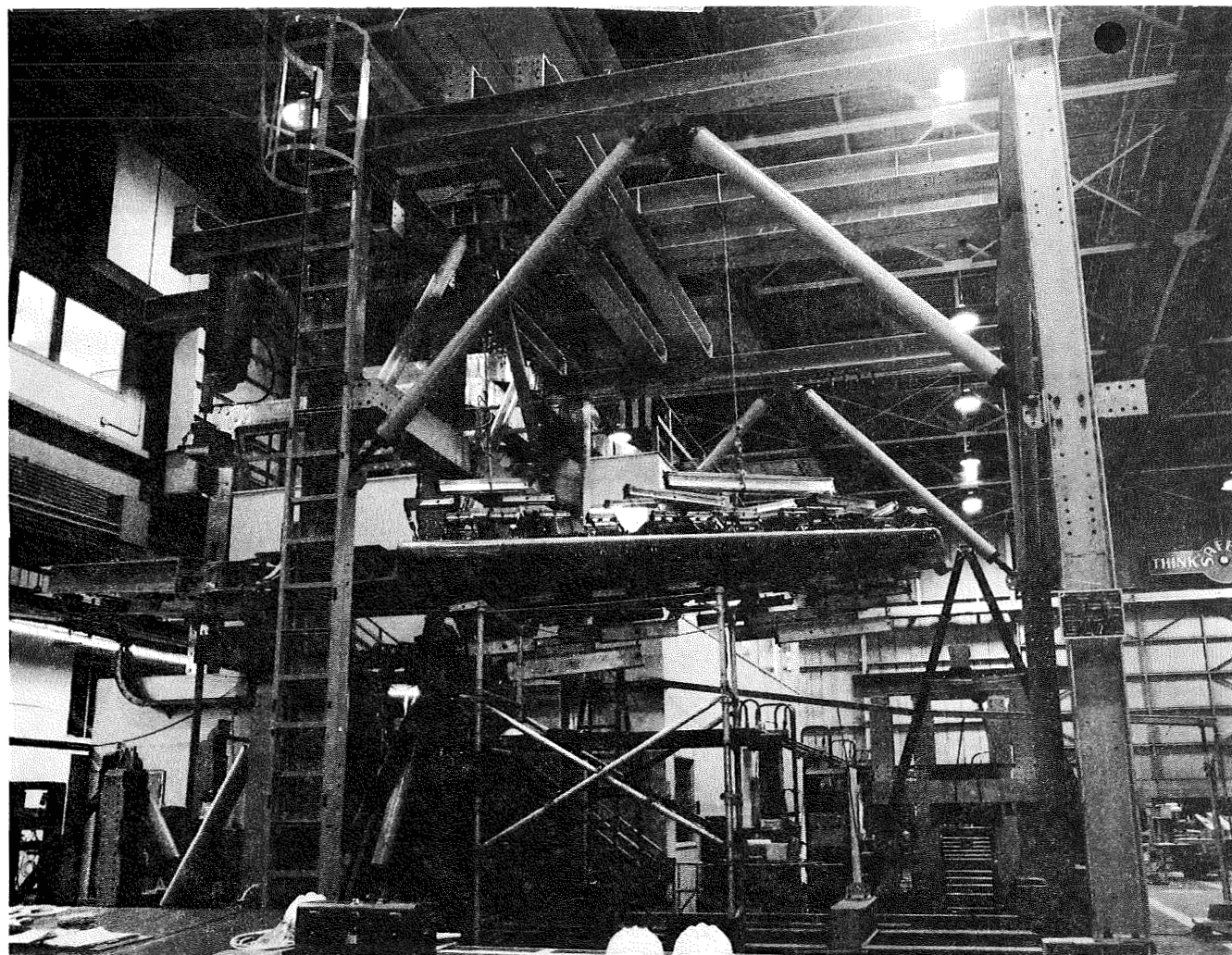
The test set-up for the full-scale ground test is shown. Strain surveys to limit load were performed for four load cases. Thermal linkage functional tests at high and low temperatures were performed to verify the thermal compensating linkage. The lateral stiffness of the elevator attachments was determined.

The test box was spectrum loaded for one-half lifetime to verify no intrinsic damage growth. Small cuts, impact damage, and damaged fastener holes were introduced into the test box. The box was spectrum loaded for one full lifetime to demonstrate that visible damage will not propagate during one lifetime of spectrum loading. Four ultimate load conditions were applied to the test box. Following these tests, a sequence of tests were performed in which the lug pins were removed to simulate center section lug failures. The lightning protection system was verified by subjecting an outboard tip section to a lightning test.

