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SECTION 11

GENERAL DATA

DESCRIPTION

THE FAIRING T.E. WING EXTENSION IS NO PRIMARY STRUCTURAL COVER MAT'L FIBER GLASS PER DMS 2288, TYPE 3, CLASS 2 GRADE F - $THICK._{PLY} = .01''$, LOCATED IN THE ELBOW WING EXTENSION / UPR. WINGLET TRAILING EDGE.

DAC 25-2216 (3-81)

PREPARED BY: C. Pou

DATE: 3/89

TITLE: WINGLET ASSEMBLY STRENGTH ANALYSIS

CHANGE LETTER(S):

MCDONNELL DOUGLAS CORPORATION

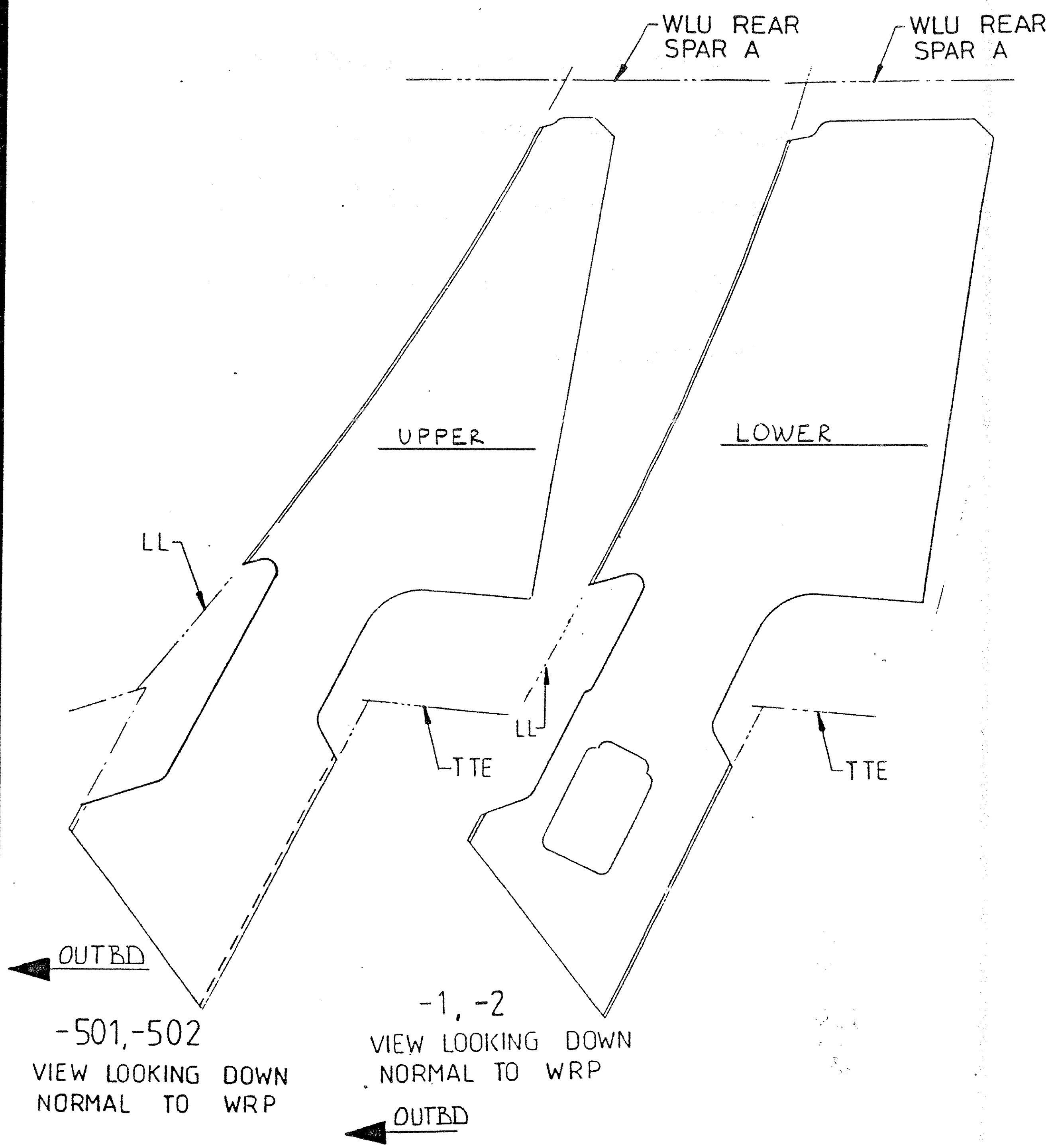
PAGE: IV-11-3

MODEL: MD-11

REPORT NO.: MDC-J7552

VOLUME NO.: IV

DWG ARB 7766
FAIRING ASSY T.E. LIGHT WING EXTEN.



-501, -502
VIEW LOOKING DOWN NORMAL TO WRP

-1, -2
VIEW LOOKING DOWN NORMAL TO WRP

SECTION 13

STRENGTH ANALYSIS

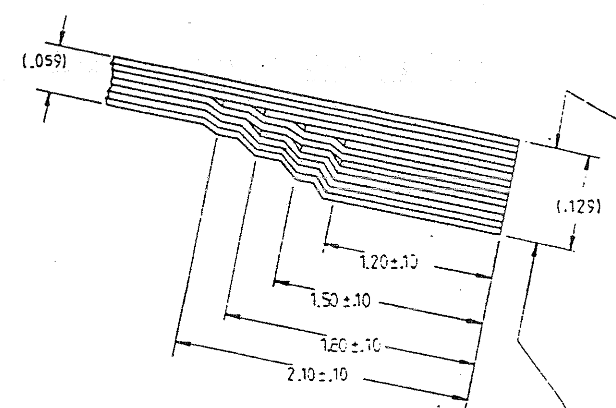
DWG ARB 7766
FAIRING ASSY T.E. LIGHT WING EXT.

UPPER

LOAD CONDITION: WL-1 ◁1

ANALYZE THE PANEL AS A RECTANGULAR PLATE LOADED NORMALLY BY AN AVERAGE PRESSURE:

$$w = p_A = -.8 \ LB/_{IN^2}$$



PLY Nº	DASH Nº	FIBER DIR
1	-3	±45°
2	-5	±45°
3	-7	±45°
4	-9	±45°
5	-11	±45°
6	-13	±45°
7	-15	±45°
8	-17	±45°
9	-19	±45°
10	-21	±45°
11	-23	±45°
12	-25	±45°
13	-27	±45°
14	-29	±45°

FIBER GLASS - PER DMS 2288, TYPE 3, CLASS 2
STYLE 1581 GRADE F $THICK._{PLY} = .01"$ Nº 5 PLIES

FIBER GLASS - PER DMS 2288, TYPE 3, CLASS 2
STYLE 120 GRADE E $THICK._{PLY} = .0045$ Nº 2 PLIES

◁1 REF. PAGE IV-12-3

FAIRING ASSY T.E. LIGHT WING EXT.

UPPER CONT'D

Panel Geometry

Length = 20.50"
Width = 5.00"

Lamina properties

1st material 120
El = 2843000.0 PSI
Et = 2756000.0 PSI
Glt = 609000.00 PSI
vlt = .1100E+00
thick.= .4500E-02 IN
2nd material
7781
El = 3248000.0 PSI
Et = 2900000.0 PSI
Glt = 507000.00 PSI
vlt = .1100E+00
thick.= .1000E-01 IN

Stacking Sequence

Ply No.	Mat. No	Angle (degrees)
1	1	45
2	2	45
3	2	45
4	2	45
5	2	45
6	2	45
7	1	45

Laminate Elastic Moduli

Ex = 1596221.0 PSI
Ey = 1596221.0 PSI
Gxy = 1369197.2 PSI
vxy = .5273E+00
thick.= .5900E-01 IN

PREPARED BY: C. Pou

DATE: 3/89

TITLE: WINGLET ASSEMBLY STRENGTH ANALYSIS

CHANGE LETTER(S):

PAGE: IV-11-4

MODEL: MD-11

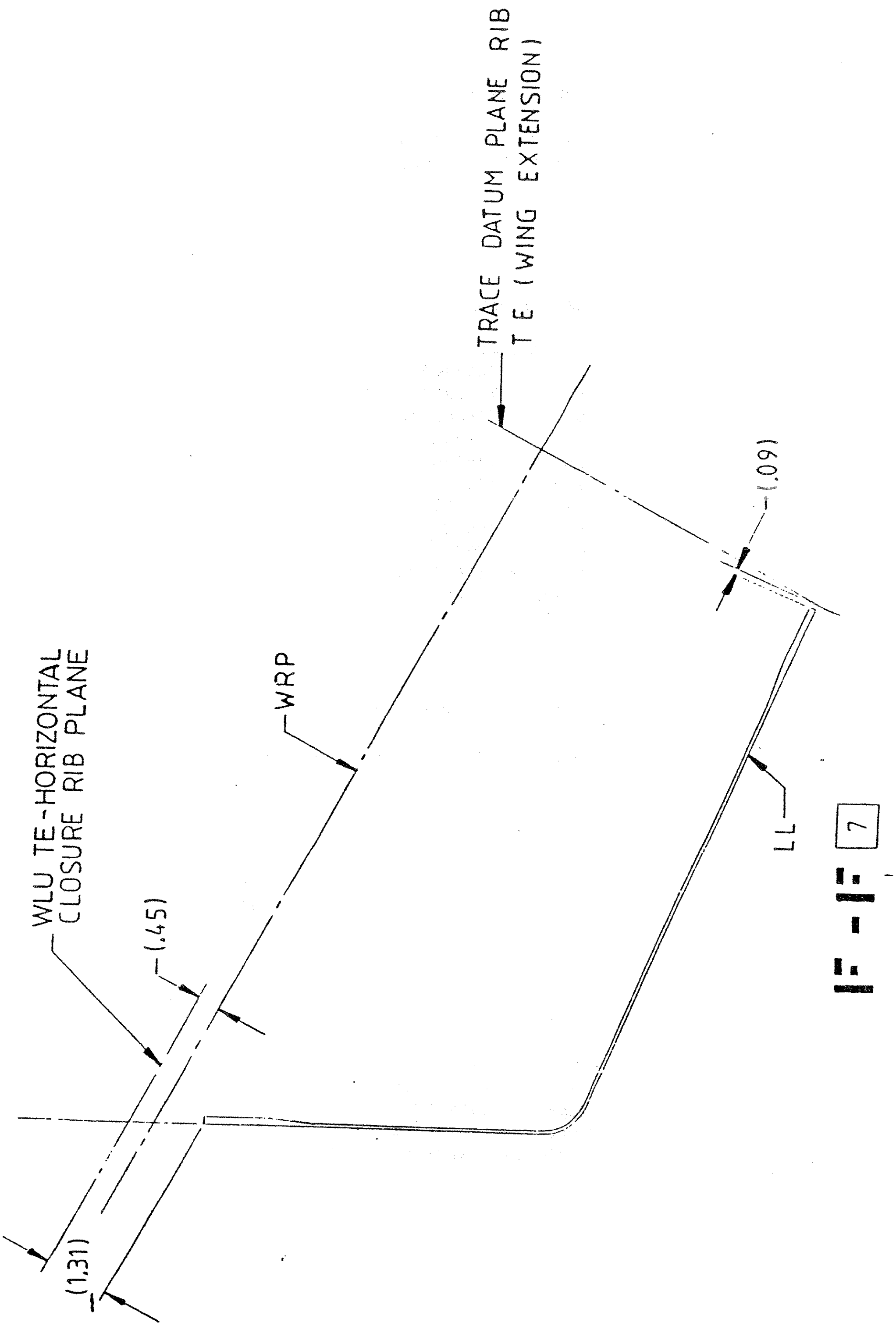
REPORT NO.: MDC-J7552

VOLUME NO.: IV

MCDONNELL DOUGLAS CORPORATION

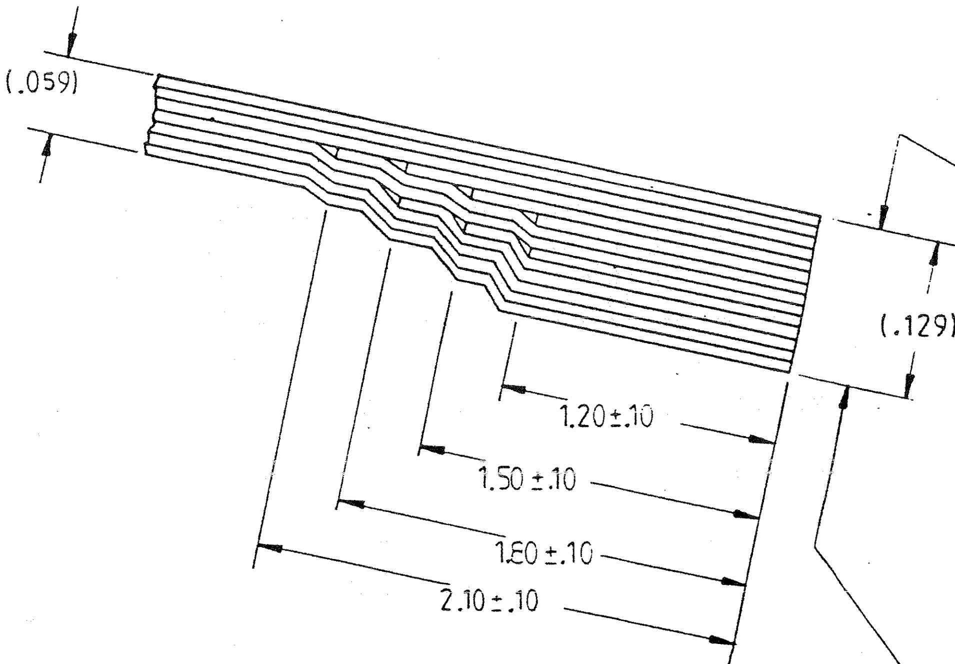
DWG ARB 7766

FAIRING ASSY T.E. LIGHT WING EXT.



