Part I

Metallic Repair Structural Repair for Engineers - Part I

/

99 12 5 -19
100 3 11

列印

提 要 表

系統識別號：	C09904447
計畫名稱：	波音公司飛機結構修理訓練「Structures - Metallic Repair: Structural Repair for Engineers - Part I」
報告名稱：	波音公司飛機結構修理訓練「Structures - Metallic Repair: Structural Repair for Engineers - Part I」
計畫主辦機關：	交通部民用航空局
出國人員：	姓名 / 服務機關 / 服務單位 / 職稱 / 官職等 / E-MAIL 信箱 陳玉成 / 交通部民用航空局 / 標準組 / 技士 / 薦任(派) / 聯絡人 ericchen@mail.caa.gov.tw
前往地區：	美國
參訪機關：	波音公司訓練中心
出國類別：	實習
出國期間：	民國99年12月05日 至 民國99年12月19日
報告日期：	民國100年03月11日
關鍵詞：	結構修理、結構分析
報告書頁數：	63頁
報告內容摘要：	報告內容在說明本次參加美國波音公司飛機結構修理訓練課程：「Metallic Repair Structural Repair for Engineers - Part I」之課程重點。報告從飛機結構設計考量、結構修理對飛機氣動力之影響、飛機結構負載、飛機結構修理材料選用、結構修理用扣件選用、飛機搭接結構分析、修理方法之耐用性及飛機結構修理設計要求等方面進行說明。
電子全文檔：	C09904447_01.pdf
出國報告審核表：	C09904447_A.doc
限閱與否：	否
專責人員姓名：	陳碧雲
專責人員電話：	02-23496197

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Part I Metallic

Repair Structural Repair for Engineers - Part I

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2010/Dec/06
- Class Introduction
- Design Considerations
- Aerodynamic Forces
- External Loads and Structure
- Internal Loads and Load Paths

2010/Dec/07
- Internal Loads and Load Paths
- Materials and Processes
- Fasteners

2010/Dec/08
- Shear Joints
- Class Problems – Joints

2010/Dec/09
- Shear Joints
- Class Problems – Joints
- Shims, Plugs

2010/Dec/10
- Field Trip (Boeing Everret Factory)

2010/Dec/13
- Corrosion Protection
- Fatigue Design Requirements
- Class Problems – Fatigue
- Repair Design Concepts

2010/Dec/14	●	Shear Beam Design
	●	Chord Repair
	●	Class Problem – Stringer Repair Review
2010/Dec/15	●	Examination #1
	●	Class Problems – Chord Repairs
	●	Class Problems – Floor Beam
2010/Dec/16	●	Class Problems – Floor Beam
	●	Shear Web Repair
	●	Class Problems – Shear Web
2010/Dec/17	●	Examination #2

Part I

( )

( )

20

30 B777 B737NG

( )

60%

(Chemical Milling) (Pocket)

( )

9~16

(Downtime)

(Lift) (Weight) (Thrust)

(Drag) (Aerodynamic

Efficiency)

$$\text{MACH NUMBER (M)} = \frac{\text{TRUE AIRSPEED}}{\text{SPEED OF SOUND (AT ALTITUDE)}}$$

$$\text{AERODYNAMIC EFFICIENCY} = \text{M} \times \frac{\text{LIFT}}{\text{DRAG}}$$

AERODYNAMIC EFFICIENCY

L/D 13~18

0.7~0.85

(Patch)

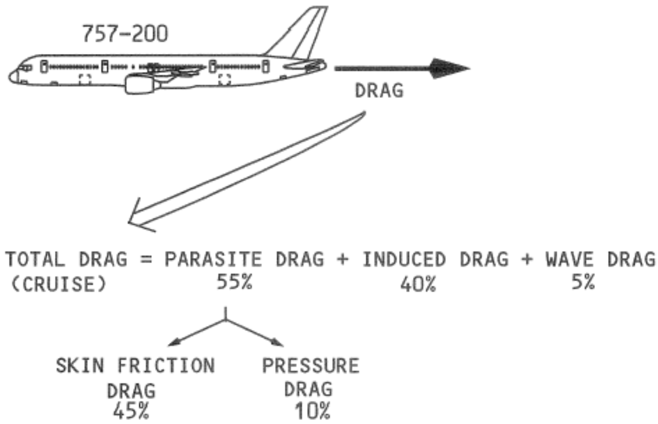
(Internal Patch)

(External Patch)

(/Pitot Tube)

(Parasite Drag)

(Induced Drag) (Wave Drag)



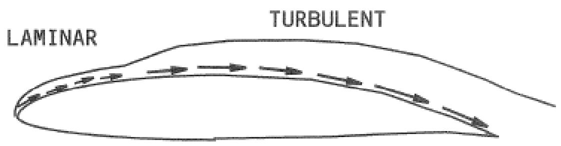
( ) (Parasite Drag)

(Boundary Layer)

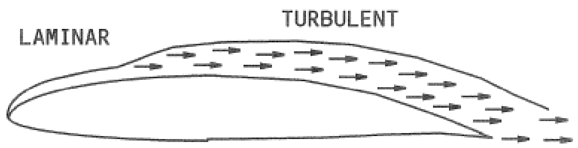
(Skin Friction Drag)

(Pressure Drag)

(Form Drag) (Pressure-Retarding Forces)



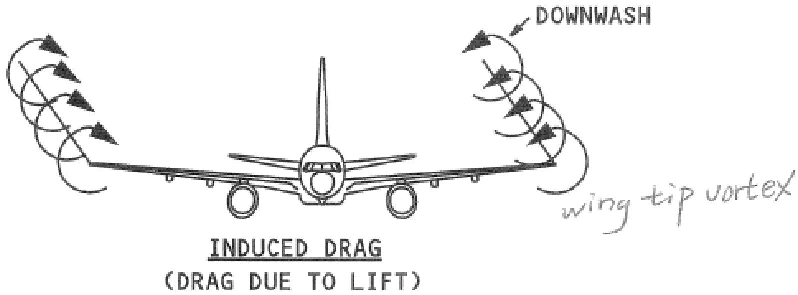
SKIN FRICTION DRAG



PRESSURE DRAG

( ) (Induced Drag)

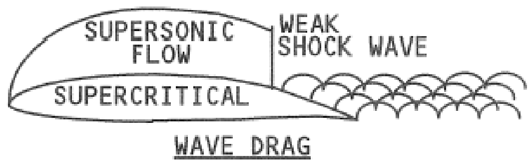
(Vortex) (Downwash)



( ) (Wave Drag)

(Shock Waves)

0.7~0.85



( ) (Excrescence Drag)

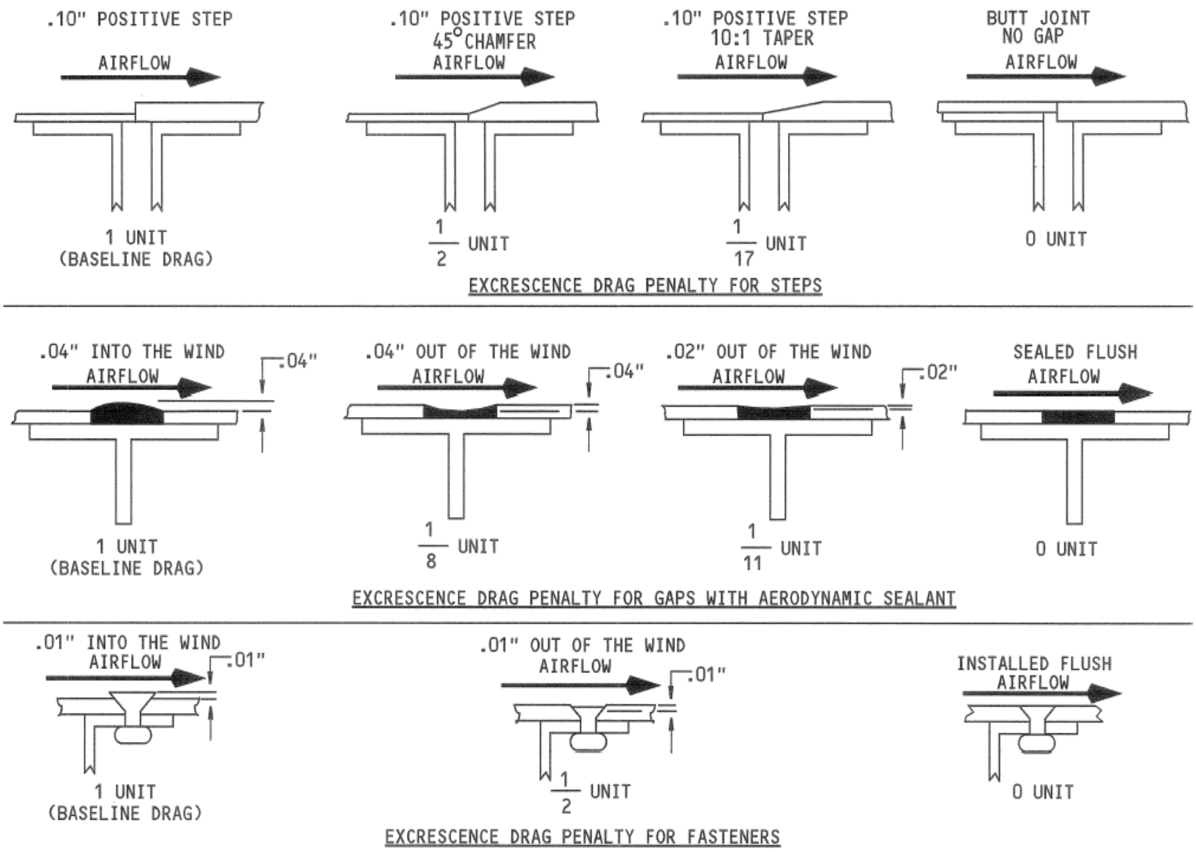
(Excrescence Drag) (Gap)

(Air Leak) (

) ( )

3.5~10% 1

(Chamfer) (Sealing)



1

(Operating Loads)

FAR 25.301

(Limit Loads)

FAR 25.303 1.5

(Factory of Safety) (Ultimate Loads)

Design Criteria	FAR	FAR
OPERATING LOADS	**LIMIT LOADS**	**ULTIMATE LOADS**
• TYPICAL IN-SERVICE LOADS	• MAXIMUM LOAD EXPECTED AS SPECIFIED BY THE FAR	• LIMIT LOAD x Factor of Safety (FAR 25.301)
• FATIGUE LOADS (Damage Tolerance)	• NO PERMANENT DETRIMENTAL DEFORMATION (FAR 25.305) yield	• NO CATASTROPHIC FAILURE (FAR 25.305)
• LOAD FACTOR approx. 1.4g's	• LOAD FACTOR 2.5g's (FAR 25.337)	• LOAD FACTOR APPROX. 3.75g's HOLD LOAD FOR 3 SECONDS (FAR 25.305)
• 2-3 fps SINK SPEED ON LANDING	• 10 fps SINK SPEED ON LANDING (FAR 25.473)	• APPROX. 12 fps SINK SPEED ON LANDING
• $\Delta P_{Cabin\ Design}$ = 8-9 psi	• $\Delta P_{Limit\ load} = 1.33 \times \Delta P_{Pressure\ Relief\ Valve}$ (FAR 25.365)	• $\Delta P_{Ultimate\ load} = 1.5 \times 1.33 \times \Delta P_{Pressure\ Relief\ Valve}$

LOAD CATEGORIES AND CHARACTERISTICS (static testing)

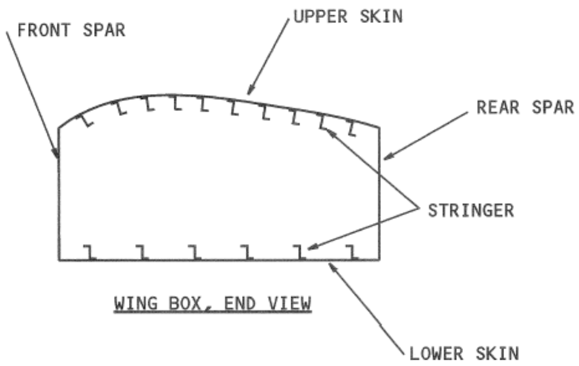
2

( ) (Wing Loads)

– (Wing Box)

(/Stiffener)

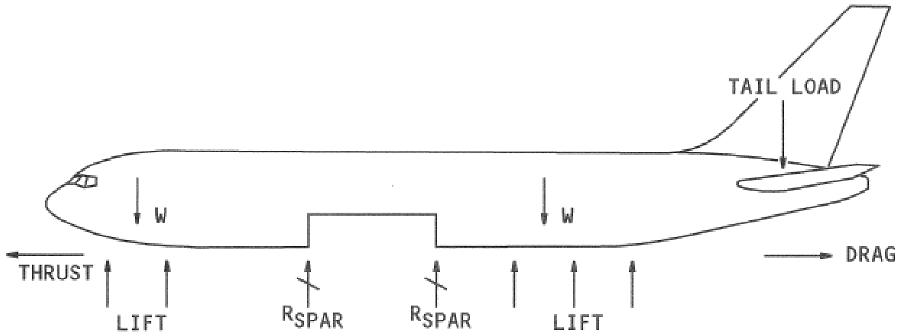
(Compression) (Tension)



( ) (Fuselage Loads)

(Pitching Moment)

(Payloads)



FUSELAGE LOADS

(Fuselage

Skin) (Stringer)/ (Longeron) (Frame)

(Bulkhead)

1. (Fuselage Skin)

2. (Stringer)/ (Longeron)

3. (Frame)

4. (Bulkhead)

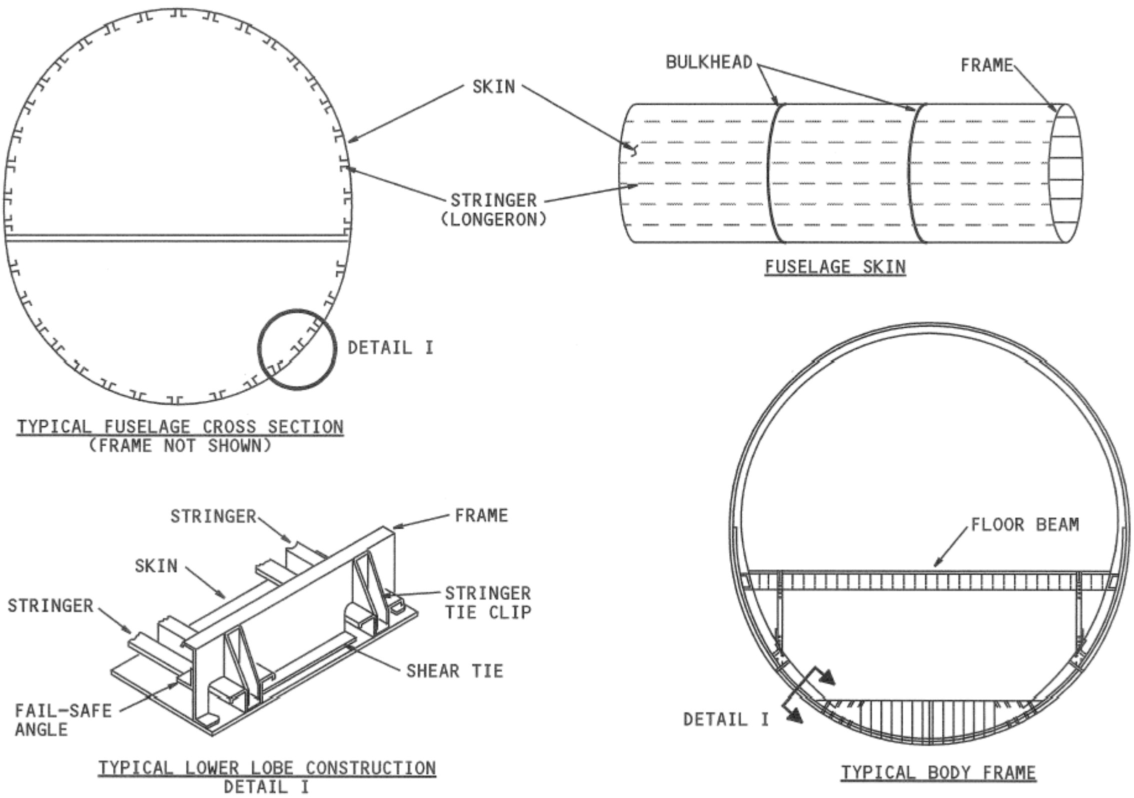
(Payloads) (Floor Beam)