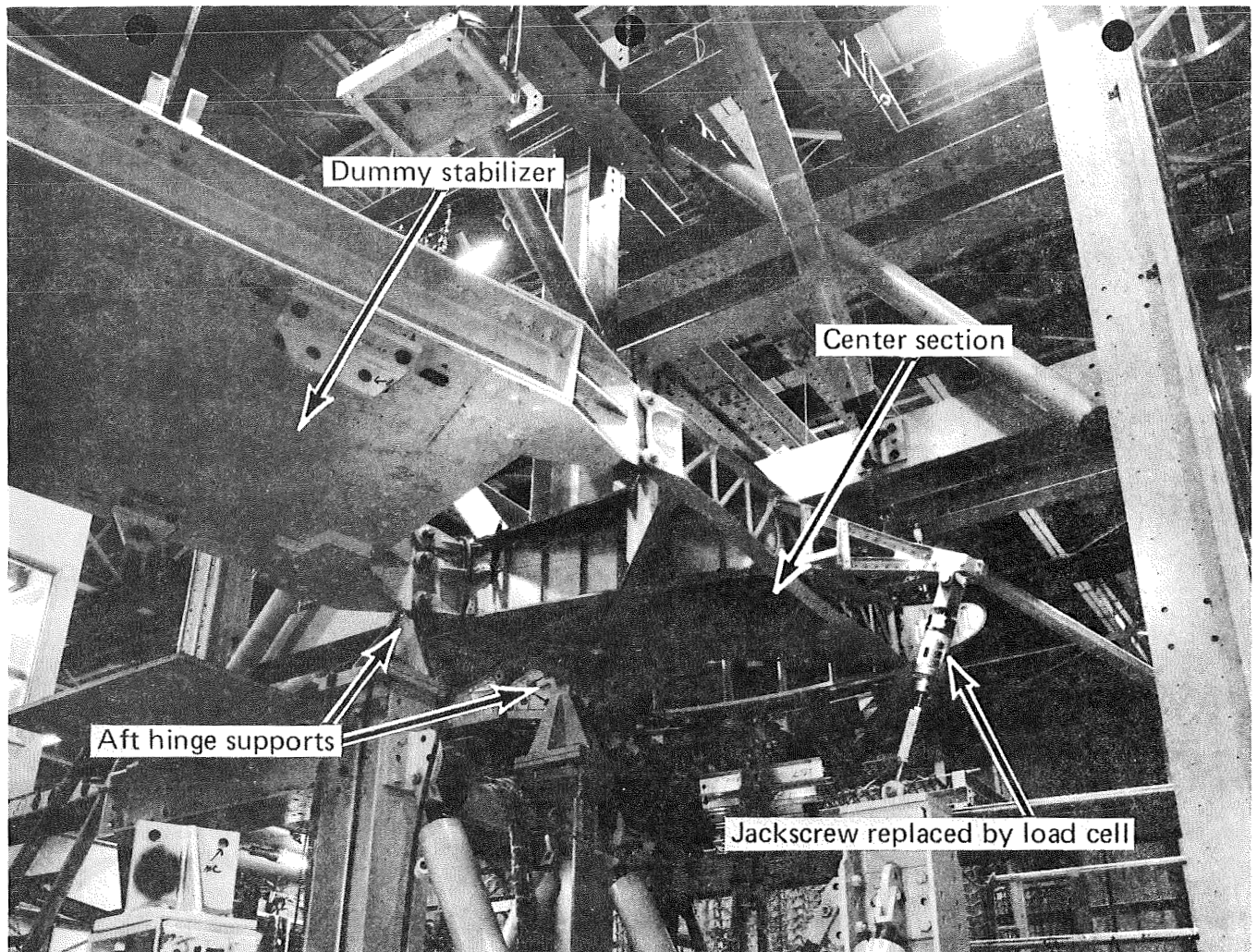
Full-Scale Ground Test



This photograph shows the full-scale test specimen mounted in the support jigs. Loads were applied by a system of pads to simulate spanwise and streamwise load distribution.



This photograph shows the stabilizer's center section interface. Attachment of the stabilizer is made with five bolts, three at the rear spar and two at the front spar.



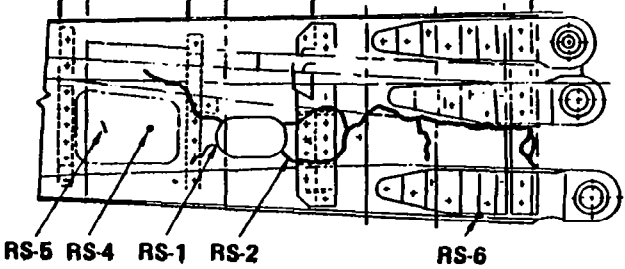
Test Configuration—Failure

- Removed pin in upper lug rear spar
 - Simulated center section failure
- Applied load case 4010 (down bending)
 - 67% DUL required
- Failure occurred at 61% DUL

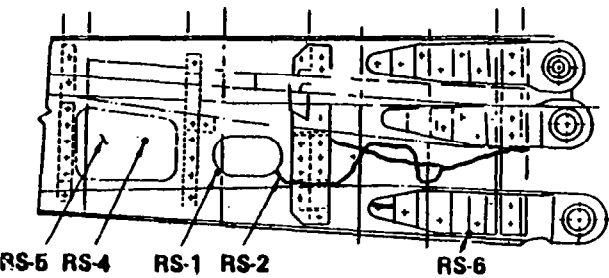
It can be seen from these illustrations of the failure of the rear spar that the crack extension modes varied from a tension failure at the most inboard end, which went completely through the surface and through the thickness of the web, to the beginning of a shear failure, some of which initiated interlaminarly. The propagation of the flaws from the most inboard to the most outboard cracks shown was verified by the strain gage data, which showed the inboard gages going nonlinear earlier than the outboard gages.

Failure Description

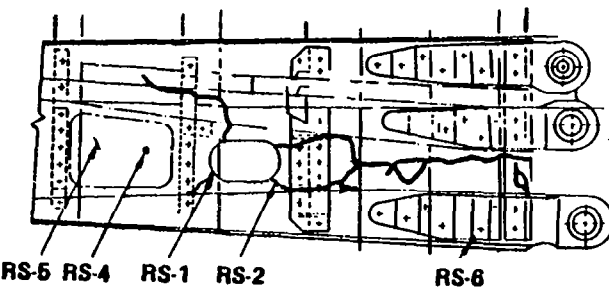
STABILIZER	STABILIZER	STABILIZER	STABILIZER
STATION	STATION	STATION	STATION
101.9	92.7	83.5	68.14