FAIRING T.E. LIGHT WING EXTENSION

MAT'L MECHANICAL PROPERTIES 1



PLY Nº	DASH Nº	FIBER DIR
1	-3	±45°
2	-5	±45°
3	-7	±45°
4	-9	±45°
5	-11	±45°
6	-13	±45°
7	-15	±45°
8	-17	±45°
9	-19	±45°
10	-21	±45°
11	-23	±45°
12	-25	±45°
13	-27	±45°
14	-29	±45°

J - J 7

DIAGRAMMATIC ONLY
SCALE NONE

FIBER GLASS - PER DMS 2288, TYPE 3, CLASS 2
STYLE 1581 GRADE F THICK.$_{PLY}$ = .01" Nº 5 PLIES

FIBER GLASS - PER DMS 2288, TYPE 3, CLASS 2
STYLE 120 GRADE E THICK.$_{PLY}$ = .0045 Nº 2 PLIES

1 REF. 14

FAIRING T.E. LIGHT WING EXTENSION

MAT'L MECHANICAL PROPERTIES CONT'D

	STYLE 120		STYLE 1581		MIL HDBK	
	WARP (0°)	FILL (90°)	WARP (0°)	FILL (90°)	WARP (0°)	FILL (90°)
TENSION F_{tu}	30.8	29.4	37.8	30.1		
COMPRESSION F_{cu}	35.5	34.3	42.	33.6		
SHEAR F_{su}	10. 16.8 (± 45°)		11.9 19.6 (± 45°)			
MODULUS E_T	1960	1900	2240	2000		
MODULUS E_C	2240	2100	2450	2240		
MODULUS G	420 840 (± 45°)		350 980 (± 45°)			
BEARING F_{bru} (e/D=2)	-		30			

LAMINATE ROOM TEMPERATURE PROPERTIES (daN/mm^2)

FAIRING T.E. LIGHT WING EXTENSION

MAT'L MECHANICAL PROPERTIES CONT'D

	STYLE 120		STYLE 1581		MIL HDBK	
	WARP (0°)	FILL (90°)	WARP (0°)	FILL (90°)	WARP (0°)	FILL (90°)
TENSION F_{tU}	30.8	29.4	37.8	30.1		
COMPRESSION F_{CU}	35.5	34.3	42.	33.6		
SHEAR F_{SU}	10. 16.8 (± 45°)		11.9 19.6 (± 45°)			
MODULUS E_T	1960	1900	2240	2000		
MODULUS E_C	2240	2100	2450	2240		
MODULUS G	420 840 (± 45°)		350 980 (± 45°)			
BEARING F_{bru} (e/D=2)	-		30			

LAMINATE ROOM TEMPERATURE PROPERTIES (daN/mm^2)

	DMS 2288 Type 3, Class 2 Grade E, Style 120		DMS 2288 Type 3, Class 2 Grade F, Style 1581	
	WARP (0 deg)	FILL (90 deg)	WARP (0 deg)	FILL (90 deg)
Tension, F_{tu}	44.67 ksi	42.64 ksi	54.82 ksi	43.66 ksi
Compression, F_{CU}	51.49 ksi	49.75 ksi	60.91 ksi	48.72 ksi
Shear F_{su} (+/- 45)	24.36 ksi		28.43 ksi	
Shear F_{su} (0/90)	14.50 ksi		17.26 ksi	
Modulus, E_T	2.84 Msi	2.75 Msi	3.25 Msi	2.90 Msi
Modulus, E_C	3.24 Msi	3.04 Msi	3.55 Msi	3.25 Msi
Modulus, G	0.61 Msi		0.51 Msi	
F_{bru}	--	--	43.5 ksi	

FAIRING T.E. LIGHT WING EXTENSION

MAT'L MECHANICAL PROPERTIES CONT'D

	STYLE 120		STYLE 1581		MIL HDBK	
	WARP (0°)	FILL (90°)	WARP (0°)	FILL (90°)	WARP (0°)	FILL (90°)
TENSION F_{tu}	30.8	29.4	37.8	30.1		
COMPRESSION F_{cu}	35.5	34.3	42.	33.6		
SHEAR F_{su}	16.8 (10. ± 45°)		19.6 (11.9 ± 45°)			
MODULUS E_T	1960	1900	2240	2000		
MODULUS E_C	2240	2100	2450	2240		
MODULUS G	840 (420 ± 45°)		980 (350 ± 45°)			
BEARING F_{bru} (e/D=2)	-		30			

LAMINATE ROOM TEMPERATURE PROPERTIES (daN/mm^2)

	DMS 2288 Type 3, Class 2 Grade E, Style 120		DMS 2288 Type 3, Class 2 Grade F, Style 1581	
	WARP (0 deg)	FILL (90 deg)	WARP (0 deg)	FILL (90 deg)
Tension, F_{tu}	44.67 ksi	42.64 ksi	54.82 ksi	43.66 ksi
Compression, F_{cu}	51.49 ksi	49.75 ksi	60.91 ksi	48.72 ksi
Shear F_{su} (+/- 45)	24.36 ksi		28.43 ksi	
Shear F_{su} (0/90)	14.50 ksi		17.26 ksi	
Modulus, E_T	2.84 Msi	2.75 Msi	3.25 Msi	2.90 Msi
Modulus, E_C	3.24 Msi	3.04 Msi	3.55 Msi	3.25 Msi
Modulus, G	0.61 Msi		0.51 Msi	
F_{bru}	--	--	43.5 ksi	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND GENERAL COMMENTS

This document presents the structural analysis methods and associated material properties used to evaluate the structural response and failure of composite materials which are specified in this document. The composite material systems considered in the report are made up of aligned fibers held together by a matrix. The material systems considered in this report along with the fiber volume fraction on which the baseline properties are based upon are listed in Table 1.

Table 1. Composite Material Systems.

Mat Letter	Description	V_f (%)
A	AS4/3501-6 (carbon/epoxy) prepreg 350°F 100psi autoclave cure	58.0
B	AS4/EA9396C2 (carbon/epoxy) wet lay-up 190°F vacuum bag cure	44.0
D	IM6/3501-6 (carbon/epoxy) prepreg 350°F 100psi autoclave cure	58.0
G	T300/F913 (carbon/epoxy) prepreg 250°F 100psi autoclave cure	58.0
H	Kevlar 49/F913 (aramid/epoxy) prepreg 250°F 100psi autoclave cure	46.0
I	E-Glass/ F913 (glass/epoxy) prepreg 250°F 100psi autoclave cure	45.0
K	WT650/5250 (carbon/BMI) prepreg 350 100psi autoclave cure and 440 or 475 post cure	55.5
L	E7K8/AS4 (Carbon/epoxy) prepreg 300°F autoclave cure	58.0
T	Glass/EA9396C2 (carbon/epoxy) wet lay-up 200°F vacuum bag cure	45.1

The strength values reported as strains throughout this report are based specifically on certain laminate stiffnesses. **For any MS calculation, it is imperative that the structure stress and strain and failure stress and strain being compared be based upon the same stiffnesses and thicknesses.** For example, the stiffnesses used in a FEM to determine the structure strain should be based upon the same stiffnesses used to determine the failure strains that the FEM strains are compared to. See Section 3, for converting strains.

The properties in this report are for fiber patterns which have no more than 55% of the fibers in one direction and at least 10% of the fibers in the 0°, 45°, -45° and 90° directions.

This document presents RTA average values for stiffness properties and environmentally conditioned average, B-basis allowables and A-basis allowables for strength properties. Because of the brittle low strain to failure characteristics of composites, failure in just a relatively small region can initiate catastrophic failure of the whole structure. However, the one failure mode that involves significant amounts of deformation is the bearing failure mode. Thus, for non-bearing failure modes, A-basis allowables should be used for primary non-strength redundant composite structure. Because of the brittle low strain to failure characteristics of composites, primary structure should not be considered strength redundant unless proven otherwise. B-basis allowables may be used for any composite failure mode in secondary structure.

2. DEFINITIONS

2.1 Terminology

Terms used in this document are listed in Table 2.

Table 2. Definition of Terms.

Term	Definition	Ref.	Note
MS	Margin of Safety		
Orthotropic material	Anisotropic material which has $A_{16} = A_{26} = 0$		
Avg	Average		
SD	Standard deviation		
CoV	Coefficient of Variation = SD / Avg		
FAW	Fiber areal weight		
V_f	Fiber volume fraction		
ρ	Density		
t	Plate thickness		
t_{csk}	Countersunk thickness	7.3	
E_l	Lamina longitudinal modulus		1,2
E_t	Lamina transverse modulus		1,2
ν_{lt}	Lamina longitudinal-transverse poison's ratio		1,2
G_{lt}	Lamina longitudinal-transverse shear modulus		1,2
E_1	Laminate longitudinal modulus	3.2.1	1,2
E_2	Laminate transverse modulus	3.2.1	1,2
ν_{12}	Laminate longitudinal-transverse poison's ratio	3.2.1	1,2
G_{12}	Laminate longitudinal-transverse shear modulus	3.2.1	1,2
Ex	Laminate X direction modulus	3.2.1	1,2
Ey	Laminate Y direction modulus	3.2.1	1,2
νxy	Laminate X-Y poison's ratio	3.2.1	1,2
Gxy	Laminate X-Y shear modulus	3.2.1	1,2
R_m	Material conversion ratio	3	
R_{mf}	Material conversion ratio for fiber	3.1	
R_{mm}	Material conversion ratio for matrix	3.1	
R_{mn}	Material conversion ratio for poison's ratio	3.1	
R_r	Reference conversion ratio	3	
R_{me}	Conversion ratio for material failure strain to structure strain.	3.2.1	
R_{re}	Conversion ratio for structure strain to material failure strain.	3.2.1	
R_{ms}	Conversion ratio for material failure stress to structure stress.	3.2.2	
R_{rs}	Conversion ratio for structure stress to material failure stress.	3.2.2	
R_{env}	Environmental adjustment factor	4.1	
R_{bd}	Bearing ratio for hole diameter	7.1	
R_{bt}	Bearing ratio for thickness	7.1	
R_{bp}	Bearing ratio for hole pitch	7.1	
R_{blt}	Bearing ratio for bolt type	7.1	
R_{gap}	Bearing ratio for gaps	7.1	
R_{bcsk}	Bearing ratio for countersunk	7.1	
R_{end}	Bearing ratio for end edge distance	7.1	
R_{edg}	Bearing ratio for side edge distance	7.1	
R_{ds}	Bearing ratio for double shear	7.1	
R_{cure}	Vacuum rather than autoclave adjustment ratio		
R_{lcsk}	Loaded hole ratio for countersunk	7.2	
R_{le}	Loaded hole ratio for side edge distance	7.2	

Table 2 (continued).

Term	Definition	Ref.	Note
R_{ucsk}	Unloaded hole ratio for countersunk	7.2	
R_{ud}	Unloaded hole ratio for diameter	7.2	
R_{ue}	Unloaded hole ratio for side edge distance	7.2	
R_{uw}	Unloaded hole ratio for width	7.2	
K_{uieo}	Unloaded hole infinite plate elastic orthotropic stress concentration factor	2.1	
ε_{un}	Unnotched failure strain		
ε_{unl}	Unnotched longitudinal lamina failure strain	5	1,2
ε_{unt}	Unnotched transverse lamina failure strain	5	1,2
ε_{uns}	Unnotched shear lamina failure strain	5	1,2
F_{un}	Unnotched failure stress		
F_{unl}	Unnotched longitudinal lamina failure stress	5	1,2
F_{unt}	Unnotched transverse lamina failure stress	5	1,2
F_{uns}	Unnotched shear lamina failure stress	5	1,2
F_{crk}	Crack gross failure stress		
ε_{p}	Principal strain		1
ε_{by}	Bypass strain	7	1,2
ε_{uh}	Unloaded hole failure strain	7	1,2
ε_{oh}	Open hole failure strain		
ε_{fh}	Filled hole failure strain		
ε^{o}	Midplane strain		
f_{br}	Bearing stress	7	
τ_{t}	Transverse shear stress	7.3	2
F_{brl}	Loaded hole net-section failure stress	7.2	2
F_{pt}	Transverse shear failure stress for fastener pull-through	7.3	2
F_{br}	Bearing failure stress	7.1	2
P	Bolt hole pitch	7	
D	Bolt hole diameter	7	
W	Bolt hole effect strip width	7	
E	Edge distance	7	
se	Side edge distance	7	
ee	End edge distance	7	
n	Number of time ply pattern is repeated		
N	Number of test replicates		
A, a*	Designates ambient or RTA conditions		

*for cases when used as a subscript.

1. Added "t" or "c" subscripts refer to tension or compression, respectively
2. See comments below about added subscripts "a", "e", "m", "v" or "q"

$$K_{uieo} = 1 + \sqrt{2\left[\sqrt{\frac{E_x}{E_y}} - v_{xy}\right] + \frac{E_x}{G_{xy}}}$$

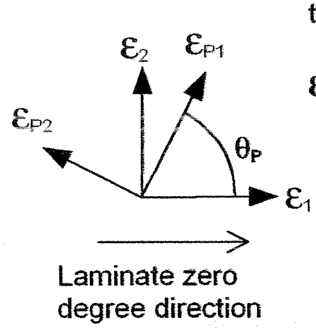
The last letter in a subscript of a material property term shall assign special meaning to the parameter it is a subscript for. If the last letter is "a", then the property is a "baseline" property from Section 5 through Section 7 that has not been adjusted for a material specification, an environmental condition or a structure stiffness or strain or any other variation from the baseline configuration. If the last letter is "e" then the property is an "environmental" property, which is determined by multiplying a baseline property by the appropriate R_{env} ratio in Table 4. If the last letter is "m" then property is a "material" property, which is determined by multiplying an environmental property by the appropriate R_m ratio in Table 3. If the last letter is "v" then the property is a "structural" property, which is determined by multiplying a material property by a R_{me} ratio calculated according to Section 3.2. If the last letter is not "a", "e", "m" or "v" then the property has been properly adjusted by all the appropriate factors and ratios so that it can be directly compared to the corresponding structure stress or stain in the MS calculation. A "q" on the end of a subscript designates the value for that term is a requirement for the parameter with the same subscript without the "q".

Figure 1 shows the laminate orientation and principal strains. The principal tension strain (ε_{pt}) is the maximum tension strain of ε_{P1} and ε_{P2}. The principal compressive strain (ε_{pc}) is the maximum compression strain of ε_{P1} and ε_{P2}.

$$\tan(2\theta_{Np}) = 2\,N_{12} \,/\, (N_1 - N_2) \qquad N_{p1,p2} = \frac{N_1+N_2}{2} \pm \sqrt{\left(\frac{N_1-N_2}{2}\right)^2 + N_{12}^2} \qquad N_{ps} = (N_{p1} - N_{p2})\,/\,2$$

$$\tan(2\theta_P) = \gamma_{12} \,/\, (\varepsilon_1 - \varepsilon_2)$$

$$\varepsilon_{P1,P2} = \frac{\varepsilon_1+\varepsilon_2}{2} \pm \sqrt{\left(\frac{\varepsilon_1-\varepsilon_2}{2}\right)^2 + \left(\frac{\gamma_{12}}{2}\right)^2}$$



For orthotropic laminates **only**:

$$\varepsilon_1 = \sigma_1 / E_1 - \sigma_2 \nu_{12} / E_2 \qquad \sigma_1 = \frac{\varepsilon_1 + \nu_{21}\varepsilon_2}{1-\nu_{12}\nu_{21}} E_1$$

$$\varepsilon_2 = \sigma_2 / E_2 - \sigma_1 \nu_{12} / E_1$$

$$\gamma_{12} = \tau_{12} / G_{12} \qquad \nu_{21} = E_2 \nu_{12} / E_1 \qquad \sigma_2 = \frac{\varepsilon_2 + \nu_{12}\varepsilon_1}{1-\nu_{12}\nu_{21}} E_2$$

Figure 1. Laminate orientation and principal strains and loads.

