SSC-260

A SURVEY OF FASTENING TECHNIQUES FOR SHIPBUILDING

SHIP STRUCTURE COMMITTEE
1976

SHIP STRUCTURE COMMITTEE

AN INTERAGENCY ADVISORY
COMMITTEE DEDICATED TO IMPROVING
THE STRUCTURE OF SHIPS

ADDRESS CORRESPONDENCE TO:

Secretary
Ship Structure Committee
U.S. Coast Guard Headquarters
Washington, D.C. 20590

SR-207

The Ship Structure Committee recognized, as a result of studies sponsored on the use of aluminum and fiberglass in ship construction, that a variety of joining techniques must be considered. Many mechanical and adhesive techniques have been employed in other industries. Some of these methods might have a marine application and provide an alternative to welding.

This report describes the study that was made of these alternative fastening techniques. It is not an endorsement by the Ship Structure Committee of any concept or process. Many of these concepts would require a more penetrating examination before they could be adopted. However, much of the material has not been readily available to the marine community. In some cases this information might prove useful especially in weight critical applications.

This report is published to assist in developing cost effective and safe fastening techniques. Comments on this report and suggestions for areas of critical need in ship structural research would be most welcome.

W. M. BENKERT
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

SSC-260

Final Report

on

Project SR-207, "Fastening Techniques Evaluation"

A SURVEY OF FASTENING TECHNIQUES FOR SHIPBUILDING

by

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Boeing Commercial Airplane Company

under

Department of the Navy
Naval Sea Systems Command
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U. S. Coast Guard Headquarters
Washington, D.C.
1976

ABSTRACT

This report is aimed at defining fastening processes and techniques that are not widely used in ship construction today in terms of their applicability and potential for improving cost, construction, reliability, and maintenance of hull structures and attachments. The study includes similar and dissimilar metal-to-metal and metal-to-nonmetal joints, a generic fastener matrix of typical fasteners, fastener installation equipment and processes, proposed applications of explosion-bonded materials, and cost comparisons of various fabrication techniques. Fusion welding, diffusion bonding, friction welding, and adhesive bonding are discussed. Several fastener standards and vendor proprietary fasteners are included as figures. Extractions from Boeing Design Manual sections on mechanical fastening and adhesive bonding are included as reference attachments. Fastening systems and techniques that merit further study or verification are identified.

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I. INTRODUCTION

IA. BACKGROUND

There are many differences and similarities between conventional ship and airframe assembly methods. These differences range from the obvious to the very subtle and are related to the particular fabrication techniques and the design philosophy of the structures.

In both industry situations, customer/user performance criteria within the context of regulatory agency requirements influence the direction taken by the designer and builder in producing a vehicle to satisfy customer needs for a price.

The aerospace industry has been challenged to extend its capability in many areas. Premiums attached to weight of airframes resulted in the introduction of honeycomb construction and adhesive bonding. Several other joining processes received impetus. These include plasma and electron beam welding, diffusion bonding, and mechanical fastening.

Parallel with the above activity, the jet commercial transport came of age. This growth in the commercial market provided the opportunity to develop new processes offering cost-effective returns. The quest for increased customer acceptance emerged in one form as extended-life airframe warranties (fatigue-rated structure).

These factors contributed to the utilization of a full complement of material forms (sheet, plate, extrusions, castings, forgings, weldments); materials (aluminum, steels, titanium, nickel magnesium, glass-reinforced plastics, etc.); alloys within a basic metal family; and heat-treat tempers to their best advantage. As a result, a delivered aircraft represents a conglomeration of materials and material conditions, each of which may require a unique joining method. Outfitted ships represent a similar conglomeration of materials and joining methods. The net result is a full complement of joining methods ranging from diffusion bonding, fusion and resistance welding, adhesive bonding, and a wide variety of mechanical fasteners. This area of joining becomes extremely significant and is the basic subject of this report.

The principal method of airframe structural joining is mechanical fastening. These fasteners range in size from 3/32-inch diameter, for riveting of floating nut plates, to high-strength alloy steel and titanium bolts of 2-inch diameter. Structurally rated blind rivets, families of vendor proprietary interference fit fastener systems, and several classes of riveting make up the process inventory. These include fastener types and installation processing criteria for fluid-tight fasteners classified for use in integral fuel tank structures. Another classification of fasteners is available for fatigue-rated fluid-tight applications. Some of the principal considerations for fastening of airframe include low fabrication cost and capital equipment requirements, proven reliability, repairability/panel replaceability, fail-safe design philosophy, and fatigue considerations. End item inspectability is also a pertinent consideration.

Portable tools and mechanized equipment (including multiaxis numerically controlled panel riveters) have been developed to install the various types of fasteners.

Unlike aircraft, the quantities of ships constructed on a particular production run are relatively few in number. The extensive use of hard tooling and jigging is not warranted in the assembly stages due to the high costs involved. However, production and modular assembly concepts developed in the shipbuilding industry have been adopted for widespread use in the airplane industry. These include the use of full-scale lofting, free-floating jigs (one degree of freedom) common to both industries and construction by compartments or sections.

The interest of the government and the civilian sector in fast-ship concepts, such as the hydrofoil and surface-effect ships, has led to the need for new fastening or joining techniques. Some of the newer techniques already being investigated in the shipbuilding industry (such as bimetallic joinings) are documented in this report, along with fastening systems that have in the past been used parimarily in the aircraft industry.

IB. SCOPE

On the basis of prior screening, a selection was made of specific types of attachments to be studied in greater detail. These include: Several aspects of equipment and systems installation and joints between dissimilar materials (metals and nonmetals combinations). Both of these were studied for:

a) Fabrication cost and practicality

b) Maintenance requirements and savings

c) Corrosion and fracture characteristics

d) Inspection requirements

e) Weight

f) Fatigue capabilities

g) Comparison with other methods

h) Reliability

The following joining problems were studied with respect to the above criteria:

a) The use of bimetal strips or fillers produced by diffusion bonding, roll bonding, or explosive bonding for conventional welding of dissimilar metals

b) Use of flanged, formed bead structure for dissimilar metals explosively bonded in place

c) Use of friction welding for dissimilar metal stud welding

d) Use of explosive or diffusion bonding to produce dissimilar metal sleeves for melt-through joining with portable, automatic tube welders

e) Use of explosive bonding to jacket foreign metal structures for prevention of underwater electrolysis

f) Use of special edge members and shock-absorbing sleeves for attachment of nonmetals

g) Bulkhead penetrations

h) Mechanical fastening for structural and nonstructural joints

i) Adhesive bonding of similar and dissimilar metal joints

j) Hole preparation

k) Coldworking holes for increased fatigue strength

l) Fluid-tight flush fasteners for hydrodynamic environments.

As this study is conceptual in nature, no hardware has been fabricated. Individual applications of proposed techniques will require evaluation on their own merits.

II. INVESTIGATION AND ANALYSIS

IIA. IDENTIFICATION OF PROBLEM AREAS FOR STUDY

This part of the program involved research of available data from several sources, including the Defense Documentation Center, local and company libraries, reports made available to Boeing from the Ship Structure Committee, and visits to vessels under construction and in service. These visits provided first-hand information as to use-experience problems associated with ship structure, and, in addition, served to familiarize the authors in the language of the industry.

Based on initial discussions with the advisory group and subsequent consultations and reviews, it was determined that connections and attachments made below a ship's waterline would be internal connections only and that nothing should penetrate the outer hull. However, above the waterline, where connections and attachments other than welding have been proven economical and safe, such information is in the recommendations contained in this report.

Welding of conventional steel ship structure is discussed briefly in this study because it is based on well-established processing knowledge. Emphasis was placed on identifying fabrication problems in steel and aluminum structure, systems attachments, and what is generally known as outfitting.

Based on service experience and history, it has been determined that one of the major problems encountered in the fabrication of aluminum structure is that of galvanic incompatibilities caused by the coupling of dissimilar metals in the presence of a sea-water electrolyte. The galvanic-corrosion problem manifests itself in many areas during initial construction and while the vessel is in subsequent use. The areas where galvanic corrosion can be located and identified range from the attachment of the deckhouse to hull structure and of equipment foundations to structure. The major emphasis of this problem is to identify these areas and to suggest alternative fabrication or attachment methods. Table 1 identifies areas pertinent to the scope of this input and includes a brief summary of proposed alternatives. Discussion in the remarks column is sometimes brief because of space limitations. Additional discussion may be found in the sections of this report referenced in the remarks column.

IIB. GENERIC FASTENER MATRIX

Mechanical fasteners are produced commercially in a wide variety of sizes, shapes, alloys, protective finishes, and heat treatments. Their respective installation requirements vary from squeeze deformation to interference fits. The current fastener inventory can satisfy a multitude of requirements, both structural and nonstructural. These applications include fluid-tight and fatigue-rated joints, riveted lap joints in thin structure, and attachment of systems and equipment.

The generic fastener matrix (Table 2) lists a number of different families of fasteners used in the aircraft industry that have potential for application in fabrication of ship structure. With few exceptions, these are government-approved standard parts. In fact, several of these fasteners are already being used in specialized applications in the shipbuilding industry.

TABLE 1

ALTERNATE APPLICATIONS TABLE

Problem area or type	Present practice	Proposed alternatives	Remarks
Aluminum deckhouse fabrication	Steel and aluminum structure Weld stiffeners and hatches to bulkheads Deckhouse-to-deck major load-carrying joint	Prefabricate superstructure Rivet stiffeners to bulkhead Design framing to be primary load carrying members	Conventional riveting Cost-effective method of joining Less distortion and warpage High maintainability and repairability Riveting tooling-safe operations, low costs No welding allowables or gage limitations Applicable to other structure—joiner bulkheads, framing, etc. (Refer to section II D)
Joining aluminum deckhouse to steel deck (galvanic corrosion)	Lap joint Apply primers and sealants Drill and install Huck bolts Apply sealants to joint fillets Prime and paint Requires steel coaming above deck	Prefabricate deckhouse/superstructure Use bimetallic strip as interface Weld strip to coaming Eliminate coaming, weld directly to deck (Litton Shipyard practice)	Explosive bonded bimetallic strips afford Molecular bond of dissimilar metals Excellent corrosion resistance Low maintenance requirement Formability Cost-effective installation (Refer to section II D)
Attachment of steel deck machinery to aluminum deck (galvanic corrosion)	Apply primer and paint to faying surfaces Install gaskets, plastic chocking, or waster pieces Bolt through deck/framing Apply sealant to fillets Paint	Install bimetallic pads at interface Weld steel to steel, aluminum to aluminum Add CRES bolts if necessary	Bimetallics Allow similar metal-to metal joints Galvanic couple isolators Machinable Can be shimmed for critical alignments (Refer to section II D and enclosures)
Compatibility of pump, pump connections, valves, and fittings	Conventional steel structure Allow steel pipe/pump systems Allows bronze/steel valve connections Requires heavy duty pipe (schedule 80) Aluminum structure Install waster washer Requires paints, primers, sealants	Aluminum structure Use bimetallics for aluminum pipe to steel pump/valve connections Use bimetallics as isolation mounts Use bimetallics as bulkhead penetrations for watertight compartment	Bimetallics Allow dissimilar metal pipe-to-pipe connections Lessen ship weight with aluminum pipe Save costs of nonsteel pumps and valving Watertight bulkhead penetrations Allow projection stud welds where necessary Eliminate waster pieces for pump mounts (Refer to section II D and enclosures)
Mechanical fastening	Steel structure attachments Projection stud welding Fusion welding Cost-effective processes Aluminum structure Isolation mounts CRES fasteners Sacrificial bushings and washers	Steel structure Projection welding best cost-effective method Proprietary high-strength fasteners available for systems attachments Aluminum structure Families of commercial fasteners available in various alloys and configurations Bimetallic and trimetallic strip and sheet available in many alloy combinations	Refer to fastener matrix section of this report for specific types, applications, and specifications. Refer to table 2

TABLE 2
GENERIC FASTENER AND APPLICATIONS MATRIX

Generic name	Identification	Alloys	Characteristics and suggested applications
	Solid-shank structural rivet (see Appendix H 17.611)		
Flush head	MS20426	5056 AR	Characteristics
	BACR15DY	A-286	Primarily shear rated
	MS20427M	Monel	Available with protective coatings
	BACR15EE	Ti-6Al-4V	Fluid-tight processes available
			Fatigue rated
Universal head	MS20470	5056 Al	Applications
	BACR15DX	A-286	Below waterline applications
	MS20615M	Monel	Thin-gage applications
	BACR15EW	Titanium alloys	Thin sheet lap and butt joints
Slug	BACR15BD	5056 Al	Structural shear and tension joints
			Fluid-tight assemblies and bulkheads
Index head	BACR15FH	2117 Al	Hand-driven installations
		2024-T351	Machine or yoke squeeze installations
			Electromagnetic riveting
	Structural blind fasteners (see fig. 2)		
Protruding head	NAS1398C	A-286	Characteristics
	NAS1398NW	Monel	High strength
	NAS1398B	5056 Al	Available with protective coatings
	BB678	CRES	Labor saving installations
	BB352	CRES/6061	Shear and tensile rated
Flush head	NAS1399B	5056 Al	Locked stem—hold filling and non-hole-filling
	NAS1399C	A-286	Fluid tight with sealant
	NAS1399MW	Monel	Applications
	BB677	CRES	Limited-access areas
	BB351	CRES	Thin sheet and sandwich construction
	BB449	A-286	Brackertry attachments
		6061 Al	Temporary repairs
			Closeout panel attachment
	Nonstructural blind fasteners (see Appendix H 17.613)		
Protruding head	MS20602	5056 Al	Characteristics
	NAS1738	5056 Al	Low strength
	NAS1738	Monel	Locked stem—hole filling and non-hole-filling
			Hollow shank
Flush head	MS20603	5056 Al	Applications
	MS20605	Monel	Nonstructural attachments
	NAS1739	5056 Al	Nutplates
	NAS1739	Monel	Name plates
	Blind nuts (see table 3)		
Protruding head	BN540	CRES	Characteristics
	BN549	A-286	Structural rated
			Fluid tight
Flush head	BN360	CRES	Flush and protruding head
	BN555	A-286	Labor savings
	BN562	Ti-6Al-6V-2Sn	
	BN158	5056 Al	Applications
Three-piece system	BNB1108	A-286	High-temperature applications
	BNB1109	A-286	Fuel and fluid tanks
	BNB1110	A-286	Structural and brackerty attachments
	BNB1111	Ti-6Al-6V-2Sn	Systems attachments
			Honeycomb sandwich panel attachments

TABLE 2

CONCLUDED

	Structural threaded fasteners (see figs 6 and 7)		
Protruding head	BUS1634 BUS1734 BUS1936	Steel alloy CRES Steel alloy	Characteristics High strength Fluid tight (with seal nuts or sealant) Tensile and shear rated Predetermined torque without torque wrench Various protective coatings and finishes Removable for repair and modification Applications High-temperature applications Fit-up bolts for joining assemblies Above and below waterline applications Deck machinery attachment
Flush head	BUS1434 BUS1535 BUS1836	Steel alloy CRES Steel alloy	
Six wing	SW1050 SW1055 SW2060 SW2262 SW2565 SW2855	4140 A-286 H-11 270 ksi H-11 230 ksi Ti-6Al-4V Ti-6Al-6V-2Sn	
	Structural lockbolts (see Appendix H 17.634)		
Flush head	BACB30GQ NAS1436-42 NAS1456-62	Aluminum alloy Steel alloy Titanium alloy, CRES	Characteristics Shear and tension rated Fatigue rated Fluid-tight bolts and collars available Various protective coatings and finishes High-temperature and corrosion resistant Weight savings Labor saving Applications Limited-access applications Panel lap or butt joints Bracketry and equipment support attachments Fluid-tight joints
Protruding head	BACB30GP NAS1446-52 NAS1465-72 BACB30DX A	Aluminum alloy Steel alloy Titanium alloy CRES	
Stump type	NAS1414/1422 NAS1424/1434 NAS2060V/2712V	4037/8740 Optional Ti-6Al-4V	
	Quick release fasteners (see Appendix H 17.634)		
Protruding head	BACS21Y	Steel alloy CRES	Applications Equipment covers Access panels Tension loads to 1700 lb Shear loads to 3580 lb
Flush head	BACS21X	Steel alloy CRES	

Note: See text for general discussion and cited enclosures and figures for additional details.

Before some of these fasteners can be used for broad applications by the designer or naval architect, it is essential that design parameters or engineering allowables be established for each fastener system. A wealth of data exists within the shipbuilding and aerospace industry on the various physical and chemical properties of these fasteners. This information is usually a part of the individual fastener standard and is usable at "par" in any industry.

This degree of transferability does not always apply in the case of product applications. These application criteria are often called design allowables, design parameters, or design standards. They are defined as the complex body of information that delineates the limits within which a structure can be designed. They often include the maximum safe stress levels for a desired environment for fasteners; allowances for structural mismatch at the time of joining; allowances for fitup stresses; corrosion allowances; fatigue considerations; etc. In sophisticated structural systems, such as large commercial ships and aircraft, they vary widely as a function of the intended performance envelope and useful life of the particular vehicle.

Specifically, these involve:

a) A full range of fastener sizes, lengths, and materials

b) Various types of joints

  1) Single lap

  2) Double lap

  3) Butt

  4) Fluid tight

  5) High load transfer

c) Various applied loads

  1) Direction

  2) Magnitude

  3) Frequency

d) Environment

  1) Thermal considerations

  2) Corrosion-prevention requirements

  3) Material compatibility

  4) Material properties

e) Structural life requirements

  1) Stress limitation, corrosion

2) Fatigue limits

3) Stress concentration factor

f) Structural maintainability and repairability

1) Tooling required for installation

2) Tooling required for maintenance

3) Accessibility after assembly

g) Safety margin and fail-safe requirements

h) Hole tolerances

1) Fastener fit

2) Fastener installation

3) Fastener repair/replacement.