● WEB CRACKS,
FORWARD FACE

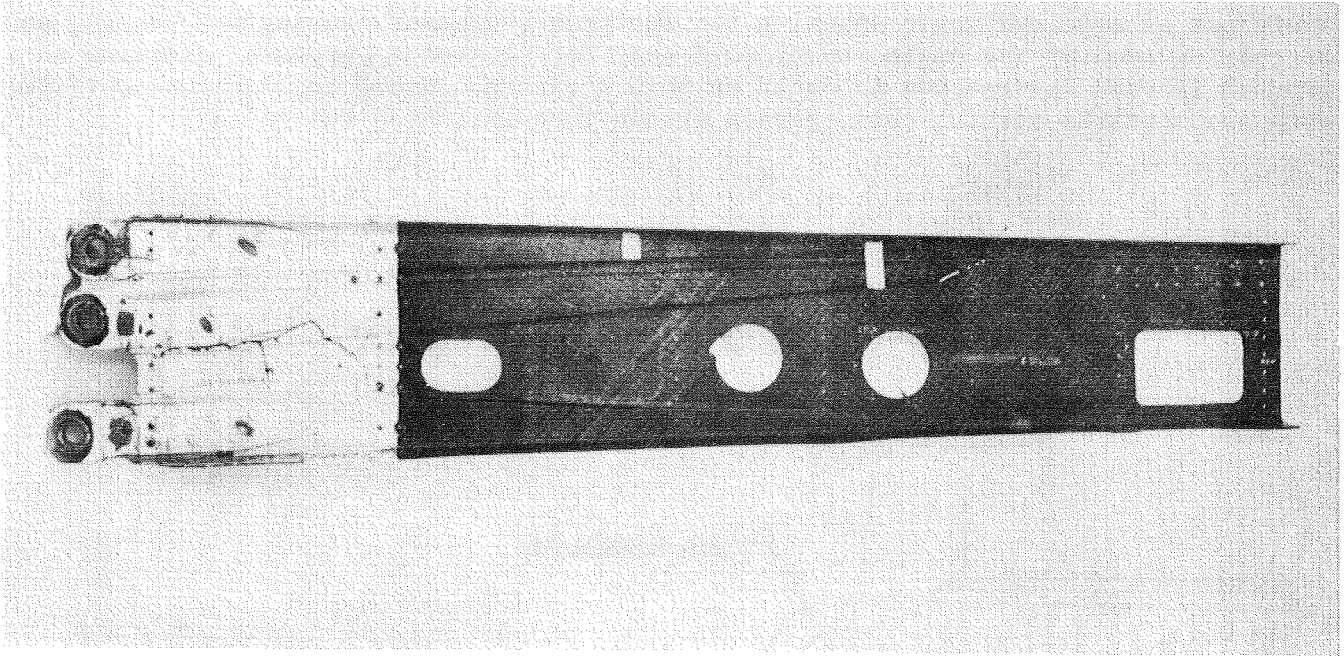


● THROUGH THICKNESS
CRACK

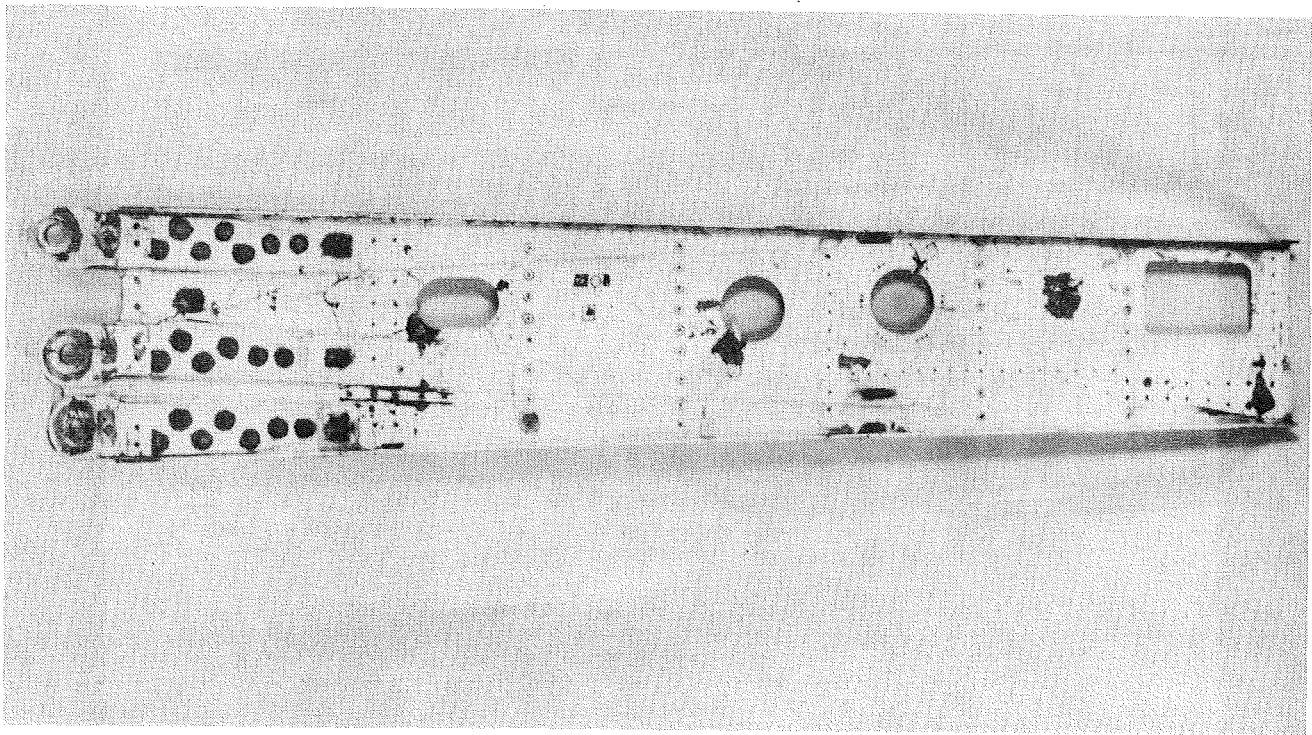


● WEB CRACKS,
AFT FACE

These photographs show the spar after it had been removed from the horizontal stabilizer for a closer examination.