Shear Tie

3

4 B747

Stringer Skin (Load Chart)

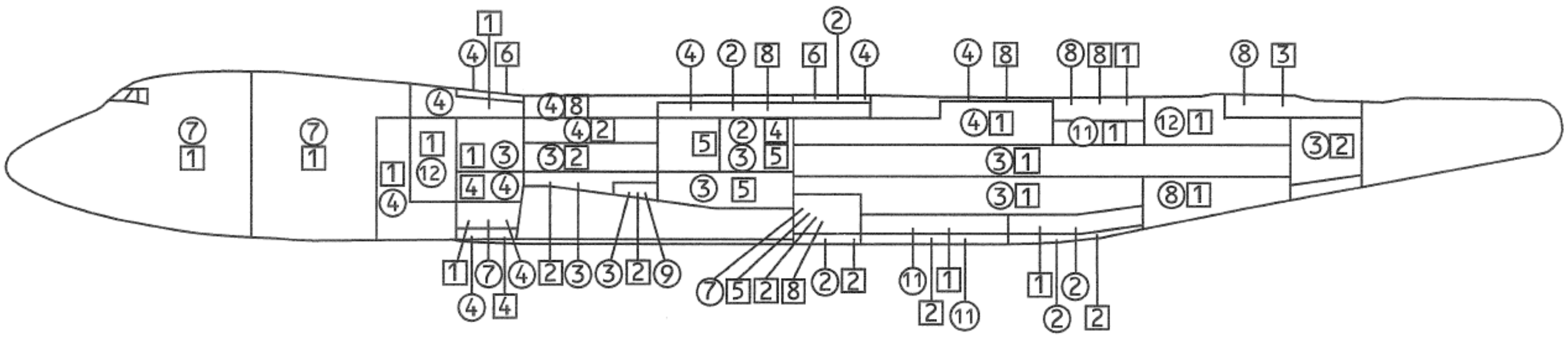


LOADS – FUSELAGE – INTERNAL

3

( ) (Empennage Loads)

(Tension) (Compression)



1. HOOP TENSION
   (18 psi diff. pressure at ultimate)
2. FLAPS DOWN MANEUVER
   (N = 3.0)(CRIT @ MAX LANDING WT)
3. ENGINE OUT (N = 1.5)
   (RUDDER MANEUVER)(CRIT @ MAX GW)
4. POS MANEUVER (N = 3.75)
   (CRIT FROM MAX OEW TO MAX GW)
5. 90 DEGREE GEAR TOW (CRIT @ MAX GW)
6. SKIN WORKS WITH STIFFENER AS
   BENDING MATERIAL
7. STIFFENER DESIGNED TO STABILIZE SKIN
8. INSTANT ELEVATOR
   (CRIT @ MAX GW)(NEG TAIL LOAD)
9. 4 POINT BRAKED ROLL (CRIT @ MAX TAXI WT)
10. 4 POINT LEVEL LANDING
11. INSTANT ELEVATOR
    (CRIT @ MAX GW)(POS TAIL LOAD)
12. BRAKED TURN

○ STRINGER DESIGN CONDITION

□ SKIN DESIGN CONDITION

▭ BOTH SKIN AND STRINGER

<u>FUSELAGE CRITICAL LOAD CHART</u>

for skin and stringer

LOADS – DESIGN CRITERIA

4 B747 Stringer Skin (Load Chart)

( )

80%

2XXX (2024)

(Fracture Toughness)

7XXX

(Anodizing)

(Chemical Conversion Coating)

(Solution Heat Treatment)

(Age Hardening) “T”

5

(Static Strength) (Yield Strength)/Fty

(Ultimate Strength)/Fu

EXAMPLE: -T6 5 1 1

STANDARD HEAT TREATED DESIGNATION — -T6

- 5 — A "5" INDICATES THE MATERIAL HAS BEEN STRESS RELIEVED; A "2" INDICATES THE MATERIAL HAS BEEN HEAT TREATED BY THE USER, TYPICALLY AFTER FORMING
- 1 — MATERIAL WAS STRETCHED TO ACCOMPLISH STRESS RELIEF. THE DIGIT 2 WOULD BE USED HERE WHEN COMPRESSIVE METHODS ARE USED.
- 1 — INDICATES MINOR STRAIGHTENING USE TO MEET STRAIGHTNESS AND FLATNESS TOLERANCES. THIS DIGIT IS A 0 IF NO STRAIGHTENING IS ALLOWED.

TEMPER DESIGNATION

-T3: Solution heat-treated, cold worked, and naturally aged to a substantially stable condition. Applies to products which are cold worked to improve strength after solution heat-treatment.

-T4: Solution heat-treated and naturally aged to a substantially stable condition. Applies to products which are not cold worked after solution heat-treatment.

-T42: Solution heat-treated and naturally aged by the user. Applies to 2024-0 and 6061-0. (formed and heat treated)

-T6: Solution heat-treated and artificially aged. Applies to products which are not cold worked after solution heat-treatment.

-T62: Solution heat-treated and artificially aged by user. Applies to a number of alloys such as 2024, 6061, and 7075 which have been heat-treated and aged by the user.

-T73: Solution heat-treated and overaged. This temper applies to several 7000 series alloys and indicates a greater degree of overaging required for higher stress corrosion resistance. Material in this temper is also immune to exfoliation corrosion. As applied to the 7075 or 7175 alloys, the -T73 temper is virtually immune to stress corrosion. improve from T6

MATERIALS - ALUMINUM ALLOY HEAT TREATMENT

5 “T”

-

(Limit Loads)

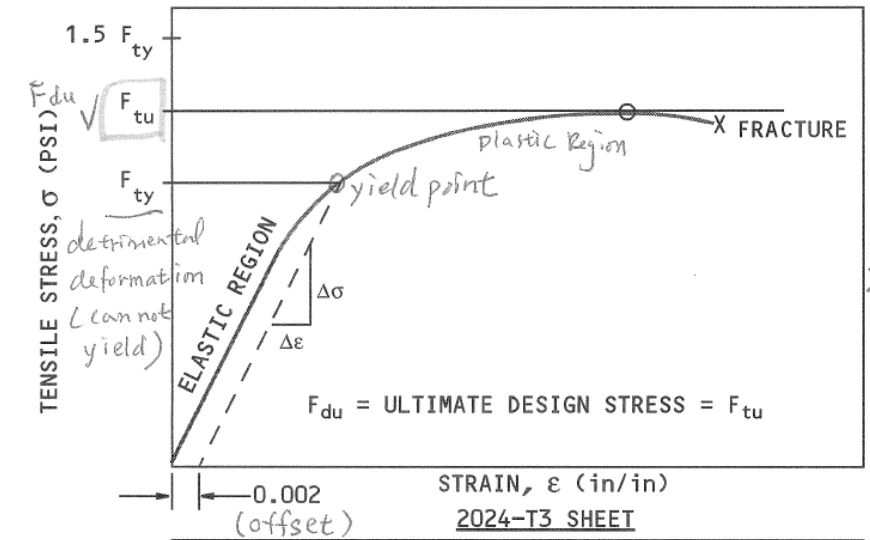
FAR 25.303 1.5

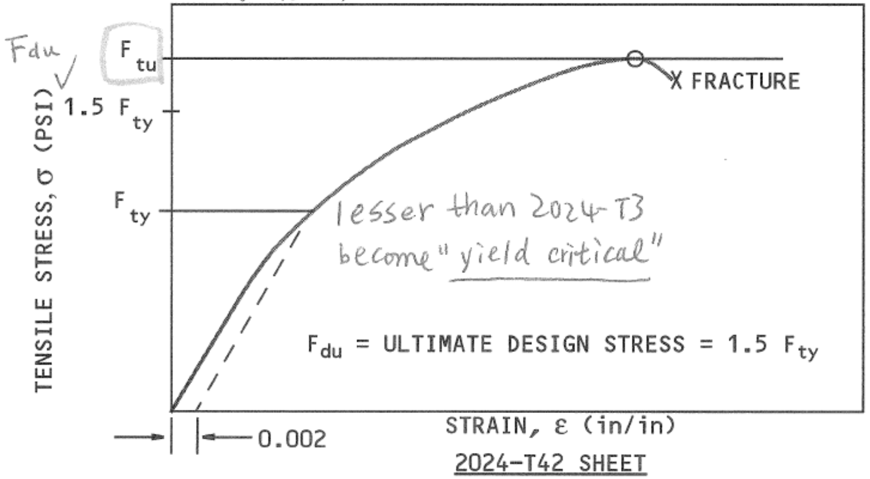
(Factory of Safety)(=1.5Fty) (Ultimate Loads) (Ultimate Strength)/Fu (Design Ultimate Stress)/Fdu

6

(Statistical Basis) A, B, S A-Basis 95% 99%( ) B-Basis 95% 90%( ) S-Basis

( ) FAR 25.613 ( ) B-Basis A-Basis A-Basis B-Basis 7 A, B (Statistical Basis)





MATERIALS – STATIC STRENGTH

F_{ty} = MATERIAL YIELD STRENGTH AT 0.002in/in PERMANENT ELONGATION

F_{tu} = MATERIAL ULTIMATE STRENGTH

☆

F_{du} = ULTIMATE DESIGN STRESS = LESSER OF F_{tu} OR $(1.5 \times F_{ty})$

L_o = ORIGINAL LENGTH

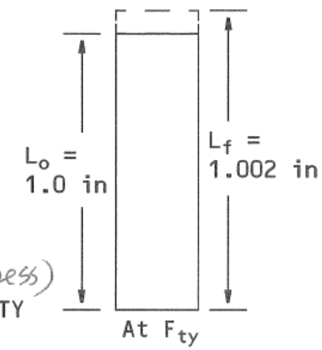
L_f = FINAL LENGTH

STRAIN, $\varepsilon = \frac{L_f - L_o}{L_o}$

STRESS, $\sigma = \frac{P}{A_o}$ (stiffness)

E = MODULUS OF ELASTICITY

$= \frac{\Delta\sigma}{\Delta\varepsilon}$ (ELASTIC REGION)



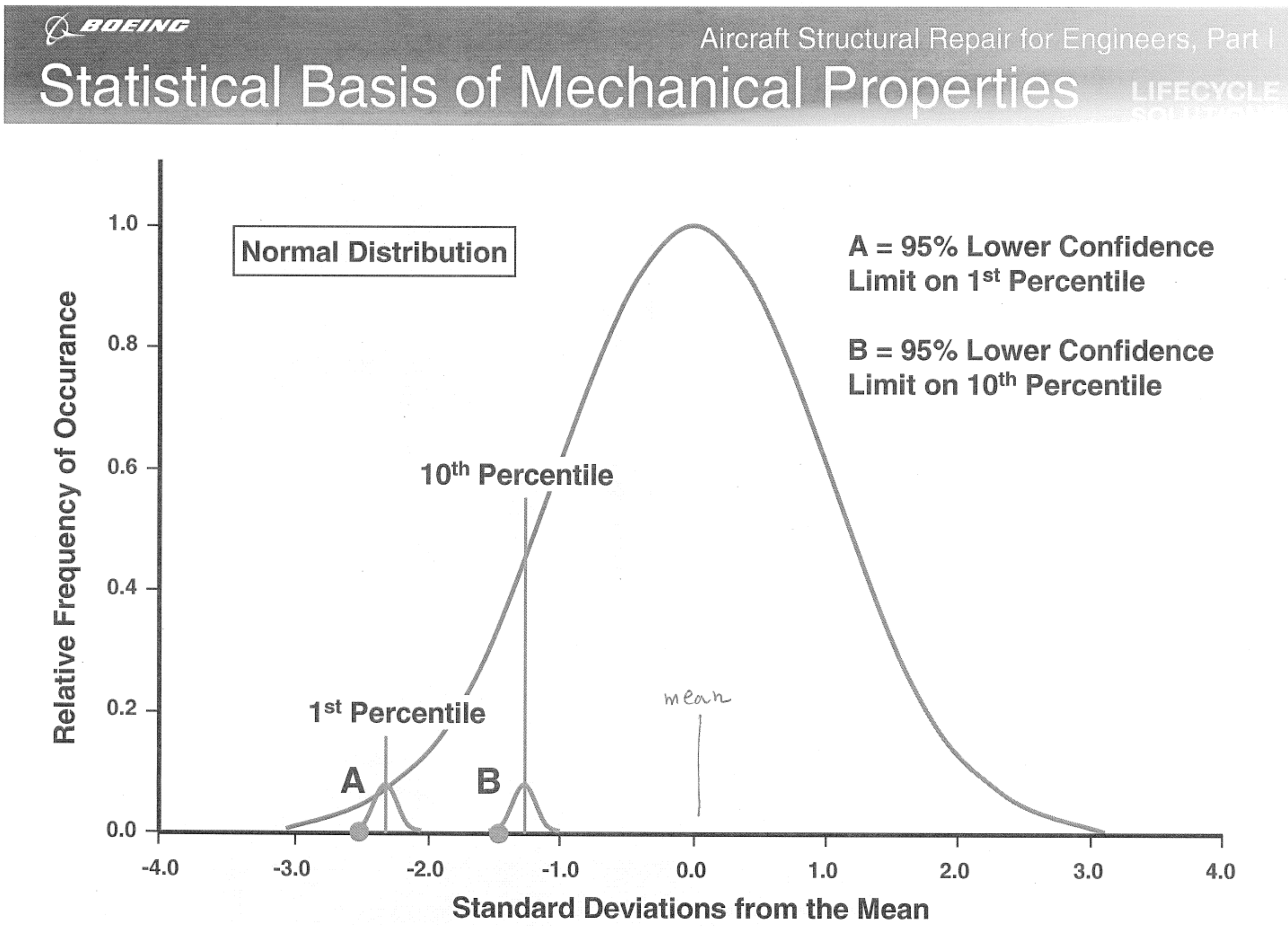
＊鋼為鋁合金之3倍

＊Margin of Safety (MS)