2.2 Environmental Conditions

The structure usually must be designed for environmental conditions. Cold dry (CD) involves the material having an equilibrium moisture content developed to at normal humidity and a temperature of -65°F. Hot wet (HW) involves the material having an equilibrium moisture content developed to at 85% relative humidity and a typical service temperature of 165°F. For fiber dominated in-plane failure modes, the critical environmental condition for tension is cold dry (CD) and for compression is hot wet (HW).

3. APPROPIATE STIFFNESS AND THICKNESS FOR FAILURE CHECKS

The properties reported in Section 5 through Section 7 are based specifically on certain laminate stiffnesses and thicknesses. These properties are called the "baseline" properties. **For any MS calculation, it is imperative that the structure stress and strain and failure stress and strain being compared be based upon the same stiffnesses and thicknesses. Thus, all properties in Section 5 through Section 7 should be multiplied by the appropriate material ratio, R_m or R_r.** If the stiffness and thickness used to determine the structure stress or strain are different than the stiffness and thickness used to determine the failure stress or strain, then the structure stress or strain or the failure stress or strain should be converted so that they are both based upon the same stiffnesses and thickness as shown below.

Baseline property * R_m = structure property or reference property * R_r = baseline property

An appropriate conversion should be done for each laminate stiffness and thickness definition that is checked for failure. For example, the stiffnesses and thicknesses used in a FEM to determine the structure strains should be based upon the same stiffnesses and thicknesses used to determine the failure strains that the FEM strains are compared to. The following section presents the formulas for R_m or R_r.

The lamina stiffnesses that determined the laminate stiffness, which all the baseline failure strains are based upon, are listed in Table 5. The fiber volume fraction which all the stiffness, failure strains and stresses are based upon are listed in Table 1

3.1 Specified Material Systems (DMS)

Composite material systems are specified by the Douglas material specifications (DMS). Unless specified otherwise, the baseline properties listed in Section 5 through Section 7 are based upon the specified V_f defined in Table 1. To convert the baseline properties to properties based upon other thickness, the baseline properties should be multiplied by the appropriate R_m values to convert the baseline properties to material properties. Table 3 lists R_m values for certain material specifications. Section 5 through Section 7 designates for each parameter whether to use the fiber (R_{mf}), matrix (R_{mm}) or pois (R_{mn}) ratio.

Table 3. Specified Material Systems and R_m Values.

Mat Spec.	Grade Class Type	Mat Let.	Material Type	Nom. Thk. (in)	FAW (g/m^2)	Vf	D_L (g/cm^3)	Fiber R_{mf}	Matrix R_{mm}	Pois R_{mn}
DMS1926	T3	IC	Cloth (120)	0.0045	104	0.355	1.728	0.815	1.152	1.017
DMS1926	T8	IC	Cloth (181)	0.0100	293	0.451	1.851	1.001	0.999	1.000
DMS1926	TK120	HC	Cloth (120)	0.0045	61	0.368	1.336	0.814	1.158	1.017
DMS1926	TK285	HC	Cloth (285)	0.0100	170	0.462	1.353	1.003	0.997	1.000
DMS2224	G1	AT	Tape	0.0035	95	0.597	1.580	1.028	0.962	0.997
DMS2224	G2	AT	Tape	0.0055	145	0.580	1.572	1.000	1.000	1.000
DMS2224	G3	AT	Tape	0.0072	190	0.580	1.572	1.001	0.999	1.000
DMS2224	G4	AC	Cloth (PW)	0.0075	193	0.566	1.564	0.977	1.032	1.003
DMS2224	G5	AC	Cloth (5HS)	0.0105	280	0.587	1.575	1.011	0.985	0.999
DMS2224	G6	AC	Cloth (8HS)	0.0138	370	0.590	1.577	1.016	0.978	0.998
DMS2224	G7	AT	Tape	0.0067	185	0.607	1.586	1.045	0.938	0.995
DMS2224	G8	AC	Twill	0.0105	280	0.587	1.575	1.011	0.985	0.999
DMS2224	G9	AC	Twill	0.0138	370	0.590	1.577	1.016	0.978	0.998
DMS2224	G10	AT	Tape	0.0100	280	0.616	1.590	1.060	0.919	0.993
DMS2279	T3,T5	KC	Cloth (8HS)	0.0145	366	0.555	1.559	1.000	1.000	1.000
DMS2288	GA	GT	Tape	0.0055	145	0.580	1.572	1.000	1.000	1.000
DMS2288	GB	GC	Cloth (PW)	0.0075	193	0.566	1.564	0.977	1.031	1.003
DMS2288	GC	GC	Cloth (5HS)	0.0105	280	0.587	1.575	1.011	0.985	0.999
DMS2288	GD	GC	Cloth (8HS)	0.0138	370	0.590	1.577	1.016	0.978	0.998
DMS2288	GE	IC	Cloth (120)	0.0045	104	0.355	1.728	0.815	1.152	1.017
DMS2288	GF	IC	Cloth (181)	0.0100	293	0.451	1.851	1.001	0.999	1.000
DMS2288	GG	HC	Cloth (120)	0.0045	61	0.368	1.336	0.814	1.158	1.017
DMS2288	GH	HC	Cloth (285)	0.0100	170	0.462	1.353	1.003	0.997	1.000
DMS2288	GI	GC	Twill	0.0105	280	0.587	1.575	1.011	0.985	0.999
DMS2288	GJ	GC	Twill	0.0138	370	0.590	1.577	1.016	0.978	0.998
DMS2322	G1	DT	Tape	0.0037	95	0.574	1.551	0.991	1.013	1.001
DMS2322	G2	DT	Tape	0.0056	145	0.579	1.554	0.999	1.002	1.000
DMS2322	G3	AC	Cloth (CF)	0.0073	186	0.560	1.561	0.967	1.044	1.004
DMS2337	GB	LT	Tape	0.0100	280	0.616	1.590	1.0597	0.919	0.993
DMS2337	GE	LC	Cloth (5HS)	0.0145	360	0.546	1.554	0.9435	1.077	1.006
DMS2386	GA	BC	Cloth (PW)	0.0097	193	0.438	1.498	0.995	1.004	1.000
DMS2386	GB	or	Cloth (5HS)	0.0140	280	0.440	1.499	1.000	1.000	1.000
DMS2386	GC	JC	Cloth (8HS)	0.0185	370	0.440	1.499	1.000	1.000	1.000
Glass Dry	181	TC	Cloth (181)	0.0100	293	0.451	1.851	1.001	0.999	1.000

3.2 Arbitrary Thickness and Stiffness

If the stiffness and thickness which the structure strains are based upon are not determined according to the method in this report, then the structure strains are considered arbitrarily related to V_f and the baseline strains in this report. If the stress and strain of the structure being analyzed are determined by some arbitrary thickness or stiffness, then the R_m or R_r values should be calculated according to the method described in this section. The formulas in this section are based upon the assumption that the load carrying capacity of the structure is determined on the basis of the representative thickness the material properties are based upon.

3.2.1 Stiffness and Strain Conversion

3.2.1.1 General

$$\begin{Bmatrix} N \\ M \end{Bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{Bmatrix} \varepsilon^o \\ \kappa \end{Bmatrix} \qquad \begin{Bmatrix} \varepsilon^o \\ \kappa \end{Bmatrix} = \begin{bmatrix} a & b \\ b & d \end{bmatrix} \begin{Bmatrix} N \\ M \end{Bmatrix} \quad \text{where} \quad \begin{bmatrix} a & b \\ b & d \end{bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix}^{-1}$$

$$\varepsilon = \varepsilon^o + z\,\kappa$$

For orthotropic laminates: $\kappa_X = d_{11} M_X + d_{12} M_Y$, $\kappa_y = d_{12} M_X + d_{22} M_Y$, $\kappa_{xy} = d_{66} M_{XY}$

Units: A: lb/in , B: in-lb/in , D: in-lb , a: in/lb , b: in/(in-lb) , d: 1/(in-lb) , κ_X: 1/in

3.2.1.2 Orthotropic Laminates

If the stiffnesses are given as matrix values of the matrices, **G** or **A**, then the matrix values can be converted to the normal stiffness properties by the following formula.

For the longitudinal-transverse direction of orthotropic material:

$E_1 = (A_{11} A_{22} - A^2_{12}) / (t A_{22})$, $E_2 = (A_{11} A_{22} - A^2_{12}) / (t A_{11})$, $\nu_{12} = A_{12} / A_{22}$, $G_{12} = A_{66} / t$

$G = A / t$; thus,

$E_1 = (G_{11} G_{22} - G^2_{12}) / G_{22}$, $E_2 = (G_{11} G_{22} - G^2_{12}) / G_{11}$, $\nu_{12} = G_{12} / G_{22}$, $G_{12} = G_{66}$

θ - Angle between laminate longitudinal axis and direction of the failure strain check

Ex_m - Stiffness used to determine material failure strain, εx_a

t_m - nominal thickness used in this document to determine the material failure stress or strain

Ex_S - Stiffness used to determine the structure strain, εx_S

t_S - nominal thickness used to determine the stress and strain level of the structure

$c = \cos(\theta)$, $s = \sin(\theta)$

For orthotropic material:

$$1/Ex = c^4/E_1 + (1/G_{12} - 2\nu_{12}/E_1) s^2c^2 + s^4/E_2$$

$$1/Ey = s^4/E_1 + (1/G_{12} - 2\nu_{12}/E_1) s^2c^2 + c^4/E_2$$

$$1/Gxy = 2\,(2/E_1 + 2/E_2 + 4\nu_{12}/E_1 - 1/G_{12})\, s^2c^2 + (1/G_{12})\,(s^4 + c^4)$$

$$\nu xy = Ex\,[\,\nu_{12}/E_1\,(s^4 + c^4) - (1/E_1 + 1/E_2 - 1/G_{12})\, s^2c^2\,]$$

Conversion from material strain (ε_m) to structure strain (ε_S).

$\varepsilon_{XS} = \varepsilon_{Xm}\,(E_{Xm} / E_{XS})\,(t_m / t_S) = R_{me}\,\varepsilon_{Xm}$ where "x" is the direction of the failure strain check.

Conversion from structure strain (ε_S) to material strain (ε_m).

$\varepsilon_{Xa} = \varepsilon_{XS}\,(E_{XS} / E_{Xm})\,(t_S / t_m) = R_{re}\,\varepsilon_{XS}$ where "x" is the direction of the failure strain check.

3.2.2 Thickness and Stress Conversion

Conversion from material stress (σ_m) to structure stress (σ_S).

$\sigma_S = \sigma_m\,(t_m / t_S) = R_{ms}\,\sigma_m$

Conversion from structure stress (σ_S) to material stress (σ_m).

$\sigma_m = \sigma_S\,(t_S / t_m) = R_{rs}\,\sigma_S$

4. GENERAL ADJUSTMENT RATIOS

4.1 Environmental (R_{env})

Unless stated otherwise, all reported strength values in this document are for RTA conditions. The RTA strength values are denoted by the last letter in the subscript which is an "a". When environmental conditions are to be considered the RTA strength values should be multiplied by the appropriate minimum R_{env} ratio which is the lowest for all the environmental condition to be considered. These values are listed in Table 12. As shown below, the "a" in the subscript for the strength values is changed to "e" for the environmentally adjusted strengths.

For stress $F_{xxxe} = R_{env} F_{xxxa}$ and for strain $\varepsilon_{xxxe} = R_{env}\, \varepsilon_{xxxa}$

Table 4. Environmental Adjustment Ratios (R_{env}).

Mat	Cnd.	Tmp (F)	F_{untl}	F_{untt}	F_{oht}	F_{uncl}	F_{unct}	F_{ohc}	F_{bry}	F_{bru}	F_{uns}	F_{ils}	F_{pty}	F_{ptu}
AT	CD	-65	0.905		0.94									
AC	CD	-65	0.927	0.927	0.94									
BC	CD	-65	0.849	0.849	0.960	1.385	1.385				1.262			
DT	CD	-65	0.870		1.000									
GT	CD	-65	0.927	0.927	0.966									
GC	CD	-65	0.891	0.891	0.966									
HC	CD	-65	0.889	0.889										
IC	CD	-65	0.891	0.891										
KC	CD	-65	0.960	0.960		1.047	1.047	1.094			1.002			
LT	CD	-65	0.940	0.927	0.950									
LC	CD	-65	0.923	0.923	0.950									
AT	CW	-65	1.00	1.00		0.968								
AC	CW	-65	1.00	1.00		0.933	0.933							
DT	CW	-65		1.00										
AT	AW	75												
AC	AW	75				0.882								
AT	HD	200												
AC	HD	200				0.793								
AT	HW	180	1.00	1.00		0.957		0.82	0.808	0.883	0.76		0.804	0.899
AC	HW	180	1.00	1.00		0.891	0.891	0.82	0.808	0.883	0.76		0.804	0.899
AT	HW	200										0.562		
AC	HW	200				0.496						0.562		
BC	HW	160	0.862	0.862	0.862	0.723	0.723	0.796			0.706			
DT	HW	160		1.00		0.809		*		0.978	0.76		0.771	0.887
GT	HW	160	0.958			0.714	0.64	0.770		0.888	0.726			
GC	HW	160	1.000	1.000		0.613	0.613	0.770		0.888	0.695			
HC	HW	160	0.930	0.930		0.534	0.534	0.67			0.653			
IC	HW	160	0.789	0.789	0.791	0.613	0.613	0.770		0.888	0.695			
KC	HW	325	0.843	0.843	0.860	0.626	0.626	*			0.747			
LT	HW	165	0.895			0.815	0.640	0.82			0.926			
LC	HW	165	0.933	0.933		0.726	0.726	0.80			0.820			
TC	HW	165	0.47	0.47	0.58	0.53	0.53	0.60			0.706			

"Typ" labels; "T"-tape, "C"-cloth
*See specific property section for environmental properties.

4.2 Honeycomb (R_{hnc})

The R_{hnc} factor is the adjustment ratio for the strength of skins that are cocured onto honeycomb. During the curing process such skins can have undulation induced into them as they dip into the cells of the honeycomb that supports them during the curing process. R_{hnc} values for prepreg and wet lay-up materials are plotted in Figure 2 versus the honeycomb skin thickness. These R_{hnc} values apply to the skin on the bag side. For all laminates which are not attached to honeycomb or precured prior to being attached to honeycomb the R_{hnc} ratio is 1.00.