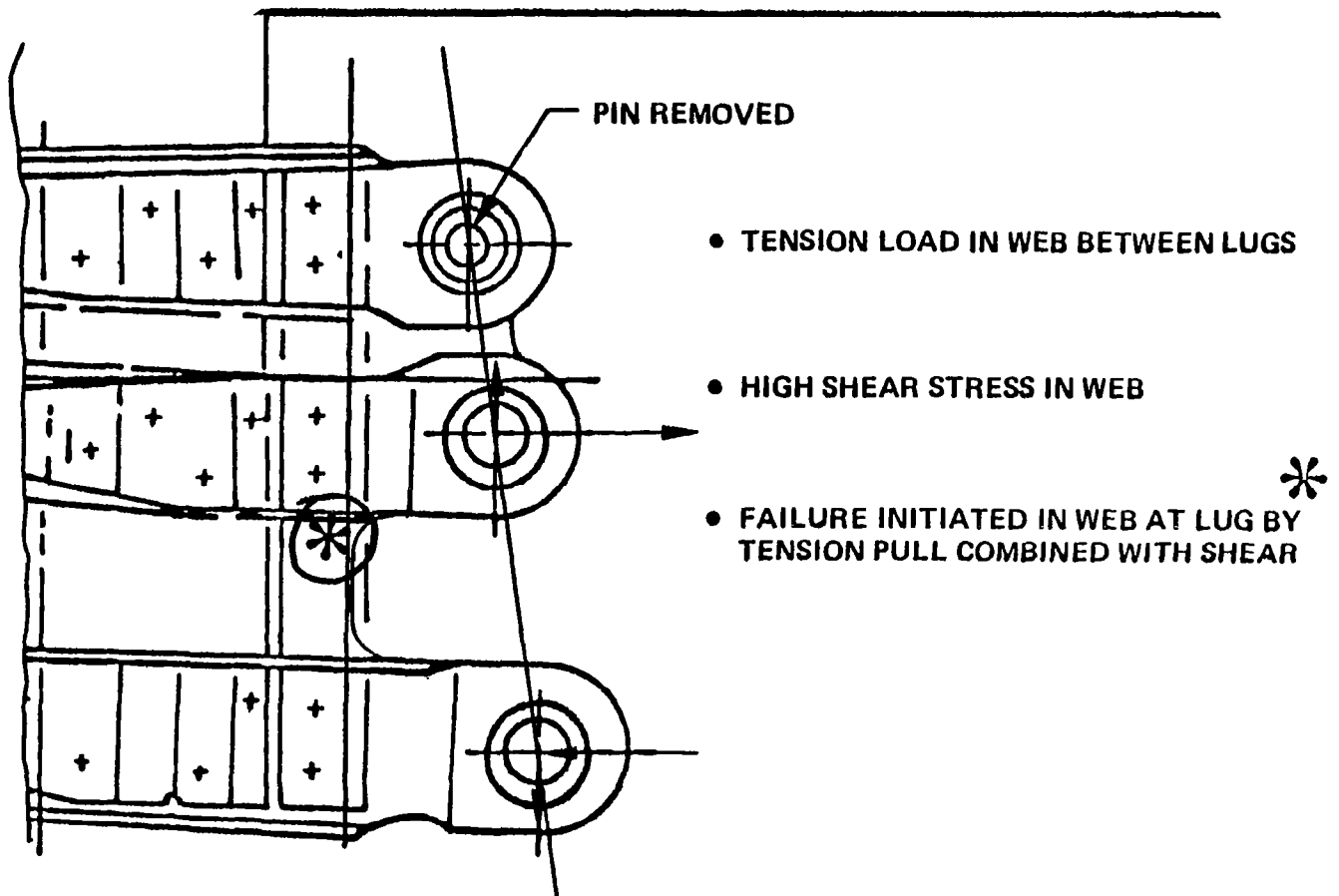
WEB CRACKS, FORWARD FACE



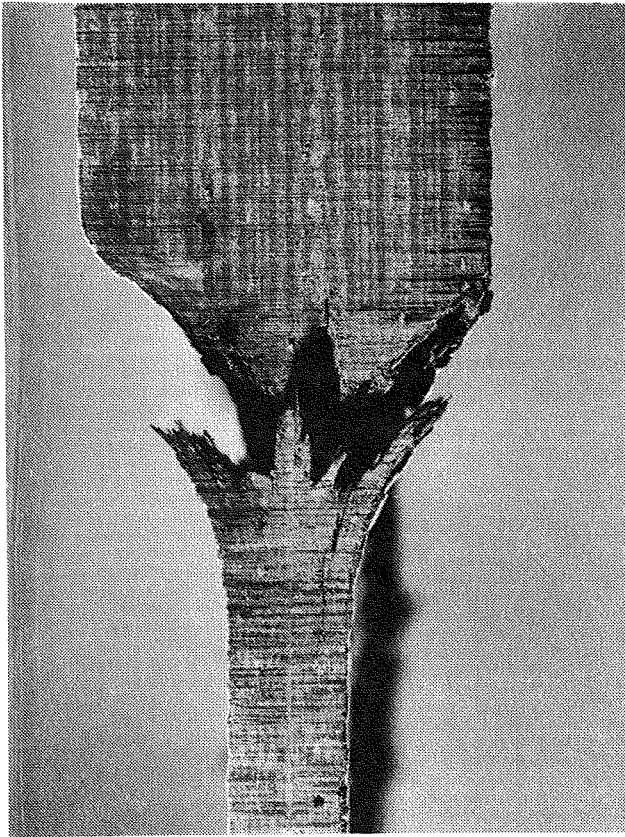
WEB CRACKS, AFT FACE

This figure indicates the loading which initiated the failure just below the fail-safe lug at the most inboard location. This failure propagated aft, creating a shear concentration in the web which then propagated in a shear mode, causing the damage seen in the previous photographs. This tension load between the fail-safe lug and the lower lug is caused by the dihedral change at the side of the body. There was an aluminum angle spanning the lug areas; however, during the design, some of the lug area of the angle was trimmed away for clearance purposes, allowing a greater imposed deformation to occur at this location. Since the web must perform with a compatible strain, this tension strain then initiated the failure.

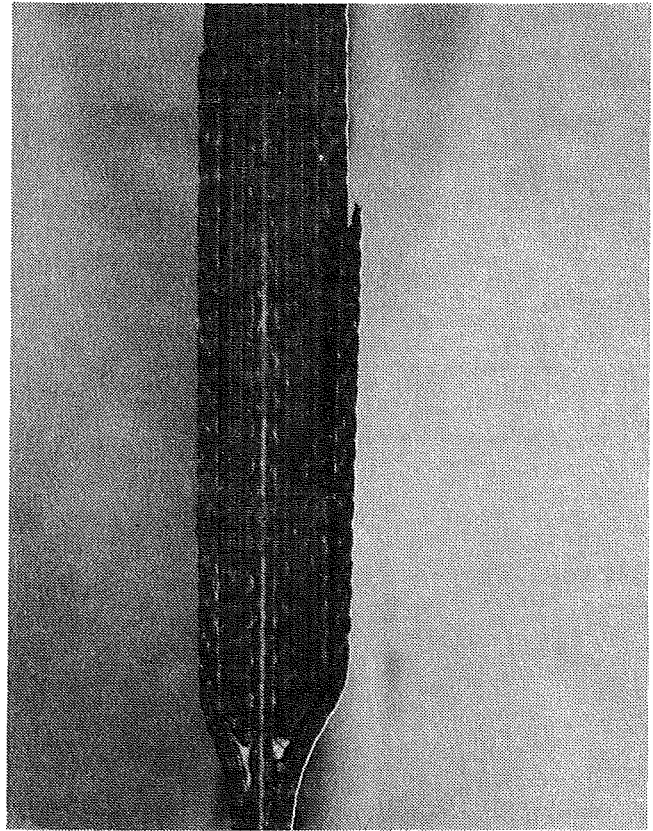
Damage Tolerance Failure Sequence



This photograph illustrates the detail of the tension failure. The lug areas are made of co-cured highly uniaxially oriented fiber slabs which are then wrapped in two channel halves with cloth to form the "I" section of the spar. The two halves and the cap strip are then bonded together in a single envelope bagging operation. The failure occurred where the wrapped plies of cloth turned the corner and therefore took the tension load in the resin direction, as previously described. Only XX plies were continuous straight up the center of the web. Therefore, this compatible deformation initiated the failure.



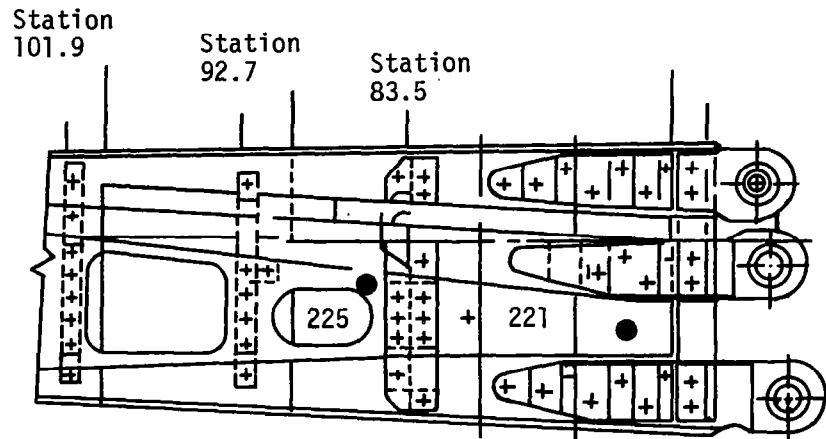
TENSILE FAILURE OF INBOARD WEB



DELAMINATION OF FACE PLYS

It can be seen, as was previously mentioned, that the most inboard gage was nonlinear at a load below which the outboard gage was still linear, indicating that the failure was beginning to propagate from the inboard to the outboard direction.

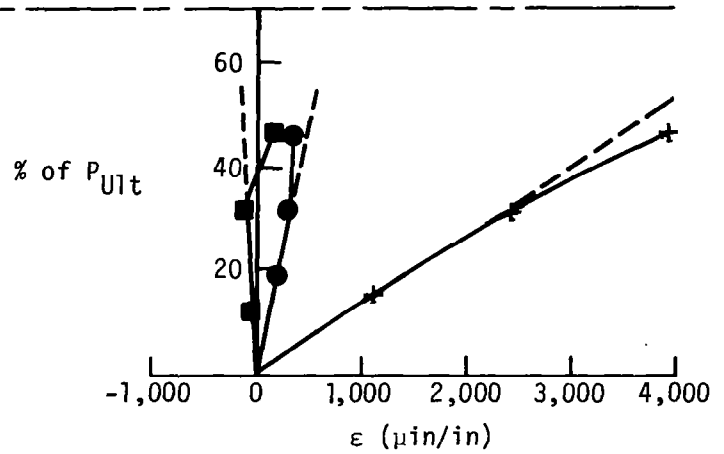
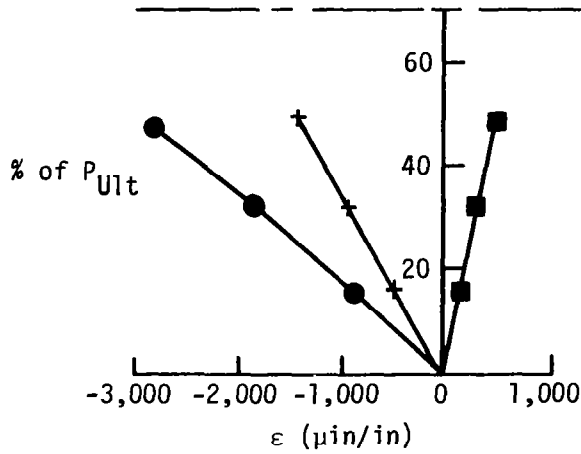
DAMAGE TOLERANCE- TEST FAILURE STRAIN GAGE READINGS