$(F_{du}/f_{tu\text{-applied}} - 1) \times 100\%$

or

$(P_{allow}/P_{applied} - 1) \times 100\%$



7 A, B (Statistical Basis)

(Edge

Margin, e) e/D

e/D=2.0 =2.0D ±

0.05 inches e/D

1.7 2D

0.05 inches

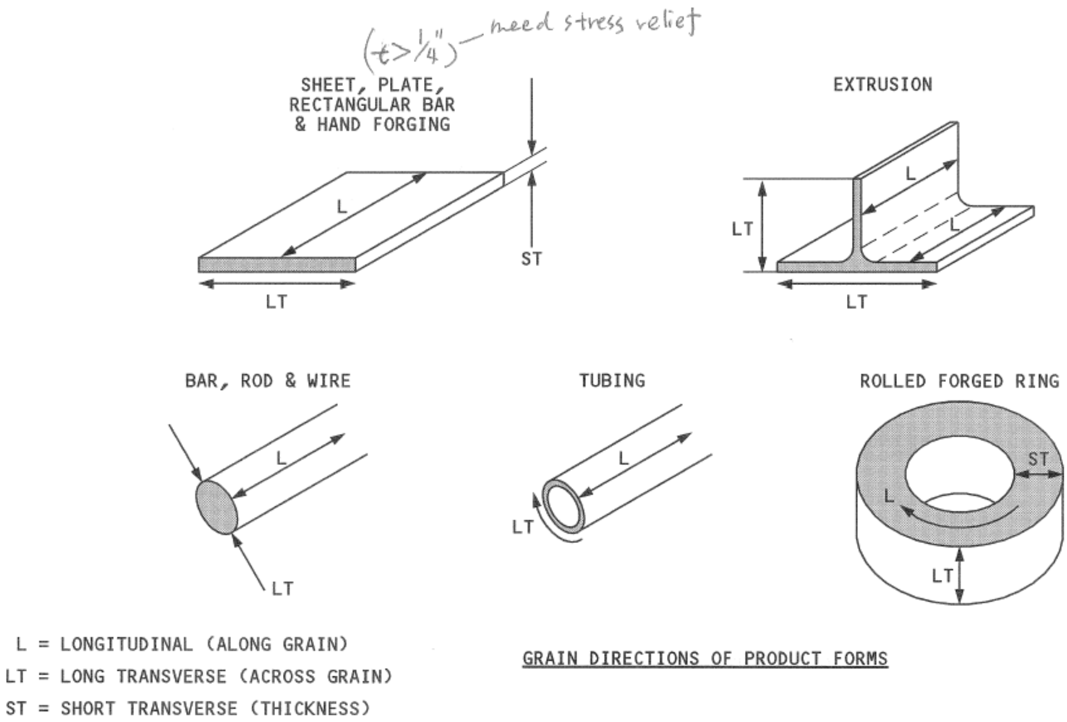
(Grain)

L

(Longitudinal Direction) LT

(Long Transverse Direction) ST

(Short Transverse Direction) 8



8

(Fasteners)

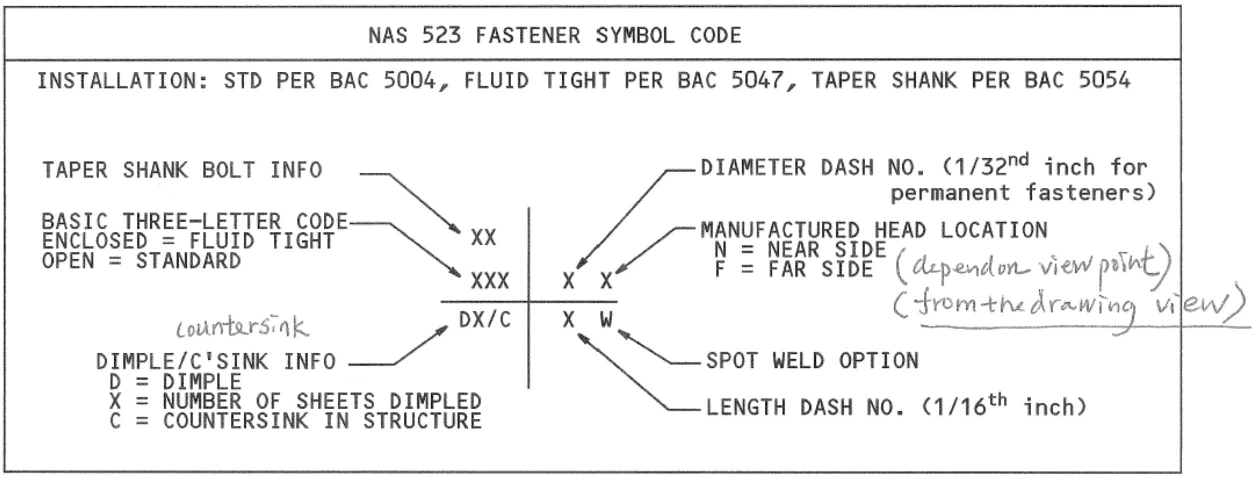
(Load Transfer)

( )

(9)

BACR15BB8D8

10



9

R=Rivet
B=Bolt

BOEING PART NUMBER PREFIXES

BACR15	Rivet
BACB30	Bolt, Lockbolt or Hex-drive (Hi-Lok)
BACC30	Collar
BACN10	Nut or Nutplate
BACW	Washer
BACF	Filler
BACS	Shim or Screw

FULL PART NUMBER FOR RIVETS

BACR15__*_**
__ = Head Style
* = Diameter (1/32")
_ = Material (letter code)
** = Grip Length (1/16")

FULL PART NUMBER FOR BOLTS

BACB30__*_**
__ = Head Style and Material
* = Diameter (1/32")
_ = Finish (letter code)
** = Grip Length (1/16")

10

( )

(Permanent Fasteners)

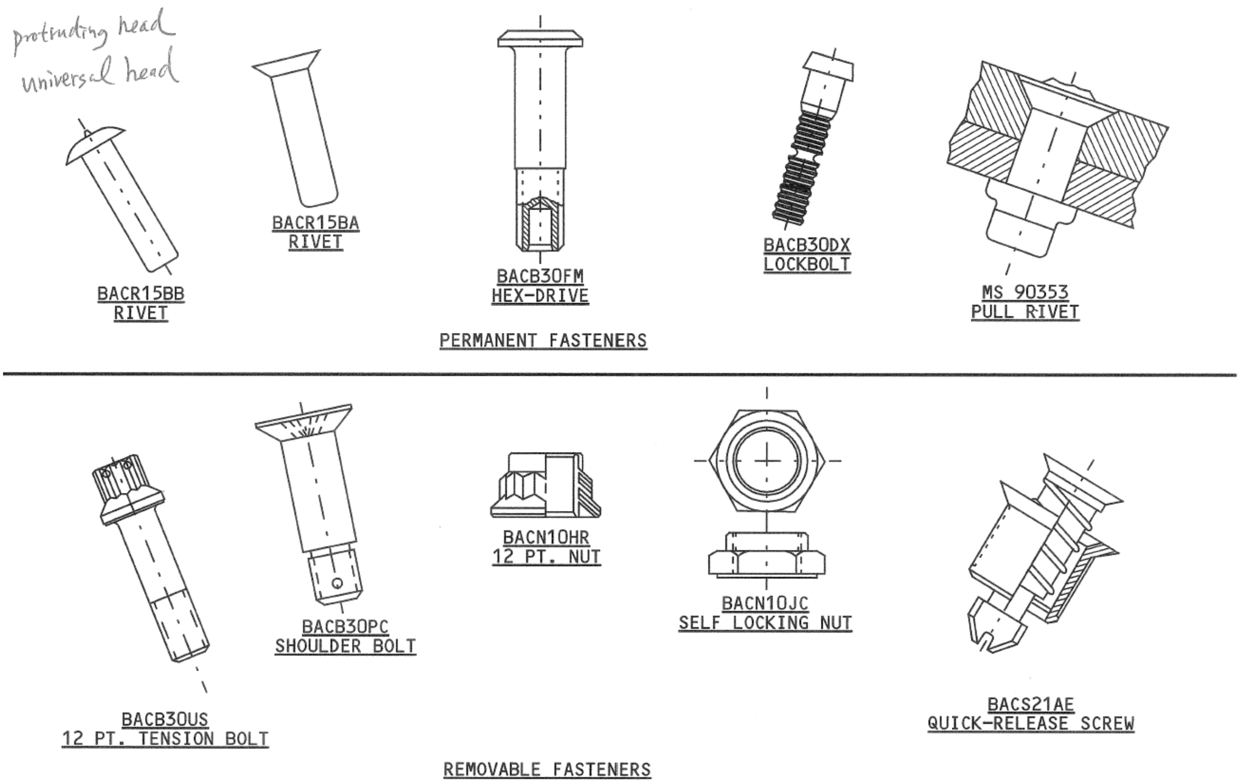
(Removable Fasteners)

Tension Head Shear Head

(Blind Fasteners)

1. (Permanent Fasteners) (Removable Fasteners)

Rivets Lockbolts Hex-Drive Bolts (Hi-Lok) (Fatigue or Structural Bolts) 11



11

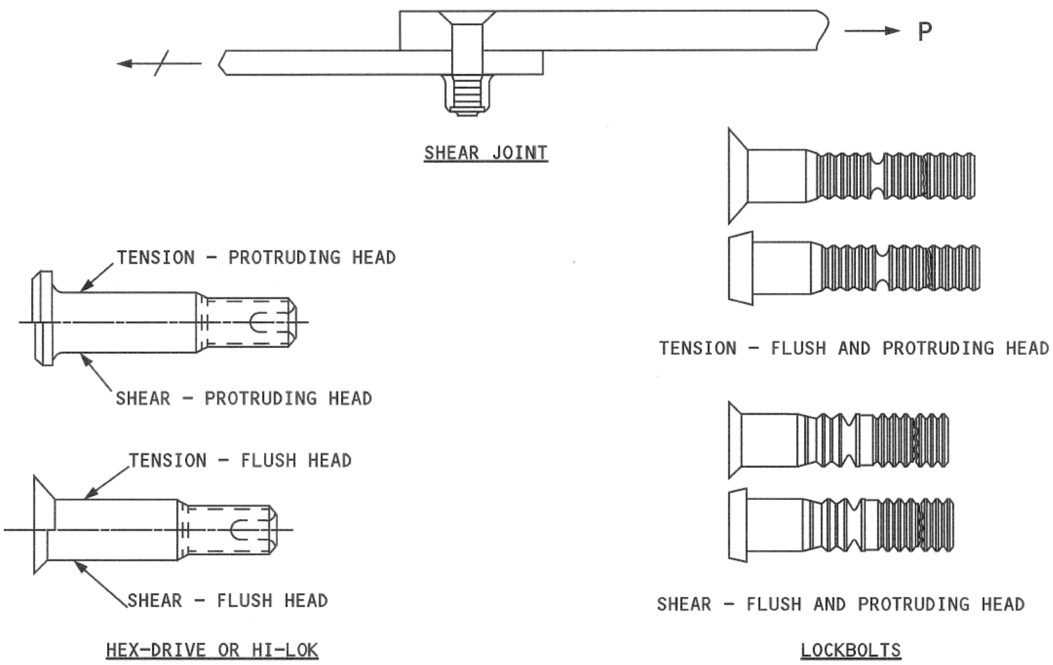
2. Tension Head Shear Head

Shear Head Shear Head

Tension Head Tension Protruding Head

Tension Flush Head Tension Head

Shear Head 12



12 Tension Head Shear Head

3. (Blind Fastener)

(Blind Bolts) (Blind Rivets)

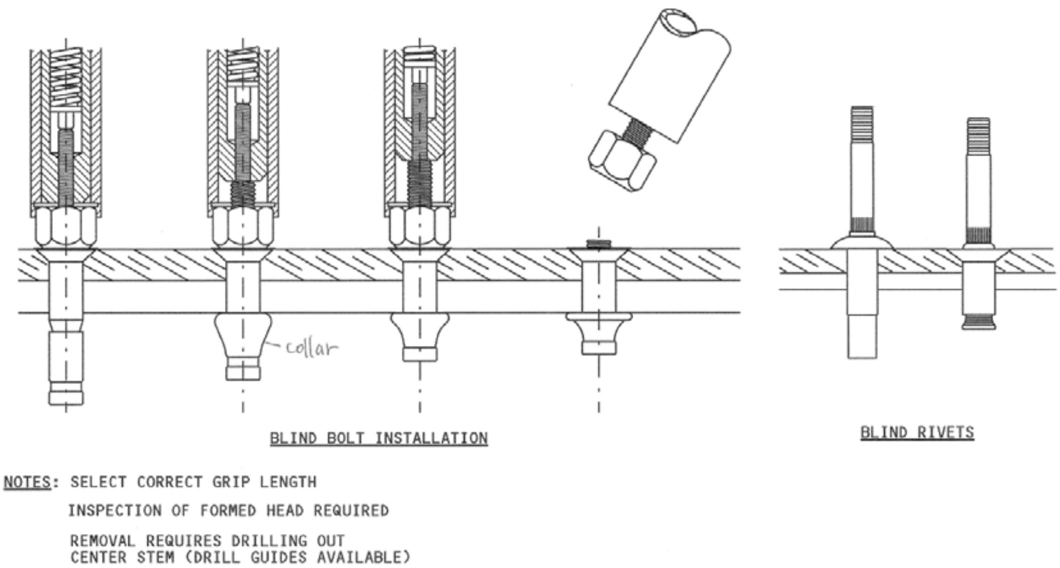
(Grip Length)

SRM

(Time-Limited Repair)

(Repetitive Inspection)

(Blind Bolts) (Blind Rivets) 13



13 (Blind Bolts) (Blind Rivets)

4. (Hole Fit)

(Clearance Fit) (Transition Fit) (Interference Fit)

(Clearance Fit) (Shank Diameter) Class I, II, III Class I (Removable Fastener) Class I

Class II Nutplate Class

III

(Interference Fit)

(Permanent Fasteners)

(Transition Fit)

(Permanent Fasteners)

5. (Oversize)

(Transition Fit)

(Fatigue Resistance) 14 Hex-Drive Bolt

oversize the shank diameter

PART NUMBER	DESCRIPTION	A	D	H	TD	
BACB30MY6K	3/16 HEX DRIVE	.295-.315	.1885-.1895	.045-.055	.181-.184	
BACB30MY6K*X	1/64 OVERSIZE	.295-.315	.2016-.2026	.045-.055	.181-.184	1st Oversize
BACB30MY6K*Y	1/32 OVERSIZE	.295-.315	.2172-.2182	.045-.055	.181-.184	2nd Oversize

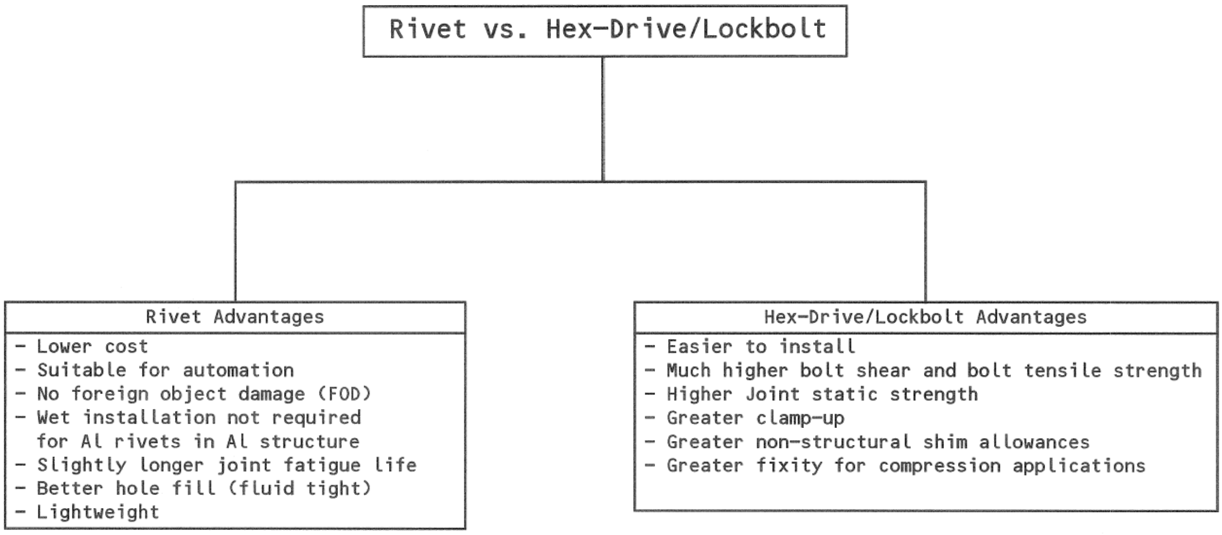
FACTORY FASTENER	REPAIR FASTENER TYPE	TYPICAL REPAIR FASTENER SIZE
RIVET	RIVET	SAME DIAMETER
RIVET	HEX-DRIVE OR LOCKBOLT	1/32 OVERSIZE
HEX-DRIVE OR LOCKBOLT	HEX-DRIVE OR LOCKBOLT	1/64 OVERSIZE