For nonstructural attachments and joints, not all of the above considerations would come into play. These are included and referenced primarily to structural joints as would be found in hull-plate-to-stiffener or bulkhead-to-framing joints.

This body of information has been developed in the aircraft industry over a period of several years. It is in the form of design manuals, process specifications, and manufacturing manuals. This information is subject to varying degrees of transferability to the design of ship structure for reasons previously delineated.

The problem encountered in transferring design allowables from one industry to another are typified by the following: Whereas the allowables for coldworking of fastener holes in 2000- and 7000-series aluminum alloys would be directly transferrable, the allowables for coldworking holes in 270-300 ksi steel would not be usable for the weldable alloys usually used for ship structure. It would be necessary to conduct a series of fatigue and corrosion tests before coldworking of holes in low-strength steel could be used. Obviously, in situations where the same alloys, loading parameters, and service environments are involved, the allowables are directly transferrable.

IIC. MECHANICAL FASTENING AND HOLE PREPARATION

Mechanical fasteners have been with us since the earliest days of shipbuilding and can be expected to be with us in the foreseeable future. Most of the implementation of advanced joining techniques in the fabrication of current airframe structures has been in the category of detail part and subassembly manufacture. These new processes offer significant advantages; however, they often require more stringent in-process control, new equipment, and facilities and are more efficient for shop environments in contrast to field application.

As other subassembly fastening systems (such as bonding) gain wider acceptance, mechanical fasteners will still have many applications in final assembly

BOEING

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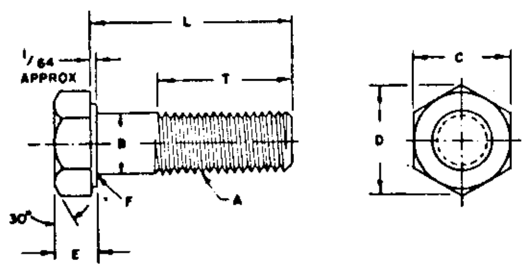
FED. SUP. CLASS 5306

This standard has been approved by the Naval Ship Engineering Center, Department of the Navy, and is mandatory for use by that activity. All other military activities are required to employ this standard where suitable.



APPROVED 8 MAY 1957 REVISED (A) 19 AUGUST 1966 [2> BY BOEING 12 DEC 66

(Project 5306-N012Sh) (A) For changes see sheets 1 through 5

Custodians	Other Int.		
Ships		MILITARY STANDARD BOLTS, MACHINE, HEXAGON HEAD, SEMI-FINISHED, CORROSION RESISTING STEEL UNC-2A, NONMAGNETIC	MS16208 (SHIPS)
Procurement Specification (A) MIL-B-857			SHEET 1 OF 5

[2> ENGINEERING INFORMATION:
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MS 16208 (SHIPS) SHEET 1 OF 5

BOLTS, MACHINE, HEXAGON HEAD, SEMI-FINISHED, CORROSION RESISTING STEEL, UNC-2A, NONMAGNETIC

MS 16208 (SHIPS) SHEET 1 OF 5

BOEING STANDARD

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FIGURE 1

EXAMPLE MACHINE BOLT STANDARD

joining and attachment of equipment and systems. Mechanical fastening is cost effective, can usually be performed with low-cost assembly tools, and is forgiving of tolerance accumulation between sections to be joined.

At one time, spot welding of skins to stiffeners was widely used in the aircraft industry. As reliability, performance, repairability, and service life requirements become more stringent, it was determined to be more effective to change to riveted and/or bolted structure. It appears that, some day in the future, the airframe will be bonded.

Mechanical fasteners have undergone a continuous evolution to keep pace with changing requirements. In fact, there is such a wide assortment of fastener types and designs available that care must be exercised to avoid the proliferation that comes from using a variety of fasteners for duplicate applications.

The Boeing Company is currently undergoing standards revisions to eliminate much of the fastener proliferation that has occurred. Fasteners that are no longer recommended for future design or current maintenance are being removed from inventory.

The Chrysler Corporation has recently reduced the number of different fasteners in its inventory from 3500 to the use of only 50 options. An internally generated fastener manual for designers consists of three main sections: general guidelines for fastener selection; a listing of preferred structural fasteners; and a listing of preferred nonstructural fasteners (Reference (1)). Metrification is another factor that should not be ignored in activities relating to the standardization of fasteners.

Methods that could be employed to control proliferation are (1) design standards, (2) central control of purchasing of fasteners, (3) controlled increments of grip length and diameter, (4) use of standard sizes, (5) use of coarse threads for fasteners over 1/4-inch diameter and fine threads for smaller diameters, and (6) standardize fasteners to one alloy for each application.

Mechanical fastening systems, per se, have as many potential applications as there are fastener types.

FASTENER STANDARDS

Standards describing fastener types and their properties include: Military Specifications (MS), Society of Automotive Engineers (SAE), National Aerospace Standards (NAS), and Army/Navy Standards (AN). In addition to these standards, there are individual company standards and specifications, such as the Boeing BAC standards and proprietary fasteners of various manufacturers. Several examples of these standards are shown in Figures 1, 2, and 3.

The *Assembly Directory and Handbook*, published yearly by Hitchcock Printing Co., Wheaton, Ill., is a specifications guide and technical reference that is of invaluable assistance to design and assembly personnel. It contains lists of standards and products available from absorbers to zippers. Complete sections on fastener standards and specifications (NAS, MS, AN, etc.) are printed as are manufacturer names (Reference (2)).

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NATIONAL AEROSPACE STANDARD

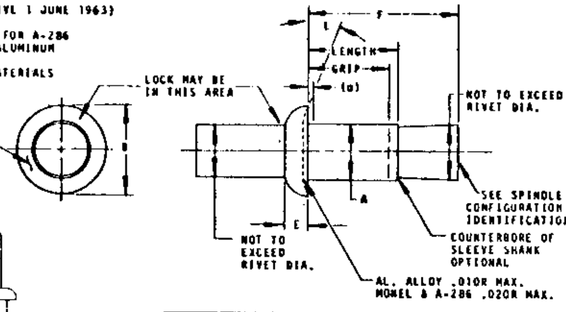
AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC., 1725 DE SALES STREET N.W., WASHINGTON, D.C. 20036

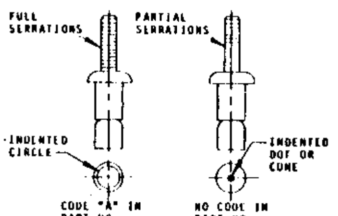
HEAD MARKING (TO BECOME EFFECTIVE 1 JUNE 1963)

MATERIAL CODE - M FOR MONEL, C FOR A-286
NO LETTER FOR ALUMINUM

GRIP NUMBER OPTIONAL FOR ALL MATERIALS

MANUFACTURER'S IDENTIFICATION
MANDATORY FOR RIVETS
RECEIVED AFTER
1 JULY 1971





SPINDLE CONFIGURATION IDENTIFICATION

RIVET DIAMETER NUMBER	RIVET SIZE NOMINAL DIAMETER	A +.003 -.001 (DIA)	B (DIA.)	E +.010 -.000	L (MAX.)
4	.125	.125	.250 ±.012	.054	12°
5	.156	.156	.312 ±.016	.067	10°
6	.190	.187	.375 ±.019	.080	8°
8	.250	.250	.500 ±.025	.107	6°

INTERCHANGEABILITY: THE "A" CODE RIVETS (FULL SERRATIONS) AND NO CODE RIVETS (PARTIAL SERRATIONS) ARE PHYSICALLY AND FUNCTIONALLY INTERCHANGEABLE EXCEPT FOR INSTALLATION TOOLS (PULLING HEADS).

– CAUTION – RIVETS WITH DIFFERENT SPINDLE CONFIGURATIONS CANNOT BE INSTALLED WITH THE SAME TOOL (PULLING HEAD); SEE PARAGRAPH 6.3 OF NAS1400.

(a) .001 SHANK DIA INCREASE PERMISSIBLE WITHIN .100 INCH OF BASE OF HEAD

FOR MATERIAL, FINISH AND COLOR SEE SHEET 2

CODES-

ADD LETTER B AFTER BASIC PART NUMBER TO INDICATE 5056 ALUMINUM ALLOY SLEEVE
ADD LETTER D AFTER BASIC PART NUMBER TO INDICATE 2017 ALUMINUM ALLOY SLEEVE
ADD LETTER M AFTER BASIC PART NUMBER TO INDICATE MONEL SLEEVE
ADD LETTER C AFTER BASIC PART NUMBER TO INDICATE A-286 CORROSION RESISTANT STEEL SLEEVE
ADD LETTER W AFTER MATERIAL CODE LETTER TO INDICATE CADMIUM PLATED SLEEVE
ADD LETTER S AFTER MATERIAL CODE LETTER TO INDICATE SILVER PLATED SLEEVE
ADD LETTER A IN PLACE OF (-) BETWEEN DIAMETER & GRIP TO INDICATE RIVET WITH FULL SERRATED STEM

EXAMPLE OF PART NUMBERS:

NAS1398M4-4 = NICKEL-COPPER-ALLOY (MONEL) RIVET, .125 DIA WITH .188 TO .250 GRIP RANGE WITH NO FINISH ON SLEEVE, WITH PARTIAL SERRATED STEM AND INDENTED DOT OR CONE IDENTIFICATION.

NAS1398B4-4 = 5056 ALUMINUM-ALLOY RIVET, .125 DIA WITH .188 TO .250 GRIP RANGE, WITH PARTIAL SERRATED STEM AND INDENTED DOT OR CONE IDENTIFICATION.

NAS1398MW4A4 = NICKEL-COPPER-ALLOY (MONEL) RIVET, .125 DIA WITH .188 TO .250 GRIP RANGE CADMIUM PLATED, WITH FULL SERRATED STEM AND INDENTED CIRCLE IDENTIFICATION.

NAS1398D4A4 = 2017 ALUMINUM-ALLOY RIVET, .125 DIA WITH .188 TO .250 GRIP RANGE, WITH FULL SERRATED STEM AND INDENTED CIRCLE IDENTIFICATION.

(2) COMPLETELY REDRAWN

List of Current Sheets	
SHEET NO.	REV. NO.
1 2	2 2

CUSTODIAN: NATIONAL AEROSPACE STANDARDS COMMITTEE

PROCUREMENT SPECIFICATION	TITLE	CLASSIFICATION
NAS 1400	RIVET-BLIND, PROTRUDING HEAD, LOCKED SPINDLE	STANDARD PART NAS1398 Sheet 1 of 2

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APPROVAL DATE APRIL 1961 REVISION (1) 1 OCT 1962 (2) 15 Sept. 1969 [6> BY BOEING 10 JUN 70

ENGINEERING INFORMATION: SEE BOEING SUPPLEMENT TO NAS1398 (PAGE 80.71.5.1.3) FOR RIVET CODES, RECOMMENDED USES, MATERIALS AND FINISH.
PROCUREMENT INFORMATION: SEE BOEING SUPPLEMENT TO NAS1398 (PAGE 80.71.5.1.3) FOR SOURCES AND PERMISSIBLE SUBSTITUTIONS.
WICHITA AND VERTOL DIVISIONS AND THEIR SUBCONTRACTORS: RIVETS WITH THE "A" CODE ARE INACTIVE FOR DESIGN.

[6> BY BOEING

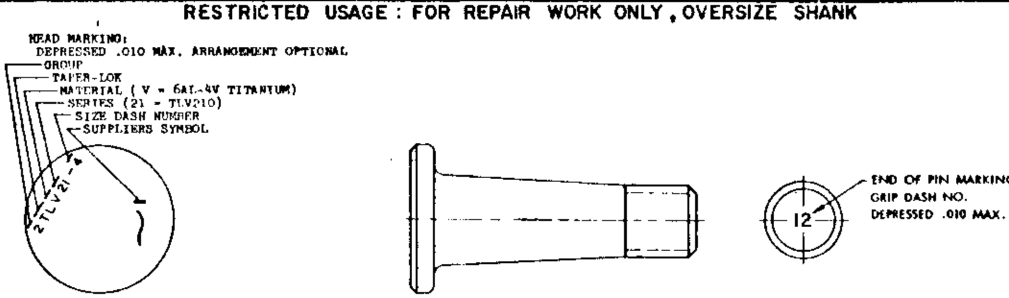
BOEING STANDARD

FIGURE 2

EXAMPLE BLIND RIVET STANDARD

BOEING

RESTRICTED USAGE : FOR REPAIR WORK ONLY, OVERSIZE SHANK



SEE SHEET 1 FOR DIMENSIONS NOT SHOWN.

TABLE V [6]

NOM THREAD SIZE (UNJF-3A)	6AL-4V TITANIUM ALLOY					
	UNPLATED, LUBECO #2123 DRY FILM LUBRICANT		UNPLATED, PHOSPHATE FLUORIDE, CETYL ALCOHOL LUBRICANT		UNPLATED, PHOSPHATE FLUORIDE, DRY FILM LUBRICANT (MIL-L-8937)	
	BOEING STANDARD NUMBER BACB30MW	SUPPLIER PART NUMBER [illegible]	BOEING STANDARD NUMBER BACB30MW	SUPPLIER PART NUMBER [illegible]	BOEING STANDARD NUMBER BACB30MW	SUPPLIER PART NUMBER [illegible]
.1900-32	3-*X	-3-*	3E*X		3S*X	
.2500-28	4-*X	-4-*	4E*X		4S*X	
.3125-24	5-*X	-5-*	5E*X		5S*X	
.3750-24	6-*X	-6-*	6E*X		6S*X	
.4375-20	7-*X	-7-*	7E*X		7S*X	
.5000-20	8-*X	-8-*	8E*X		8S*X	
.5625-18	9-*X	-9-*	9E*X		9S*X	
.6250-18	10-*X	-10-*	10E*X		10S*X	
.7500-16	12-*X	-12-*	12E*X		12S*X	
.8750-14	14-*X	-14-*	14E*X		14S*X	
1.0000-12	16-*X	-16-*	16E*X		16S*X	
1.1250-12	18-*X	-18-*	18E*X		18S*X	
1.2500-12	20-*X	-20-*	20E*X		20S*X	
1.3750-12	22-*X	-22-*	22E*X		22S*X	
1.5000-12	24-*X	-24-*	24E*X		24S*X	
1.6250-12	26-*X	-26-*	26E*X		26S*X	
1.7500-12	28-*X	-28-*	28E*X		28S*X	

* = GRIP DASH NUMBERS IN .062 INCREMENTS. SEE SHEETS 3 THRU 6 FOR GRIP AND LENGTH DIMENSIONS.

[6] CADMIUM PLATED, ALLOY STEEL, OVERSIZE BOLTS PER BACB30FB (PAGE 80.1.6.12.5) ARE TO BE USED AS REPLACEMENTS FOR BACB30MW TITANIUM STANDARD BOLTS IN ALUMINUM STRUCTURED AIRCRAFT.

FOR FLAGNOTES, MATERIAL, FINISH, COLOR IDENTIFICATION AND PROCUREMENT INFORMATION, SEE SHEET 2.

AN OVERSIZE TAPER SHANK BOLT HAS LARGER "A", "B" AND "B1" DIMENSIONS AS PROVIDED BY THE NEXT LARGER GROUP NUMBER. THE "K", "K1" GRIP AND LENGTH DIMENSIONS ARE THE SAME FOR STANDARD AND OVERSIZE BOLTS. FOR "A" DIMENSIONS, SEE SHEET 1, FOR "B", "B1", "K" AND "K1" DIMENSIONS (WHICH CONTROL DIAMETER TAPER TO 0.250 INCH PER FOOT) SEE BPS-F-76.

USAGE AND APPLICATION INFORMATION

THESE OVERSIZE BOLTS ARE TO BE USED AS REPLACEMENTS FOR BOLTS SHOWN ON SHEET 1, WHEN THE HOLE FOR THE STANDARD SIZE BOLT IS OVERSIZE, OR MUST BE MADE OVERSIZE TO CORRECT DAMAGE OR MISALIGNMENT.

CODE: FIRST DASH NUMBER INDICATES NOM. THREAD SIZE IN .062 INCREMENTS. SECOND DASH NUMBER INDICATES MAX. OF THE GRIP RANGE IN .062 INCREMENTS.

EXAMPLE OF BOEING STANDARD NUMBER: BACB30MW6-10X - BOLT, UNPLATED, LUBECO #2123 DRY FILM LUBRICATED, OVERSIZE SHANK; FOR REPLACEMENT OF BACB30MW6-10.

SEE NOTE UNDER TABLE V REGARDING CADMIUM PLATED BOLTS.