Gage	225		
Channel	A ●	B +	C ■
	622	623	624

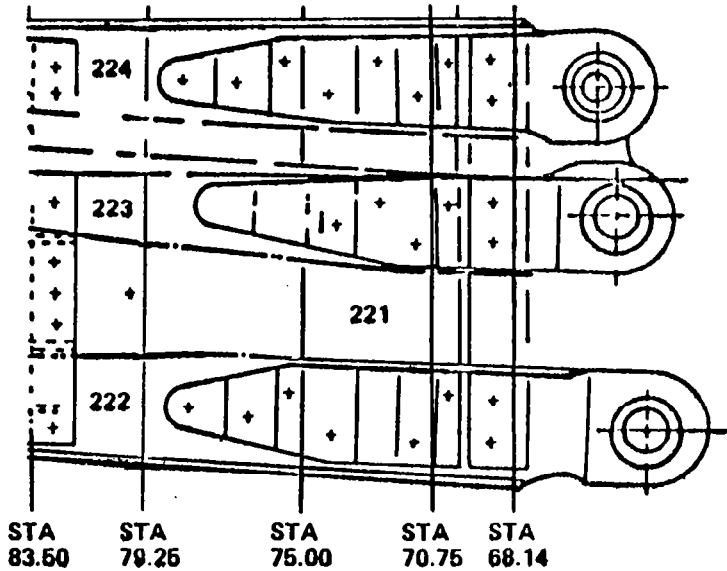
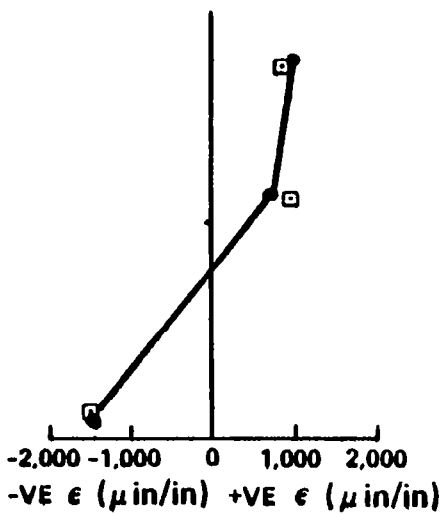
Limit load

Gage	221		
Channel	A ●	B +	C ■
	619	620	621



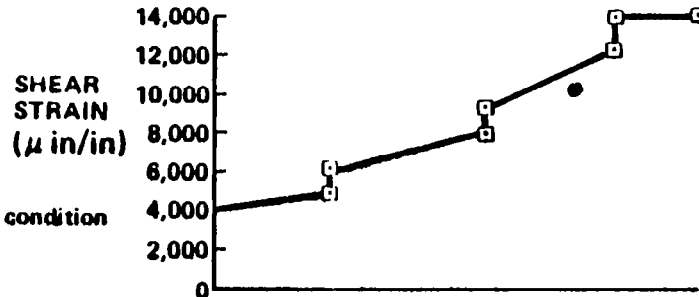
The accuracy of the finite element analysis as compared to strain gage data is shown in this figure. The extremely high shear strains that occurred during this test are illustrated. The additional shear strain induced by the tension failure would raise the local shear strain in the web above the capability established from test data.

Damage Tolerance Finite Element and Strain Gage Comparison



- Test
- Atlas

● Load case 4010, limit load fail-safe condition



After establishing the failure mechanism, a plan for repair and avoidance of this failure mode was established. The conclusions shown here played a critical role in establishing the repair process.

Damage Tolerance

Conclusions

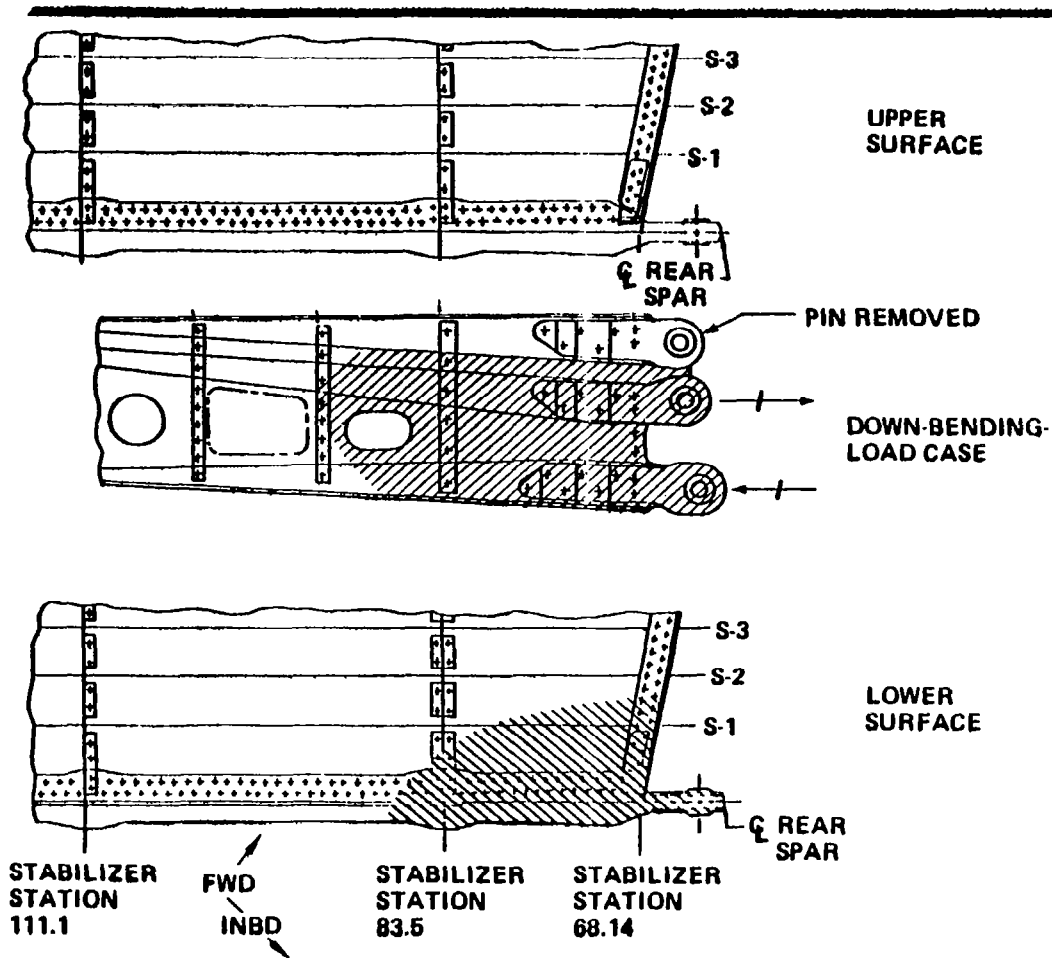
- **Load level**
 - **61% as tested**
 - **67% required**

- **Rear-spar web detail insufficient for fail-safe loading**

- **This area only critical area of stabilizer for this condition**

Only the areas of the horizontal stabilizer that are critical for this condition are shaded in this figure.