14 /Hex-Drive Bolt

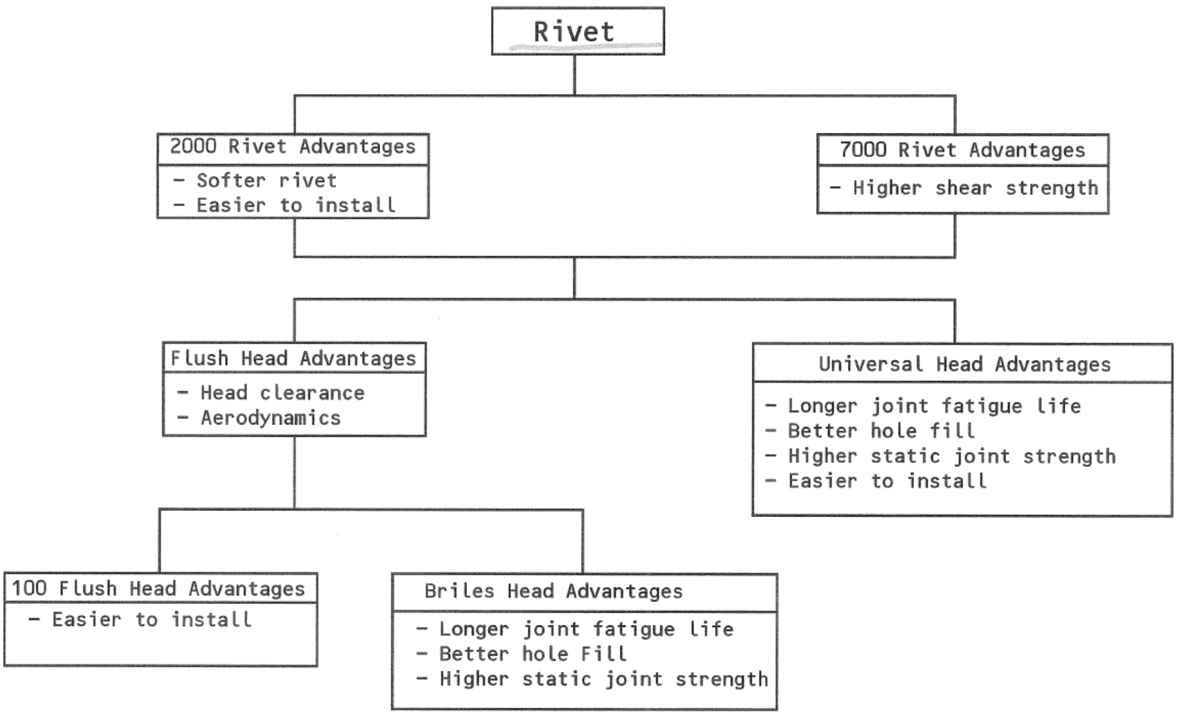
( )

15, 16, 17 Rivet Lockbolt/Hex Drive Bolt

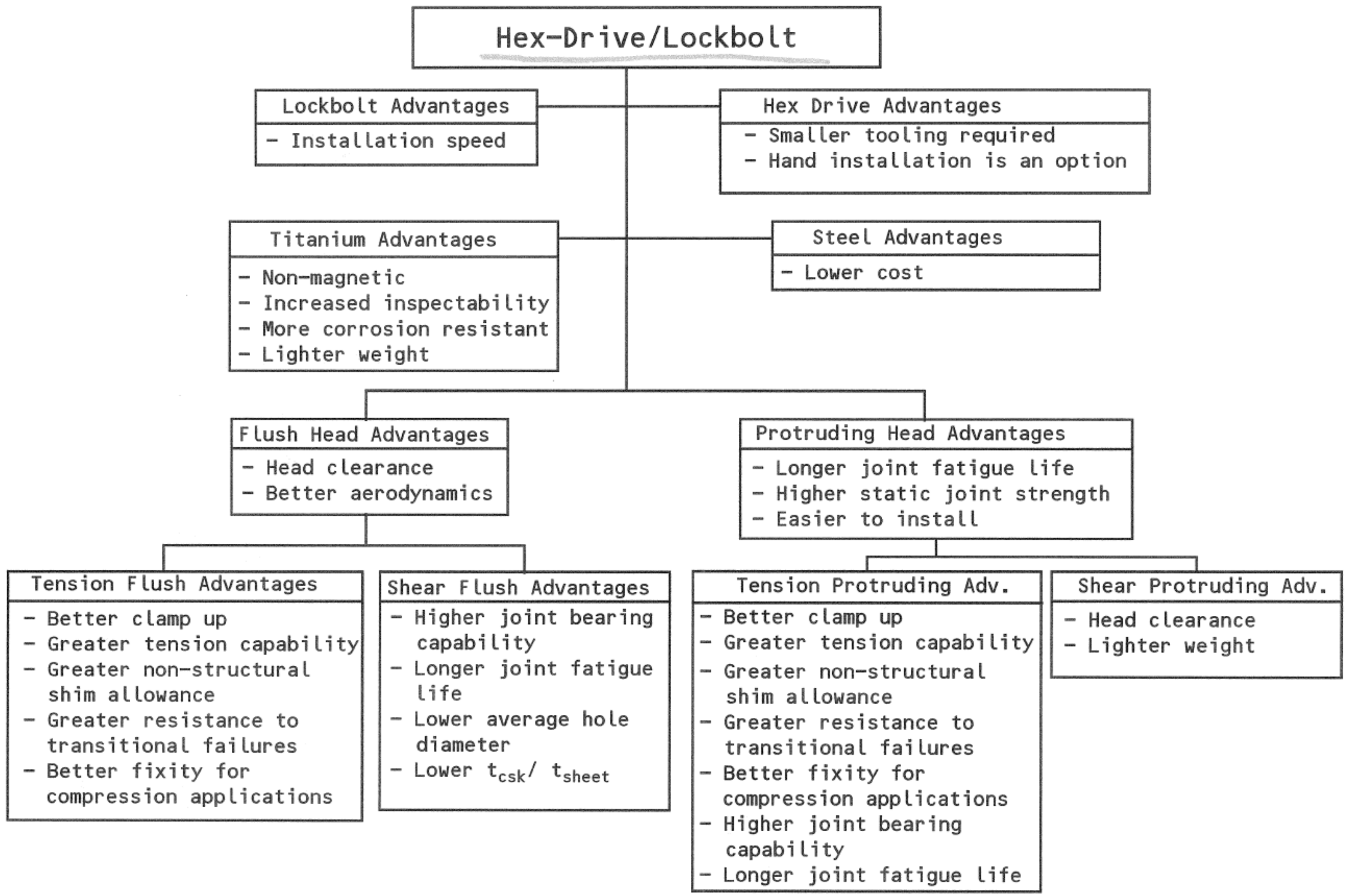
Rivet Lockbolt Hex Drive Bolt



15 Rivet Lockbolt/Hex Drive Bolt



16 Rivet



JOINTS - FASTENER SELECTION

17 Lockbolt Hex Drive Bolt

( )

1. – (Skin Longitudinal Lap Joint)

15

Finger Doubler

(Non-Eccentric Load Transfer)

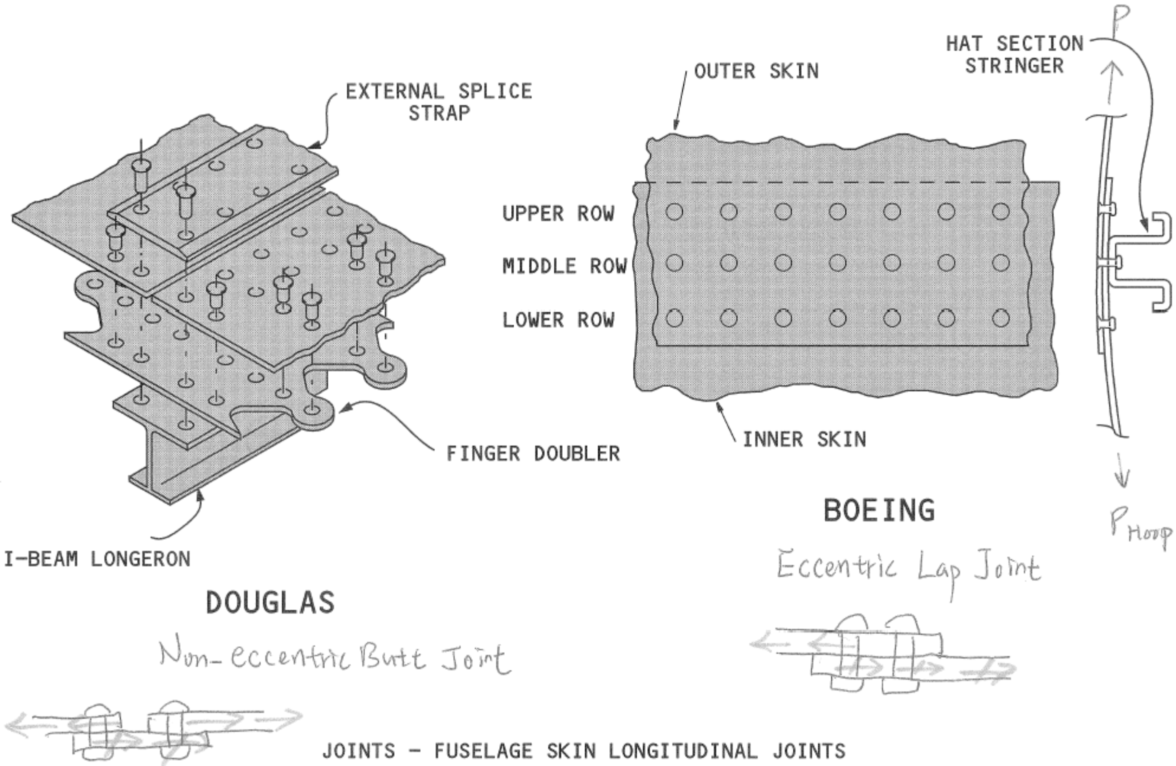
(Double Shear)

(Eccentric Load

Transfer) (Single Shear)

18

(Skin Lap Joint)

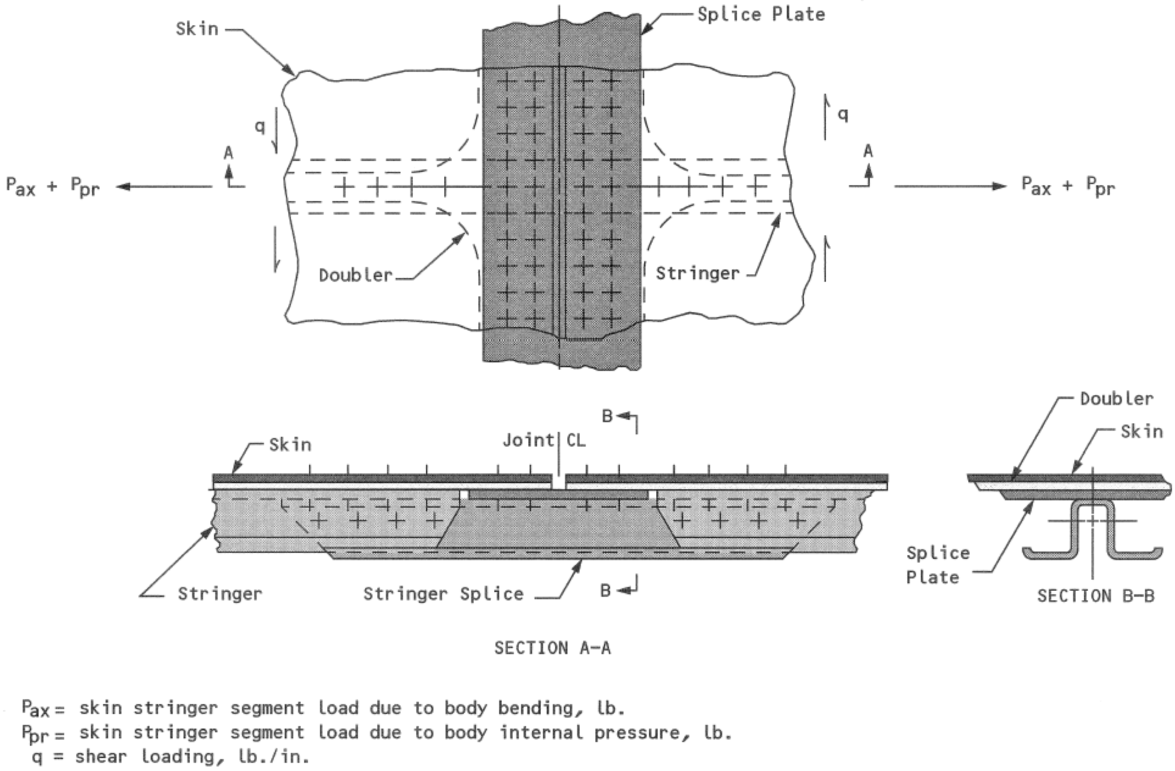


18 (Skin Lap Joint)

2. – (Skin Circumferential Joint)

(Skin Butt Joint) (Internal Splice Plate) (Stringer) Splice Fitting (Bending Moment) (Crown) (Tension) (Keel Beam) (Compression) Lockbolt Hi-Lok

19 (Skin Circumferential Joint)



19 (Skin Circumferential Joint)

3. – (Fuselage Frame Joint)