DATE 10 FEB 67 REV. (A) 22 NOV 67 (B) 29 MAY 68 (C) 10 MAR 70

CODE IDENT NO. 81205

BAC B30MW SH 7

BOLT, TAPER SHANK, PROTRUDING SHEAR HEAD, 6AL-4V TITANIUM ALLOY

BAC B30MW SH 7

BOEING STANDARD

 PAGE 80. 12. 6. 9. 7

FIGURE 3

EXAMPLE TAPER SHANK BOLT STANDARD

DRILLING FASTENER HOLES THRU BRAZED HONEYCOMB FOR ATTACHING WING PANELS

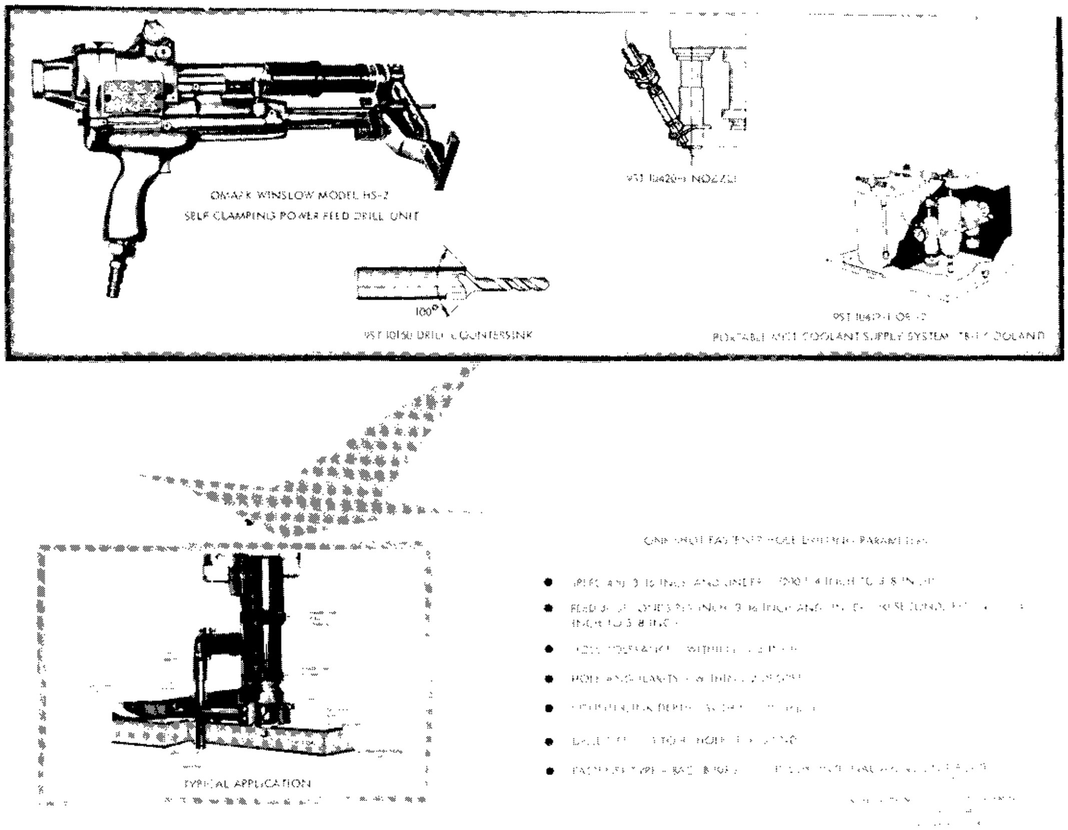


FIG. 4 - OMARK-WINSLOW HS-2 SPACEMATIC DRILL

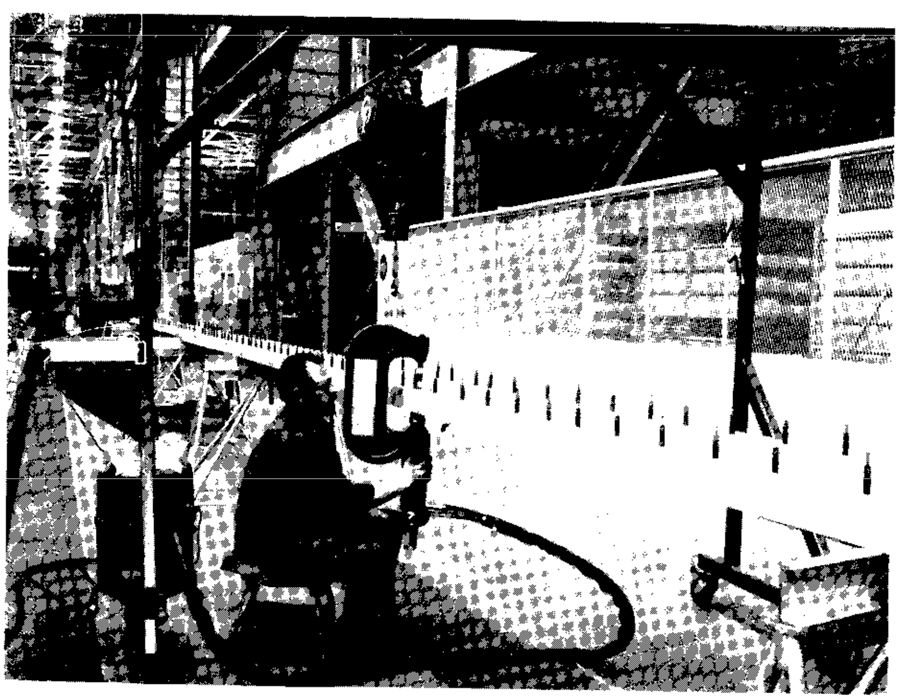


FIG. 5 - SQUEEZE YOKE RIVBOLT INSTALLATION ON 747 SPAR

Another magazine published biweekly by Penton Publication, Cleveland, Ohio, is the *Machine Design Magazine*. This journal features periodic reference issues devoted to fastening and joining and several other specific fields and areas of application. The reference issue reviewed for this report contains articles and technical literature on products ranging from screws, bolts, and studs to special-purpose fasteners such as spring clips and self-sealing fasteners.

FASTENERS: TYPES, APPLICATIONS, AND INSTALLATIONS

Fatigue-rated structural fasteners are available with straight and tapered shanks, flush and protruding heads, many alloys ranging from aluminum to titanium, and with several types of corrosion-preventive coatings or electrodepositions that can be applied to provide a fluid-tight condition.

Installation conditions include: Interference fits, net fits, clearance fits, . and taper hole/shank interference fits. Holes can be precision drilled and reamed or broached, then coldworked to increase fatigue resistance.

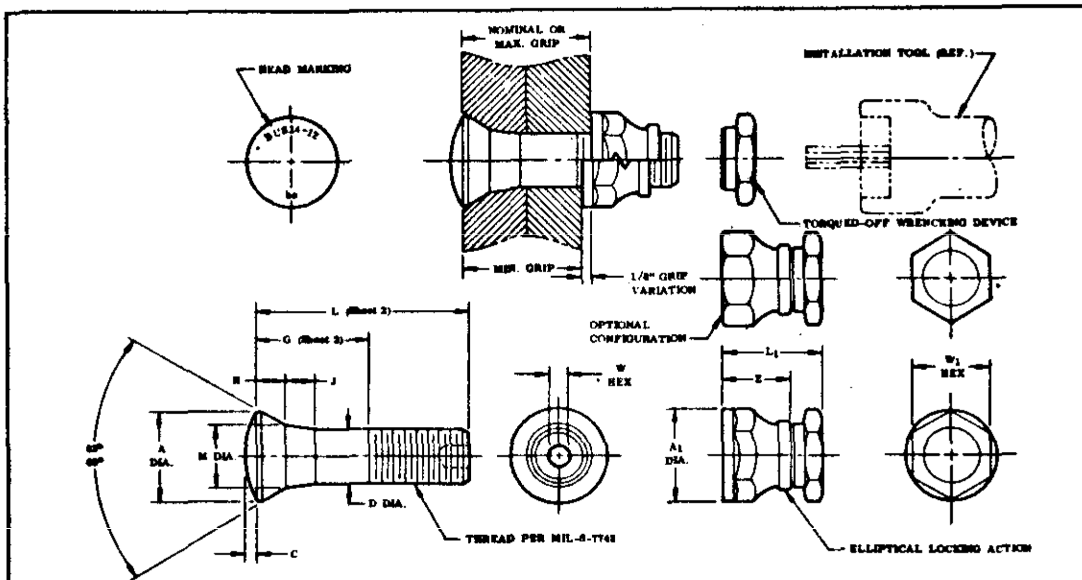
Fasteners can be installed by squeeze operation, pull or push operation, or slip-fitted into a hole. Fastener retention is maintained by a torqued nut, a swaged collar, or by deforming the fastener.

Installation processes vary from fastener to fastener, depending on the application and stress limitation. Drilling equipment required to produce holes varies in price depending upon the size and quality of the hole required. For example, the Omark-Winslow HS-2 drilling unit averages $1,500 per unit (Figure 4). This drilling unit has very close tolerance and depth stop capabilities, and its use is intended where less sophisticated units are not adequate. They also manufacture large-cpacity hydraulic drill motors.

Fastener installations are normally one- or two-man operations. The installation of titanium RivBolts in the 747 spar is shown in Figure 5. The C-yoke is semiportable and requires a spring balance for handling; however, smaller units are available. Equipment costs are generally low. Maintenance and repair are also low.

A matrix of typical fasteners is included with this report (Table 2). It is intended to serve as a guide in selecting fasteners for application in various structural and nonstructural assemblies. A few examples are discussed in the following paragraphs.

BUS Fasteners. The Hi-Shear Corporation began marketing a proprietary family of marine fasteners during the 1960s. The BUS Hi-Lok fastener (Figure 6) is a two-piece, high-strength, torque-controlled, threaded structural fastener designed specifically for naval and commercial ship construction. The BUS Hi-Lok consists of a high-strength marine-type bolt; a high-clamping nut with a wrenching hex torque-off feature for torque control; and matching lightweight, air-driven, installation tooling with Hi-Lok adapters designed for minimal clearances. This system is designed to provide hole-sealing capability. The manufacturer claims the BUS Hi-Lok system exceeds the vibration requirement of Mil-Std-167 and the strength requirement of Mil-B-23470. The Hi-Shear Corporation offers a marine fastener system booklet that contains this information.



BUS HI-LOK ASSEMBLY		BUS14 HI-LOK BOLT							④	BUS34 HI-LOK NUT						
FIRST DASH NO.	NOM. DIA.	THREAD	A DIA.	C	D DIA.	H	J	M DIA.	W HEX SOCKET	FIRST DASH NO.	NOM. DIA.	THREAD	A_1 DIA. MAX.	Z	L_4	W_1 HEX
-5	5/16"	5/16-18UNC-2A	.476 .456	.045	.322 .306	.127	.187 .125	.342 .332	1/8"	-5	5/16"	5/16-18UNC-2B	.677	.380	.570	1/2"
-6	3/8"	3/8-16UNC-2A	.576 .556	.062	.385 .369	.157	.219 .156	.406 .396	5/32"	-6	3/8"	3/8-16UNC-2B	.846	.456	.693	9/16"
-8	1/2"	1/2-13UNC-2A	.778 .758	.080	.510 .493	.221	.281 .219	.530 .520	7/32"	-8	1/2"	1/2-13UNC-2B	.966	.586	.875	3/4"
-10	5/8"	5/8-11UNC-2A	.970 .930	.113	.635 .617	.279	.344 .281	.655 .645	1/4"	-10	5/8"	5/8-11UNC-2B	1.010	.715	1.072	7/8"
-12	3/4"	3/4-10UNC-2A	1.163 1.122	.133	.760 .741	.347	.406 .344	.780 .770	5/16"	-12	3/4"	3/4-10UNC-2B	1.300	.856	1.282	1-1/8"
-14	7/8"	7/8-9UNC-2A	1.355 1.304	.153	.885 .866	.407	.469 .406	.905 .895	5/16"	-14	7/8"	7/8-9UNC-2B	1.445	.990	1.486	1-1/4"
-16	1"	1-8UNC-2A	1.542 1.485	.180	1.010 .990	.464	.531 .469	1.030 1.020	3/8"	-16	1"	1-8UNC-2B	1.730	1.130	1.697	1-1/2"

BUS14 HI-LOK BOLT

NOTES:
1. Heat treat to 120,000 psi minimum tensile per MIL-H-6875.
2. Material, surface finish, inspection, and testing as applicable shall be in accordance with Hi-Shear Spec. 300, Section I.

MATERIAL: Carbon steel per QQ-S-406.

④ FINISH: BUS14-( )-( ) – Black oxide.
BUS14PB-( )-( ) – Cadmium plate per QQ-P-416, Type II, Class 3.

CODE: First dash number indicates nominal diameter in 16ths. Second dash number indicates nominal (max.) grip length in 16ths with grip coverage of 1/8" (see sheet 2)

EXAMPLE: BUS14-12-16 = 60° countersunk oval head with tapered-section shank, 12/16 or 3/4 nominal diameter, 3/4-10UNC-2A thread, with 16/16 or 1" nominal grip.

BUS34 HI-LOK NUT

MATERIAL: Carbon steel per Spec. QQ-S-406.

FINISH: BUS34-( ) – Cetyl alcohol lube per Hi-Shear Spec. 305.
BUS34PB-( ) – Cadmium plate per QQ-P-416, Type II, Class 3, plus cetyl alcohol lube per Hi-Shear Spec. 305.

CODE: Dash number indicates nominal thread size in 1/16ths.

EXAMPLE: BUS34-12 = 12/16 or 3/4 nominal diameter with 3/4-10 thread.

HOLE PREPARATION DATA			
NOM. DIA.	DRILL SIZE	MAX HOLE SIZE	COUNTERSINK DIA.
5/16	5/16 (.312)	21/64 (.328)	1/2 (.500)
3/8	3/8 (.375)	25/64 (.390)	19/32 (.594)
1/2	1/2 (.500)	33/64 (.515)	13/16 (.812)
5/8	5/8 (.625)	41/64 (.640)	1 (1.000)
3/4	3/4 (.750)	49/64 (.765)	1-3/16 (1.188)
7/8	7/8 (.875)	57/64 (.890)	1-3/8 (1.375)
1"	1" (1.000)	1-1/64 (1.015)	1-9/16 (1.562)

BUS1434 HI-LOK ASSEMBLY

CODE: First dash number indicates nominal diameter in 1/16ths. Second dash number indicates nominal (max.) grip in 1/16ths.

EXAMPLE: BUS1434-12-16
- 16/16 or 1" Nominal Grip Length
- 12/16 or 3/4" Nominal Diameter
- Hi-Lok Fastener Assembly which includes: BUS14 Bolt and BUS34 Nut

U.S. Patents 2,940,495; 3,130,957; Design 191,083. Other U.S. and Foreign Patents granted and pending.

hi-shear CORPORATION 2600 SKYPARK DRIVE TORRANCE CALIFORNIA 90509 Area Code 213 · 775-2181 · 326-8110

DRAWN	DATE	APPROVED	DATE	REVISION	DATE	TITLE
AHS	5-16-69	E. Gundersen	6-6-69	④ AHS	11-10-70	HI-LOK BOLT AND NUT ASSEMBLY CARBON STEEL 60° COUNTERSUNK OVAL HEAD TAPERED-SECTION SHANK

DRAWING NUMBER **BUS1434** (Sheet 1 of 2)

2-3001

FIGURE 6

HI-SHEAR BUS HI-LOK FASTENER STANDARD

Six-Wing Fasteners. The six-wing fastener system is also available for high-tensile strength applications (Figure 7). These fasteners have a unique protruding torque head and are available for tensile or shear applications as well as high temperatures. The six-wing series is available in several alloys with tensile strengths from 160,000 to 240,000 psi. This fastener is designed for joints requiring high clamp forces, high tensile strength, and fatigue resistance. The attachment of machinery to the deck or the engine to the engine support mounts are examples of potential uses. The unique wrenching feature facilitates bolt removal when replacement or repairs are necessary.

Blind Fasteners. Several proprietary systems of blind fasteners and blind nuts are available from several sources (Tables 3, 4, and 5). These are available in flush and protruding heads as well as various alloys and heat treatments (see matrix). The distinguishing features of each fastener vary and depend on design or intended application.

Tables 3, 4, and 5 indicate representative fasteners and are not included as single sources or types. As an example, the Voi-Shan Visu-Lok is available in corrosion-resistant steel, a flush-head configuration, and can be used for panel closeout.

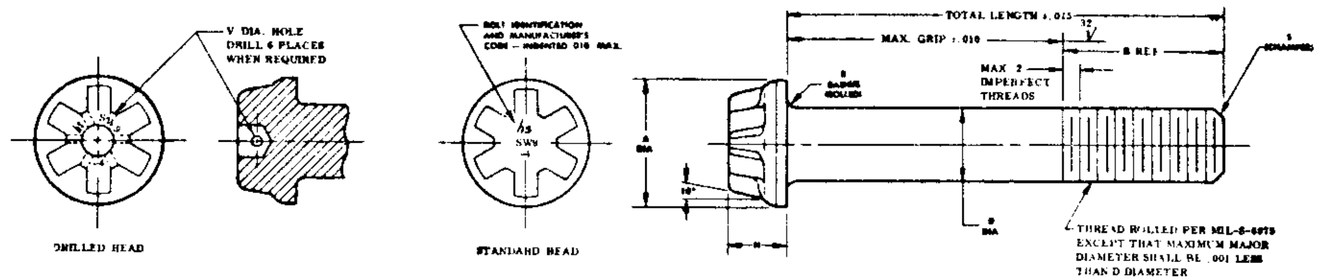
Lockbolts. In addition to the fastener systems mentioned, there are several lockbolt systems available for consideration. Lockbolts come in various configurations, such as flush and protruding heads, several alloys ranging from aluminum to titanium, various protective finishes, and are used for structural joints in tension and shear applications. Past naval applications have included use of steel protruding-head lockbolts for attachment of the deckhouse to the deck via a lap joint formed by the deckhouse and steel deck coaming. The manufacture of aircraft requires the installation of lockbolts in many areas. Structural applications include attachment of window and hatch reinforcing doublers and stiffeners in the body sections. Primary structural applications include installation of the wedgehead lockbolt on the aerodynamic surfaces of the wing to make the wing skin/stringer joint and for high-shear load-transfer joints or skin splices.

Rivets. Rivets are available in a variety of alloys, heat treats, coatings, and head configurations, a few of which are shown in Appendix H. Those listed in the matrix are fatigue rated and fluid-tight rated for structural applications. Rivets can be installed in thin sheets (less than 1/8 inch) and thick lap or splice joints; do not require tight hole tolerances; and are easily installed by hand-driving, machine-riveting, electromagnetic-riveting, and portable squeeze-riveting processes. Rivets can be installed in plain holes for interior structural applications or into countersunk holes for exterior, below-the-waterline, structural applications. Squeeze operations are generally throat limited, depending on application. Riveting the longitudinal framing on modular units and hull plates would minimize distortion of the structure caused by continuous seam welding. Splice-butt joints, similar to those in aircraft wing structure, could be applied to primary hull structure (Figure 8). An example of hand riveting is shown in Figure 9 and of numerically controlled (N/C) machine riveting in Figure 10.