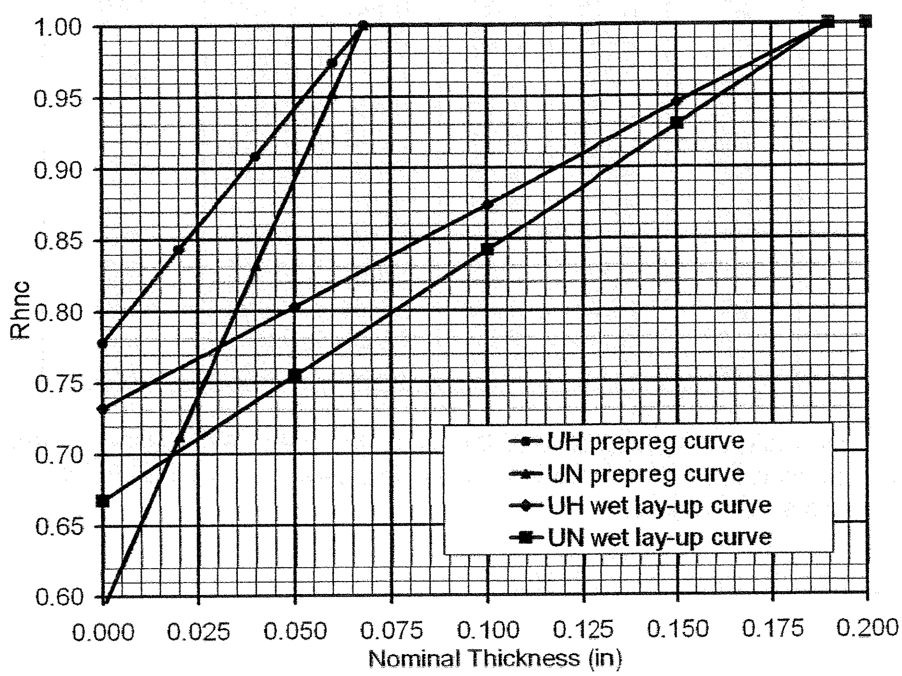


Figure 2. R_{hnc} Values.

5. UNNOTCHED LAMINA STRENGTH AND STIFFNESSES PROPERTIES

The lamina stiffnesses are listed in Table 5. The lamina RTA unnotched failure values are listed in Table 6. The lamina critical R_{env} are listed in Table 7. The lamina critical environment unnotched strengths are listed in Table 8.

The MS for the unnotched laminate strength is determined by comparing the principal strain to the lamina unnotched strength property as shown in the equation below. If the laminate has at least 10% of the fibers in all 45 degree intervals, then matrix failure should not be considered critical. Thus, for this case all shear strengths and tape transverse strengths do not need to be checked.

$MS = \varepsilon_{unt} / \varepsilon_{pt} - 1$ or $MS = \varepsilon_{unc} / \varepsilon_{pc} - 1$

For a specific material and associated thickness the material stiffness property is determined according to the formula below. The baseline stiffness property is listed in Table 5 and R_m is listed in Table 3.

Material stiffness property = baseline stiffness property * R_m

Table 5. Lamina RTA stiffnesses and thermal expansion coefficients.

Mat	E_l (msi)	E_t (msi)	G_{lt} (msi)	ν_{lt}	α_l (μin/in/°F)	α_t (μin/in/°F)
AT	19.76	1.41	0.50	0.340	0.40	20.0
AC	9.64	9.64	0.43	0.069	2.0	2.0
BC	7.35	7.35	0.351	0.066	2.0	2.0
DT	21.90	1.39	0.65	0.350	0.40	20.0
GT	17.68	1.41	0.500	0.324	0.40	20.0
GC	9.59	9.59	0.526	0.047	2.0	2.0
HC	4.44	4.44	0.270	0.034	0.0	0.0
IC	3.71	3.71	0.526	0.031	4.5	4.5
KC	9.55	9.55	0.842	.0448	2.0	2.0
LT	18.33	1.30	0.500	0.280	0.40	20.0
LC	9.70	9.70	0.526	0.049	2.0	2.0
TC	3.13	3.13	0.351	0.121	4.5	4.5

For a specific material and associated thickness the material baseline environmental failure property is determined according to the formulas below. The baseline ambient failure property is listed in Table 6 and R_{env} is listed in Table 4.

$\varepsilon_{une} = \varepsilon_{una} * R_{env}$, $F_{une} = F_{una} * R_{env}$

Table 6. Lamina RTA baseline unnotched failure values.

Mat	Stat.	Strain (με)					Stress (ksi)				
		ε_{untla}	ε_{untta}	ε_{uncla}	ε_{uncta}	ε_{unsa}	F_{untla}	F_{untta}	F_{uncla}	F_{uncta}	F_{unsa}
AT	Avg	11904	4156	11515	24674	26000	235.2	5.86	227.5	34.79	13.00
	B alw	10112	2444	9955	21831	17980	199.8	3.45	196.7	30.78	8.99
	A alw	8795	1248	8820	19846	12380	173.8	1.76	174.3	27.98	6.19
AC	Avg	11639	11639	12722	12722	28700	112.2	112.2	122.6	122.6	14.35
	B alw	9723	9723	10527	10527	21996	93.7	93.7	101.5	101.5	11.00
	A alw	8254	8254	8874	8874	17314	79.6	79.6	85.5	85.5	8.66
BC	Avg	11000	11000	7926	7926	66009	80.8	80.8	58.3	58.3	23.17
	B alw	8878	8878	6222	6222	62603	65.3	65.3	45.7	45.7	21.97
	A alw	7377	7377	5017	5017	60195	54.2	54.2	36.9	36.9	21.13
DT	Avg	12608	5147	12259	25332	20000	276.1	7.15	268.5	35.21	13.00
	B alw	11277	3488	10094	20614	13831	247.0	4.85	221.1	28.65	8.99
	A alw	10308	2313	8503	17332	9523	225.7	3.21	186.2	24.09	6.19
GT	Avg	16513	4156	9440	24674	27400	291.9	5.86	166.9	34.79	13.70
	B alw	15230	2447	8430	21830	25400	269.3	3.45	149.0	30.78	12.70
	A alw	14308	1248	7700	19844	24000	253.0	1.76	136.1	27.98	12.00
GC	Avg	13589	13589	10335	10335	31200	130.3	130.3	99.1	99.1	15.60
	B alw	12051	12051	9531	9531	27400	115.6	115.6	91.4	91.4	13.70
	A alw	10898	10898	8933	8933	25000	104.5	104.5	85.7	85.7	12.50
HC	Avg	14613	14613	6350	6350	54593	64.7	64.7	28.1	28.1	14.74
	B alw	13581	13581	5977	5977	44038	60.2	60.2	26.5	26.5	11.89
	A alw	12828	12828	5716	5716	36820	56.8	56.8	25.3	25.3	9.94
IC	Avg	13185	13185	20756	20756	29658	48.9	48.9	77.0	77.0	15.60
	B alw	11406	11406	18353	18353	26046	42.3	42.3	68.1	68.1	13.70
	A alw	10134	10134	16707	16707	23764	37.6	37.6	62.0	62.0	12.50
KC	Avg	13254	13254	9167	9167	16705	126.6	126.6	87.5	87.5	14.07
	B alw	11676	11676	7064	7064	15687	111.5	111.5	67.5	67.5	13.21
	A alw	10496	10496	5595	5595	14964	100.2	100.2	53.4	53.4	12.60
LT	Avg	12605	5377	11539	24077	25940	231.0	6.99	211.5	31.30	12.97
	B alw	11128	4200	9816	18769	21900	204.0	5.46	179.9	24.40	10.95
	A alw	10096		8515			185.1		156.1		
LC	Avg	12658	12658	11193	11193	27400	122.8	122.8	108.6	108.6	13.70
	B alw	11174	11174	9505	9505	19600	108.4	108.4	92.2	92.2	9.80
	A alw	10138	10138	8219	8219		98.3	98.3	79.7	79.7	
TC	Avg	14579	14579	11125	11125	44444	45.6	45.6	34.8	34.8	15.60
	B alw	13084	13084	9147	9147	39031	41.0	41.0	28.6	28.6	13.70
	A alw	12002	12002	7757	7757	35613	37.6	37.6	24.3	24.3	12.50
	Avg										
	B alw										
	A alw										

Notes for Table 6

Table 7 lists the most critical R_{env} ratio and the R_m ratio to be used with unnotched failure properties.

Table 7. Summary of R_{env} and R_m ratios for unnotched failure properties.

Mat	HW Temp (°F)	Parm.	E_l F_{untla} ε_{untla}	E_t F_{untta} ε_{untta}	E_l F_{uncla} ε_{uncla}	E_t F_{uncta} ε_{uncta}	G F_{unsa} ε_{unsa}	ν_{lt}	α_1	α_2
Any		R_m	Fiber	Matrix*	Fiber	Matrix*	Fiber*	pois	fiber	matrix
Any		R_m	Fiber	Fiber	Fiber	fiber	Fiber*	pois	fiber	fiber
AT	180	R_{env}	0.905	1.000	0.957	1.000	0.760			
AC	180	R_{env}	0.927	0.927	0.891	0.891	0.760			
BC	160	R_{env}	0.849	0.849	0.723	0.723	0.706			
DT	160	R_{env}	0.870	1.000	0.809	1.000	0.760			
GT	160	R_{env}	0.963	0.963	0.714	0.640	0.726			
GC	160	R_{env}	0.891	0.891	0.613	0.613	0.695			
HC	160	R_{env}	0.889	0.889	0.534	0.534	0.653			
IC	160	R_{env}	0.789	0.789	0.613	0.613	0.695			
KC	325	R_{env}	0.843	0.843	0.626	0.626	0.747			
LT	165	R_{env}	0.895	0.927	0.815	0.640	0.926			
LC	165	R_{env}	0.923	0.923	0.726	0.726	0.820			
TC	165	R_{env}	0.470	0.470	0.530	0.530	0.706			

*For stiffness use designated adjustment ratio, but for strength use 1.00 adjustment ratio.

It is recommended for laminates which have a fiber critical failure mode that the lamina average values be used for the matrix critical properties which are F_{tt}, F_{tc} and F_s for tape and F_s for cloth when used in the laminate analysis such as done in the STENGTH program. The Table 9 values follow these guidelines.

The Table 8 properties are determined by multiplying the appropriate Table 6 value by the appropriate R_{env} factor in Table 7.

For a specific material and associated thickness the design failure property is determined according to the formulas below. The baseline environmental failure property is listed in Table 8, R_m is listed in Table 3, R_{hnc} is listed in Section 4.2. For materials designated autoclave cure in Table 1, but are actually vacuum bag cured, R_{cure}=0.80 to account for a lower compressive strength due to vacuum bag cure, otherwise R_{cure}=1.00.

$\varepsilon_{un} = \varepsilon_{une} * R_{hnc} * R_{cure}$, $F_{un} = F_{une} * R_{hnc} * R_m * R_{cure}$

Table 8. Lamina critical environment unnotched failure values.

Mat	Stat.	Strain ($\mu\varepsilon$)					Stress (ksi)				
		ε_{untle}	ε_{untte}	ε_{uncle}	ε_{uncte}	ε_{unse}	F_{untle}	F_{untte}	F_{uncle}	F_{uncte}	F_{unse}
AT	Avg	10773	4156	11020	24674	19760	212.9	5.86	217.7	34.8	9.88
	B alw	9151	2444	9527	21831	13665	180.8	3.45	188.3	30.8	6.83
	A alw	7959	1248	8441	19846	9409	157.3	1.76	166.8	28.0	4.70
AC	Avg	10789	10789	11336	11336	21812	104.0	104.0	109.3	109.3	10.91
	B alw	9014	9014	9379	9379	16717	86.9	86.9	90.4	90.4	8.36
	A alw	7652	7652	7907	7907	13159	73.8	73.8	76.2	76.2	6.58
BC	Avg	9339	9339	5731	5731	46602	68.6	68.64	42.1	42.1	16.36
	B alw	7537	7537	4499	4499	44198	55.4	55.40	33.1	33.1	15.51
	A alw	6263	6263	3627	3627	42498	46.0	46.03	26.7	26.7	14.92
DT	Avg	10969	5147	9917	25332	15200	240.2	7.15	217.2	35.2	9.88
	B alw	9811	3488	8166	20614	10511	214.9	4.85	178.8	28.7	6.83
	A alw	8968	2313	6879	17332	7238	196.4	3.21	150.6	24.1	4.70
GT	Avg	15902	4002	6740	15791	19892	281.1	5.64	119.2	22.3	9.95
	B alw	14667	2356	6019	13971	18440	259.3	3.32	106.4	19.7	9.22
	A alw	13779	1202	5498	12700	17424	243.6	1.69	97.2	17.9	8.71
GC	Avg	12108	12108	6335	6335	21684	116.1	116.1	60.8	60.8	10.84
	B alw	10738	10738	5843	5843	19043	103.0	103.0	56.0	56.0	9.52
	A alw	9710	9710	5476	5476	17375	93.1	93.1	52.5	52.5	8.69
HC	Avg	12991	12991	3391	3391	35649	57.6	57.6	15.0	15.0	9.63
	B alw	12074	12074	3192	3192	28757	53.5	53.5	14.1	14.1	7.76
	A alw	11404	11404	3052	3052	24043	50.5	50.5	13.5	13.5	6.49
IC	Avg	10403	10403	12723	12723	20612	38.6	38.6	47.2	47.2	10.84
	B alw	8999	8999	11250	11250	18102	33.4	33.4	41.7	41.7	9.52
	A alw	7996	7996	10241	10241	16516	29.7	29.7	38.0	38.0	8.69
KC	Avg	11173	11173	5739	5739	12478	106.7	106.7	54.8	54.8	10.51
	B alw	9843	9843	4422	4422	11718	94.0	94.0	42.2	42.2	9.87
	A alw	8848	8848	3502	3502	11178	84.5	84.5	33.4	33.4	9.41
LT	Avg	11281	4984	9404	15409	24020	206.8	6.48	172.4	20.0	12.01
	B alw	9959	3893	8000	12012	20279	182.6	5.06	146.6	15.6	10.14
	A alw	9036		6940			165.6		127.2		
LC	Avg	11683	11683	8126	8126	22468	113.3	113.3	78.8	78.8	11.23
	B alw	10314	10314	6901	6901	16072	100.0	100.0	66.9	66.9	8.04
	A alw	9358	9358	5967	5967		90.8	90.8	57.9	57.9	
TC	Avg	6852	6852	5896	5896	31378	21.4	21.4	18.5	18.5	11.01
	B alw	6150	6150	4848	4848	27556	19.2	19.2	15.2	15.2	9.67
	A alw	5641	5641	4111	4111	25142	17.7	17.7	12.9	12.9	8.83

Notes for Table 8

The material stiffnesses and critical environment strength properties are listed in Table 9. These values were determined by multiplying the appropriate R_m factor designated in Table 3 by the appropriate value in Table 5 or Table 8.

For a specific design, material and associated thickness the design failure property is determined according to the formulas below. The specified material failure property is listed in Table 9 and R_{hnc} is listed in Section 4.2.

$F_{unt} = F_{unte} * R_{hnc}$, $F_{unc} = F_{unce} * R_{hnc}$

Table 9. Material Stiffness and Critical Environment B-alw Strength Properties.