(Fuselage Frame) Shear Tie

(Stringer) Shear Tie

Shear Tie 20

Shear Tie Shear Tie

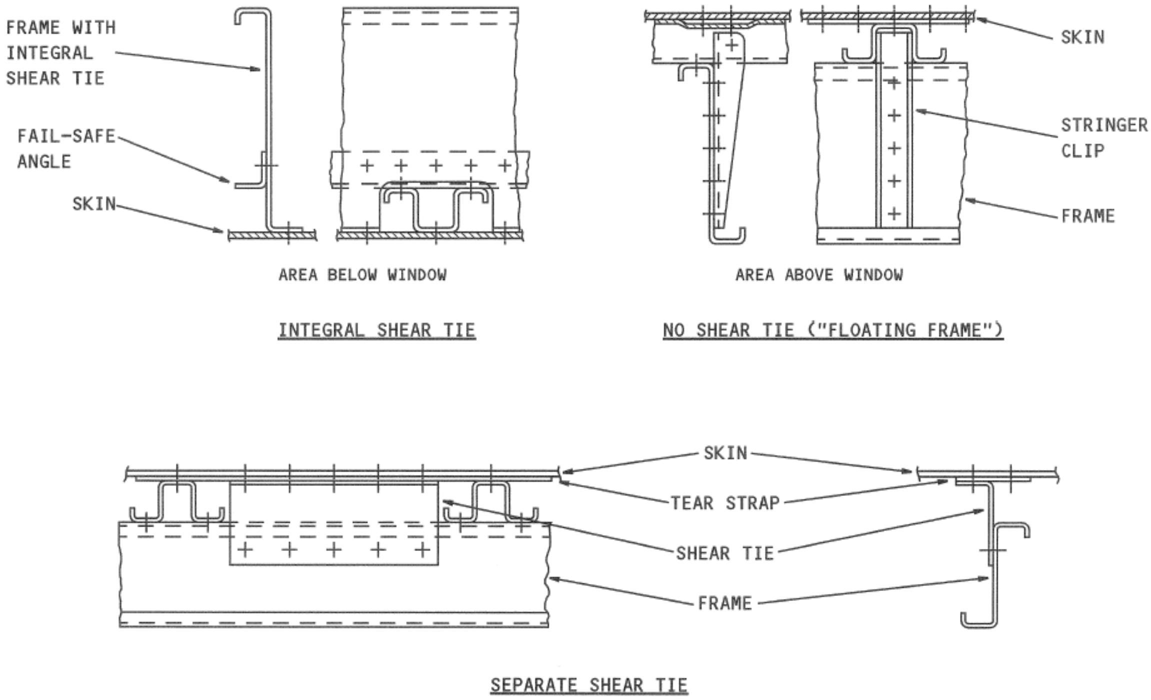
Structural Clip Clip Shear

Tie

Integral Shear Tie Fail-Safe Angle

(Hoop Stress) Shear Tie

Fuselage Stringer Clip

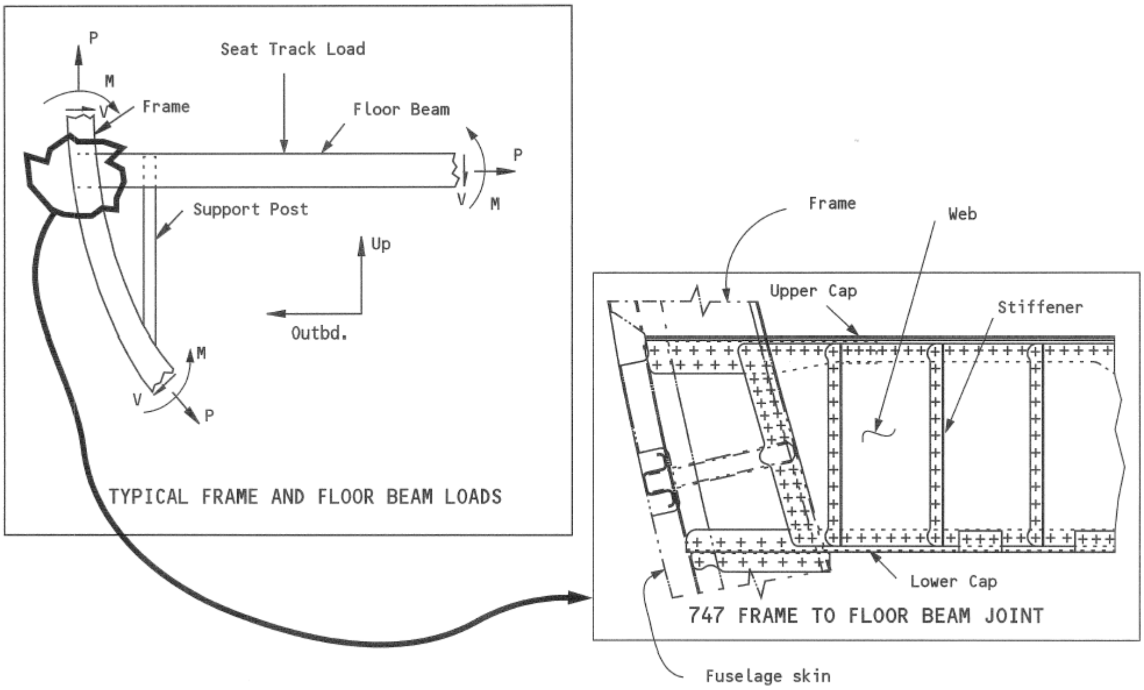


20 Shear Tie

4. – (Fuselage Frame to Floor Beam Joint)

Support Post Shear Tie Doubler

21 Shear Tie



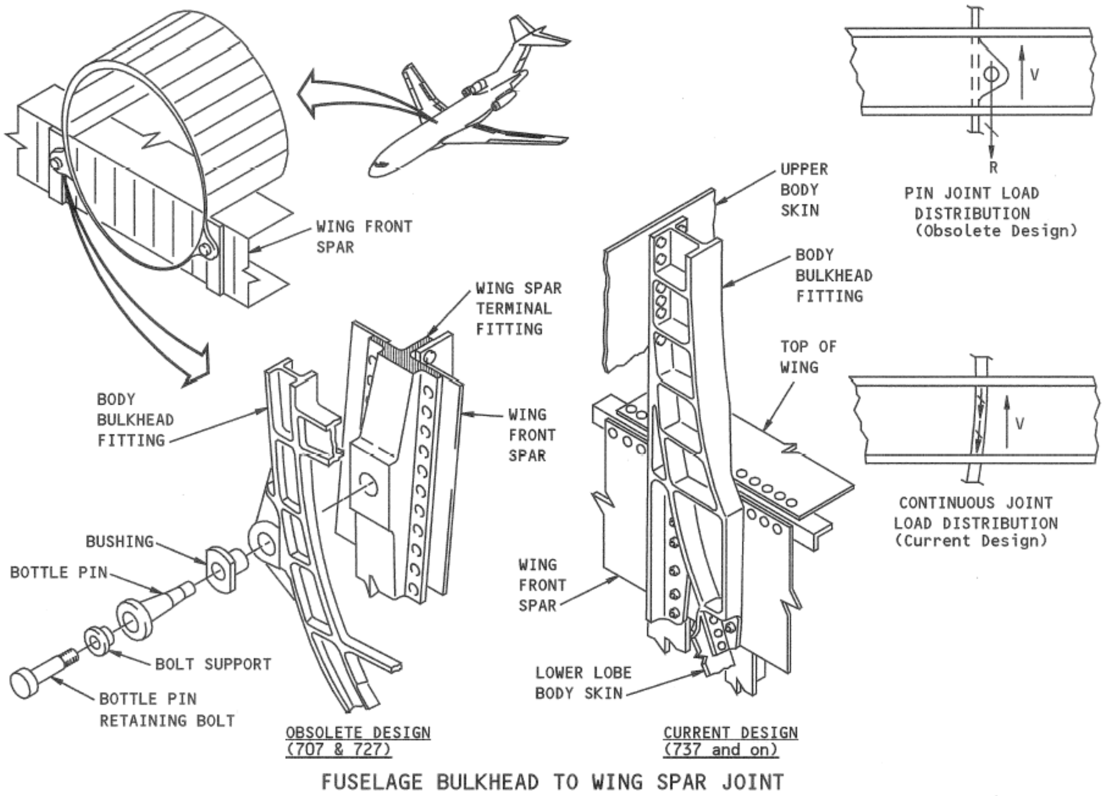
21

5. (Wing to Body Joint)

(Fail-Safe) (Wing Spar) (Fuselage Bulkhead Forgings) Spanwise Loads 22 (Wing to Body Joint)

6. (Wing Skin Spanwise Joint)

(Stringer)



22 (Wing to Body Joint)

( ) (Joint Failure Mode)

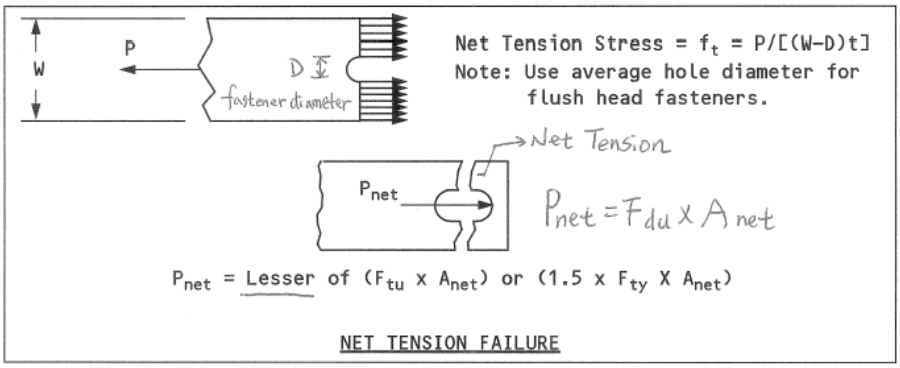
Net Tension Failure Tear Out Failure Bearing Failure Fastener Shear Failure Transitional Failure

(Load Capability) (Critical Failure Mode)

1. Net Tension Failure

Net Tension Failure (Tension Stress)

23

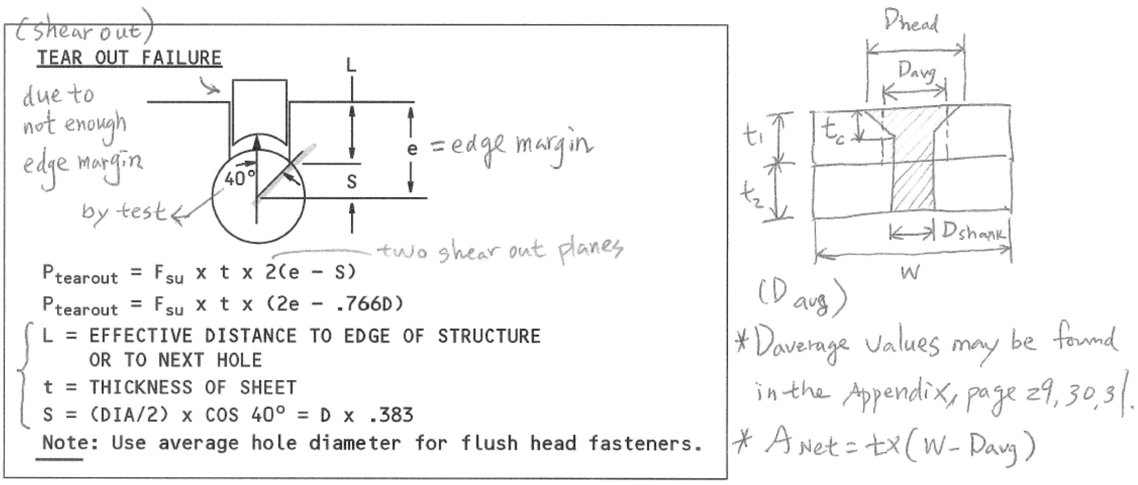


23 Net Tension Failure/

2. Tear Out Failure (Shear Out Failure)

(1.7D)

(Shear Failure)



24 Net Tension Failure

3. Bearing Failure

Bearing Failure

(Hole Deformation)

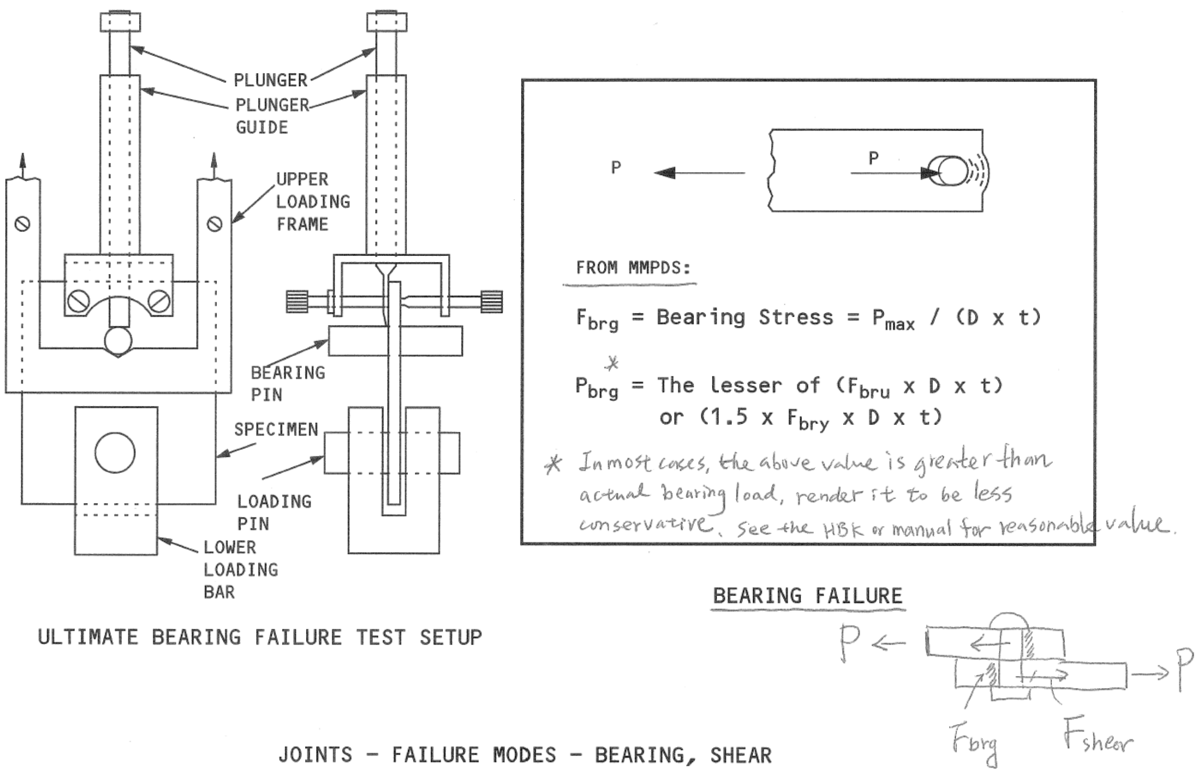
(Hole Elongation) Bearing

Failure

25

1.7D Bearing Failure

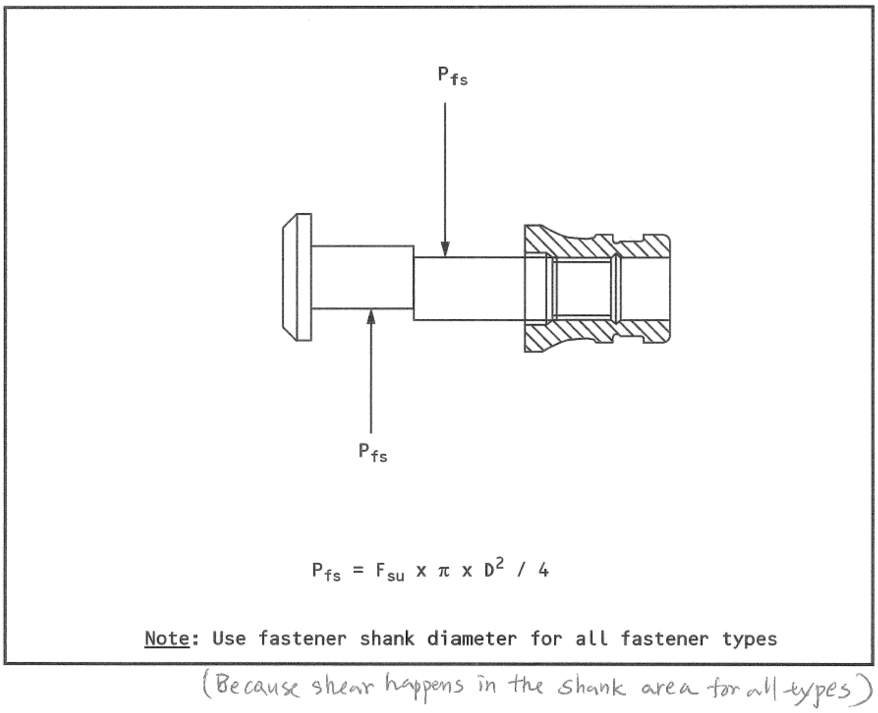
SRM 2D 0.05 inches



25 Bearing Failure

4. Fastener Shear Failure(　　　　　　　　)

26



FASTENER SHEAR

26 Fastener Shear Failure(　　　　　　　　)

Net Tension Failure

Tear Out Failure Bearing Failure Fastener

Shear Failure

(Joint Allowable Table)

1

P_{joint} = Lowest of P_{net}, $P_{tearout}$, P_{brg} or P_{fs}

Failure Mode	Preferred Method of Solution	Allowable Alternate Method
Net Tension*	P_{net} = Lesser of ($F_{tu} \times A_{net}$) or ($1.5 \times F_{ty} \times A_{net}$)	None
Tear Out*	Use SRM or MMPDS Joint Tables	$P_{tearout} = F_{su} \times t \times (2e - .766D)$ e = edge margin
Bearing	Use SRM or MMPDS Joint Tables	P_{brg} = Lesser of ($F_{bru} \times D \times t$) or ($1.5 \times F_{bry} \times D \times t$) (caution!)
Fastener Shear**	Use SRM or MMPDS Joint Tables	$P_{fs} = F_{su} \times \pi \times D^2 / 4$

*Use D_{avg} for countersink fasteners.
**Use D_{shank} for both protruding and countersink fasteners

The joint allowable, P_{joint}, is the lowest value of P_{net}, $P_{tearout}$, P_{brg}, P_{fs}.