Modularized or "jumboized" structure could be mechanically fastened with fatigue-rated fasteners in preassembled units. Attachment of internal structure and ribbing could be facilitated by portable rivet-squeeze units, thus eliminating the need for welding "all around" in aluminum structure.

hi-shear CORPORATION
1600 SKYPARK DRIVE
TORRANCE CALIFORNIA 90509
AREA CODE 213 · 775-3181

① STANDARDS MANUAL



FIRST DASH NUMBER	NOMINAL DIAMETER	THREAD	A DIA. ±.005	B REF.	D DIA	H ±.010	S CHAMFER	R RADIUS	CONCENTRICITY X	CONCENTRICITY Z	V DIA. +.005 −.000	① PHYSICAL PROPERTIES OF SW9 BOLT AND SW50 NUT ASSEMBLY* TENSION LBS. MIN	FATIGUE LOW LOAD	FATIGUE HIGH LOAD
① -3	3/16	10-32UNJF-3A	.346	.444	.1895 .1885	.160	1/32" x 45°	.041 .031	.003	.0040	.047	3,620	145	1,450
-4	1/4	1/4-28UNJF-3A	.433	.554	.2495 .2485	.200	1/32" x 45°	.041 .031	.005	.0045	.047	6,470	259	2,590
-5	5/16	5/16-24UNJF-3A	.526	.641	.3120 .3110	.250	3/64" x 45°	.041 .031	.006	.0045	.055	10,200	408	4,080
-6	3/8	3/8-24UNJF-3A	.644	.687	.3745 .3735	.300	3/64" x 45°	.057 .047	.006	.0045	.055	15,200	608	6,080
-7	7/16	7/16-20UNJF-3A	.745	.783	.4370 .4360	.350	3/64" x 45°	.057 .047	.009	.006	.055	20,600	825	8,250
-8	1/2	1/2-20UNJF-3A	.823	.830	.4995 .4985	.400	3/64" x 45°	.057 .047	.010	.006	.070	27,500	1,050	10,300
-9	9/16	9/16-18UNJF-3A	.933	.914	.5620 .5610	.450	1/16" x 45°	.057 .047	.011	.006	.070	34,800	1,300	13,000
-10	5/8	5/8-18UNJF-3A	1.045	.981	.6240 .6230	.500	1/16" x 45°	.073 .063	.012	.006	.070	43,200	1,650	16,600
-12	3/4	3/4-16UNJF-3A	1.225	1.096	.7490 .7480	.600	1/16" x 45°	.073 .063	.015	.006	.070	63,200	2,250	22,500
-14	7/8	7/8-14UNJF-3A	1.433	1.308	.8740 .8730	.700	5/64" x 45°	.073 .063	.014	.009	.070	86,300	3,000	30,000
-16	1	1-12UNJF-3A	1.620	1.537	.9990 .9980	.800	5/64" x 45°	.073 .063	.015	.009	.070	112,000	3,800	38,000

GENERAL NOTES:
1. Concentricity: "A" to "D" diameters within values for "X" TIR. "D" to pitch diameters within values for "Z" TIR.
2. Shank shall be straight within .005 TIR per inch of bolt grip length.
3. Bearing surface squareness within .005 TIR of shank diameter.
4. Dimensions to be met after plating.
5. Surface texture per USASI B46.1.

MATERIAL: Alloy steel per MIL-S-5626 (4140) or per MIL-S-6049 (8740) or per MIL-S-8844 (4340).

HEAT TREAT: 160,000–180,000 psi tensile per MIL-H-6875.

FINISH: Cadmium plate per QQ-P-416, Type II, Class 2.

PROCUREMENT SPEC.: Hi-Shear Corporation Product Spec. 330.

CODE: First dash number indicates nominal diameter in 1/16ths.
Second dash number indicates maximum grip in 1/16ths.
Add "H" before first dash number to designate drilled head.

EXAMPLE: SW9-4-12 = 1/4-28 Six-Wing bolt, 12/16 or 3/4 maximum grip, standard head.
SW9H4-12 = 1/4-28 Six-Wing bolt, 12/16 or 3/4 maximum grip, drilled head.

① *See applicable nut standards page for detail dimensions.

Design Patent 203,412. Other U.S. and Foreign Patents Pending.

TITLE (Sheet 1 of 3)

THE SIX-WING® BOLT

ALLOY STEEL — LONG THREAD

DRAWN	DATE	APPROVAL	DATE	REVISION	DATE	DRAWING NUMBER
AHB	11-11-70	Cessna		①	1-14-71	SW9

CODE IDENTIFICATION NO. 73197

SW9

S-8001

FIGURE 7

HI-SHEAR SIX-WING FASTENER STANDARD

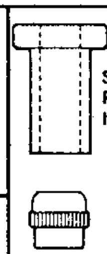
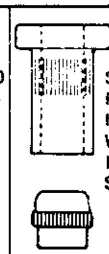
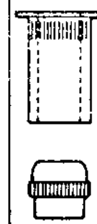
TABLE 3
BLIND NUT SELECTION CHART—COUNTERSUNK HEAD TYPE[a]

MATERIALS AND FINISHES		SUGGESTED MAXIMUM TEMPERATURE FOR USE – F	SPECIAL CSK HEADS	SHEAR CSK HEAD	SHALLOW CSK HEAD	SHALLOW CSK HEAD WITH KNURLED SHANK	SHALLOW CSK HEAD WITH EXPANDER WITH DOME END	SHALLOW CSK HEAD WITH KNURLED SHANK AND EXPANDER WITH DOME END	SHALLOW CSK HEAD WITH KNURLED SHANK AND EXPANDER WITH ANNULAR RIDGES	SHALLOW CSK HEAD WITH KEYLOCK	SHALLOW CSK HEAD WITH KEYLOCK SLEEVE HAS THREADED END
SLEEVE	EXPANDER		SPECIAL TOOLING	"A" TOOLING	"B" TOOLING	"B" TOOLING	"B" TOOLING	"B" TOOLING	"B" TOOLING	"B" TOOLING	"B" TOOLING
305 S.S.	431 S.S. CADMIUM PLATE	450°	BN387			BN516	BN388 BN388L				
305 S.S.	17-4PH S.S. CADMIUM PLATE	450°			BN389		BN535				
305 S.S.	431 S.S. SILVER PLATE	450°		BN514							
305 S.S. SANDBLAST	431 S.S. CADMIUM PLATE	450°		BN356	BN360 (RECOMMENDED FOR GENERAL PURPOSE USE) BN360-64 BN360PB BN521						
305 S.S. SANDBLAST	431 S.S. SILVER PLATE	450°				BN587					
305 S.S. CADMIUM PLATE	431 S.S. CADMIUM PLATE	450°		BN369PB		BN510PB					
305 S.S. SANDBLAST	A-286 ALLOY SOLID FILM LUBRICANT	900°		BN520	BN525 BN596						
305 S.S. SANDBLAST	A-286 ALLOY SILVER PLATE	700°		BN520GA	BN525GA BN596G						
305 S.S. SANDBLAST	BERYLCO 33-25 CETYL ALCOHOL	400°			BN543						
A-286 ALLOY CADMIUM PLATE	431 S.S. SILVER PLATE	450°			BN372P						
A-286 ALLOY SANDBLAST	431 S.S. SILVER PLATE	450°		BN545G BN555G	BN372						
A-286 ALLOY SANDBLAST	A-286 ALLOY SOLID FILM LUBRICANT	800°		BN565							
A-286 ALLOY SANDBLAST	17-4PH S.S. SILVER PLATE	800°			BN536						
A-286 ALLOY SANDBLAST	A-286 ALLOY SOLID FILM LUBRICANT	500°			BN377 BN553		BN537 BN537LR				
A-286 ALLOY SANDBLAST	A-286 ALLOY SILVERPLATE	1200°			BN548						
A-286 ALLOY	CETYL ALCOHOL LUBRICANT, CADMIUM PLATE, OR SILVER PLATE	450° OR 1200°									BTN1 BTN1PB BTN1G ONE PIECE BLIND NUT
316 S.S. SANDBLAST	A-286 ALLOY SOLID FILM LUBRICANT	800°		BN538							
ARMCO 18-9LW S.S. SANDBLAST	431 S.S. CADMIUM PLATE	450°	BN546 ARE "B" TYPE TOOLING								
5056 AL. ANODIZE	431 S.S. CADMIUM PLATE	250°								BN155 BN157	
5056 AL. ANODIZE	A-286 ALLOY SOLID FILM LUBRICANT	250°								BN158 NON-MAGNETIC	

[a]Reprinted from Hi-Shear Blind Nuts and Blind Bolts catalog

TABLE 4

BLIND NUT SELECTION CHART—PROTRUDING HEAD TYPE[a]

MATERIALS AND FINISHES		SUGGESTED MAXIMUM TEMPERATURE FOR USE - F.	 STANDARD PROTRUD-ING HEAD "C" TOOLING	 STANDARD PROTRUD-ING HEAD WITH KNURLED SHANK "C" TOOLING	 THIN PROTRUD-ING HEAD "C" TOOLING	 VERY THIN PROTRUD-ING HEAD WITH KNURLED SHANK "C" TOOLING
SLEEVE	EXPANDER					
305 S.S.	431 S.S. CADMIUM PLATE	450°		BN540		BN533
305 S.S.- CADMIUM PLATE	431 S.S. CADMIUM PLATE	450°	BN356PB	BN540PB		
305 S.S. SANDBLAST	431 S.S. CADMIUM PLATE	450°	BN356 BN519LH		BN530	
305 S.S.	431 S.S. SILVER PLATE	450°				BN533G
305 S.S. SANDBLAST	431 S.S. SILVER PLATE	450°	BN356G		BN530G	
305 S.S. SANDBLAST	A-286 ALLOY SOLID FILM LUBRICANT	500°	BN542			
347 S.S. SANDBLAST	A-286 ALLOY SOLID FILM LUBRICANT	500°	BN523			
A-286 ALLOY SANDBLAST	A-286 ALLOY SILVER PLATE	1200°	BN549			

[a]Reprinted from Hi-Shear Blind Nuts and Blind Bolts catalog.

TABLE 5
VOI-SHAN VISU-LOK BLIND FASTENER

National CALIFORNIA DIVISION

CUSTODIAN: ENGINEERING STANDARD COMMITTEE FOR BLIND BOLTS 3423 SOUTH GARFIELD AVENUE LOS ANGELES, CALIFORNIA 90040

VSI VOI-SHAN A DIVISION OF VSI CORP

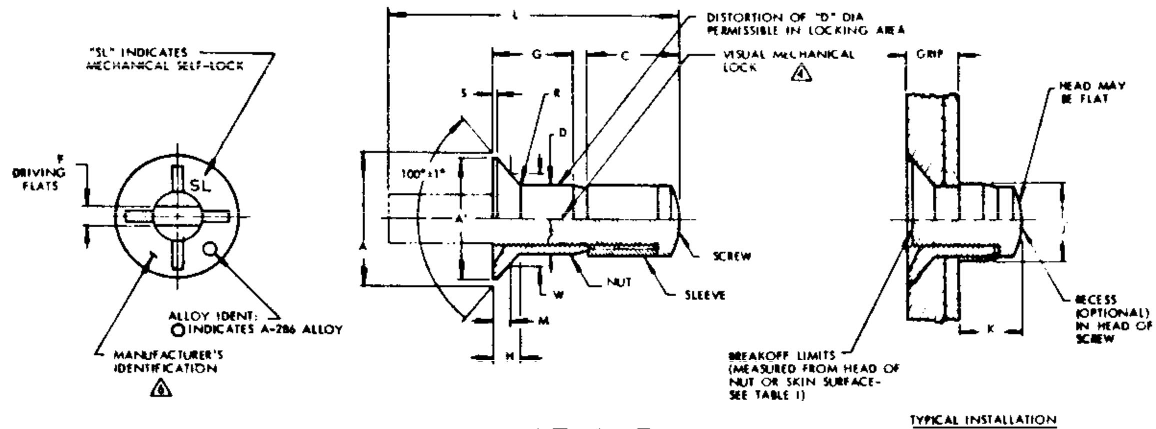


TABLE I

PART NUMBER	NOM DIA	A DIA THEO	A' DIA MIN	C MAX	D DIA	F DRIVING FLATS	H REF	J DIA MAX	K MAX	M GAGE PROT	R RAD	S MAX	W GAGE DIA	BREAK-OFF LIMITS	PREVAILING TORQUE IN. LBS. MIN	DOUBLE SHEAR STRENGTH LBS. MIN	TENSILE STRENGTH LBS. MIN
PLT120-5-(*)	.1635	.332 .325	.296	.268	.1645 .1625	.086 .081	.069	.244	.271	.0276 .0238	.030 .010	.012	.2671 .2667	+.086 -.006	1.0	2,700	820
PLT120-6-(*)	.1980	.385 .378	.342	.303	.1990 .1970	.104 .099	.077	.300	.309	.0299 .0259	.030 .015	.015	.3147 .3143	+.072 -.016	1.5	4,530	1,400
PLT120-8-(*)	.2590	.507 .499	.463	.354	.2600 .2580	.135 .130	.102	.384	.350	.0353 .0307	.030 .015	.015	.4245 .4241	+.072 -.026	2.5	7,200	2,100
PLT120-10-(*)	.3105	.635 .626	.577	.423	.3115 .3095	.152 .147	.134	.427	.406	.0409 .0357	.040 .020	.020	.5389 .5385	+.072 -.031	3.5	10,350	3,600
PLT120-12-(*)	.3735	.762 .752	.696	.510	.3745 .3725	.185 .180	.160	.516	.479	.0466 .0407	.040 .020	.023	.6532 .6528	+.072 -.031	4.0	15,750	5,600

(*) SEE TABLE II FOR SECOND DASH NUMBERS AND APPROVED CALLOUT.

TABLE II

SECOND DASH NUMBER	G GRIP ▲	GRIP RANGE		L ±.015				
		MIN	MAX	PLT120-5-(*)	PLT120-6-(*)	PLT120-8-(*)	PLT120-10-(*)	PLT120-12-(*)
-2	.156	.094	.156	.795	.916			
-3	.219	.157	.219	.858	.978	1.006	1.158	
-4	.281	.220	.281	.920	1.041	1.069	1.221	1.304
-5	.344	.282	.344	.983	1.103	1.131	1.283	1.367
-6	.406	.345	.406	1.045	1.166	1.194	1.346	1.429
-7	.469	.407	.469	1.108	1.228	1.256	1.408	1.492
-8	.531	.470	.531	1.170	1.291	1.319	1.471	1.554
-9	.594	.532	.594	1.233	1.353	1.381	1.533	1.617
-10	.656	.595	.656	1.295	1.416	1.444	1.596	1.679
-11	.719	.657	.719	1.358	1.478	1.506	1.658	1.742
-12	.781	.720	.781	1.420	1.541	1.569	1.721	1.804
-13	.844	.782	.844	1.483	1.603	1.631	1.783	1.867
-14	.906	.845	.906	1.545	1.666	1.694	1.846	1.929
-15	.969	.907	.969	1.608	1.728	1.756	1.908	1.992
-16	1.031	.970	1.031	1.670	1.791	1.819	1.971	2.054
-17	1.094	1.032	1.094	NOT AVAILABLE IN -5 DIAMETER	1.853	1.881	2.033	2.117
-18	1.156	1.095	1.156		1.916	1.944	2.096	2.179
-19	1.219	1.157	1.219		1.978	2.006	2.158	2.242
-20	1.281	1.220	1.281		2.041	2.069	2.221	2.304
-21	1.344	1.282	1.344		2.103	2.131	2.283	2.367
-22	1.406	1.345	1.406		2.166	2.194	2.346	2.429
-23	1.469	1.407	1.469		2.228	2.256	2.408	2.492
-24	1.531	1.470	1.531		2.291	2.319	2.471	2.554
-25	1.594	1.532	1.594		2.353	2.381	2.533	2.617
-26	1.656	1.595	1.656		2.416	2.444	2.596	2.679
-27	1.719	1.657	1.719		2.478	2.506	2.658	2.742
-28	1.781	1.720	1.781		2.541	2.569	2.721	2.804
-29	1.844	1.782	1.844		2.603	2.631	2.783	2.867
-30	1.906	1.845	1.906		2.666	2.694	2.846	2.929
-31	1.969	1.907	1.969		2.728	2.756	2.908	2.992
-32	2.031	1.970	2.031		2.791	2.819	2.971	3.054

NATIONAL CODE IDENT. NO. 98524

▲ "G" TOLERANCES: FOR -5 & -6 SIZES $^{+.030}_{-.010}$, FOR -8 & -10 SIZES $^{+.040}_{-.010}$, FOR -12 SIZE $^{+.050}_{-.010}$

VOI-SHAN CODE IDENT. NO. 92215

PATENT PENDING

APPROVED DATE	TITLE	STANDARD
13 NOVEMBER 1970	VISU-LOK, FASTENER, BLIND INTERNALLY THREADED, EXTERNAL SLEEVE HIGH TEMPERATURE (A-286 ALLOY) FLUSH HEAD, SELF-LOCKING	PLT 120
REV. LETTER AND DATE		SHEET 1 OF 2