DMS	Grade Type Class	Mat	E_l (msi)	E_t (msi)	G_{lt} (msi)	V_{lt}	F_{untle} (ksi)	F_{untte} (ksi)	F_{uncle} (ksi)	F_{uncte} (ksi)	F_{unse} (ksi)
1926	T3	IC	3.02	3.02	0.606	0.032	39.9	39.9	49.8	49.8	10.84
1926	T8	IC	3.71	3.71	0.525	0.031	39.9	39.9	49.8	49.8	10.84
1926	TK120	HC	3.62	3.62	0.313	0.035	43.6	43.6	11.5	11.5	9.63
1926	TK285	HC	4.45	4.45	0.269	0.034	53.7	53.7	14.1	14.1	9.63
2224	G1	AT	20.32	1.36	0.481	0.339	185.9	5.86	193.6	34.8	9.88
2224	G2	AT	19.76	1.41	0.500	0.340	180.8	5.86	188.3	34.8	9.88
2224	G3	AT	19.77	1.41	0.500	0.340	180.9	5.86	188.4	34.8	9.88
2224	G4	AC	9.42	9.42	0.444	0.069	84.87	84.87	88.29	88.29	10.91
2224	G5	AC	9.74	9.74	0.424	0.069	87.84	87.84	91.38	91.38	10.91
2224	G6	AC	9.80	9.80	0.421	0.069	88.3	88.3	91.86	91.86	10.91
2224	G7	AT	20.66	1.32	0.469	0.338	189	5.86	196.9	34.8	9.88
2224	G8	AC	9.74	9.74	0.424	0.069	*86.9*	*86.9*	*90.4*	*90.4*	*10.91*
2224	G9	AC	9.80	9.80	0.421	0.069	*86.9*	*86.9*	*90.4*	*90.4*	*10.91*
2224	G10	AT	20.94	1.30	0.460	0.338	191.6	5.86	199.5	34.8	9.88
2279	T3,T5	KC	9.55	9.55	0.842	0.045	94.0	94.0	42.2	42.2	10.51
2288	GA	GT	17.68	1.41	0.500	0.324	259.2	5.64	106.4	22.3	9.95
2288	GB	GC	9.37	9.37	0.543	0.047	100.6	100.6	54.69	54.69	10.84
2288	GC	GC	9.69	9.69	0.518	0.047	104.1	104.1	56.61	56.61	10.84
2288	GD	GC	9.75	9.75	0.514	0.047	104.7	104.7	56.91	56.91	10.84
2288	GE	IC	3.02	3.02	0.606	0.032	39.9	39.9	49.8	49.8	10.84
2288	GF	IC	3.71	3.71	0.525	0.031	39.9	39.9	49.8	49.8	10.84
2288	GG	HC	3.62	3.62	0.313	0.035	43.6	43.6	11.48	11.48	9.63
2288	GH	HC	4.45	4.45	0.269	0.034	53.7	53.7	14.15	14.15	9.63
2288	GI	GC	9.69	9.69	0.518	0.047	104.1	104.1	56.61	56.61	10.84
2288	GJ	GC	9.75	9.75	0.514	0.047	104.7	104.7	56.91	56.91	10.84
2322	G1	DT	21.69	1.41	0.658	0.350	212.9	7.15	177.1	35.2	9.88
2322	G2	DT	21.87	1.39	0.651	0.350	214.6	7.15	178.6	35.2	9.88
2322	G3	AC	9.33	9.33	0.449	0.069	84.06	84.06	87.45	87.45	10.91
2337	GB	LT	19.42	1.19	0.460	0.278	193.5	6.5	155.4	20.0	12.01
2337	GE	LC	9.15	9.15	0.566	0.049	94.3	94.3	63.1	63.1	11.23
2386	GA	BC	7.31	7.31	0.352	0.066	55.11	55.11	32.93	32.93	16.36
2386	GB	BC	7.35	7.35	0.351	0.066	55.39	55.39	33.09	33.09	16.36
2386	GC	BC	7.35	7.35	0.351	0.066	55.39	55.39	33.09	33.09	16.36
WtLyUp Glas	181	TC	3.13	3.13	0.351	0.121	19.2	19.2	15.2	15.2	9.67

6. INTERLAMINAR STRENGTHS

This section defines strengths for failure modes that can be directly determined from basic interlaminar properties of the composite.

Table 10. Interlaminar Shear Strength (F_{ilsa}) (ksi)

Mat	Avg.	B alw	A alw
AT	10.47	8.96	7.83
AC	10.47	8.96	7.83

$$F_{ilse} = R_{env} F_{ilsa}$$

7. HOLES

Bolt holes can fail by either pull-through, tear out, shear out, bearing, net-section tension or net-section compression. This section describes the method for determining the allowables for the pull-through, bearing, net-section tension and net-section compression failures.

Figure 3 shows the bolt hole orientation relative to the principal strain axis and the laminate "X" direction which in Figure 3 is defined by the zero degree fiber direction. The principal bypass strain (ε_P) shown in Figure 3 is used in checking the strength of the bolt hole. For uniaxial loading conditions, the directions of the bearing and bypass load are parallel as shown in Figure 3. In these uniaxial loading conditions the bearing load is reacted uniaxially and the effective bypass load is the axial load on the opposite side of the bearing load reaction as shown in Figure 3. For cases that are essentially uniaxial, the principal strain on the bypass load side should be a conservative and fairly accurate estimate of the effective bypass strain for the bolt hole. The bolt hole geometrical parameters used in this section are defined in Figure 4.

If an finite element model which models the bolts by individual bar elements is used to determine bolt loads, the average strain of the elements on the bypass side of the bar element representing the bolt should be used as the estimate for the bypass strain. Also, when estimating bypass strains from elements caution should be used when using small element sizes to the extent that more than two element exist between bolt holes. In such cases the strains of the elements right next to the bar element can be much higher than the average bypass strain level.

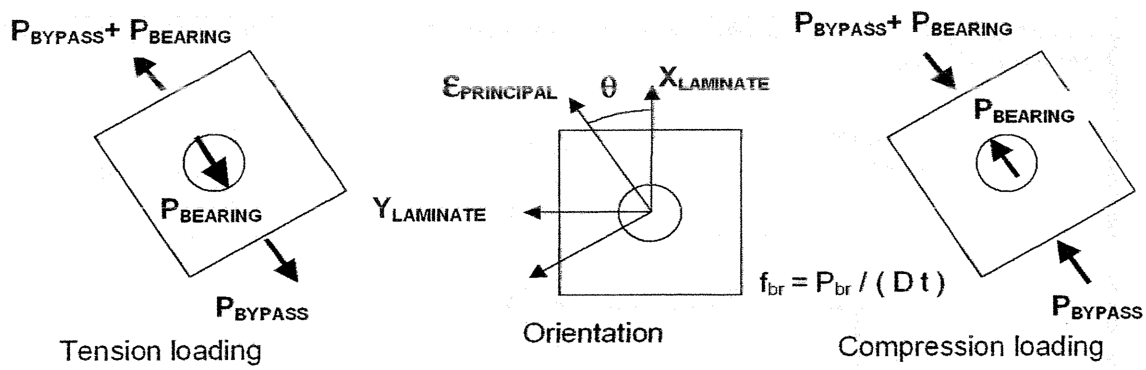


Figure 3. Bolt hole orientation and loading.

For determining R_{ue}, R_{uw} and R_{le} use the following values:
For side edge hole No.1: $W_1=(P_1/2)+se$. If $2se<P_1$ then $E=se$ else $E=P_1/2$.
For in-between hole No.2: $W_2=(P_1+P_2)/2$. If $P_2<P_1$ then $E=P_2/2$ else $E=P_1/2$.

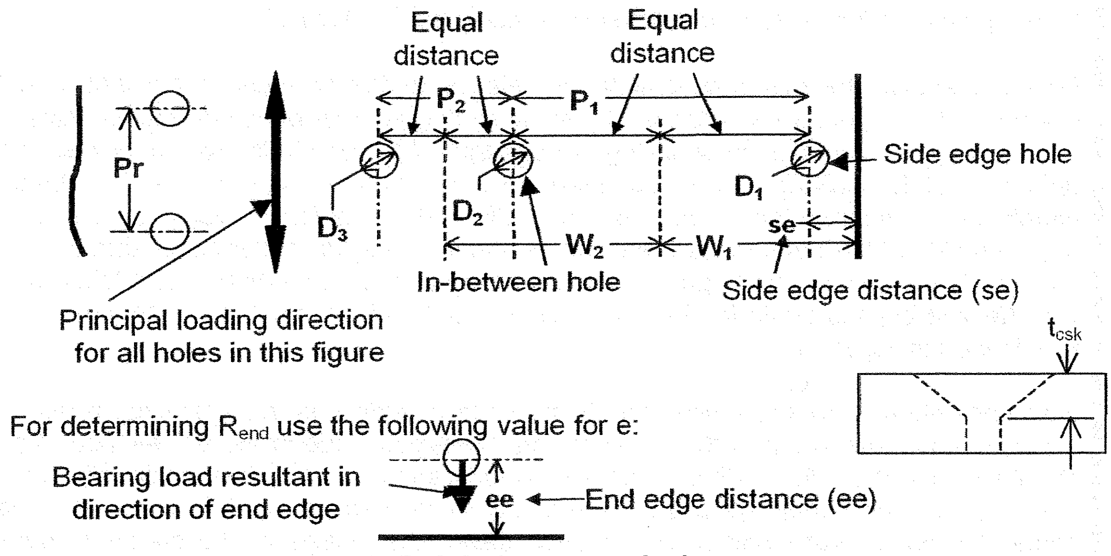


Figure 4. Bolt hole geometrical parameters.

Determining the bolt hole allowable load involves constructing the bearing bypass failure envelope shown in Figure 5.

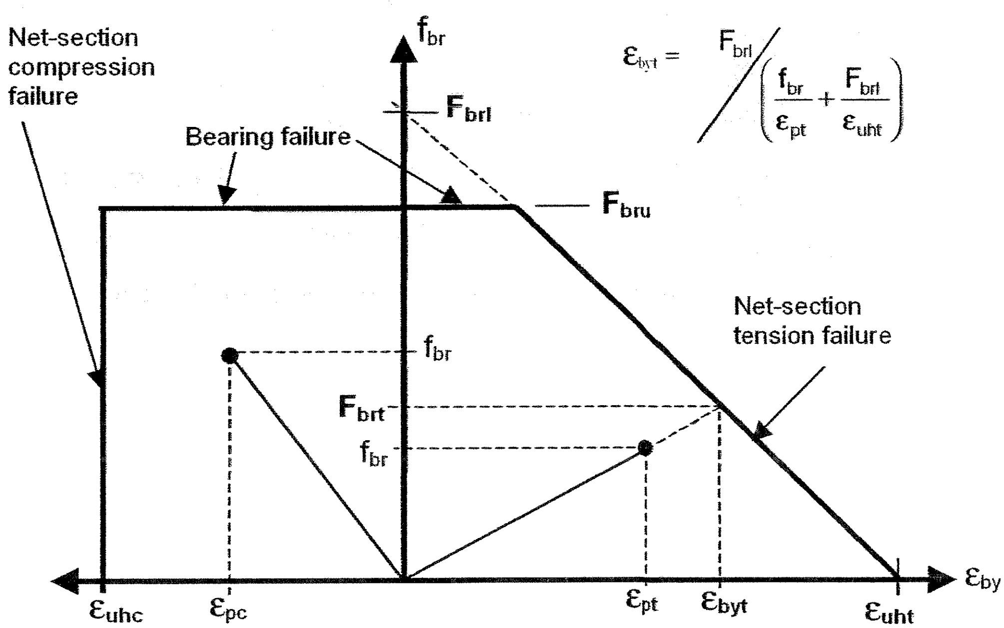


Figure 5. Bearing-tension bypass interaction chart.

The F_{bru} value is obtained from Section 7.1. The net-section strength values (ε_{uht},ε_{uhc},F_{brl}) are obtained from Section 7.2.

The margin of safety (MS) is determined by comparing either the bearing stress (f_{br}) or principal bypass strain (ε_p) to their failure values as shown below.

Net-Section Tension: $MS = \varepsilon_{byt} / \varepsilon_{pt} - 1$

Net-Section Compression: $MS = \varepsilon_{uhc} / \varepsilon_{pc} - 1$

Bearing: $MS = F_{bru} / f_{br} - 1$

If the bolt hole bearing load is more than 5 degrees off from the direction of the principal bypass loading direction, then two bolt hole net-section strength checks should be performed. The strength should be checked in the direction of the bearing load resultant and in the direction of the principal bypass load. In both checks the maximum bypass strain and the bearing load resultant should be compared to their corresponding failure strengths.

The above net-section failure values are for the midplane strain. According to test results, the ½ hole bending strength is the same as the unnotched bending strength; thus, the net-section bending strength should be based upon the unnotched strength. Thus, the most critical surface strain (s) due to just bending should be compared to the unnotched failure strain. The combined bending and midplane strength check is shown below.

Net-Section Tension: $MS = 1 / [\, \varepsilon^{0}_{pt} / \varepsilon_{byt} + (\varepsilon^{s}_{pt} - \varepsilon^{0}_{pt}) / \varepsilon_{unt} \,] - 1$

Net-Section Compression: $MS = 1 / [\, \varepsilon^{0}_{pc} / \varepsilon_{uhc} + (\varepsilon^{s}_{pc} - \varepsilon^{0}_{pc}) / \varepsilon_{unc} \,] - 1$

7.1 Bearing Strengths

The bearing strength should be determined according to the formula below. The bearing strength (F_{bru}) is obtained from this Section by adjusting the baseline strength (F_{brua}) by the appropriate adjustment ratios shown in the formulae below. The baseline strength can be determined for any laminate from the information in Section 7.1.2. The values for the adjustment ratios can be determined from the information in Section 7.1.1.

$$F_{bru} = R_{env} R_{mf} R_{bd} R_{bt} R_{bp} R_{blt} R_{gap} R_{bcsk} R_{end} R_{edg} R_{ds} R_{cure} F_{brua}$$

R_{edg}=1.00 for se/D≥3.0, R_{edg}<1.00 for se/D<3.0

To prevent hole wear under fatigue loading, a maximum value of 75ksi shall be used for F_{bru}, for structure that will have to endure fatigue loads.