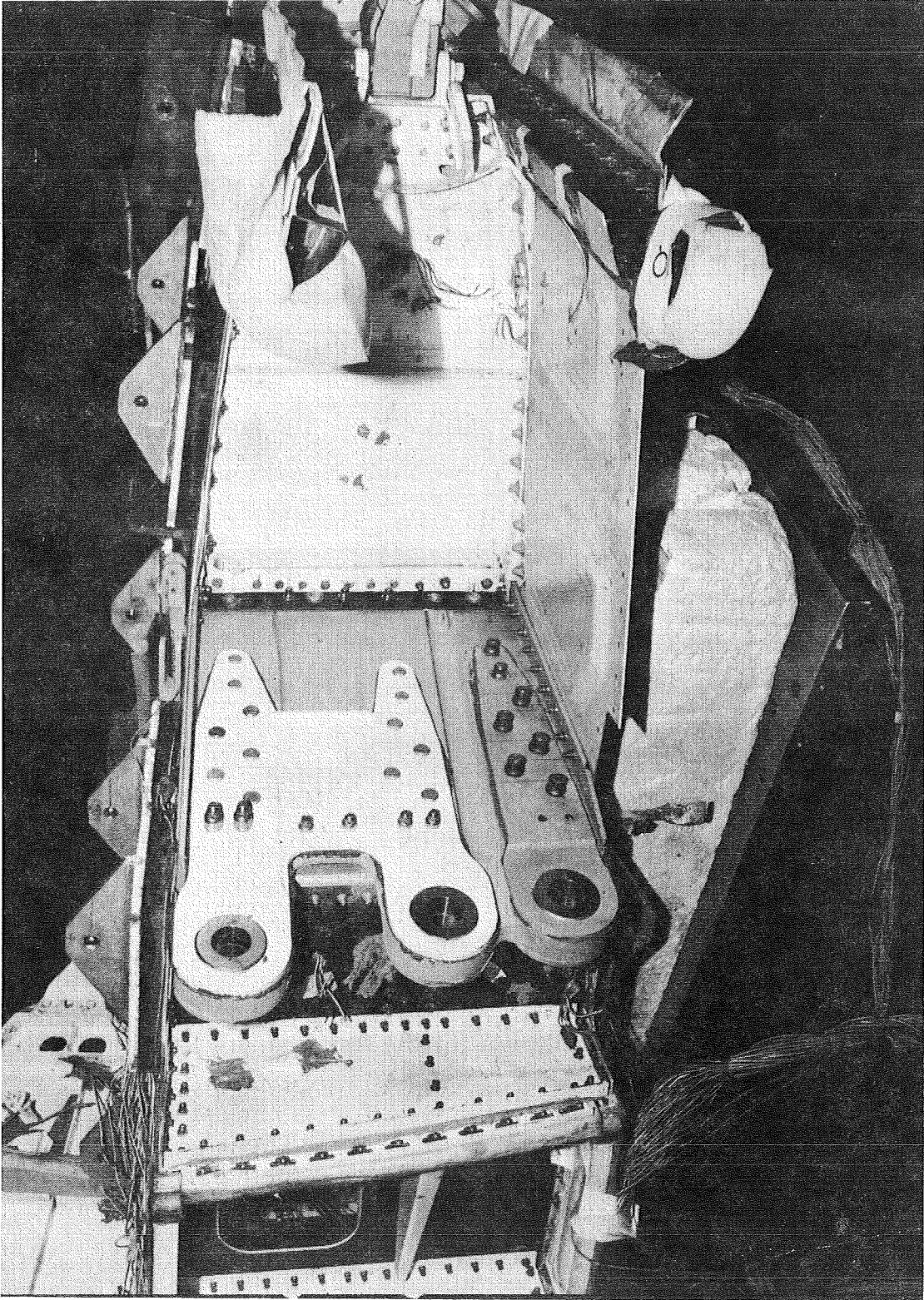
Only Area of Structure Critical for Upper-Pin-Removed Fail-Safe Case



Repair Plan

- Design a reinforcement for the rear-spar web area
- Verify adequacy of rear spar by analysis
- Apply modification to all five shipsets

This photograph shows the steel repair plate on the rear spar. The steel was used to assure minimum tension elongation and to minimize the thickness in the fit-up areas.



In considering what is needed in the future to support the analysis and design of composite wings and bodies for commercial transports, we must consider the possible criteria requirements as well as the design goals. To improve the weight savings and to sustain the kind of damage that can be expected in service, it is believed that an increased design strain capability is needed, both in design and in material application. We will have to fulfill category #2 and possibly category #3 of the damage tolerance requirements if the raising of the strain level causes flaw growth. Obviously, in moving to the wing, high end loads will be encountered. As an example, these high end loads will require careful design at the side of the body in order to remove the high concentrated loads from the stringers. This design analysis and test matrix will be particularly critical in the success of wing design. Similarly, diffusion into large fuselage structural shells of concentrated loads (e.g., the keel beams) will be extremely important, and careful analysis will be required. The determination of buckling criteria is essential to establishing a good weight savings capability for composites in fuselage shells. Good criteria and test data, as well as validating analysis, are particularly important. We must also consider the possibility that new uses will require a wider range of environmental conditions. Finally, raising the strain level in these critical structure components may again require us to consider fatigue damage. We need to have a matrix fatigue damage rule.

WING & BODY - FUTURE ANALYSIS CONSIDERATIONS

POSSIBLE CRITERIA, REQUIREMENTS OR DESIGN GOALS THAT WILL INFLUENCE ANALYSIS NEEDS

INCREASE IN DESIGN STRAINS

DAMAGE TOLERANCE REQUIREMENTS

CATEGORIES #2 & #3

HIGH LOAD TRANSFER JOINTS

SIDE OF BODY JOINTS
KEEL BEAM

BUCKLING CRITERIA (AT OR BELOW LIMIT?)

HIGHER TEMPERATURE (/MOISTURE) REQUIREMENTS

BODY (WITH INSULATION)

FATIGUE CONSIDERATIONS

MATRIX DAMAGE RULE

There are three or four areas that need to be considered in developing the analytical capabilities to be used in these major components of primary structure. They sound fairly simple, particularly the ones associated with strength, but since we will be asked to design closer to the capability of the material, the ability to predict both the ultimate strength and the residual strength requirements accurately in the design is much more important for both the static and damage tolerance conditions. Therefore, high competence in both aspects of the analysis and in validation by test is of extreme importance. Interlaminar effects, working the material in its weak direction, are of extreme concern to everyone. We must be able to predict interlaminar flaw growth, first of all from a grow-no-grow criteria and then under cyclic load. Those loads which induce these normal load stresses or strains are often secondary kick loads induced by eccentricities or secondary load paths. In metal structures these loads are often not a major concern, except possibly in fatigue. The secondary load calculations must improve in accuracy since they will most likely be the initiating phenomena for interlaminar flaw growth and failure.