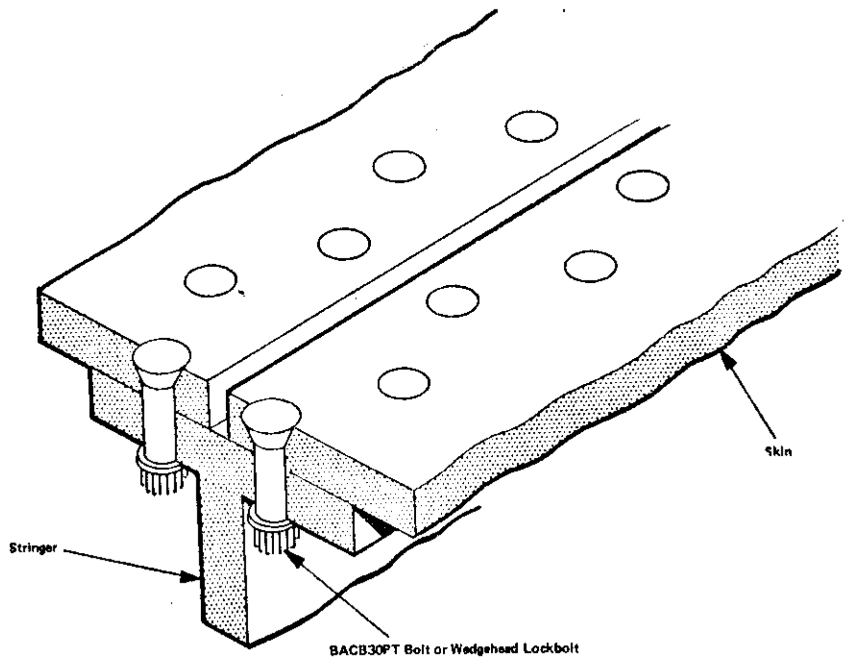


FIG. 8 - WING SPLICE JOINT

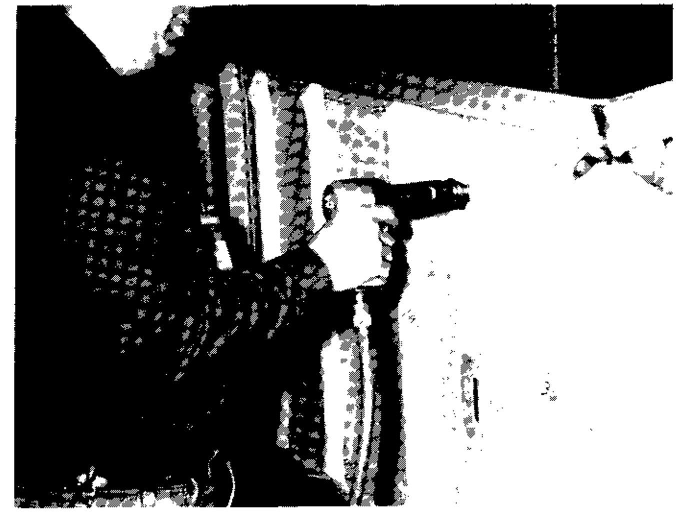


FIG. 9 - HAND RIVETING 727 SPAR

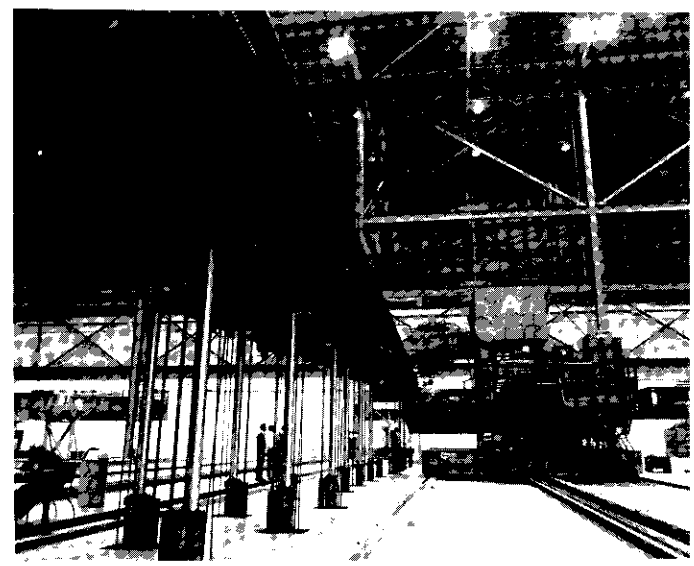


FIG. 10 - RIVETING STRINGERS TO 747 UPPER WING PANEL ON GEMCOR DRIVEMATIC RIVETING MACHINES

Nitinol. The Navy-developed Nitinol alloy offers promise as a riveting material. Composed of nickel, titanium, iron, and cobalt in various percentages, Nitinol can be formed to a configuration, chilled, and reformed to allow easy installation. Upon warming, the Nitinol assumes its original formed configuration. Nitinol is currently being used commercially in tubing fittings and blind fasteners. Grumman Aircraft is conducting an evaluation program on Nitinol fasteners (Reference (3)).

Drilling Equipment. Rivet installation in large panel areas, such as hull plates, can be placed on a production basis with the implementation of equipment similar to the Omark-Winslow track drill and the Boeing electromagnetic riveter (EMR). Several sources are available for various sizes of portable air and hydraulic power driven feed drill units that are equipped for speeds and feed rates for steel, aluminum, or titanium.

The track drill (Figure 11) is designed to repeatedly produce close-tolerance plain and countersunk holes. This unit travels in a vertical or horizontal motion, is self-indexing, and has a clamp force adjustable up to 1,500 pounds. The drill unit requires the attachment of a removable and reusable track and one hole initially for starting. This unit is compatible with a number of fastener systems such as precision interference pins, conventional rivets, or lockbolts. The approximate cost of the track drill is between $8,000 and $30,000, depending on the quantity and special features. A prototype unit has been tested and found practical. Plans defining the performance requirements for a production unit are being made.

Electromagnetic Riveting. Electromagnetic riveting (EMR) is a high-velocity, single-impact riveting process that converts electromagnetic energy into rivet forming energy. The EMR equipment (Figure 12) consists of a power pack and two, semi-portable, hand-held rivet guns with special power transmission cables, interconnecting air systems, and power pack. As compared to large automatic hydraulic riveting machines, the EMR equipment is substantially lower in initial procurement cost and, furthermore, features quieter operation and reduced floor space requirements. As compared to conventional hand gun driving, EMR is far superior in quality and repeatability while the noise level is reduced by several magnitudes (see Table 6). Standard available aluminum and titanium as well as steel rivets can be used with the EMR process, and rivet installations are uniform and repeatable with an extremely low rejection rate. The lower equipment cost (approximately $100,000 for a complete system plus spares) allows more flexibility in manufacturing rate.

Because of the applied dynamic impact principle in the EMR process, rather than the static force application in hydraulic machines, the EMR guns can be handheld or incorporated in a lightweight truss-frame type of structure with practically unlimited throat depths.

The EMR process was initially developed by The Boeing Company for riveting portions of the large Boeing 747 wing panels, which could not be reached by automatic riveting machines. The EMR process, however, is generally applicable to any structural design where fluid-tight, fatigue-critical, and/or large-diameter fastener installations are a requirement. EMR should not be confused with electromagnetic forming. Both use electromagnetic energy to accomplish work. EM forming uses a single coil and rigid backing plate, whereas EMR uses two series coils that deform or upset the rivet placed between them.

The EMR system is composed of a capacitor bank and two coils, each abutting against a copper-faced driving ram. The coils are contained in two separate hand-held EMR guns. The work cycle consists of charging the capacitor bank to a preset

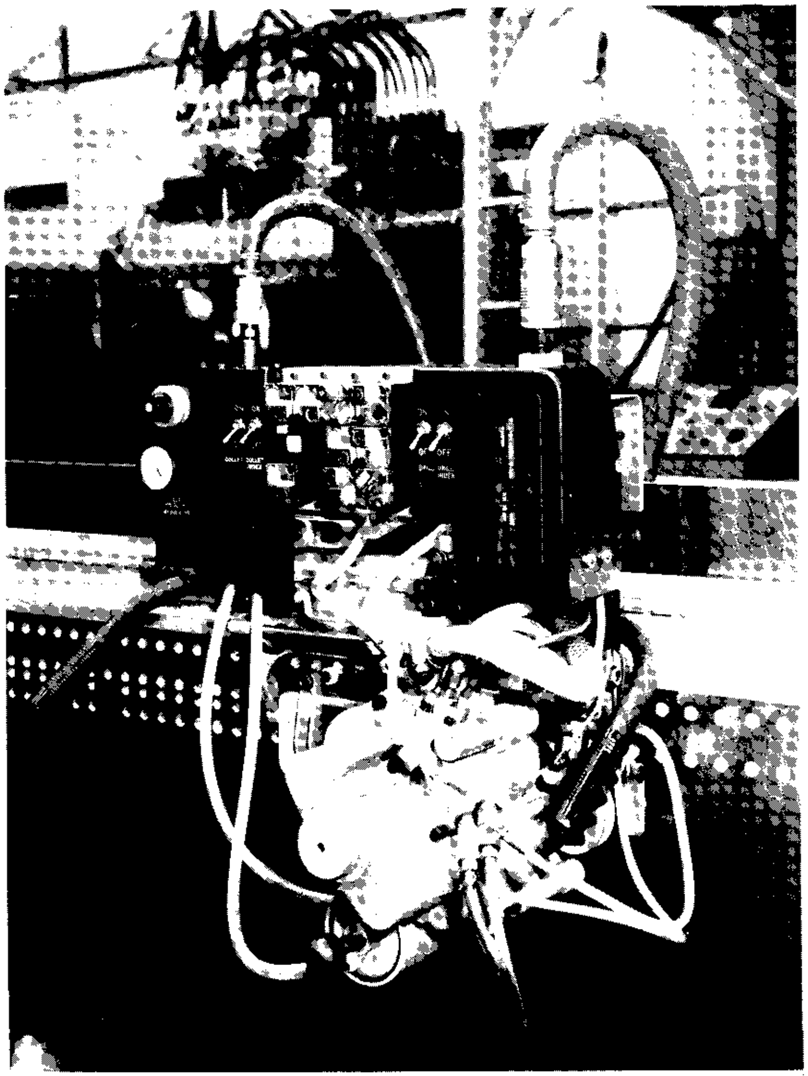


FIG. 11 - OMARK-WINSLOW TRACK DRILL

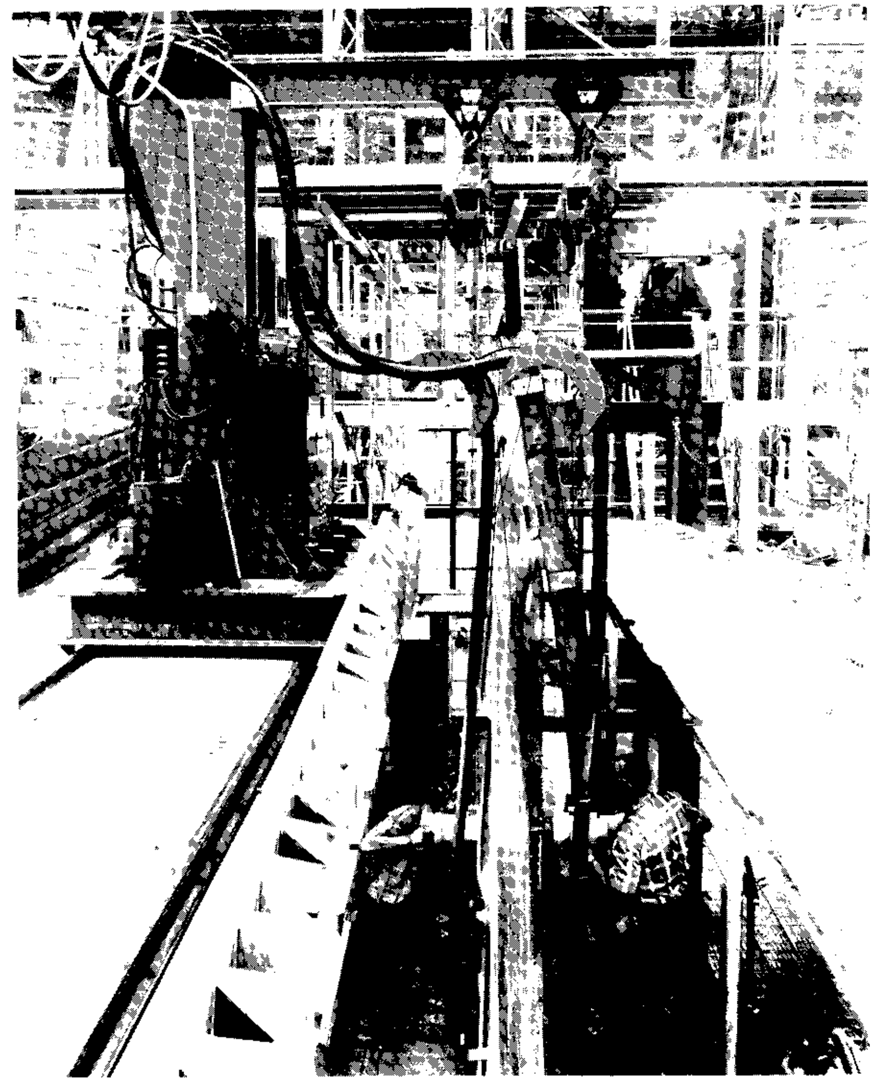
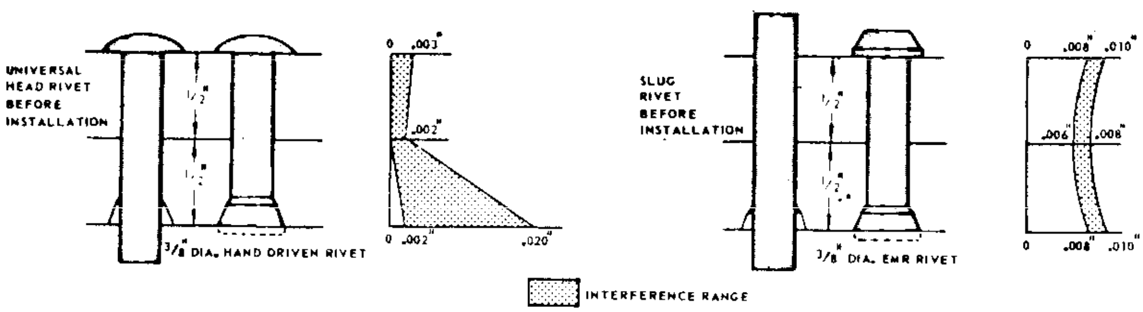


FIG. 12 - BOEING-DEVELOPED ELECTROMAGNETIC RIVETER

TABLE 6

INTERFERENCE PROFILES—HAND DRIVEN—EMR[a]



EQUIPMENT/PROCESS COMPARISONS	Large Automatic Riveting Machines	Manual Riveting	EMR
Fatigue Rated Capability	Excellent	Good	Excellent
Noise	High	Very High	Low
Maximum Practical Aluminum Rivet Capability	1/2"dia.	3/8"dia.	5/8"-3/4"dia.
Panel Size Capability	Limited	Unlimited	Unlimited
Cosmetic Quality	Excellent	Poor	Excellent
Reject Probability	Low	High	Very Low
Structural Distortion/Damage Probability	Low	High	Low
System Maintenance	High	Very Low	Low
Maximum Rivet to Rivet Rate (3/8"dia.)	7/minute	4/minute	20/minute
Direct Labor Ratio	0.85	2.1	1.0
Procurement Cost	Very High	Minimal	Relatively Low
Operator Fatigue	Low	Very High	Low

[a]Reprinted from EMR brochure.

TABLE 7

EMR TECHNICAL INFORMATION—BOEING 747 PRODUCTION SYSTEM [a]

Maximum Proven System Capability (Fatigue Rated Interference Profile)	
Aluminum Rivets	3/8" diameter x 1" grip
Titanium Rivets (Beta III)	1/4" diameter x 1/2" grip
Stainless Steel Rivets (A-286)	1/4" diameter x 1/2" grip
Deformation Time	5×10^{-4} Second
Deformation Energy	400 Ft. - lbs. (Equivalent to 30,000 lbs. static force.)
Power Pack	
Maximum Stored Energy Rating	6500 Joules
Energy Requirement (3/8" dia. Alum. Rivet)	2600 Joules (3800 Volts)
Maximum Charge Voltage	6000 Volts
Maximum Cycling Rate	20 per Minute
Input Requirements	
Electrical	440 Volt - 3 phase
Air	90 psi
Dimensions	36" wide x 48" high x 60" long
Weight	2800 pounds
Hand Guns	
Body Size	6-1/2" dia. x 15-1/2" long
Overall Length	23-1/2"
Junction Box Protrusion	6"
Recoil Mass (Internal)	45 pounds
Total Gun Weight (each)	75 pounds (Used with counter balance)
Gun Power Cables	
Type	Multiple Low Inductance Coaxial
Minimum Bend Radius	10"
Protection	Individual coaxial insulation with armored sheathing plus neoprene sheathing.
Length	Cables are custom designed for specific applications as part of a " tuned " circuit.
Coils	
Dimensions	5" dia. x 3/4" thick
Life (Driving 3/8" dia. Alum. Rivets)	Over 10,000 shots

[a]Reprinted from EMR brochure.

voltage level, followed by a rapid discharge through the series-connected coils. Synchronized by the current, the guns produce electromagnetic forces on the drivers, rapidly forming a rivet with equal and opposite forces (see Table 7). The EMR process can be used with several commercial rivet configurations and is not dependent upon high-cost proprietary fasteners. The cost of producing holes for the EMR is lower than with other fasteners such as lockbolts and requires a less expensive fastener.

EMR, when used in conjunction with the track drill, affords a cost-effective production capability for structural fastener installation (Figure 13) but is capable of functioning independently. Advantages of EMR are:

a) Proven performance in production of Boeing 747 wing panels

b) A high-rate installation capability (up to 20 rivets per minute)

c) Built-in repeatability and quality assurance

d) Interference profiles in thick material stacks not achievable with other riveting processes

e) Rivet head uniformity

f) Low-noise operation

g) Minimum operator fatigue

h) Low operator-skill requirement

i) Rapid change, conventional rivet dies

j) Relatively low capital acquisition cost

k) Minimum floor space requirement

l) Balanced impact forming of rivet to minimize structural distortion

m) Growth potential for larger rivet installation and bolt replacements

n) Manufacturing rate flexibility.