7.1.1 Bearing Adjustment Ratios

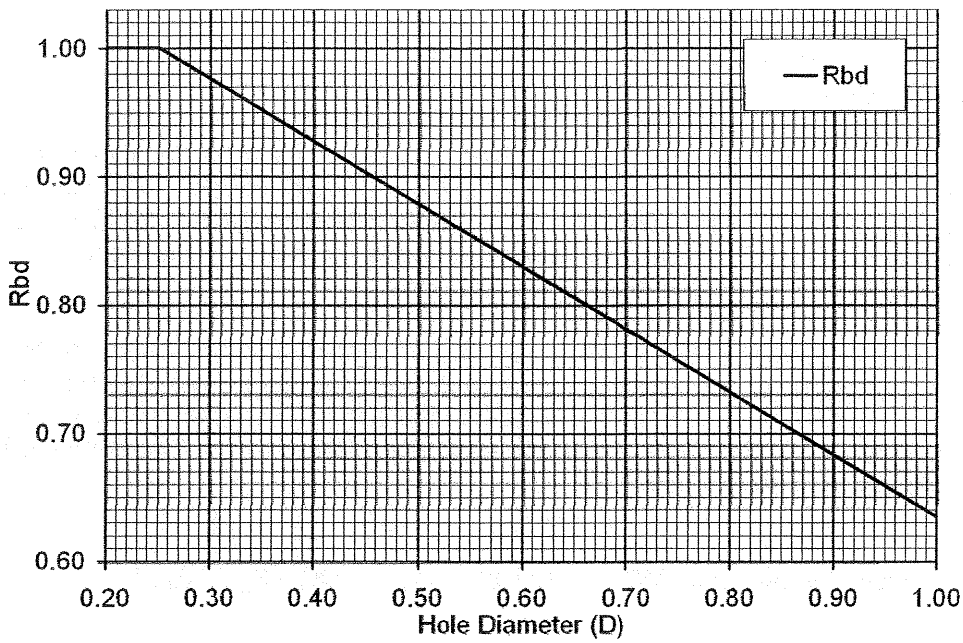


Figure 6. Rbd curve.

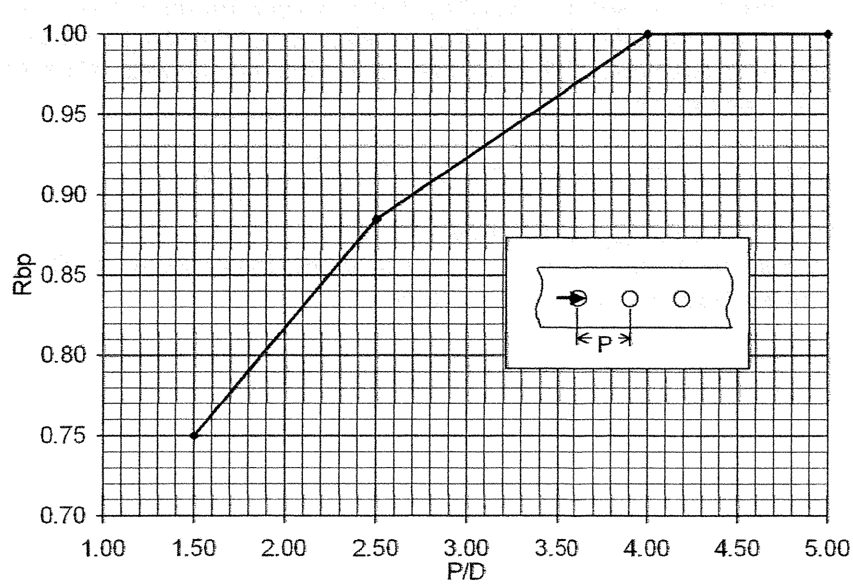


Figure 7. R_{bp} curve.

Table 11. Values for R_{blt}.

Bolt Type	R_{blt}
Bolts	1.00
Hi-Locks	1.00
Bigfoot Jo-bolts (composi locks)	0.73
Standard Jo-bolts	0.66

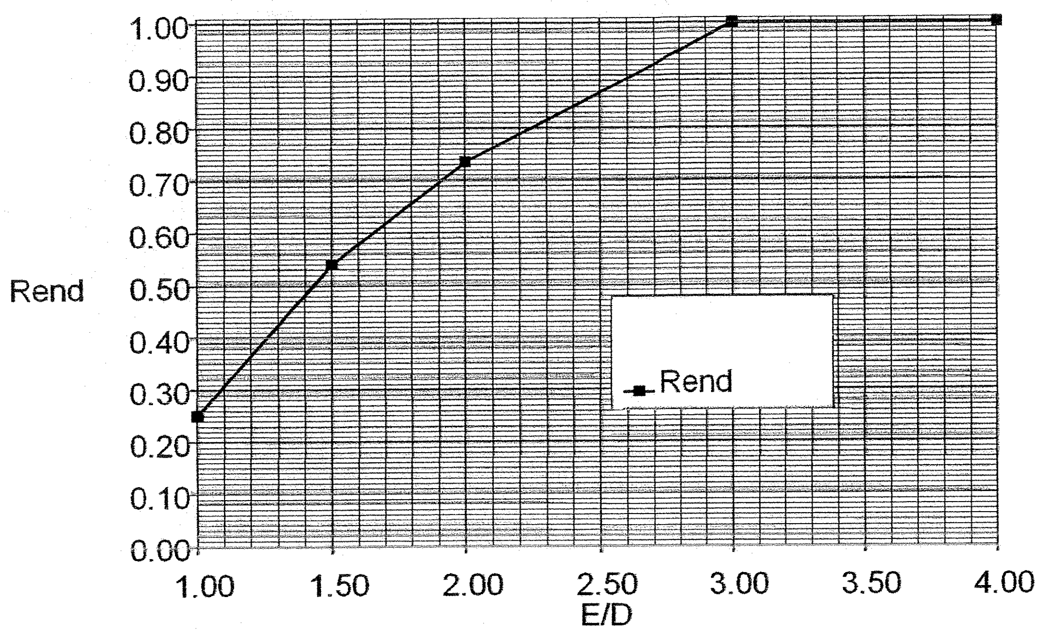


Figure 8. Curves for R_{end}.

Interpolation should be used to determine R_{edg} values in the countersunk percentage range of 0%-67%.

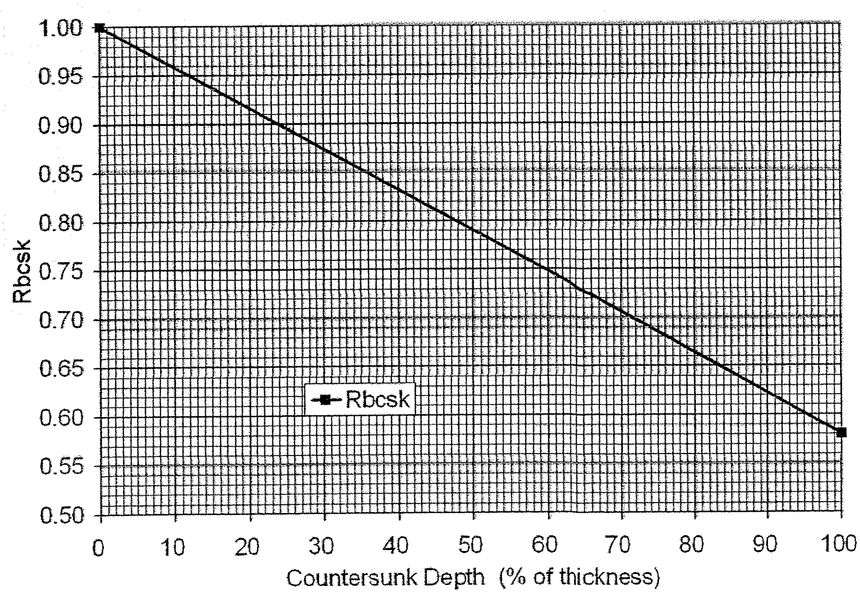


Figure 9. Curves for R_{bcsk}.

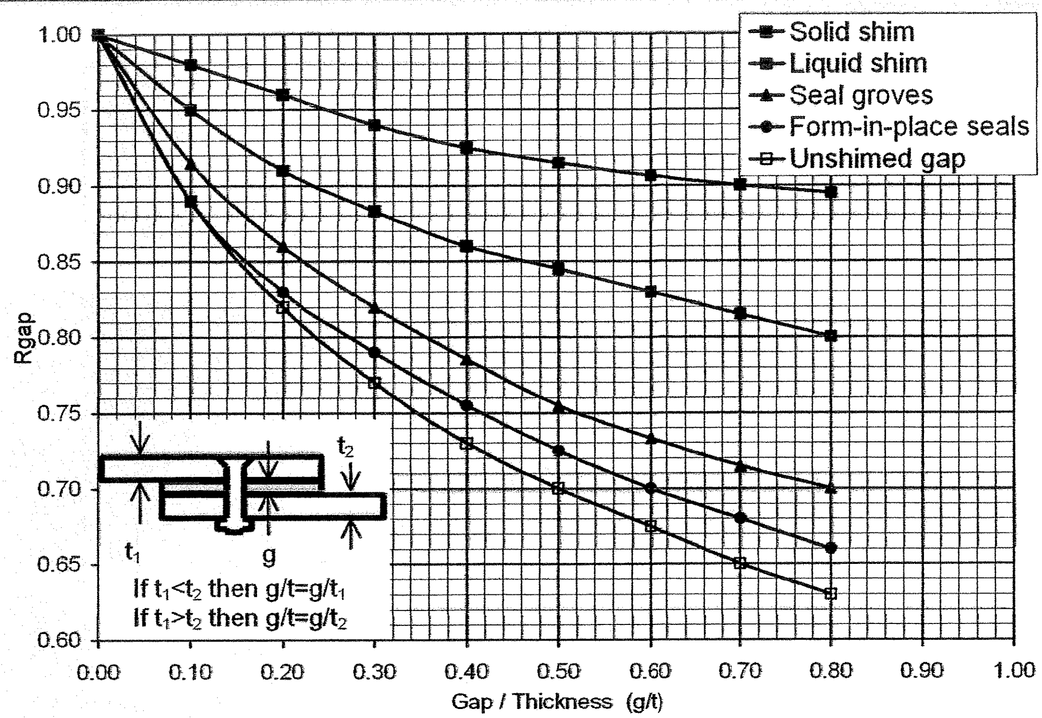


Figure 10. Curves for R_{gap}.

For single shear cases use the values plotted in Figure 10. For double shear cases where the gap exist on just one side, use an average of 1.00 and the value plotted in Figure 10.

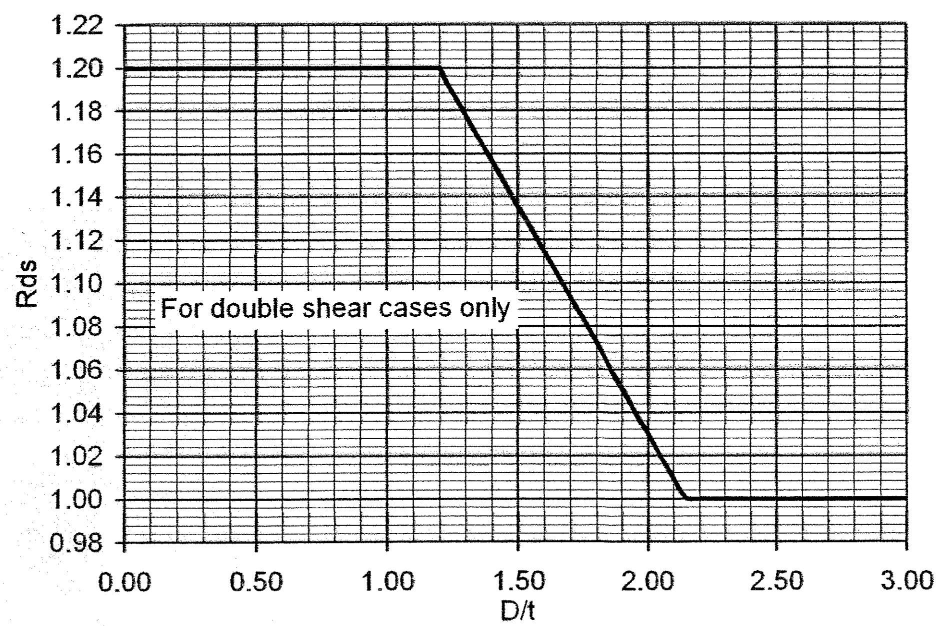


Figure 11. Curve for R_{ds}

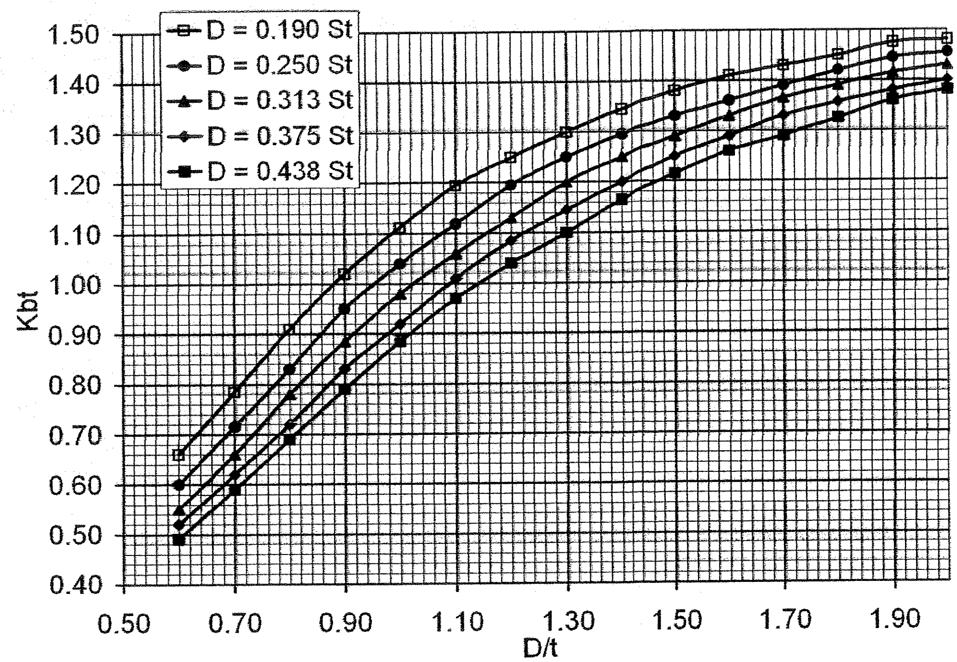


Figure 12. R_{bt} curves for steel fasteners.

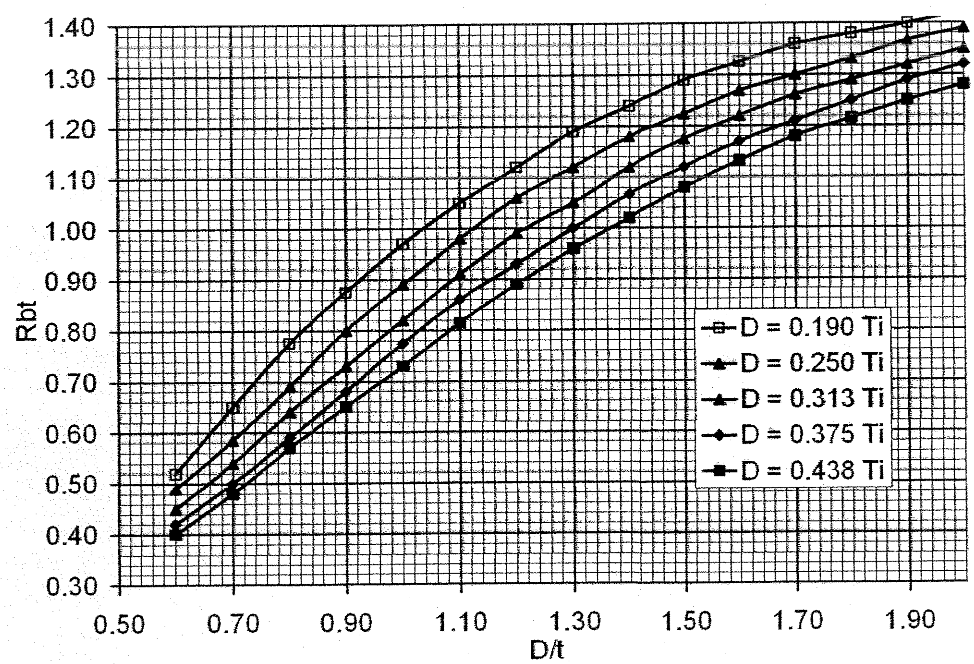


Figure 13. R_{bt} curves for titanium fasteners.