WING & BODY - ANALYSIS DEVELOPMENT AREAS

DEVELOPMENT MUST CONSIDER REQUIREMENTS OF BOTH THE REQUIREMENT ANALYSIS AND CAPABILITIES ANALYSIS

1. STRENGTH PREDICTION
 - ULTIMATE STRENGTH
 - RESIDUAL STRENGTH
 - HIGH CONFIDENCE
2. INTERLAMINAR EFFECT
 - STATIC STRENGTH
 - GROWTH PREDICTION
3. SECONDARY LOADING
 - NORMAL TO LAMINATE
 - BUCKLING INDUCED
 - PRESSURE INDUCED
 - ECCENTRICITY OR KICK LOADS INDUCED

It is important to remember that we must bring these analytical tools along as early as possible, not necessarily in the most perfected form, but in a form that can be used as we begin to make these early configuration trade-offs, material selections, and manufacturing decisions. Once a company has begun to change from those pieces of equipment currently available for machining and assembling aluminum to those required for fabricating and assembling advanced composite structure, a major commitment will have been made. Therefore, it is important that we consider the development of methods that will support us in the near-term development of these components prior to production commitment. Development and validation of these methods must go hand in hand, and test techniques and procedures must be able to produce consistent and valid results. In addition, those test results must be validated, along with the analysis on structures simulating real aircraft loading.

WING & BODY - ANALYSIS DEVELOPMENT CONSIDERATIONS

TIMING

ROLE IN EARLY CONFIGURATION SELECTION

IMPACT ON MATERIAL DEVELOPMENT & SELECTION

PLANNING OF DEVELOPMENT PROGRAMS & TESTING

VALIDATION

SUPPORT METHOD WITH ADEQUATE TESTING

TESTING INCLUDES REAL STRUCTURE APPLICATIONS

Here some thoughts are presented on what structural analytical goals should be in terms of the type of tools needed.

STRUCTURAL ANALYTICAL TOOLS GOALS

- ESTABLISH A LEVEL OF CONFIDENCE IN THE ANALYTICAL PROCESS SUCH THAT IT IS THE PRIME TOOL FOR STRUCTURAL VALIDATION
 - QUALITY SUCH THAT ANY REQUIRED FULL-SCALE TESTING WOULD ONLY BE USED TO PROVIDE FOR AIRCRAFT GROWTH OR TO UNCOVER GROSS HUMAN ERROR IN APPLICATION OF THE ANALYSIS OR MANUFACTURING METHODS
 - CAPABILITY OF BEING IMPLEMENTED IN A SIMPLE AND ECONOMIC MANNER BY A LARGE GROUP OF ENGINEERS
 - USABLE WITHIN THE CONSTRAINTS IMPOSED BY AVAILABLE DATA AND FLEXIBLE ENOUGH TO IMPROVE WITH THE EXPANSION OF AVAILABLE DATA
 - CAPABLE OF IMPACTING THE DESIGN AS WELL AS BEING USED TO ANALYZE THE DESIGN
 - VALIDATABLE BY TEST EVIDENCE

Here are some thoughts on the analysis development aspects, whether related to advanced composites or to other types of structures. For successful development, I believe that those people involved in research need a group working environment, and that working environment includes enthusiastic management backing, adequate but not excessive budgets, facilities available for developing the analytical tools in terms of computer access, test facilities, and, of course, supporting organizations. But one of the key elements for success is easy interface with production analysts and design people to ensure that the methods are going to be truly usable by the production engineers.

Making a good initial choice of which development areas to start is extremely difficult. In making prioritized lists we must make sure that we are looking for real needs and that we plan our program to meet those needs when they are required at the right depth. Let's not produce a program of perfection that is too late to support some of the earlier decisions in the development of advanced composite structure. We must be aware that our development should show true progress, not rehash over and over again the methods already available. On the other hand, let's not be afraid to adapt current methodology and carry that information from past experience.

Whether the method is used in a timely manner will depend on how familiar it is in form to something the current production stress analyst is familiar with. This takes an honest and realistic evaluation of what is available so as not to produce a replacement for something that is adequate today. Are all the items that are needed to peripherally support the analytical method well defined? Finally, take the time to establish a well-developed method specification and review this specification with the potential users, so the end product will be adequately suited to the job.

ANALYSIS DEVELOPMENT

ITEMS NEEDED FOR SUCCESSFUL DEVELOPMENT

- GOOD WORKING ENVIRONMENT
ENTHUSIASTIC BACKING
ADEQUATE BUDGET
FACILITIES
SUPPORTIVE ORGANIZATION
EASY INTERFACE WITH METHODS USER

- GOOD INITIAL CHOICE OF DEVELOPMENT AREA
REAL NEED CLEARLY IDENTIFIED
PLAN TO MEET NEED (APPROPRIATELY)
WHEN NEEDED
RIGHT DEPTH
UTILIZES CARRY-OVER FROM PAST EXPERIENCE
TRUE DEVELOPMENT PROGRESS
OR
MODIFICATION TO CURRENT METHODS
ALTERNATE METHODS EVALUATED - (HONESTLY)
REPLACEMENT
INFORMATION AVAILABLE TO SUPPORT SOLUTION
ESTABLISHED AND WELL DEVELOPED METHOD SPECIFICATION

- END PRODUCT QUALITY SUITED TO JOB

In order to produce methods of high quality, keep the process simple. In concept and in method, this produces a tremendous payoff in terms of development time, cost, and ease of utilization, and certainly helps assure the early success of both development and application. Many who are in research for a long period of time tend to become perfectionists in method development. Let's be careful of this trap while making sure that each item we add to the method is a true improvement and expands the information produced by the analysis procedure.

The key to a manager's good over-all development and management of method development is the balance of the budget he makes available relative to the quality level of the method developed. To expand on the idea of a method's usability and simplicity, it also should show adaptability to being part of other methods, in order to be available for future expansion.