Cold Expansion Sleeve System. Under applied load conditions, each hole has associated with it a region of stress concentration where the applied stresses are magnified from two to three times their normal value. Hole expansion by coldworking successfully reduces the effect of this stress concentration by causing compressive radial stresses to remain around each hole. These residual compressive stress fields effectively prevent part failures from originating at the holes.

The cold expansion sleeve system (Figure 14) is a Boeing-developed process used for increasing the fatigue life of metal structures (aluminum, titanium, and steel) by causing compressive residual stresses around the fastener hole. The system consists of the radial expansion and sizing of fastener holes to achieve greatly improved fatigue performance while simultaneously reducing installed-fastener cost through the flexibility provided in fastener selection. Low-cost fasteners can be used in cold-worked holes without reducing the fatigue rating. Rivets or lockbolts can be used instead of more expensive fatigue-rated fasteners.

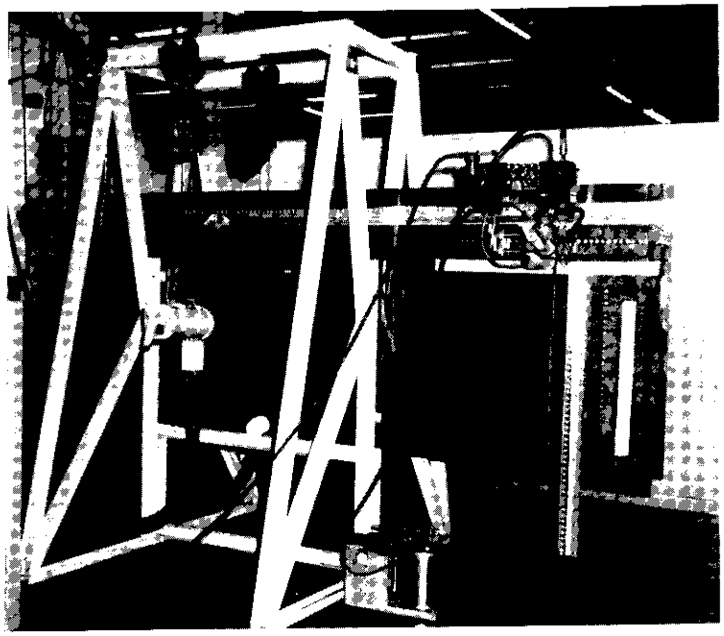


FIG. 13 - BOEING ELECTROMAGNETIC RIVETER AND OMARK-WINSLOW TRACK DRILL

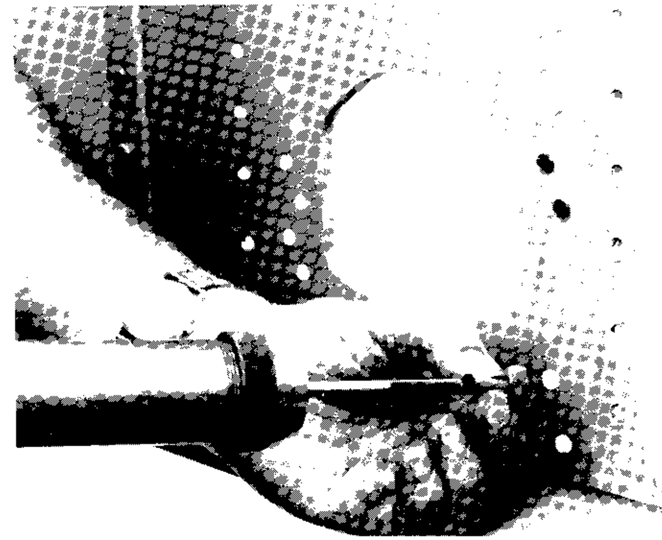


FIG. 14 - BOEING COLD EXPANSION SLEEVE SYSTEM

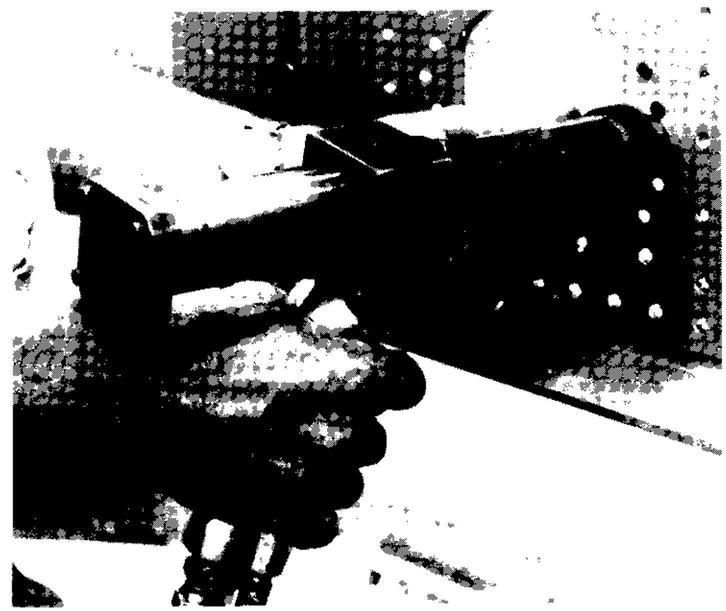


FIG.15 - AIR/HYDRAULIC PULLER FOR COLD WORKING HOLES

Radial expansion of the fastener hole is achieved by pulling a hardened steel mandrel through a patented prelubricated sleeve using either a power or manual pul (Figure 15). Once coldworked, the sleeve is removed and the fastener is installed. The cold expansion sleeve system can be used with several different fasteners, inc ing lockbolts and conventional rivets. For close-tolerance or interference-fit precision-shank fasteners, it is necessary to ream or broach the hole to size afte coldworking.

Drawing the mandrel through the split sleeve causes a radial plastic flow of metal. Compressive stresses will be found surrounding the coldworked hole for a distance extending approximately one radius from the edge of the hole. This compre sive stress region provides fatigue protection for a fastener hole. The compressiv residual stresses oppose the applied tensile stresses and act as an obstacle to th initiation and growth of fatigue cracks.

The distance from the edge of the coldworked hole that the compressive residu stress extends depends upon the amount of hole expansion. Extensive testing has be conducted to determine the optimum expansion range that occurs during coldworking.

The cold expansion sleeve system has a number of advantages: (1) It allows greater expansion of fastener holes than previously used methods, (2) the process produces a controlled amount of coldworking, (3) use of the prelubricated sleeve reduces problems of galling and tool breakage, (4) all work can be accomplished by one man from one side of the structure. The sleeve process is for a high degree of coldworking (large radial expansion), but a straight mandrel process is also available. A solid, one-piece, tungsten carbide mandrel is being used to coldwork holes in high-strength steel (300 ksi) on the 747.

<u>Honeycomb and Sandwich Panel Fasteners.</u> Lightweight nonstructural bonded pan are being incorporated into shipbuilding. This type of structure requires special fasteners and installation techniques for attachment of support equipment and panel installation.

Honeycomb sandwich structure provides optimum strength-to-weight ratios as wel as thermal and acoustic insulation. Methods of joining sandwich panels and making attachments to sandwich panels vary considerably.

Fasteners for sandwich or honeycomb structure are available commercially from several manufacturers such as the Shur-Lok Corp.; Voi-Shan, a division of VSI Corp. or the Delron Co., Inc. Table 8 is an example of sandwich panel fasteners from the Delron Company, Inc.

Before selecting a fastener, load considerations must be made for tension, she or torque loads. The type of adhesive used in the sandwich and the physical propert of the sandwich must be known. Once these questions are answered, the designer can choose the suitable fastener. Additional considerations for proper fastener selecti should include:

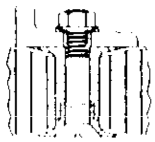
a) Type and size of fastener to be used

b) Blind or through-hole fastener

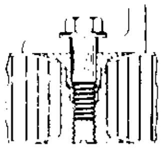
c) Flush or protruding head

TABLE 8

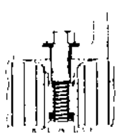
DELRON SELECTOR CHART—HONEYCOMB AND SANDWICH PANEL FASTENERS[a]



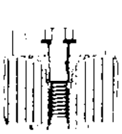
101 & 102
Grommet-type fastener, consisting of a plug and sleeve section. Used for bolting and riveting panels to structural members, flooring, bulkheads, etc. Available in thru-rivet and thru-bolt styles.



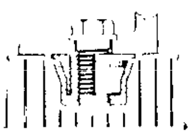
103
Grommet-type fasteners, consisting of a plug and sleeve section with internal threads. Used for bolting equipment and components to honeycomb and sandwich panels without an external nut.



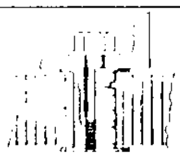
104
Grommet-type fasteners, consisting of a plug and sleeve section with non-metallic, self-locking feature? Used for bolting equipment to honeycomb and sandwich panels without an external nut.



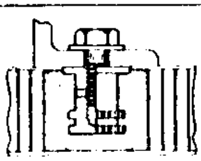
106
Grommet-type fasteners, consisting of a plug and sleeve section with internal, all metal, self locking threads. Used for bolting equipment to panels subjected to elevated temperature



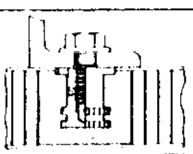
293 D & F
A mechanically installed blind fastener for light load application. Eliminates use of heavy bonding material. Available for flush and non flush applications. Preassembled two piece construction.



303F
An adjustable-type fastener for panels that vary in thickness beyond normal manufacturing limits. Available in various materials, head sizes and types, including threaded self locking. Two-piece construction.

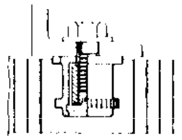


404H & G
One-piece, molded-in type fastener, designed for use with a minimum amount of potting material. Recommended for moderately high tension pull-out, compression and shear loads. Available with or without self locking feature. Grooved type available to be threaded into cover sheet.

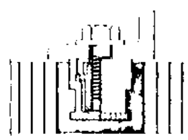


400 HE & GE
One-piece, molded-in fastener for moderately high tension pull-out and shear load. Minimum potting material required, with vent holes for injection. Available with or without threaded self-locking feature. "G" type threaded into top cover sheet.

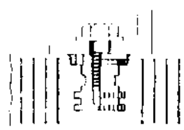
400 HF & GF
Two piece, molded-in fastener, similar to 400 HE & GE, but with a threaded inner section that provides $\frac{1}{32}$ inch, all directional, horizontal float, allowing for misalignment of mounting holes in attaching member. "G" type threaded into top cover sheet.



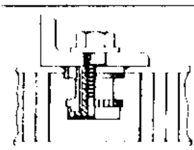
400 All-Metal
All-metal two piece, molded-in fastener, with floating nut, similar to 400 RF, but for use where panel is subjected to elevated temperatures during curing cycle, or environmental temperatures over 165 F. after installation.



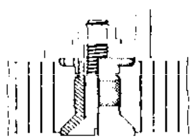
400 RF
Three-piece, molded in fastener, with floating nut, similar to 400 HF & GF, but with a removable threaded element that can be replaced, if damaged, without removing fastener. Available with or without self locking feature.



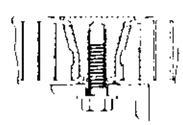
400 S & SE
One piece, molded in fastener, similar to 400 HE & GE, but with a groove in head, that may be snapped into top cover sheet for self retention during potting. SE has potting vent holes. Available with or without self locking feature



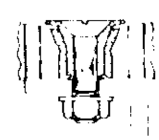
400 SF
Two piece, molded in fastener, similar to 400 S & SE, but with a threaded inner section that provides a $\frac{1}{32}$ inch, all directional, horizontal float, for misalignment of attaching members. Available with or without self locking feature.



400 HA & CA
Two piece, molded in fastener, adjustable for panel thickness variations of $\frac{1}{16}$ inch. Installed in holes as thru-bolt type. CA type designed for flush mounting of countersunk screws. Available with internal thread, with or without self locking feature.

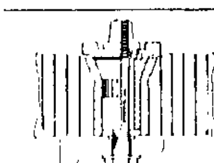


600 Flared
A structural fastener, mechanically installed. Body section is flared to grip both cover sheets for maximum pull-out and shear strength in all load directions. Available in thru-bolt, thru rivet and internal threaded, with or without self locking feature.



601 & 602
A structural fastener that provides maximum strength values by supporting the cover sheets from within the core area. Available for thru bolt and thru-rivet applications in flared and non flared types. Preassembled two piece construction.

603 & 604
A structural fastener, similar to 601 & 602 Series, with internal threads for blind applications. Available in flared and non flared types and with or without the self locking feature. Preassembled two piece construction.



700 Standard
A structural fastener incorporating a floating self-locking nut. Designed for possible misalignment in panel applications. Preassembled two piece construction. Also available, 700 F, with flaring feature that grips opposite cover sheet.

[a]Reprinted from Delron *Honeycomb and Sandwich Panel Fasterens* catalog.

d) Torque requirement of threaded types

e) Fastener material

f) Environmental temperature

g) Molded-in or mechanical connection

h) Fastener and sandwich material compatibility.

IID. EXPLOSION BONDING

The explosion bonding process of joining dissimilar metals was first developed for the chemical and aluminim processing industries. Its potential for marine applications was recognized by Naval architects and manufacturers of the material. Extensive testing to determine the physical properties and corrosion resistance of the clad materials has and is being conducted.

Increased use of electronic equipment aboard ships for communication and navigation and the demand to lower topside weight, increase maneuverability, and reduce ballast led to the introduction of aluminum superstructures. Initial installation techniques used lockbolts and sealants. As this method proved unsatisfactory, the clad materials have been implemented as transition joints between the aluminum deckhouses and steel decks. Known as bimetallics and trimetallics or transition inserts, these clad materials have been used in some shipyards. These materials are being designed into new ships in other applications.

Physical and mechanical properties of these materials, as well as several proposed applications, are elaborated upon in this section of the report.

The explosive bonding process was developed by E. I. du Pont de Nemours and Company in the late 1950s. Several years of extensive laboratory testing were conducted, ultimately resulting in commercial production of corrosion-resistant clad metals designed primarily for the chemical industry.

The procedure for achieving an explosive bond consists basically of placing the cladding plate above and parallel to a base plate. An explosive charge is then placed over the entire surface of the cladding plate and detonated from one end. The detonation travels at a rapid rate, up to 28,000 feet per second, generating an estimated pressure of 4,000,000 psi in the vicinity of the detonation (Figure 16 and Reference (4)).

The interface formed by the impinging metal causes a fluid-flow phenomenon or "jetting". The jetting that occurs removes oxides and foreign materials between the two plates. The resulting metallurgical bond is of a strength greater than the weaker of the two sheets. Hundreds of metals have been clad or bonded either to similar or dissimilar metals (Tables 9 and 10 and Reference (5)). Many of those listed in the tables were fabricated in small strips and samples to establish feasibility and are not available commercially. Other materials were clad but not reported for proprietary or classified reasons or for not being applicable to ship construction.

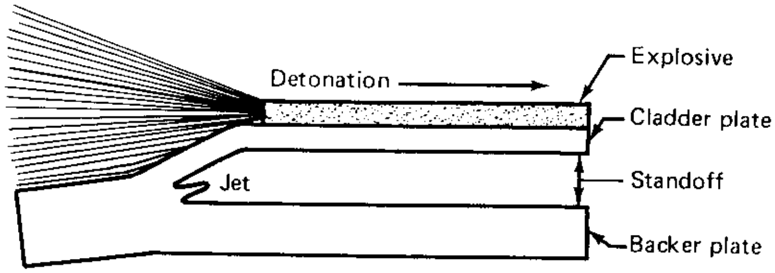


FIGURE 16

SCHEMATIC OF EXPLOSION BONDING PROCESS ILLUSTRATING JETTING PHENOMENON WHICH REMOVES OXIDES AND FOREIGN MATTER FROM SURFACES BEING JOINED

TABLE 9

METALS THAT HAVE BEEN EXPLOSIVELY BONDED TO THEMSELVES[a]

Ferrous metals	
Low-carbon steels 1004-1020 Medium-carbon steel ASTM A-285 Medium-carbon steel ASTM A-201 Medium-carbon steel ASTM A-212 Low-alloy steel ASTM A-204 Low-alloy steel ASTM A-302 Low-alloy steel ASTM A-387 Alloy steel AISI 4130 Alloy steel AISI 4340 Stainless steel type 200 series	Stainless steel 17-7PH Stainless steel type 301 Stainless steel type 304 Stainless steel type 321 Stainless steel type 347 Maraging steel, 18% nickel Ductile cast iron
Nonferrous metals	
Aluminum 1100 Aluminum 2024-T3 and -0 Aluminum 2214-T6 Aluminum 5083-H24 Aluminum 6061-T6 Aluminum 7178-0 Aluminum 7075-T6 Aluminum 1100/1.5 lithium Copper Brass Cupro-nickel Bronze Beryllium copper	Nickel Titanium—commercially pure Titanium-6Al-4V Titanium-5Al-5Sn-5Zr Titanium-8Al-1Mo-1V Titanium-13V-11Cr-3Al Zinc

[a]Extracted from DMIC document 225, Explosive Bonding, Linse, Whitman, and Carlson, Battelle Memorial Institute

TABLE 10
DISSIMILAR METAL COMBINATIONS THAT HAVE BEEN EXPLOSIVELY BONDED[a]

Low-carbon steels 1004-1020 to:
- Stainless steel–ferritic
- Stainless steel–300 series
- Stainless steel–200 series
- Ductile cast iron
- Malleable cast iron
- Aluminum and aluminum alloys
- Copper
- Brass
- Cupro-nickel
- Nickel
- Zinc
- Titanium

Medium-carbon steels ASTM A-201 and A-212 to:
- Stainless steel–300 series
- Stainless steel–200 series
- Aluminum and aluminum alloys
- Copper
- Brass
- Cupro-nickel
- Bronze
- Nickel and nickel alloys
- Titanium and titanium alloys
- Titanium 35A