7.1.2 Bearing Baseline Strength

The baseline bearing strengths are listed in Table 12. The Table 12 baseline configuration is D=0.25, Csk.=0%, single shear protruded head and Env.=RTA. These strengths are based upon a class IV hole size.

Table 12. Baseline Bearing Strengths (ksi).

Mat	Grade	Cnf.	Average		B allowable		A allowable	
			F_{brya}	F_{brua}	F_{brya}	F_{brua}	F_{brya}	F_{brua}
A	Any	SS				97.4		
B	Cloth	SS				87.7		
D	Tape	SS				88.3		
G	Any	SS				91.9		

7.2 Net-Section Strength

The net-section strength values (ε_{uht}, ε_{uhc}, F_{brl}) are obtained from this section by adjusting the baseline strengths (ε_{uhta}, ε_{uhca}, F_{brla}) by the appropriate adjustment ratios shown in the formulas below. The baseline strength can be determined for any laminate from the information in Section 7.2.2. The values for the adjustment ratios can be determined from the information in Section 7.2.1. The R_{env} for F_{brl} should be the R_{env} for ε_{uht}.

$F_{brl} = R_{hnc} R_{mf} R_{env} R_{lcsk} R_{le} * R_{cure} F_{brla}$

$\varepsilon_{uht} = R_{hnc} R_{env} R_{ucsk} R_{ud} R_{ue} R_{uw} * R_{cure} \varepsilon_{uhta}$

$\varepsilon_{uhc} = R_{hnc} R_{env} R_{ucsk} R_{ud} R_{ue} R_{uw} * R_{cure} \varepsilon_{uhca}$

If the hole is open then $\varepsilon_{uhta} = \varepsilon_{ohta}$ and $\varepsilon_{uhca} = \varepsilon_{ohca}$.

If the hole is filled by a bolt $\varepsilon_{uhta} = \varepsilon_{fhta}$ and $\varepsilon_{uhca} = \varepsilon_{fhca}$.

If no value for ε_{fh} then assume it is equal to ε_{oh}.

7.2.1 Net-Section Adjustment Ratios

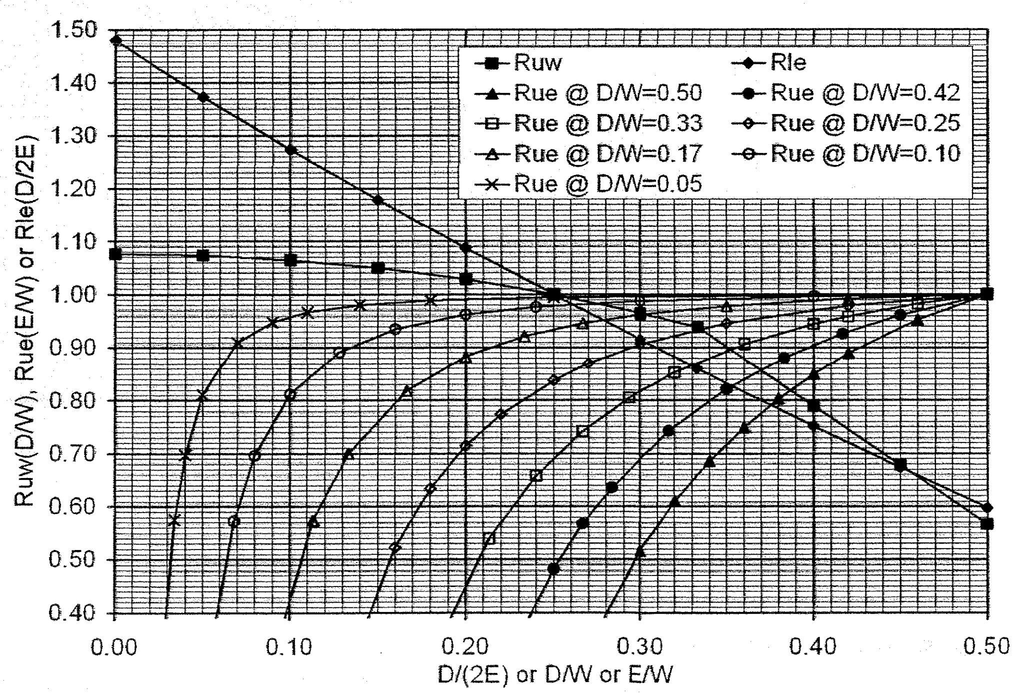


Figure 14. R_{uw}, R_{ue} & R_{le} curves.

For cases where D/W>0.05, use the $R_{ue@D/W=0.05}$ values and use (E/D)*0.05 for E/W. R_{le} is a function of D/2E. R_{uw} is a function of D/W. R_{ue} is a function of E/W, but also depends upon D/W.

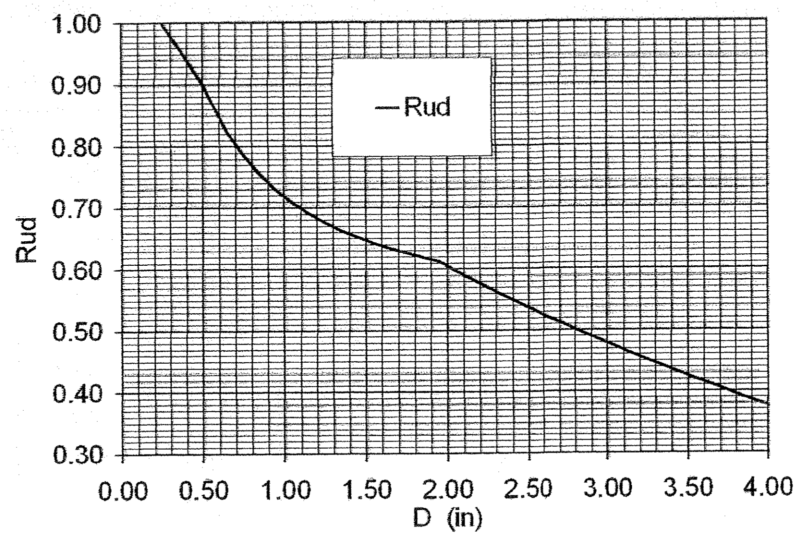


Figure 15. R_{ud} curve for D≥0.25.

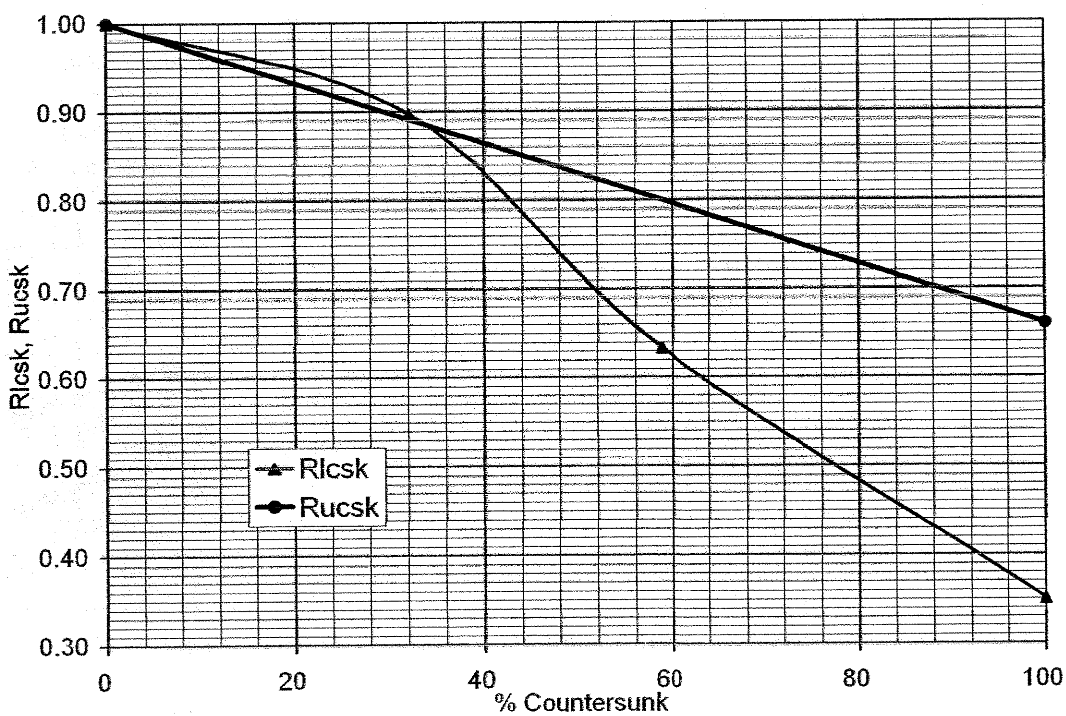


Figure 16. R_{ucsk} & R_{lcsk} curves.

7.2.2 Net-Section Baseline Strength

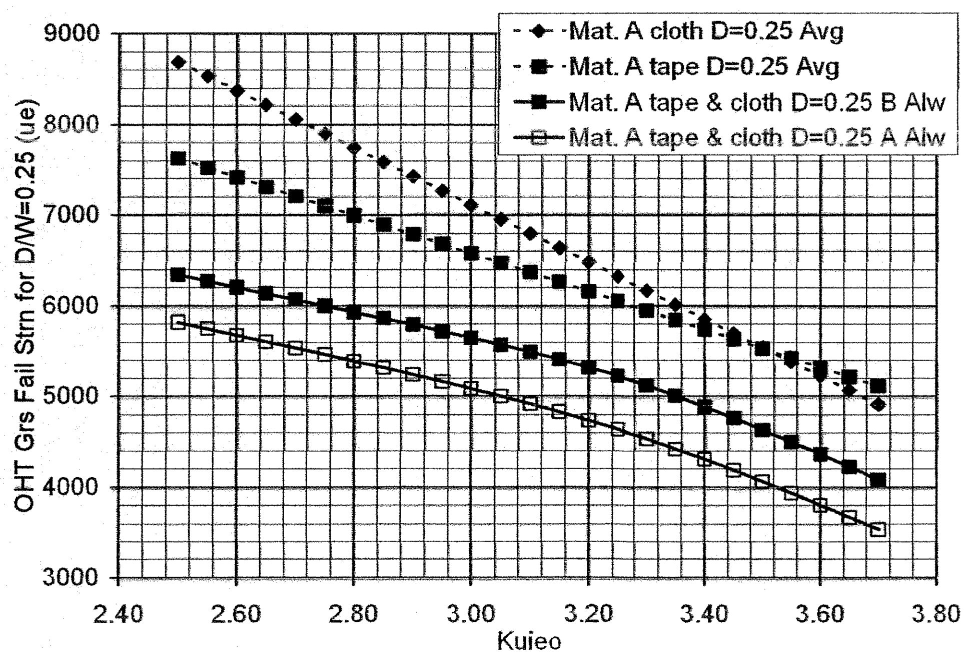
The general curves in this section can be used to determine any baseline bolt-hole net-section strength for the designated material system. The curves are a function of K_{uieo} which is defined in Section 2.1. All plots in this section are based on the gross-section stress and D/W=0.25; thus, they represent baseline strengths. The substantiation for the net-section baseline strength curves are given in the corresponding section for the specific material system.

Table 13 list the baseline net-section strengths which do not vary with K_{uieo}.

Table 13. Constant Net-Section Baseline Strength (με).

Mat	Prm.	Tension			Compression		
		Avg	B Alw	A Alw	Avg	B Alw	A Alw
DT	ε_{oha}	6851	5619	4721			
BC	ε_{oha}	5170	4173	3467	5001	3926	3165
HC	ε_{oha}	9336	7938	6982	5770	4709	3975
IC	ε_{oha}	7911	6844	6080	12453	11012	10024
KC	ε_{oha}	7484	6610	6227	7814	6610	6227
KC	ε_{ohe}				3873	3316	2910
LT	ε_{oha}	8087	6709	5766	6462	5497	4768
LC	ε_{oha}	6974	5786	4972	6268	5323	4603
TC	ε_{oha}	9098	8165	7489	9089	7473	6338

7.2.2.1 Unloaded-Hole Net-Section Tension Curves (ε_{uhta})



For K_{uieo} values where no cloth curve exists, use the tape curve for cloth.

Figure 17. General Curves for Mat A ε_{ohta}.

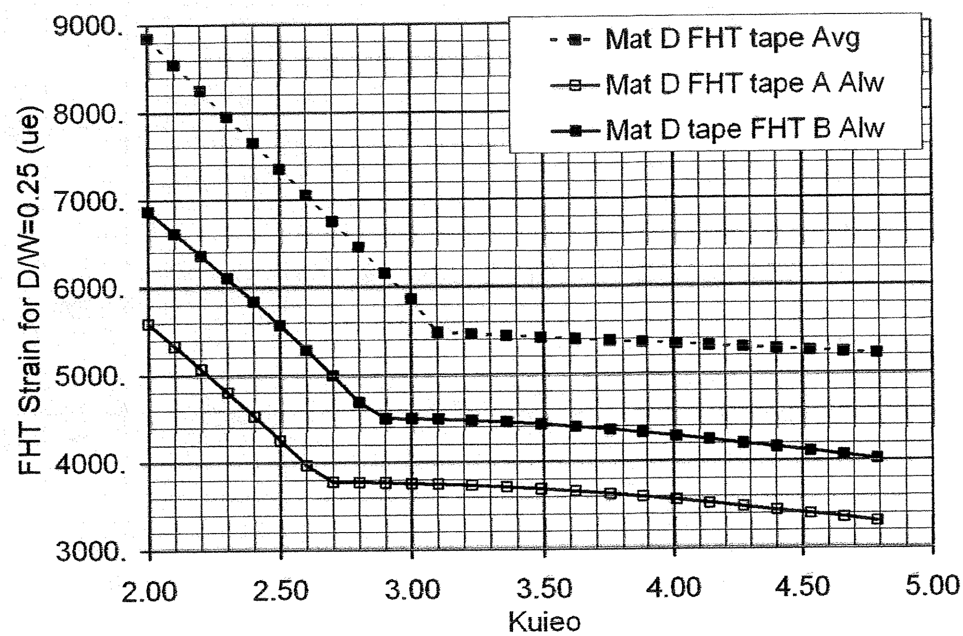


Figure 18. General Curves for Mat DT ε_{fhta}.