ANALYSIS DEVELOPMENT

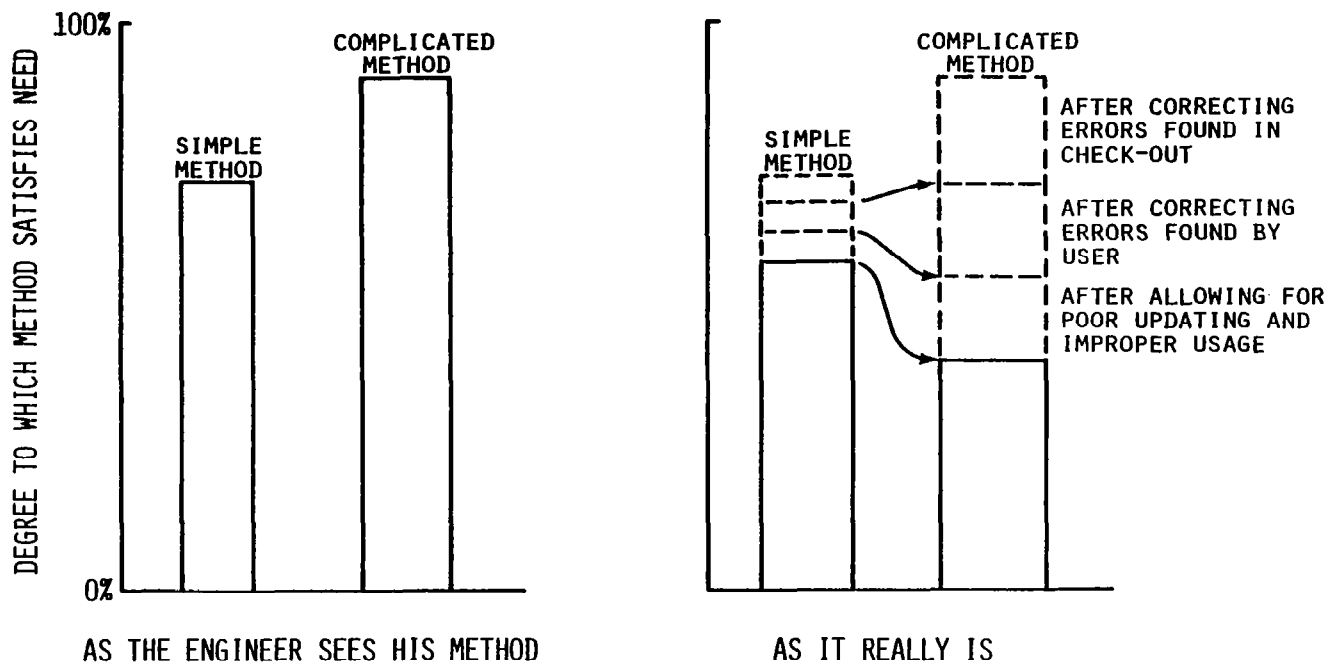
CONSIDERATION DEVELOPING QUALITY METHOD

- SIMPLE IN CONCEPT & METHOD
 - MINIMAL DEVELOPMENT TIME & COST
 - USAGE & APPLICATION EASIER
 - INHERENT SIMPLICITY - HELPS ASSURE EASY SUCCESS

- REFINEMENT OF METHOD
 - PERFECTIONISM
 - TRUE IMPROVEMENT
 - EXPANDS INFORMATION
 - BUDGET VS. QUALITY LEVEL

- ADAPTABILITY
 - USABLE AS PART OF OTHER METHOD
 - BALANCED FOR CURRENT USAGE
 - &
 - FUTURE EXPANDED APPLICATION

COMPROMISE BETWEEN SIMPLICITY AND THEORETICAL PERFECTION



Accuracy in method development is very important, and this accuracy should be validated by tests. To produce analytical tools for which there is no test validation in the real world is useless, and one or two data points are not sufficient if you expect production stress analysis personnel to accept your methodology. Testing should be repeated again and again and should be validated with test data. In establishing a method, be sure that there are no additional unnecessary additions to the solution which really do not improve the accuracy or produce more information, as previously noted. Don't join in analysis fads; make a good, unbiased judgement of the need for the method. Consider design handbook methods for end products to be as important as a computer method. The majority of detail stress analysis is still performed by hand today. Finally, keep in mind that the production analyst is your final user. If analysis methods of similar nature can be joined to form a single standard procedure, do it. Provide the flexibility for all uses and users. Can it be used in a disciplined manner by large organizations? This is critical.

ANALYSIS DEVELOPMENT

- ACCURACY
 - IMPROVED SOLUTION (OVER CURRENT)
 - NO UNNECESSARY ADDITION

- FADS
 - METHOD OF IMPLEMENTATION
 - COMPUTER VS. DESIGN MANUAL (FORMATS)
 - NEW LOOK TO OLD SOLUTION
 - PREJUDGEMENT OR PREJUDICED APPROACH
 - POOR PROGRESSIVE JUDGEMENT
 - EMOTION & SNAP JUDGEMENT
 - (PRESSURE - TIMING)

- PRODUCTION ANALYSIS & STANDARDIZATION
 - FLEXIBILITY FOR ALL USES & USERS
 - AVAILABLE TO ALL PROJECTS
 - DISCIPLINED USE BY LARGE ORGANIZATION

Proper and timely application requires a follow-up; this means provide support when it is needed, keep the user up to date on any modifications, listen to his inputs, don't be defensive. Think about expanding the method's usage and adaptability to new applications, and continue to evaluate it against new methods and recognize when it must be replaced. Then, when it must be replaced, proceed with a new development as needed.

ANALYSIS DEVELOPMENT

PROVIDE ADEQUATE FOLLOW-UP

CONTINUE INTERFACE WITH USER

PROVIDE SUPPORT WHEN NEEDED

KEEP USER UP TO DATE ON ANY MODIFICATION
USER MANUAL (REVISIONS)

LISTEN TO USER INPUTS (ACCEPT INPUTS)

EXPANDED USAGE (SCOPE & TIME)

CONTINUOUS REVIEW FOR ADAPTABILITY
OR

NEW APPLICATION

CONTINUE EVALUATION AGAINST NEW METHOD
(RECOGNIZE REPLACEMENT)

PROCEED WITH NEW DEVELOPMENT WHEN NEW REAL NEED IDENTIFIED

Finally, here are some rules for success in the analysis development:

- (1) Coordinate carefully between the researcher and user; be sure that there are no other alternate methods before you start the development, and have alternate methods available and assessed should your development not produce results.
- (2) Allow time for corrections and updates, particularly after you expose the method to the user; be sure, as you plan your development, that you plan the means of validation, since you want to have high confidence in its results.
- (3) It is a good idea not only to have those specifications developed and reviewed by the user, but to have him on board in frequent discussions during the development.

This will give the program timely evaluation, build confidence in its usage, and also ensure that it is used correctly so that you are not blamed for its error or inaccuracy. Remember, many methods operate in a production environment for a long period of time. They must be effective over this total period of time.

ANALYSIS DEVELOPMENT

DEVELOPMENT RULES FOR SUCCESS

- COORDINATION BETWEEN
DEVELOPER & USER
- BACKUP OR ALTERNATE METHOD
AVAILABILITY ASSESSED
- TIME ALLOWED FOR CORRECTION & UPDATE
AFTER USER EXPOSURE
- ESTABLISH OR ESTABLISHED MEANS OF VALIDATION
INSURANCE OF HIGH CONFIDENCE IN METHOD
- DEVELOPER/USER BOTH RETAIN PESSIMISM
- USER ON BOARD FROM START OF DEVELOPMENT
TIMELY EVALUATION
BUILDS CONFIDENCE IN USAGE
ASSURE CORRECT USAGE

METHOD OPERATES EFFECTIVELY IN PRODUCTION ENVIRONMENT
FOR A LONG PERIOD OF TIME

SUMMARY

- ANALYSIS PLAYS A MAJOR ROLE
IN CERTIFICATION & DEVELOPMENT
- ANALYSIS APPLICATION NEED TO BE
APPROPRIATE TO JOB
- ANALYSIS METHODS NEED TO BE
TEST VALIDATED
- ANALYSIS FUTURE NEEDS ARE:
PREDICTION ACCURACY
INTERLAMINAR STRESSES
SECONDARY LOADS
- ANALYSIS DEVELOPMENT MUST RECOGNIZE:
REAL NEEDS
ADVANTAGES OF SIMPLICITY

REFERENCES

1. Airworthiness Standards: Transport Category, Airplanes. FAR Pt. 25, FAA, June 1974.
2. Composite Aircraft Structures. Report No. AC 20-107, FAA, July 1978.