Medium-carbon steel ASTM A-286 to:
- Stainless steel–ferritic
- Stainless steel–300 series
- Stainless steel–200 series
- Aluminum and aluminum alloys
- Copper
- Brass
- Cupro-nickel
- Bronze
- Nickel and nickel alloys
- Titanium
- Titanium-6Al-4V

Low-alloy steel ASTM A-204 to:
- Stainless steel–300 series
- Stainless steel–200 series
- Aluminum and aluminum alloys
- Copper
- Brass
- Cupro-nickel
- Nickel and nickel alloys
- Titanium and titanium alloys
- Hastellroy B, C, F
- Hastelloy X

Low-alloy steel, ASTM A302 to:
- Stainless steel type 410
- Stainless steel–ferritic
- Stainless steel–300 series
- Stainless steel–200 series
- Aluminum and aluminum alloys
- Nickel and nickel alloys
- Titanium and titanium alloys

Alloy steel AISI 4130 to:
- Stainless steel–300 series
- Aluminum 2014-T6 and -T3

Alloy steel AISI 4340 to:
- Stainless steel–300 series

Maraging steel to:
- Stainless steel–300 series

Hadfield steel to:
- Aluminum and aluminum alloys

Stainless steel–200 series to:
- Low-carbon steel AISI 1004-1020
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel ASTM A-212
- Low-alloy steel ASTM A-204
- Low-alloy steel ASTM A-302
- Low-alloy steel ASTM A-387
- Aluminum and aluminum alloys
- Brass

Stainless steel–300 series to:
- Low-carbon steel AISI 1004-1020
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel ASTM A-212
- Low-alloy steel ASTM A-204
- Low-alloy steel ASTM A-302
- Low-alloy steel ASTM A-387
- Alloy steel AISI 4130
- Alloy steel AISI 4340
- Maraging steel
- Aluminum 6061-T6
- Copper
- Brass
- Nickel and nickel alloys
- Titanium and titanium alloys
- Molybdenum

Stainless steel type 301 to:
- Stainless steel type 347
- Titanium-6Al-4V
- Aluminum 2219

[a]Extracted from DMIC document 225, *Explosive Bonding*, Linse, Whitman, and Carlson, Battelle Memorial Institute

TABLE 10 (CONCLUDED)

Stainless steel type 304 to:
- TD nickel-chromium

Stainless steel type 321 to:
- Stainless steel type 347

Stainless steel type 347 to:
- Stainless steel type 301
- Stainless steel type 321
- Hastelloy X
- Aluminum 6061-T6

Stainless steel—martensitic, type 410 to:
- Low-alloy steel ASTM A-3870

Stainless steel—ferritic to:
- Low-alloy steel ASTM A-387
- Medium-carbon steel ASTM A-285
- Low-carbon steel AISI 1004-1020
- Titanium and Titanium alloys

Aluminum and aluminum alloys to:
- Low-carbon steel AISI 1004-1020
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel ASTM A-212
- Low-alloy steel ASTM A-212
- Low-alloy steel ASTM A-302
- Low-alloy steel ASTM A-387
- Stainless steel—300 series
- Stainless steel—200 series
- Copper
- Titanium and titanium-6Al-4V

Aluminum 1100 to:
- Titanium-6Al-4V
- Aluminum 1100/1.5 lithium

Aluminum 2014-T6 to:
- Alloy steel AISI 4130

Aluminum 2219 to:
- Stainless steel type 301

Aluminum 6061-T6 to:
- Beryllium copper
- Stainless steel type 347
- 65% beryllium-35% aluminum
- Titanium-6Al-4V
- Zircaloy-2
- Molybdenum

Brass alloys to:
- Low-carbon steel AISI 1004-1020
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel ASTM A-212
- Low-alloy steel ASTM 204
- Low-alloy steel ASTM A-302
- Cast steel
- Stainless steel—300 series
- Stainless steel—200 series
- Nickel and nickel-base alloys

Cupro-nickel alloys to:
- Low-carbon steel AISI 1004-1020
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel ASTM A-212
- Low-alloy steel ASTM A-204
- Low-alloy steel ASTM A-302

Bronze alloys to:
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel ASTM A-212
- Alloy steel 4340
- Alloy steel A6

Nickel and nickel-base alloys to:
- Low-carbon steel AISI 1004-1020
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel cSTM A-212
- Low-alloy steel ASTM A-204
- Low-alloy steel ASTM A-302
- Low-alloy steel ASTM A-387
- Stainless steel—300 series
- Brass
- Titanium and titanium alloys
- Copper
- Nickel and nickel-base alloys
- Columbium and columbium-base alloys
- Tungsten
- Iconel X

Titanium-6Al-4V to:
- Stainless steel type 301
- Aluminum 1100-0

Titanium and titanium alloys to:
- Medium-carbon steel ASTM A-285
- Medium-carbon steel ASTM A-201
- Medium-carbon steel ASTM A-212
- Low-alloy steel ASTM A-204
- Low-alloy steel ASTM A-302
- Low-alloy steel ASTM A-387
- Stainless steel—ferritic
- Stainless steel—300 series
- Maraging steel
- Aluminum alloys

In mid-1966, development work was started to produce a bimetallic transition insert for joining aluminum bus to steel anodes and cathodes in alumimum smelting plants. This joint used 1100 aluminum and 1008 steel.

BONDED SHEET

Recognizing the need for a marine industry application, Du Pont started development in 1966 of a clad sheet that would facilitate attaching the aluminum superstructure to the steel deck. The resulting bonded sheet is a triclad employing alumimum alloy 5456 bonded to A516 Grade 55 steel with a commercially pure 1100-series aluminum interface between the structural materials. The 1100-series alumimum makes a significant contribution to the ductility and impact resistance of the triclad. The resulting thickness is 1-3/8 inches. A similar product, Transition Insert, is produced commercially by the Kaiser Alumimum Co. (Reference (6)) and Northwest Technical Industries, Inc., of Port Angeles, Washington. The final product is a purchased item available in sheet or strips and is not an item that requires bonding in the shipyards. Mechanical cutting to the desired part configuration is performed in the shipyard.

Most commercial applications encountered to date utilize Du Pont's Detacouple/Detaclad sheet and plate. Thicknesses range from a few thousandths of an inch to over a foot, while the cladding metal thickness varies from 0.0001 to 1-1/2 inches (Reference (7)). The bimetallic sheet is produced in the same manner as the triclad but does not have the 1100-series alumimum alloy in the interface and can be of numerous alloy combinations. Standard welding techniques available in shipyards are acceptable for fabrication with this material. As with all inert gas welding techniques, however, adequate provisions for protection from the elements should be provided.

TUBE CLADDING

Successful tube-cladding experiments have been conducted resulting in bond combinations for tubes in the 1/2- to 8-inch-diameter range. Materials that have been bonded include: Inconel and Ziracaloy, stainless steel and Ziracaloy, stainless steel and 6061-T6 aluminum, stainless steel and aluminum, 6061-T6 aluminum and titanium, and 1100 aluminum and magnesium (Reference (8)). Tubing can be clad internally or externally, depending on the design application.

Applications for explosive bonding include tubular cladding in condenser or heat-exchanger applications and underwater spot welding of dissimilar metals without removing the water interface; both processes were developed by Battelle Institute (Reference (5)). These processes afford the possibility of cladding stern tubes and rudder stocks in aluminum or other dissimilar structure to eliminate galvanic couples.

CORROSION TESTS

Several seawater/salt-spray corrosion tests are currently under way, the most extensive being conducted by International Nickel Co., at Wrightsville Beach, North Carolina. In conjunction with Du Pont, several samples of the Detacouple strip were welded to 5456 aluminum alloy and mild steel panels and have been subjected to splash-spray tests in excess of 5 years.

A graph of the result of the unpainted sample is shown in Figure 17. Galvanic corrosion penetration has reached approximately 0.063 inch in the unpainted samples.

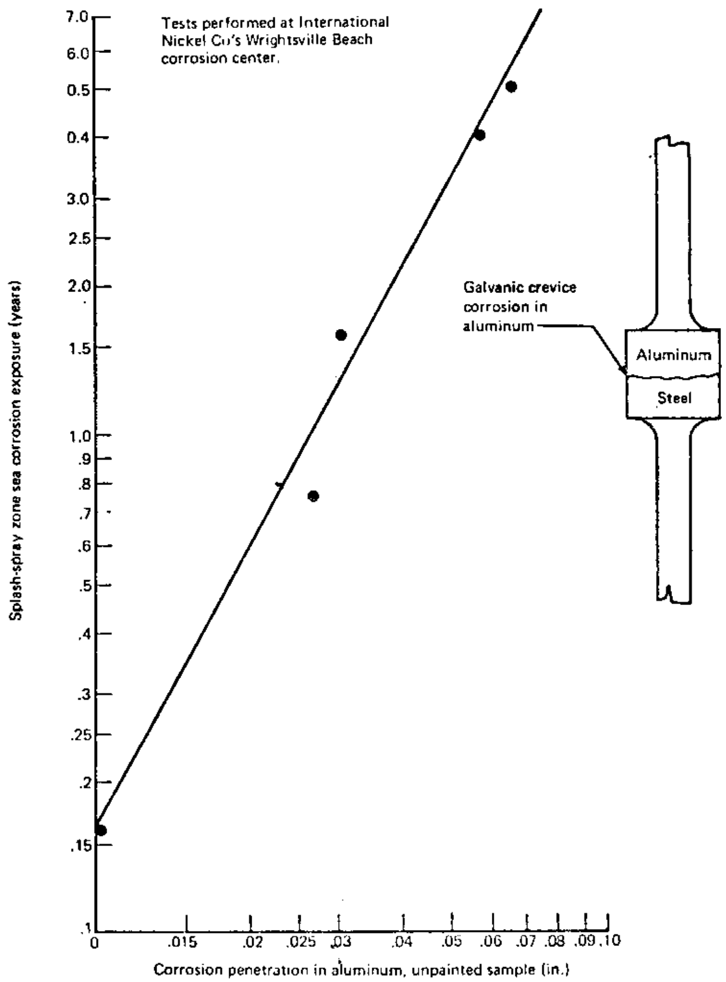


FIG. 17 - CORROSION TEST RESULTS

TABLE 11 - CORROSION TESTING OF EXPLOSION-BONDED TRANSITION JOINTS[a]

Test and specimen description	Specimen condition	Exposure duration	Depth of penetration (in.[b])
Transition joint welded to 3- X 7- X 1/4-in. 5456 aluminum and mild steel panels; splash-spray test, Wrightsville Beach, N.C., begun 11/10/67	Unpainted	3 months 12 months 27 months	0.027 0.033 0.042
	Completely painted[c]	12 months 34 months	None None
	Aluminum panel unpainted; steel panel and transition joint painted[c]	12 months 34 months	None None
16-in. X 1 in.-wide transition strip; welded on stern area of SS American Legion behind stack area; begun 6/18/68[d]	Unpainted	12 months	0.033
	Primed with zinc chromate	12 months	None
	Painted[c]	12 months	None
Continuous 5% salt-spray test ASTM B-117-57T	Unpainted	1000 hr[e]	0.060
	Painted[c]	1000 hr	None

[a]Information from *Marine Technology*, July 1971.

[b]Penetration is maximum depth in aluminum

[c]Paint consists of first coat zinc chromate vinyl paints, Pettit Paint Co., no. 6455 metal prime; second and third coats were oil-base paints.

[d]Owned by United States Lines, work performed by Sun Ship Building & Dry Dock Co.

[e]Sixteen hours of testing is considered comparable to 1 year exposure in the Detroit, Mich n environment.

Initial samples demonstrated the corrosion resistance of the bond zone. The initial corrosion product, hydrated aluminum oxide, occupies a larger volume than the aluminum consumed and acts to seal the area from additional corrosion (Reference (9)).

An identical series of corrosion tests for painted samples is currently being conducted in conjunction with the unpainted samples. The painted samples were scratched across the bond zone to simulate localized paint failure. No significant corrosion or pitting was noted after 27 months of continuous testing (Table 11).

MECHANICAL PROPERTIES

Mechanical property tests have been conducted by Du Pont (Table 12); Boeing (Reference (10)); and the Naval Ship Research and Development Center (NSRDC) Reference (11). Results of these tests are documented by the respective agencies. Results of these tests and the fatigue tests conducted by Du Pont (Table 13 and Reference (12)), can be summarized by the following:

a) Explosive bonded samples meet or exceed the claims made by the manufacturers.

b) Fracture along the aluminum-to-steel interface of a composite could not be induced by shear or tensile stress if applied evenly to both sides of the bond on equal and continuous areas.

c) Fatigue tests yielded no failures in the bond zone.

d) Continuous salt-spray corrosion tests and user contacts show the material to be acceptable for use in the saltwater environment with only minimal maintenance.

e) Use of clad materials is a cost-effective method of fabrication and in many cases offers an attractive alternative (Table 14 and Reference (13)).

SUPERSTRUCTURE/DECK INTERFACE

One major structural area where galvanic couples have caused problems has been in the attachment of aluminum superstructure to primary steel-hull structure. The initial methods for this attachment involved applying primers and sealants to the faying surfaces, fastening with steel lockbolts, and fillet sealing. This method has proved troublesome from a maintenance standpoint as sea action has caused fasteners to shear or loosen.

A typical installation of Du Pont's Detacouple as a transition joint for aluminum deckhouse to steel deck joints is shown in Figure 18 (Reference (13)).

INSTALLATION COST STUDIES

Installation cost studies conducted by Hunter's Point Naval Shipyard in 1972 reported the installation cost using Detacouple to be lower than a similar joint made with lockbolts (Table 15). While the initial costs for first-time installation show only a 14% savings over the lockbolt assembly method, it is their estimate and opinion that an additional 10% saving will result from (1) reduced forming costs for the Detacouple with the use of dies, (2) greater efficiency by mechanics as they

TABLE 12

MECHANICAL TESTING OF EXPLOSION-BONDED TRANSITION JOINTS[a]

Description of test and specimen	Specimen condition	Results	Remarks
Standard ram tensile; testing 1100 aluminum/ A-516 gr. 55 steel interface	As clad As welded[b]	20,000 psi typical ultimate tensile 15,000 psi typical ultimate tensile	Broke at 1100 aluminum/ steel interface Broke at 1100 aluminum/ steel interface
Extended ram tensile; testing strength of the 1100 aluminum interlayer	As clad As welded[b]	18,500 psi typical ultimate tensile 13,500 psi typical ultimate tensile	Broke in 1100 aluminum Broke in 1100 aluminum
Triple-lug shear ASTM A-263	As clad As welded[b]	14,000 psi typical shear stress 11,000 psi typical shear stress	Shearing of the 1100 aluminum Shearing of the 1100 aluminum
Welded tensile; 1/4-in.-thick 5456 aluminum plate welded to 1-in. transition joint welded to 1/4-in. mild steel	As clad and welded	51,600 psi typical ultimate tensile	Failed in 5456 aluminum plate at heat-affected zone
Charpy-V ASTM A-370 Testing A-516 steel	Specimen cut from steel portion of clad parallel to interface (a) Notch in steel below bond zone (b) Same as above but notch at underside of steel	 60-130 ft-lb 70-130 ft-lb	All tests carried out at 15° F[c]
IZOD (unnotched) 1/2-in. 1100 aluminum 1-1/2-in. 1008 steel	As-clad sample cut perpendicular to plane of clad Grip on steel, impact on aluminum	Tearing of aluminum	No debonding or separation of the aluminum/ steel interface
Drop weight test, E-208-66T, type P-2; 1/2 in. 1100 aluminum on A-516 gr. 55 steel	As clad	NDT-15° F	No debonding and no crack propagation into the aluminum layer
Shear test (A-263) after thermal cycling between 500 F and water (80° F), 2500 cycles; 1/2-in. 1100 aluminum/1-1/2-in. 1008 steel	As clad	14,000 psi typical shear strength	

[a]Information from *Marine Technology*, July 1971

[b]Heat treated at 600°F for 1/2 hour in air to exaggerate heat during welding. Decrease in strength is due to partial annealing of the 1100 aluminum.

[c]Typical requirement for shipboard application is 15 ft-lb at 15° F.

TABLE 13

FATIGUE TESTING EXPLOSION-BONDED TRANSITION JOINTS AND MECHANICAL CONNECTIONS[a]

Specimen type	Size (in.)		Loading per linear inch (lb)[b, c]		Cycles to failure	Remarks
	Thickness	Width	Tension	Compression		
Mechanical connections						
Four rivets	1/4	3-1/2	1250	3750	31,600	Rivet failed
Six rivets	1/4	5	1250	3000	63,300	
Explosion-bonded transition joints[e]	1/4	2	1250	3750	395,000	Fractured in heat-affected zone of 5456 aluminum weld
	1/4	2	750	2560	1,267,400	
	1/4	2	250	3750	721,500	

[a]Information taken from *Marine Technology*, July 1971

[b]Tests performed Budd Co., Philadelphia, Pa., by means of a Krouse double direct stress testing machine at at 800 cpm.

[c]Since the tension and compression stresses on the transition joint cannot be directly correlated with shear stresses on the rivets, data are presented in actual load per running inch. By holding the aluminum and steel thickness constant, data comparing actual operating capabilities are obtainable.

[d]Specimens consist of 5456 aluminum joined to HY 80 coaming using 3/8-in. CRES rivets. Specimens fabricated by shipyards using standard production procedures.

[e]Transition joint strips were 1 in. X 2 in. X composite thickness welded to 5456 aluminum and HY 80 coaming using the 4- to-1 design ratio.