27 Joint Allowable Table

Bearing Failure

(Shear Failure) Bearing Failure

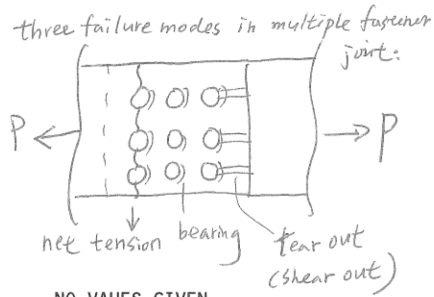
Bearing

Failure (Load Re-Distribution)

Oversize Fastener

Bearing Strength

FASTENER PART NUMBERS			BACB30DX BACB30LJ BACB30LK BACB30LM BACB30LN BACB30MB BACB30MR		BACB30NE BACB30NF BACB30NM BACB30NR BACB30NT BACB30NX BACB30PF		BACB30PU BACB30PW MS20004-24 NAS623 NAS673-678 NAS1218 NAS1223-1235		NAS1303-1320 NAS1465-1472 NAS6965-6972	
FASTENER DIAMETER			3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8
SINGLE SHEAR (LB)			2690	4650	7250	10400	14200	18600	23600	29150
SINGLE SHEAR BEARING STRENGTH (LB)	MATERIAL GAGE	0.063	1390	1830	2280					
		0.071	1560	2060	2570	3090				
		0.080	1760	2320	2900	3480	4060			
		0.090	1980	2610	3260	3910	4570			
		0.100	2200	2900	3620	4350	5050	5800		
		0.112	2470	3250	4060	4870	5700	6500		
		0.125	2690	3620	4530	5450	6350	7250	8150	9050
		0.140		4060	5050	6100	7100	8100	9150	10100
		0.160		4640	5800	6950	8100	9300	10400	11600
		0.180		4650	6500	7850	9150	10400	11700	13000
		0.200			7250	8900	10400	11900	13400	14900
		0.224				10000	11700	13300	15000	16700
		0.250				10400	12500	14200	16000	17800
		0.312					14200	17800	20000	22200
		0.375						18600	23600	26700
		0.500								29150
		0.562								
		0.625								



NO VAUES GIVEN (NOT ALLOWED, TRANSIONAL FAILURE MAY OCCUR)

(keep in bearing area)

MATERIAL BEARING FAILURE AREA

(optimized design to allow bearing before fastener single shear, easy for inspection)

FASTENER SHEAR FAILURE AREA

for load re-distribution

TENSION PROTRUDING HEAD BOLTS, LOCKBOLTS AND HEX-DRIVE BOLTS IN: ← FASTENER TYPE

7075-T6 CLAD OR BARE, SHEET OR PLATE

7075-T6, -T6510, -T6511 EXTRUSION (LESS THAN 0.185 THICK) ← JOINT MATERIALS (TABLE VALUES ARE FOR FIRST ONE LISTED)

95 KSI SHEAR STRENGTH ← FSU OF FASTENER MATERIAL

JOINTS – FASTENER ALLOWABLE TABLES (in SKM)

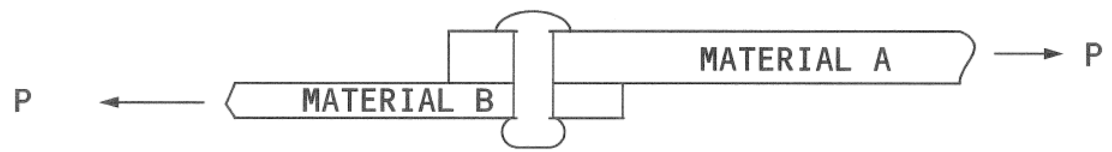
27 Joint Allowable Table

( ) (Joint Analysis)

(Joint Analysis)

28, 29

SINGLE SHEAR JOINTS



P_A = MATERIAL A SINGLE SHEAR JOINT ALLOWABLE

P_B = MATERIAL B SINGLE SHEAR JOINT ALLOWABLE

P = TOTAL JOINT ALLOWABLE = LESSER OF P_A OR P_B

P_{SRM} = SINGLE SHEAR JOINT ALLOWABLE FROM THE SRM JOINT ALLOWABLE TABLES FOR A SIMILAR TEMPER OR PRODUCT FORM OF THE SAME ALLOY AS MATERIAL A OR B.

F_{BRG} = LESSER OF (F_{BRU}) OR (1.5 X F_{BRY})

SINGLE SHEAR JOINT ALLOWABLES

IF P_A OR P_B IS AVAILABLE IN THE TABLES, USE THE TABLES

IF P_A OR P_B IS NOT AVAILABLE IN THE TABLES:

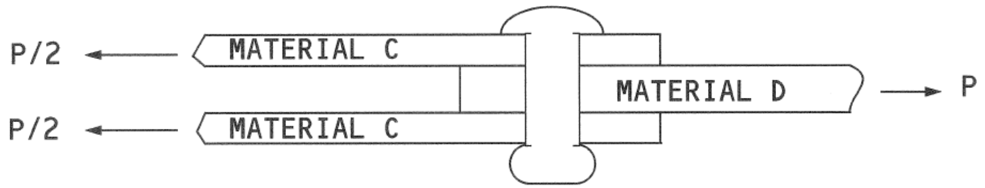
$$P_A = P_{SRM} \times \frac{F_{BRG(\text{MATERIAL A, E/D=1.7, B-BASIS})}}{F_{BRG(\text{MATERIAL THAT } P_{SRM} \text{ IS BASED UPON, E/D=1.7, B-BASIS})}}$$

$$P_B = P_{SRM} \times \frac{F_{BRG(\text{MATERIAL B, E/D=1.7, B-BASIS})}}{F_{BRG(\text{MATERIAL THAT } P_{SRM} \text{ IS BASED UPON, E/D=1.7, B-BASIS})}}$$

NOTE: P_A AND P_B SHOULD NOT EXCEED THE FASTENER SHEAR CAPABILITY

JOINTS – USING FASTENER ALLOWABLE TABLES

DOUBLE SHEAR JOINTS



P_C = MATERIAL C SINGLE SHEAR JOINT ALLOWABLE

P_D = MATERIAL D DOUBLE SHEAR JOINT ALLOWABLE (two sheets/side of material C)

P = TOTAL JOINT ALLOWABLE = LESSER OF ((2) X P_C) OR (1 X P_D)

P_{SRM} = SINGLE SHEAR JOINT ALLOWABLE FROM THE SRM JOINT ALLOWABLE TABLES FOR A SIMILAR TEMPER OR PRODUCT FORM OF THE SAME ALLOY AS MATERIAL C.

F_{BRG} = LESSER OF (F_{BRU}) OR (1.5 X F_{BRY}) (Bearing)

SINGLE SHEAR JOINT ALLOWABLES (MATERIAL C)

IF P_C IS AVAILABLE IN TABLES, USE THE TABLES

IF P_C IS NOT AVAILABLE IN TABLES:

$$P_C = P_{SRM} \times \frac{F_{BRG(\text{MATERIAL C, E/D = 1.7, B-BASIS})}}{F_{BRG(\text{MATERIAL THAT PSRM IS BASED UPON, E/D = 1.7, B-BASIS})}}$$

(Bearing)

DOUBLE SHEAR JOINT ALLOWABLES (MATERIAL D)

IF P_D IS AVAILABLE IN THE TABLES, USE THE TABLES (Rivet D.S. values are available in the tables)

IF P_D IS NOT AVAILABLE IN TABLES:

$$P_D = F_{BRG(\text{MATERIAL D, E/D = 1.7, B-BASIS})} \times D \times T$$

(E/D = 1.7: min. edge margin)

NOTE: P_C AND P_D SHOULD NOT EXCEED THE FASTENER SHEAR CAPABILITY JOINTS – USING FASTENER ALLOWABLE TABLES

(Also check the double-shear fastener capability = 2X fastener shear strength)

(Single Shear Joint) Bearing

Load Capability SRM Joint Allowable Tables

Bearing Capability

Bearing Load Capability

(Double Shear Joint) Bearing

Load Capability Bearing Capability

Bearing Capability

Bearing Load Capability

Joint Allowable Tables Bearing

Strength Joint Allowable Tables (

(-T6 -T651) (e/D))

Bearing Strength

(Yield Strength) (Ultimate Strength)

(Extrapolation) Bearing Failure

Bearing Strength Ratioing 30 Ratioing

( ) (Running Loads)

Web

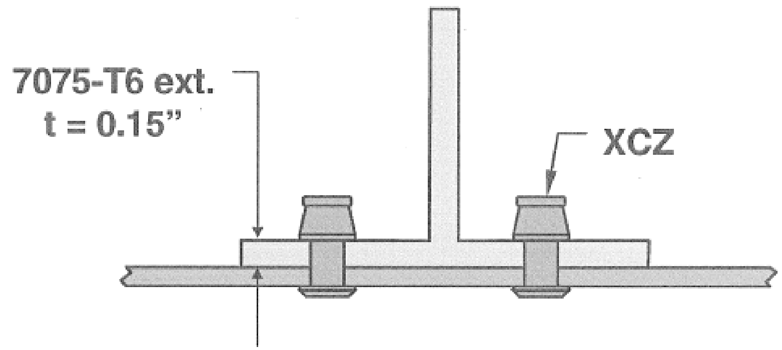
(Running Loads) 31

Example of Ratioing Joint Allowables

Example: From Problem 7

- **Material A:** 7075-T6 extrusion, t = 0.15 inch
- **What is P_{cap}?**

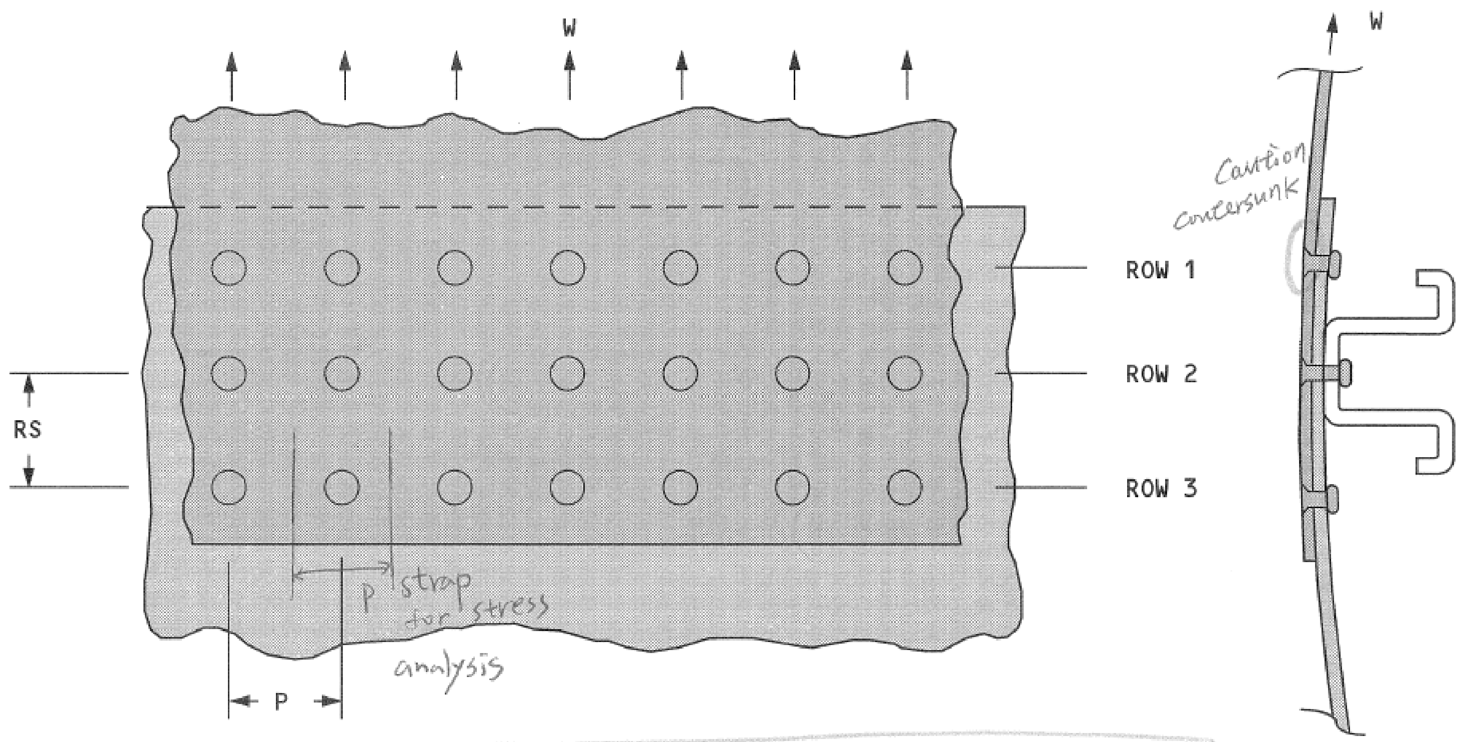
- No table value for XCZ in 7075-T6 ext.
- Closest is Fig. 5, Table III, for 7075-T6 sheet
  - Same alloy, different form
  - To ratio from test values, must use tested material
  - Tested material is listed first in the table
  - Table III is based on clad sheet



$$P_A = P_{joint\ table} \times \frac{F_{brg - A}}{F_{brg - A\ table\ matl.}}$$

$$P_{7075\text{-}T6\ ext} = P_{fig.\ 5,\ tbl.\ III} \times \frac{F_{brg - 7075\text{-}T6\ ext.}}{F_{brg - 7075\text{-}T6\ clad}}$$

30 Joint Bearing Strength (Extrapolation, Ratioing)



$$W_{max} = \frac{(\text{\# of rows}) \times (\text{joint strength of single fastener})}{(\text{fastener pitch})}$$

P = FASTENER PITCH (longitudinal spacing) W = RUNNING LOAD, LBS/INCH

RS = FASTENER ROW SPACING

TYPICAL FUSELAGE LONGITUDINAL LAP SPLICE

31 (Running Loads)

( ) (Edge Margin) (Row Spacing/Pitch)

(Edge Margin)

Shear Out Failure (Row Spacing/Pitch)

Shear Out Failure/Tear Out Failure

(Inter-Fastener Shearout)

2D ± 0.05 inch SRM

(Note)

(2D)

(Average Diameter)(Davg)

2D ± 0.05 inch

(Short Edge Margin, SEM)

SEM 32

SEM

(Net Tension or Shearout Check)

<u>Edge margins (EM) normal to the primary load path.</u>

Joints that typically carry tension loads:

- EM ≥ 1.5D : Acceptable provided the part is shot peened.
- EM < 1.5D : Not acceptable. The hole must be trimmed out and a doubler installed.
- Perform net tension checks on all parts less than 4D in width.