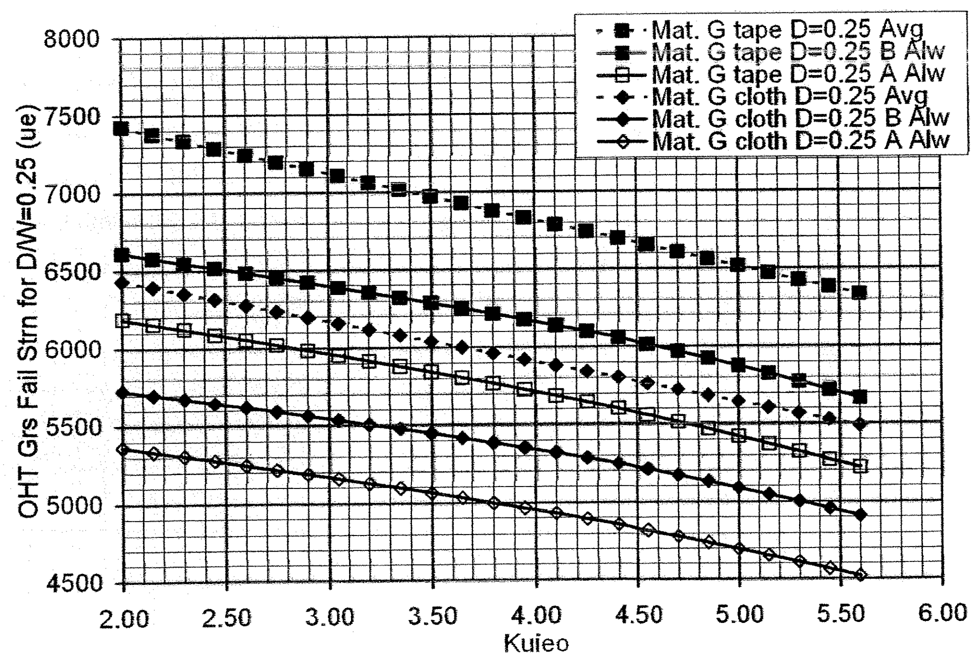


Figure 19. General Curves for Mat G ε_{ohta}.

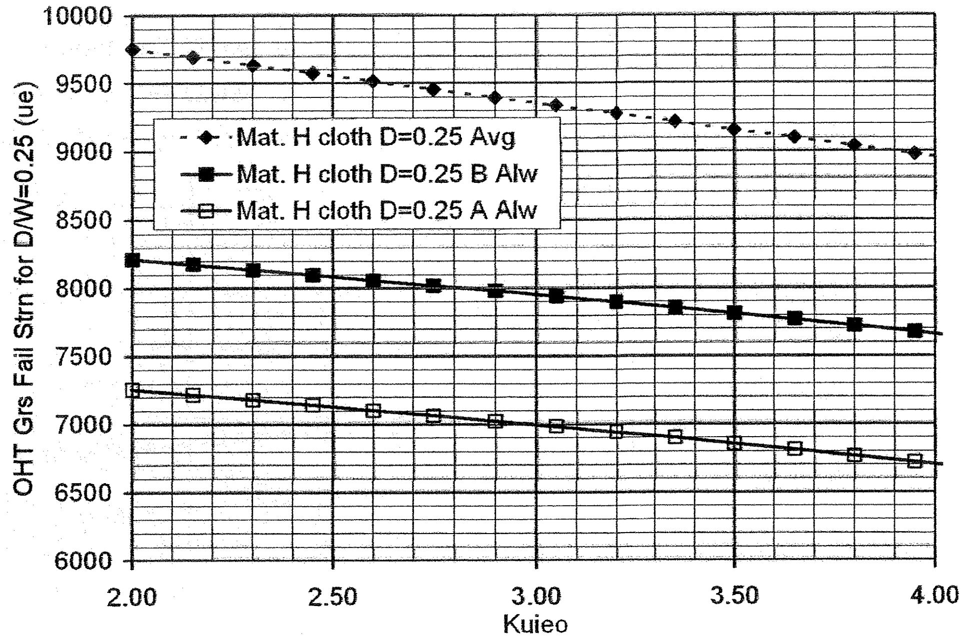
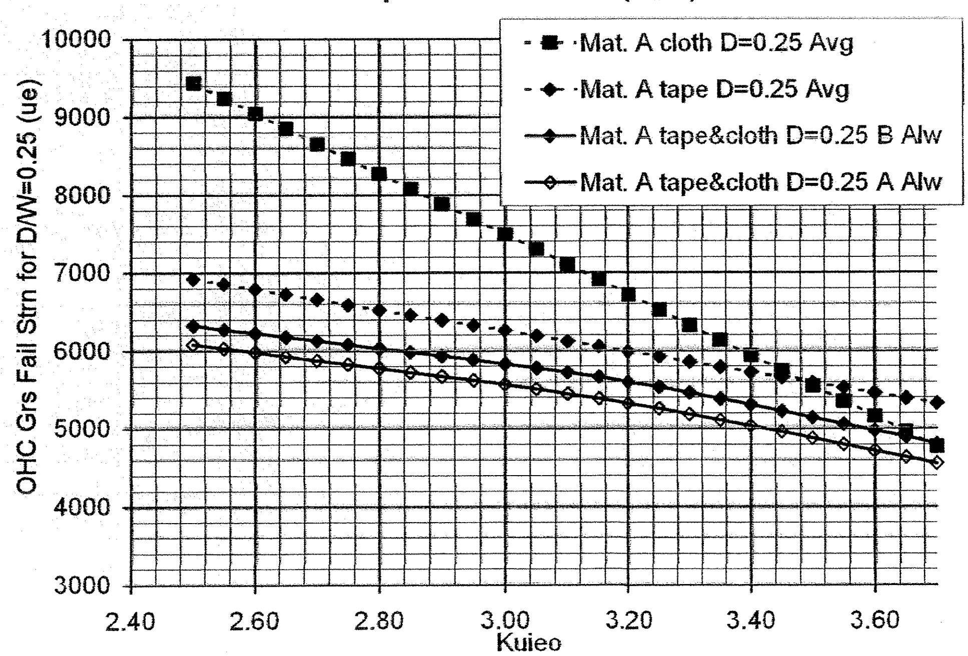


Figure 20. General Curves for Mat H ε_{ohta}.

7.2.2.2 Unloaded-Hole Net-Section Compression Curves (ε_{uhca})



For K_{uieo} values where no cloth curve exists, use the tape curve for cloth.

Figure 21. General Curves for Mat A ε_{ohca}.

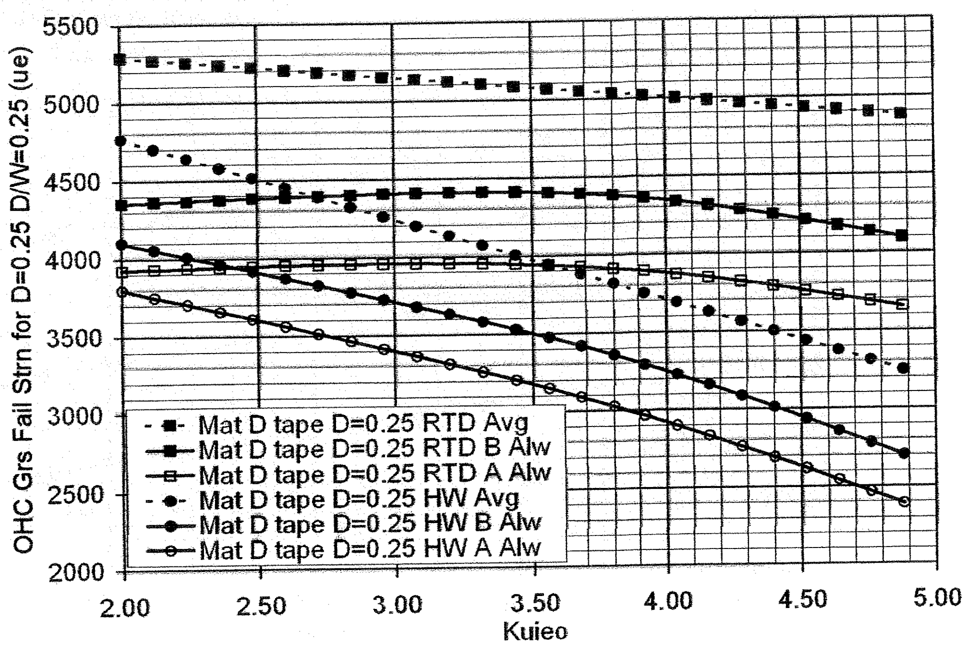


Figure 22. General Curves for Mat DT ε_{ohca} and ε_{ohce}.

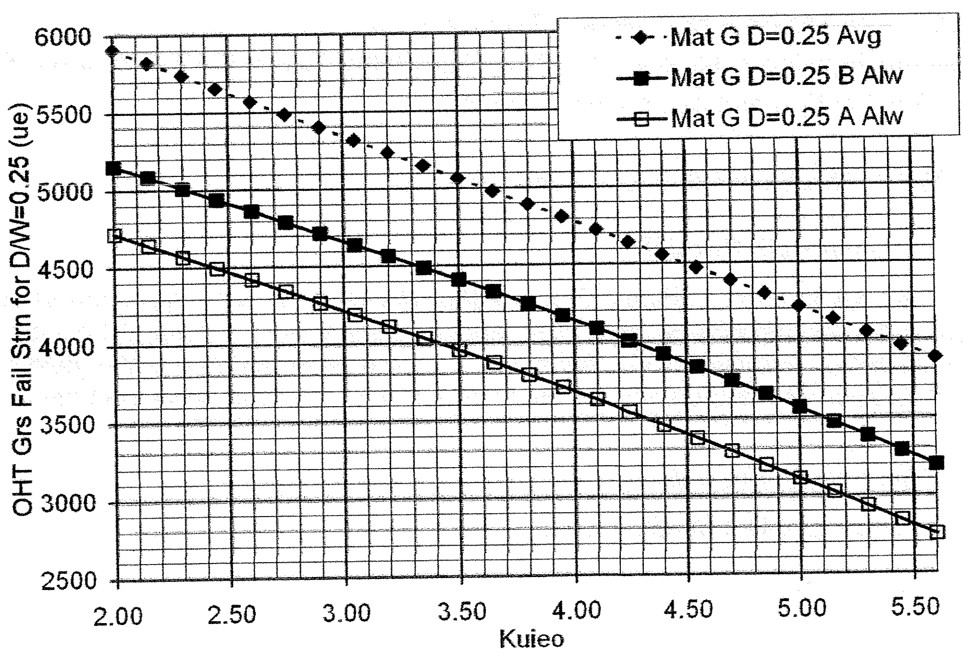


Figure 23. General Curves for Mat GC & GT ε_{ohca}.

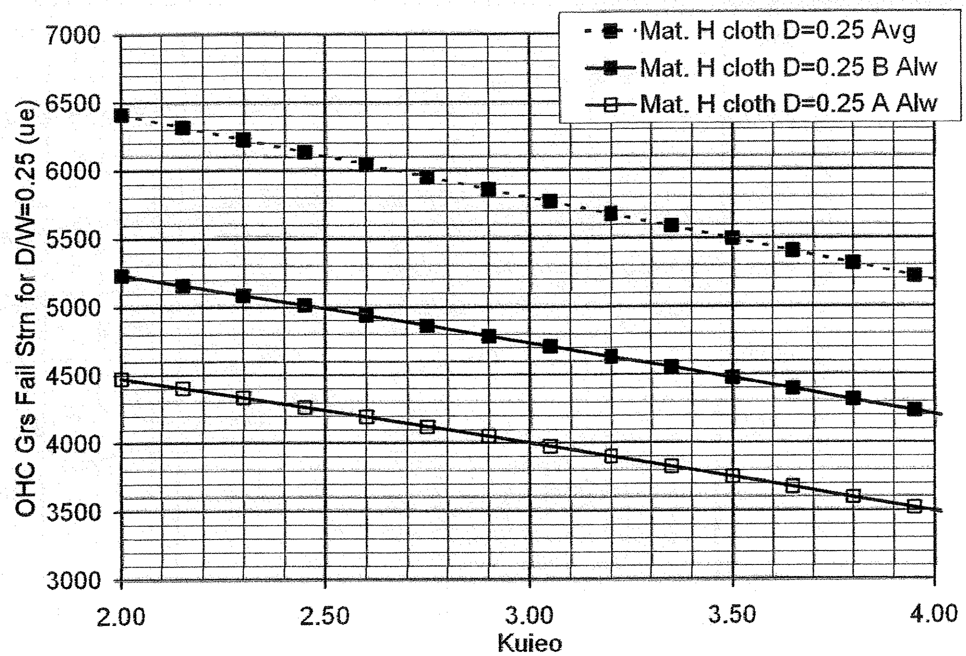


Figure 24. General Curves for Mat H ε_{ohca}.

7.2.2.3 Loaded-Hole Net-Section Tension (F_{brla})

The formula below is used to determine F_{brla} values. "E_a" is the laminate baseline axial stiffness in the direction that F_{brla} and ε_{uhta} are determined.

For Mat A: At a W/D=4.0, $F_{brla} = 2.260 * E_a * \varepsilon_{uhta}$

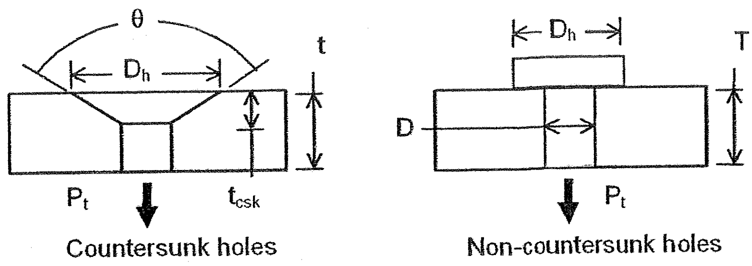
7.3 Fastener Pull-Through

Fastener pull-through loading (P_t) of a bolt produces transverse shear stress (τ_t) through the thickness around the circumference hole. The effective shear stress should be calculated according to the formula below. For shear head fasteners it is recommended to use the yield strength for ultimate load check because of the potential for the fastener head to slip through the hole.

$\tau_t = P_t / (\pi D_h (t - t_{csk}/2))$

MS for fastener pull-through: $F_{pt} / \tau_t - 1$

$F_{pt} = R_m R_{env} F_{pta}$



If $\theta > 100°$ then for D_h use $D + 2.38\, t_{csk}$

Figure 25. Geometry of countersunk hole and transverse loading.

Table 14. Fastener pull-through strengths (F_{pt}) (ksi).

Parameter	Yield F_{ptya}	Ultimate F_{ptua}
R_m for any Mat	1.00	1.00
Mat A B alw	6.14	13.0
Mat D B alw	6.14	13.0