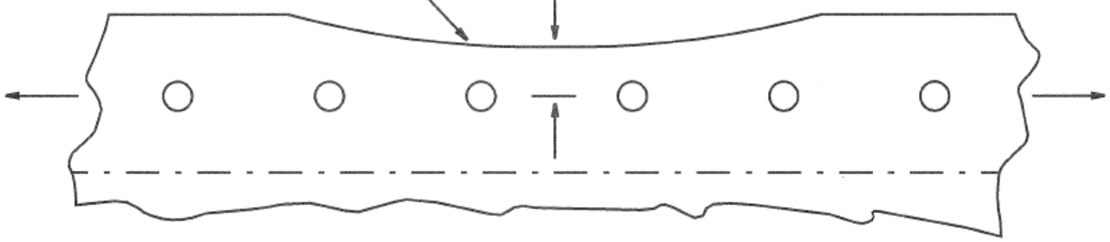
Joints that do not typically carry tension loads:

- EM ≥ 1.5D : Acceptable.
- 1D ≤ EM < 1.5D : Acceptable when not more than two fasteners are affected and two fasteners on each side can be oversized. In all other instances, a doubler must be added.
- EM < 1D : Not acceptable. The hole must be trimmed out and a doubler installed.
- Perform net tension checks on all parts less than 4D in width.

<u>Edge margins parallel to the primary load path.</u>

All joints:

- EM ≥ 1.7D : Use joint allowable tables directly.
- 1.5D ≤ EM < 1.7D : Ratio joint allowable by F_{brg}(e/D=actual) / F_{brg}(e/D=1.7D). For bolts in double shear use F_{brg}(e/D=actual) x D x t, where F_{brg} = lesser of 1.5F_{bry} or F_{bru}.
- 1.0D ≤ EM < 1.5D : Use tearout check.
- EM < 1.0D : Not acceptable. The hole must be trimmed out and a doubler added.



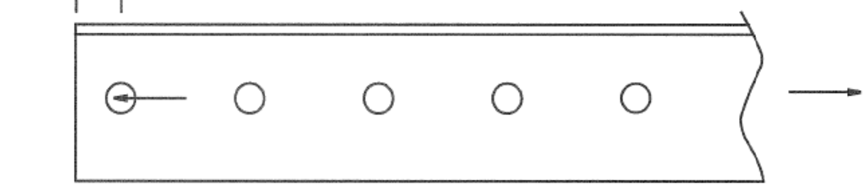
TYPICAL SHORT EDGE MARGIN NORMAL TO PRIMARY LOAD PATH

ACCEPTABLE

EM $\geq$ 1.5D [1]

NOT ACCEPTABLE

EM < 1.5D [2]



TYPICAL SHORT EDGE MARGIN PARALLEL TO PRIMARY LOAD PATH

$$P_{allow,\ e/D=1.6} = P_{allow\ table\ (e/D=1.7)} \times \frac{F_{brg\ e/D=1.6}}{F_{brg,\ e/D=1.7}}$$

ACCEPTABLE

EM $\geq$ 1.7D [3]
1.5D $\leq$ EM < 1.7D [4]
1.0D $\leq$ EM < 1.5D [5]

NOT ACCEPTABLE

EM < 1.0D [2]

(1) Shot peen part
(2) Trim out hole and repair
(3) Use joint table load
(4) Ratio load by relative F_{brg}
(5) Use tearout load

4D ~ 6D

( )

(Pull-Up Gap)

Buckling 0.01 inch

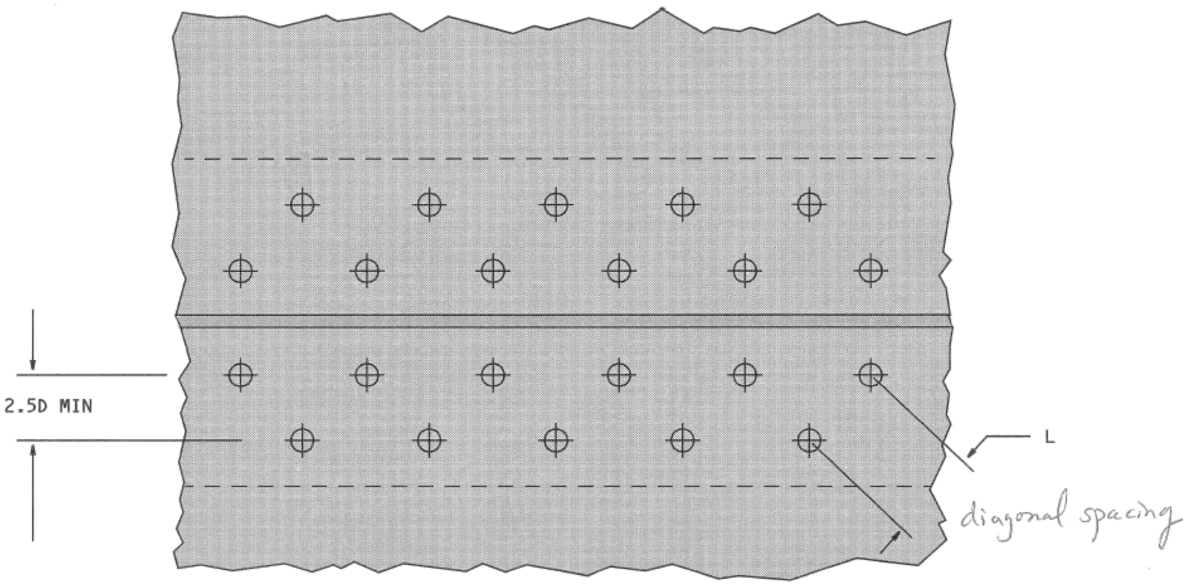
Pull-Up Stress 50% Stress

Corrosion Threshold

(Staggering)

33

(Staggering)



Staggered Rivets: $L_{rivets} \leq 3.75 \times D_{shank}$

Staggered Bolts: $L_{bolts} \leq 4.50 \times D_{shank}$

All Fastener Types: $L_{fasteners} \leq 10 \times t_{thinnest}$

33 (Staggering)

( ) (Eccentric Load)

(Fastener Pattern)

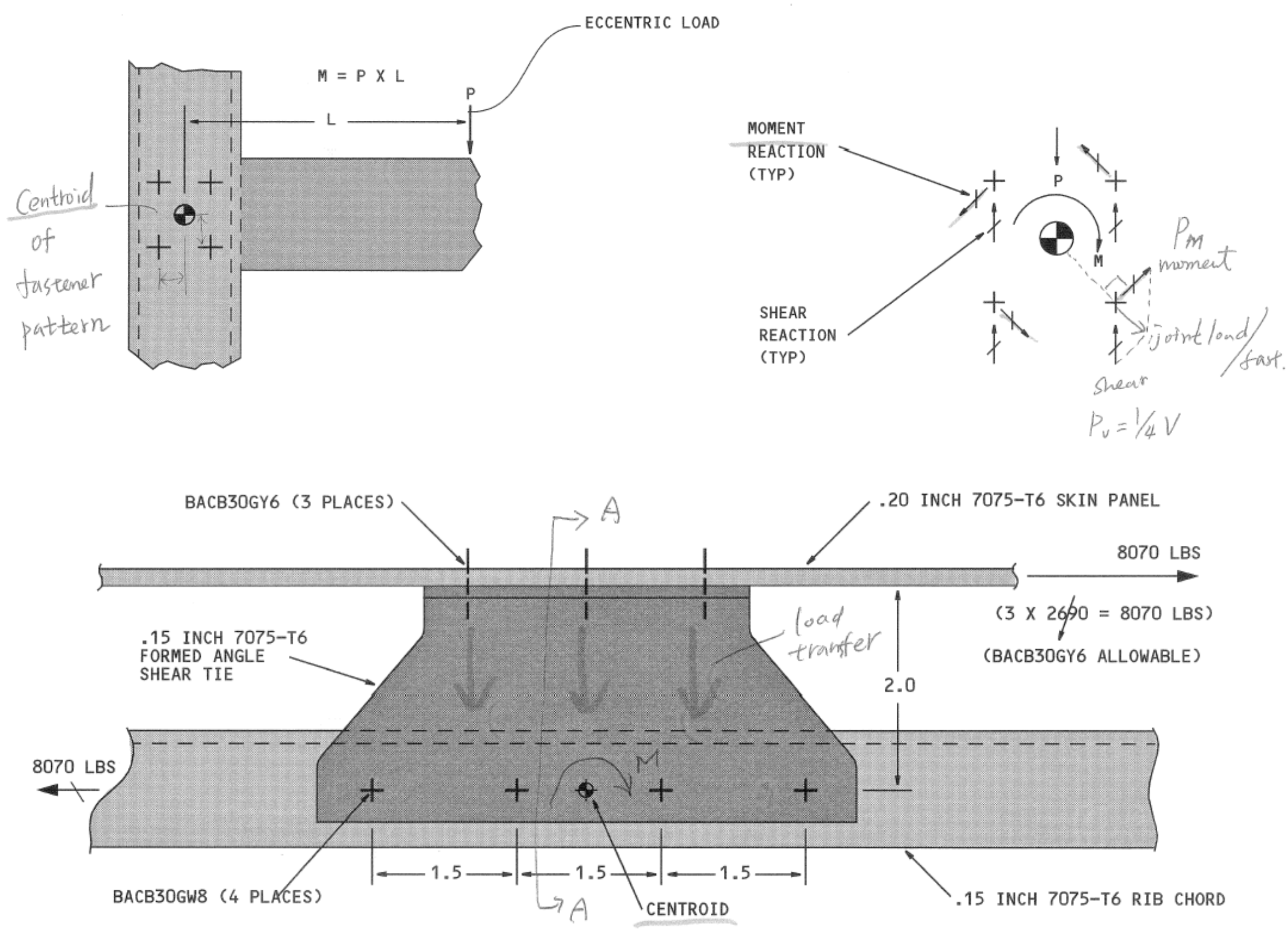
(Centroid) (Moment)

Shear Tie

(Frame Floor Beam)

(Hoop Stress) (Frame)

34

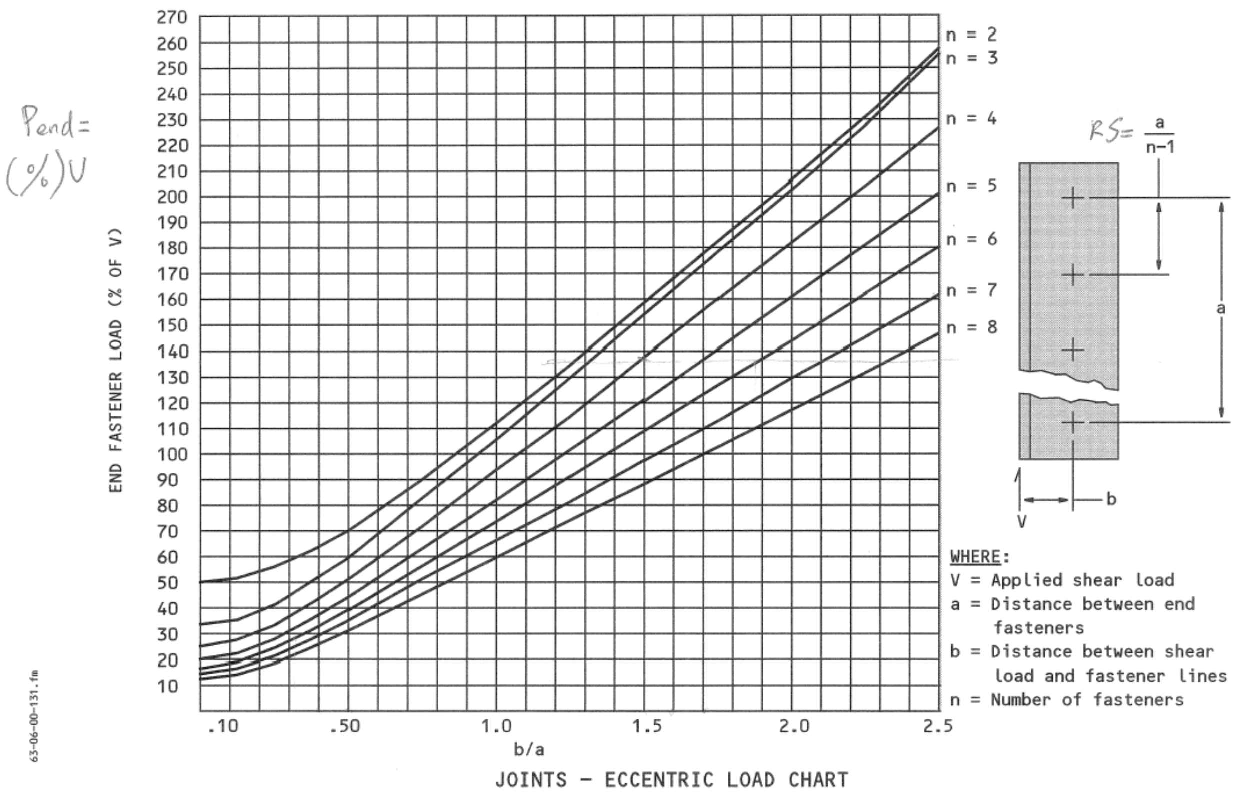


34 (Eccentric Load) Shear Tie

34 35

(Eccentric Load Chart)

/



35 (Eccentric Load Chart)

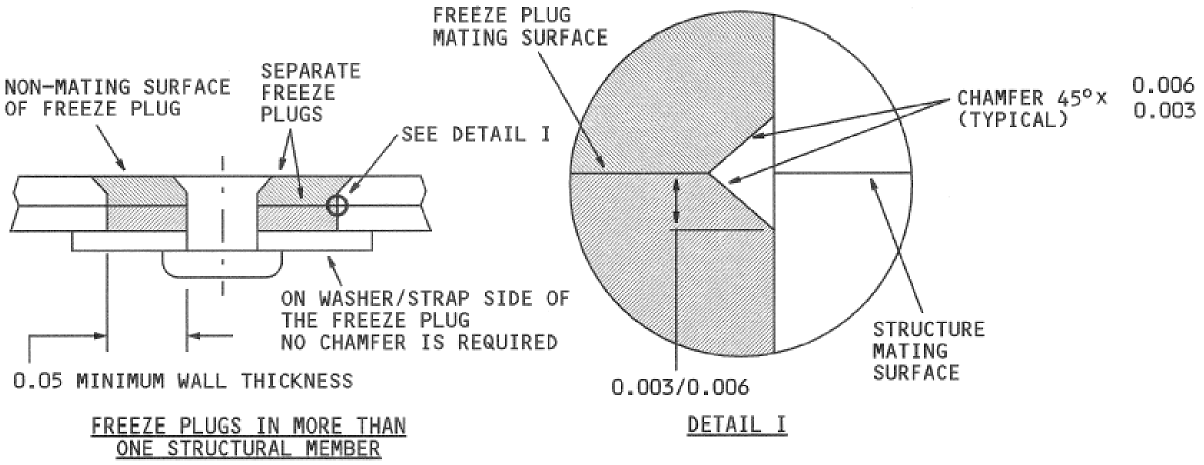
( ) (Freeze Plug)

(Freeze Plug) 36

(Freeze Plug)

(Freeze Plug)

Net Tension Failure



The following guidelines apply to the installation of aluminum freeze plugs in aluminum.

- The repaired material must be a minimum of 0.063 inch thick.
- Make freeze plugs in aluminum parts from 7075-T6.
- Make the shank diameter 1.0035 to 1.0040 times larger than the diameter of the hole.
- The freeze plug diameter must be less than or equal to 10 times the plate thickness.
- Maintain a minimum wall thickness of 0.05 inch between the freeze plug and the fastener hole.
- If a freeze plug is used to transfer load keep the plug concentric with the fastener going through plug.
- Maintain an edge margin of (1.7 x D_{plug}) for freeze plugs.
- Maintain a spacing of (2 x D_{plug}) between freeze plugs and adjacent fasteners for a single freeze plug. Maintain a spacing of (2.5 x D_{plug}) for up to 5 freeze plugs in a part.
- Make separate freeze plugs for each material in a stack up.
- Retain freeze plug with a countersink, washer, or strap.
- Make the countersink freeze plug so it and the fastener have a 100 degree countersink.
- Make the countersink depth of the freeze plug less than or equal to 50% of the material thickness.
- Maintain 0.05 inch minimum measurable material between the fastener countersink and the freeze plug countersink.

36 (Freeze Plug)

( ) (Shim)

0.005 ~ 0.01

inch

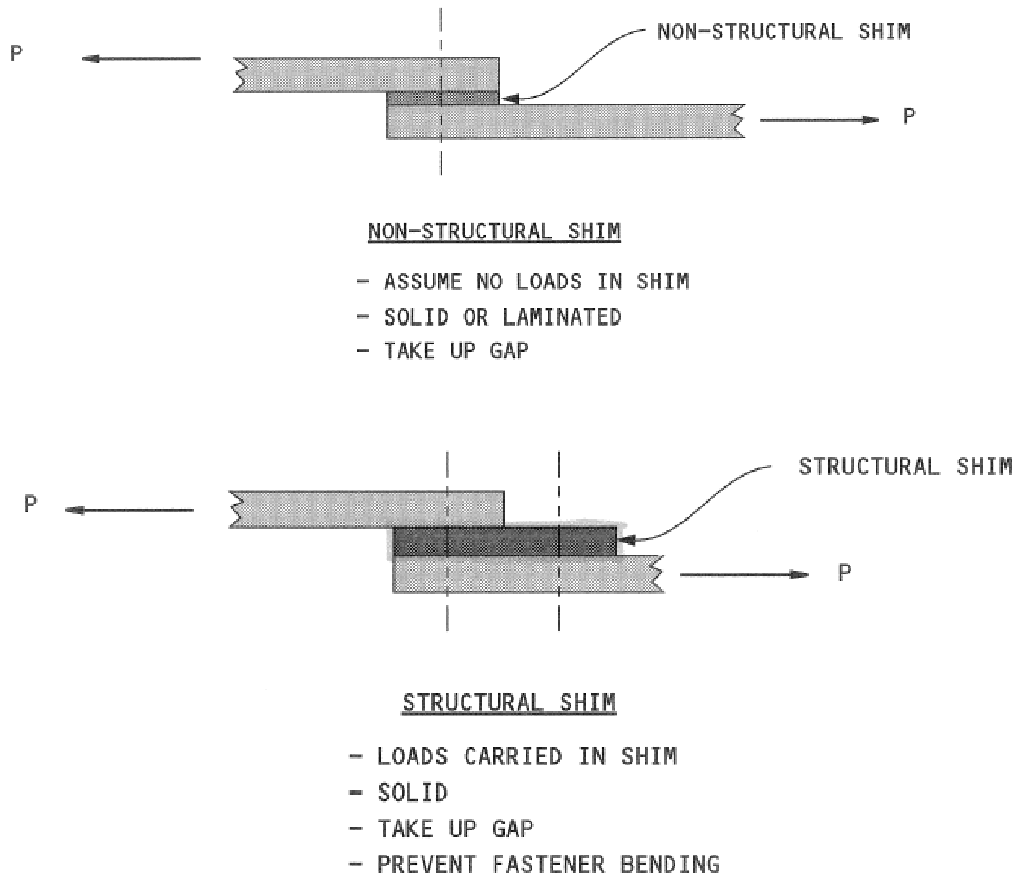
(Structural Shim) (Non-Structural

Shim) (Load Path)

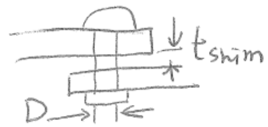
Laminated Solid Shim Laminated

Shim 0.05 inches 0.05 inches

Solid Shim Laminated Shim



37 (Shim)



SHIM THICKNESS AS A PERCENTAGE OF THE FASTENER DIAMETER	FASTENER TYPE AND MATERIAL	NON-STRUCTURAL SHIM [B]	STRUCTURAL SHIM [A]
LESS THAN 16%	RIVETS (ALUMINUM)	X	
16% AND GREATER	RIVETS (ALUMINUM)		X
LESS THAN 21%	SHEAR LOCK OR HI-LOKS BOLTS (STEEL OR TITANIUM)	X	
21% AND GREATER	SHEAR LOCK OR HI-LOKS BOLTS (STEEL OR TITANIUM)		X
LESS THAN 26%	TENSION LOCKBOLTS BOLTS OR HI-LOKS (STEEL OR TITANIUM)	X	
26% AND GREATER	TENSION LOCKBOLTS BOLTS OR HI-LOKS (STEEL OR TITANIUM)		X

777 SRM DATA

NOTES:

- EXAMPLE CALCULATION:
  FOR A 0.040 INCH THICK SHIM AND A 3/16 (0.1875) INCH DIAMETER TITANIUM SHEAR HI-LOK, THE SHIM THICKNESS AS A PERCENTAGE OF THE FASTENER DIAMETER:

$$= \frac{\text{SHIM GAGE}}{\text{FASTENER DIAMETER}} \times 100$$

$$= \frac{0.040 \text{ INCH}}{0.1875 \text{ INCH}} \times 100$$

$$= 21.3\%$$

[A] THE SHIM MUST BE FASTENED TO THE REPAIR PART OR THE INITIAL PART. THE STRUCTURAL SHIM IS USED TO PREVENT MOVEMENT THAT COULD POSSIBLY BEND THE FASTENER.

[B] THE SHIM CAN BE BONDED WITH ADHESIVE BMS 5-95 OR BAC5010, TYPE 70 TO THE REPAIR PART FOR CONVENIENCE OF INSTALLATION.

A NON-STRUCTURAL SHIM IS ALLOWED ONLY IF THE SHIM THICKNESS IS LESS THAN 21%, THUS, A STRUCTURAL SHIM IS NECESSARY. → or change diameter or change fastener type to allow to use Non-Structural Shim.

JOINTS - SHIMMING GUIDELINES

38 (Shim)

(Durability)

(Fatigue Resistance) (Corrosion Resistance)

(Wet Installation)

(Fatigue Resistance)

( ) –

(Wet Installation) 39

1. BMS 5-45

Microballoon

(Specific Gravity)

BMS 5-26 20%

2. BMS 5-95

3. BMS 5-63

Silicone

4. PR1826 PR1828

BMS 5-45 BMS 5-26

ITEM NO.	SPEC	APPLICATION CLASS	BASE	COLOR	DESCRIPTION OF USE
1	5-26	B,C,D	POLYSULFIDE	DARK GRAY	CORROSION PROTECTION AND FUEL SEAL IN FUEL TANK [1]
2	5-45	A,B,C	POLYSULFIDE	BROWN/GRAY	CORROSION PROTECTION AND FUEL SEAL IN FUEL TANK(LOW DENSITY)
3	5-63	B	SILICONE	GRAY	FIREWALL, SKYDROL RESISTANT
4	5-95	B,C,E,F,G	POLYSULFIDE	GRAY	CORROSION PROTECTION, FASTENER INSTALLATION, AERODYNAMIC
5	5-142	B	POLYSULFIDE	DARK GRAY	CORROSION PROTECTION, AERODYNAMIC (LOW DENSITY)
6	PR-1826	B	POLYTHIO ETHER	DARK GRAY	FUEL TANK REPAIR SEALANT
7	PR-1828	B	POLYTHIO ETHER	WHITE	FUEL TANK REPAIR SEALANT

SEALANT CALLED OUT ON DRAWING OR DOCUMENT / PERMISSIBLE OPTION	2	3	4	5	6	7
1	YES	NO	NO	NO	YES	YES
2		NO	NO	NO	YES	NO
3	NO		NO	NO	NO	NO
4	YES	NO		YES	YES	YES
5	YES	NO	YES		YES	YES

VENDOR EQUIVALENTS

BMS 5-45	BMS 5-63	BMS 5-95	[2] BMS 5-142
PR 1776	DAPCO 18-4	PR 1436	PR 875
PRO SEAL 890	DAPCO 2200	PR 1432	PR 1772
	DAPCO 2100	PRO-SEAL 870	

[1] BMS 5-26 HAS BEEN SUPERCEDED BY BMS 5-45

[2] BMS 5-142 IS NOT PERMITTED FOR MATING SURFACE SEAL, PRE-PACK SEALING, AND WET FASTENER INSTALLATION PROCEDURES.

[3] PR1826 HAS A PRIMER THAT MUST ALSO BE USED

( ) –

(Anodizing) Alodine

1. BMS 10-11

2. BMS 10-79

(filiform Corrosion)

3. BMS 10-20

BMS 10-100 BMS 10-60

( ) –

(Corrosion Inhibitor Compound, CIC)

CIC

CIC

1. BMS 3-23

(Mating Structures)

2. BMS 3-26

3. BMS 3-29

(High

Moisture Surface) Bilge Area

4. BMS 3-35

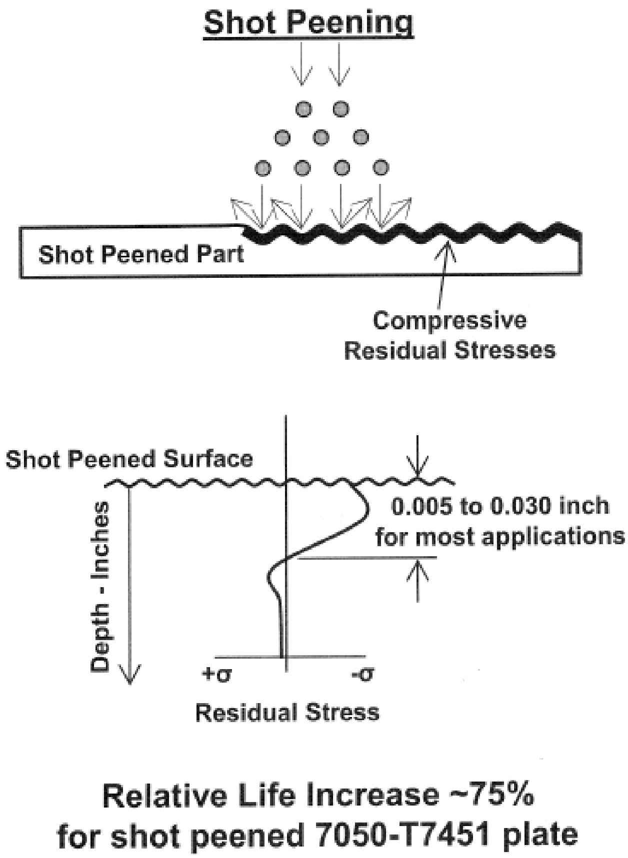
(Tack Free Surface) (Touch-Up)

( ) (Fatigue Resistant Repair)

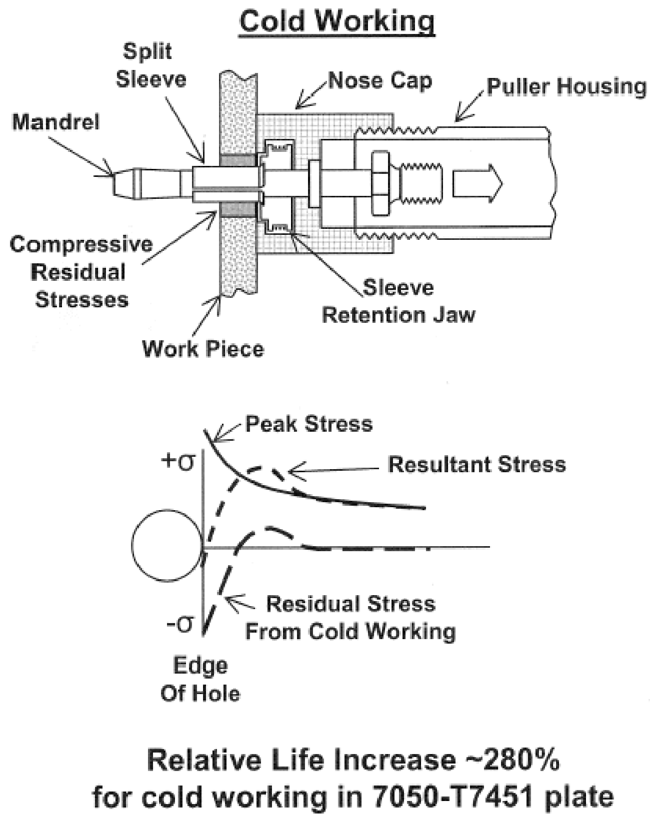
1. (Shot Peening) (Cold Work) 2024

7075

Compressive Layer Peak Stress



40 Shot Peening Surface Peak Stress



41 Cold Work Peak Stress

2. Fatigue Resistance Fastener (Rivet, Hex-Drive Bolt, Lockbolt) (Interference Fit)

Compressive Layer

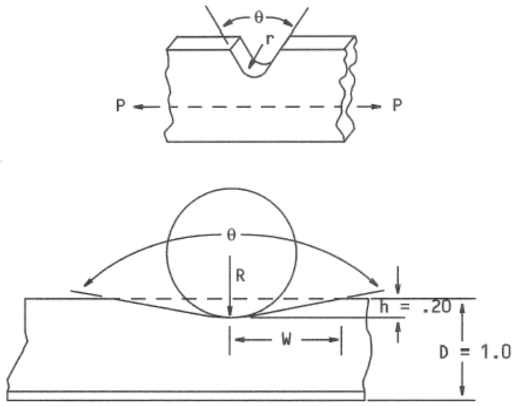
( ) (Blendout Slope)

SRM

42

30:1

20:1



STRINGR FLANGE WITH BLENDED NOTCH

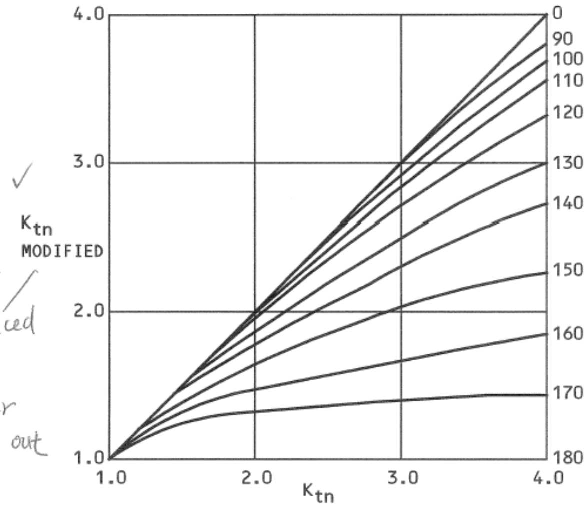
SLOPE = $\frac{W}{h}$	FOR THE 1.0 WIDE STGR. FLANGE		
RADIUS	.25	.50	1.0
5:1 SLOPE θ = 157°	1.42	1.28	1.18
10:1 SLOPE θ = 168°	1.32	1.22	1.15
20:1 SLOPE θ = 174°	1.15	1.10	1.06
30:1 SLOPE θ = 176°	1.15	1.10	1.04

MODIFIED NOTCH K_{TN}

no substantial benefit, therefore use 20:1 is sufficient!

* trim the notch out ⇒ to reduce stress concent

PLATE WITH UNSYMMETRICAL EDGE NOTCH – INFLUENCE OF SHOULDER SLOPE



reduced K_{tn} after trim out

MOD K_{tn} FOR NOTCH OF ANGLE θ, OTHER DIMENSIONS SAME

Ref 3: Peterson's Stress Concentration Factors

DURABILITY – NOTCH REMOVALS

42

FAR

(Ultimate Load)

(Patches/Doublers) (Repair Angles)

(Load Capability Calculations)

(Ultimate Load

Capability) SRM (Durability)

(FAR 25.301 FAR 25.571)

-
-
-
-
  (Ultimate Load Capability)
-
-
- SRM ( )

–

Part I

Mr. Montgomery (Monty) H. Morgan

Everret

B777, B767, B747-400 B787,

B747-8

(GEMCOR)

AMECO

6