TABLE 14

COMPARATIVE MAINTENANCE AND REPAIR ASSOCIATED WITH MECHANICAL FASTENING VERSUS DETASTRIP FOR ATTACHMENT OF ALUMINUM DECK HOUSES TO STEEL DECKS[a]

Maintenance problem or type of repair	Lockbolt fastening technique	Detastrip fastening technique	Comparative costs
Galvanic corrosion at aluminum/steel interface	There may be serious damage where the insulation is broken; repair involves dismantling, cleaning, and reassembly; damage not readily detected.	Normal ship's painting should provide adequate protection; in addition, corrosion tests indicated there would be no significant damage in case of paint failure; initial corrosion easily detected.	The Detastrip method offers potentially large savings in this area; in general, repairs will not be needed; paint failures will not be easily repaired requiring only simple cleaning and repainting; ease of detection and proper maintenance should prevent extensive repairs.
Corroded steel coaming in areas where moisture hinders maintenance	Requires replacement of coaming; involves disassembly of joint, removal of coaming, fitting new coaming, drilling holes, and reassembly.	Requires replacement of coaming; generally flame-cut coaming 1 or 2 inches below Detastrip, remove coaming, and install new coaming as if installing a patch.	Detastrip repairs should be much cheaper due to savings in labor (both removal and reinstallation) and savings in material costs.
Replacement of steel coaming and aluminum bulkhead due to structural damage (such as fire, collision, etc.) or corrosion at aluminum/steel interface	Requires removal of damaged area and replacement with new material.	Requires removal of damage and replacement with new material.	Removal costs will be approximately the same; reinstallation costs should reflect the 24% savings as determined for initial installation.
Replacement of aluminum due to corrosion at aluminum/steel interface	Sometimes required at interface where severe corrosion has taken place before detection; requires dismantling, fitting new aluminum section, drilling new holes, and re-assembly.	This repair is not anticipated for the Detastrip method of attachment do to its expected durability (based on corrosion test).	This type of repair will not be required with the Detastrip method thus providing significant improvement and savings over mechanical fastening.

[a]Information from "Fabrication Cost Comparison Study," project 2-0094 Quality Assurance Office, Hunters point Naval Shipyard.

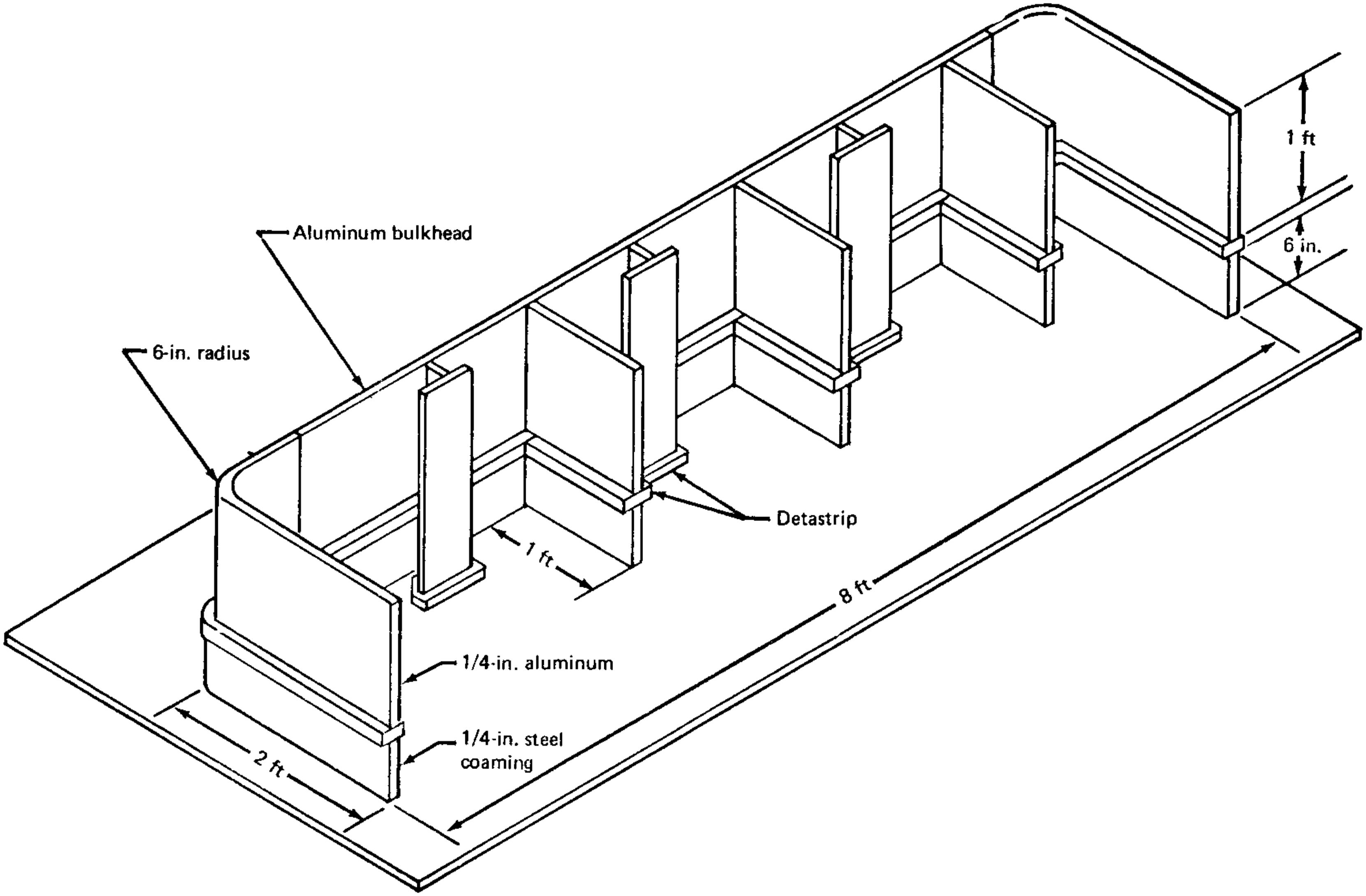


FIGURE 18

DECKHOUSE MOCKUP—ALUMINUM/STEEL TRANSITION JOINTS

TABLE 15

ALUMINUM DECK HOUSE FABRICATION COST ANALYSIS[a]

Item	Labor in manhours per linear foot			Estimated Boeing Costs
	Shop	Lockbolt	Detastrip	
Loft templates	11	0.09	.080	$0.09
Duplicate loft templates	11	0.08	.070	0.08
Fabricate steel coaming	11	0.17	.100	0.17
Drill holes (3/8 inch holes, 18/linear foot)	11	1.08	N/A	0.64
Install gasket material	11	0.02	N/A	N/A**
Install lockbolt (18/linear foot)	11	0.90	N/A	0.02
Cut to length and bevel (Detastrip)	11	*N/A	.110	N/A
Form Detastrip (radius corners)	11	N/A	.067	N/A
Fit up Detastrip (align)	11	N/A	.359	N/A
Fit up Detastrip (tack)	26	N/A	.164	N/A
Weld Detastrip to coaming 1/4 inch	26	N/A	.184	N/A
Weld Detastrip to BHD 3/8 inch	26	N/A	.365	N/A
Weld tee joint (Detastrip)	26	N/A	.109	N/A
Weld butt joint (Detastrip)	26	N/A	.067	N/A
Weld stiffener to Detastrip (aluminum)	26	N/A	.034	N/A
Drill holes (3/8 inch holes 12/stiffener)	11	0.11	N/A	0.43
Install lockbolts (12/stiffener)	11	0.10	N/A	0.01
Straight bulkhead, Detastrip welded	11	N/A	.280	N/A
Total manhours/linear foot		2.55	1.989	1.44
Labor cost at $12.00/manhour/$10.50 (Boeing)		$30.60	$23.89	15.12
Material		$12.60	$13.22	12.60
Total cost/linear foot		$43.20	$37.11	$27.72
Savings per foot: $43.20 - $37.11 = $6.09/linear foot/$15.48 per linear foot-Boeing				

Note: 1. Detastrip fabrication values were obtained from direct time study of a mockup per code 138 sketch MFI 48-72.

2. Values for lockbolt fabrication were obtained from "E" standards 383.2-0517, 0543, and 0612.

3. Boeing estimates for lockbolt installation were conducted by Industrial Engineering and based on the production capabilities and labor cost at Boeing.

Hole preparation with Quackenbush QOA-11 to drill ream, countersink, and apply SRF and install cadmium-plated sheet lockbolt in standard manhour (SMH) is:

Item	Per hole	Per foot	Per stiffener
Hole preparation	0.0356 SMH	0.64 SMH	0.43 SMH
Fastener	0.0001 SMH	0.02 SMH	0.01 SMH
	Total	0.66 SMH	0.44 SMH

*N/A – Not applicable

**N/A – Note: If two coats of BMS 10-11 H(SRF) type 1 are used, no gasket material would be required.

[a]Information extracted to include Boeing cost estimates from Hunter Point Naval Shipyard report 2-0094, and modified

become familiar with this fabrication method, (3) use of mechanized welding to reduce welding cost, and (4) greater overall efficiency for all operations due to refinement in production sequences and techniques (Reference (13)). It could also reduce costs by eliminating requirements for stocking lockbolts and purchasing the tooling required for their installation. This test represented a first-time use of Detacouple compared to 12 year's experience using mechanical fastening techniques. Boeing Industrial Engineering has conducted a similar cost analysis of the lockbolt joining method. Using the tooling data from the Hunter's Point study, the total installed cost per foot of lockbolts is $27.72. Use of aircraft fabrication techniques results in savings of 36% when compared with the shipyard installation of lockbolts.

Tacoma Boat Building Company, Tacoma, Washington indicates a man-hour labor saving of $5.00 per foot when using 345 feet of Detacouple to attach the aluminum deckhouse to steek deck on a tuna seiner. (This figure is based on labor rates only and does not include material cost. Cost studies indicated deckhouse fabrication rates to be 7.3 feet per hour for Detacouple as compared to 3.6 feet per hour for similar lockbolt installation methods.) The customer benefits from lower fabrication costs in addition to lower maintenance requirements (Reference (14)).

MACHINERY AND EQUIPMENT ATTACHMENT

Two areas subject to galvanic corrosion in aluminum structure involve outfitting and systems attachments. These areas encompass everything from the mounting of deck machinery to the attachment of nameplates and operating instructions.

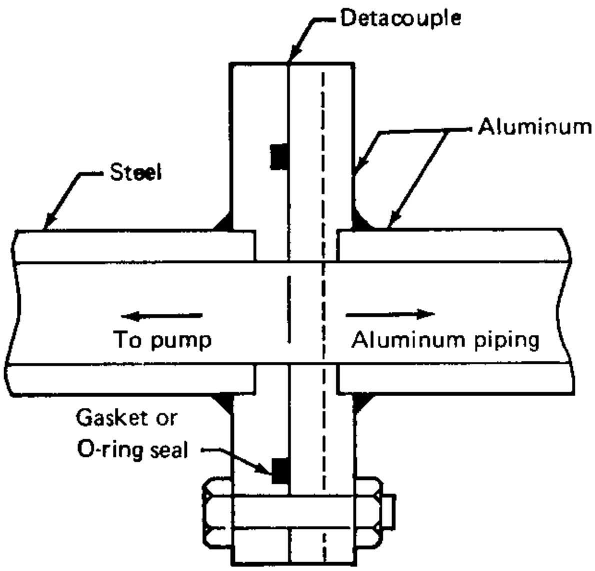
Due to strength considerations, cost, and availability, most deck machinery is fabricated from steel and iron. While this does not present a problem in conventional steel ship construction, it does compound problems when the same equipment is attached to aluminum structure.

The current method of attaching steel deck machinery and related equipment to aluminum structure requires the use of primers, leaded paints, neoprene gaskets, sacrificial pads, phenolic bushings, and liberal applications of sealant around joints. This method is not only time-consuming, costly, and inefficient, but also requires repeated applications when sacrificial pads corrode or paint and sealant are damaged.

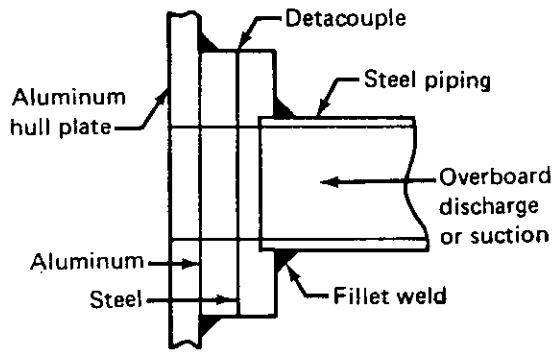
An alternate method to this approach, still allowing the use of conventional deck gear, would be to use the bimetallic sheets as pads to interface the steel machinery to the aluminum deck. With this approach, the deck machinery could be welded or mechanically fastened directly to the deck through compatible materials and would not require costly maintenance. Several suggested applications of explosion bonded materials are shown in Figure 19.

The Alcoa deep-reaching oceanographic research vehicle, Seaprobe, uses Detacouple mounts to attach equipment supports to the aluminum structure.

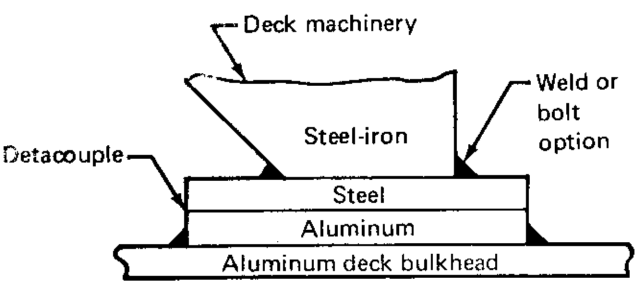
Northwest Technical Industries, Inc. (NTII) is currently working with Boeing to produce a reinforced explosive-bonded aluminum skin for the Space Shuttle program. Eight by 10-foot sheets of 2219 aluminum have had 12-inch-square plates of 2219 aluminum explosively bonded in places where cutouts will be made in the skin. These plates serve as reinforcements and eliminate the need for steel reinforcing doublers or thick plate sculpturing and machining.



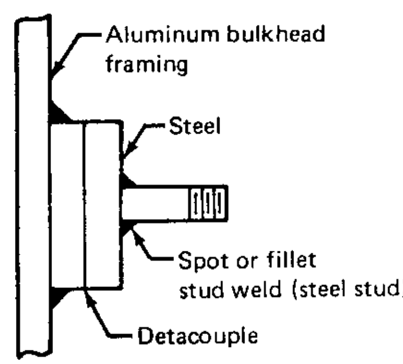
a) **Detacouple Flanges for Joining Aluminum to Steel Pipe**



b) **Overboard Discharge Flanges for Fire System Suction**



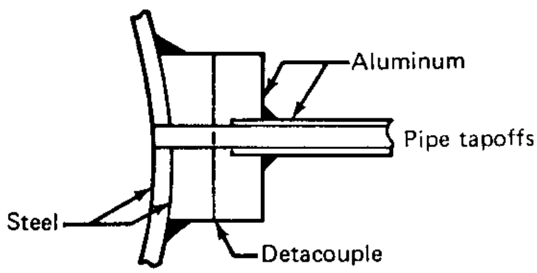
c) **Detacouple Pads for Pump Mountings to Aluminum Decks Winches, Anchor Windlass**



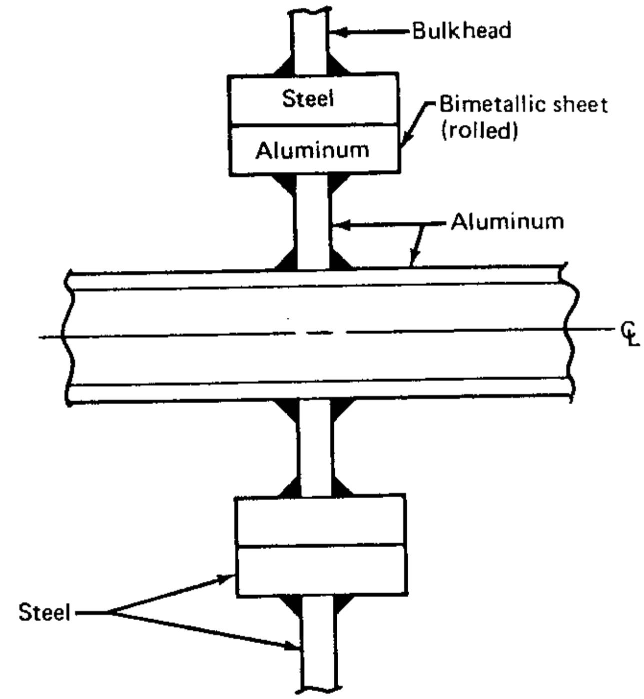
d) **Outfitting Studs—Steel to Aluminum When Necessary**

FIGURE 19

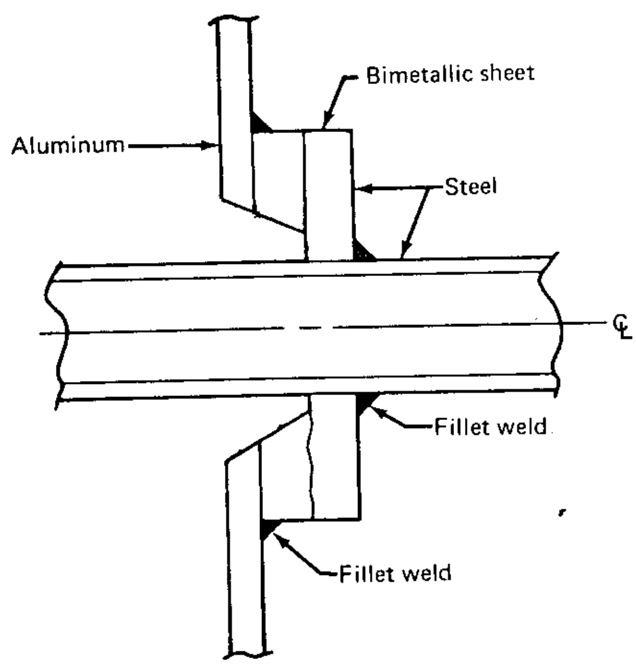
PROPOSED BIMETALLIC APPLICATIONS



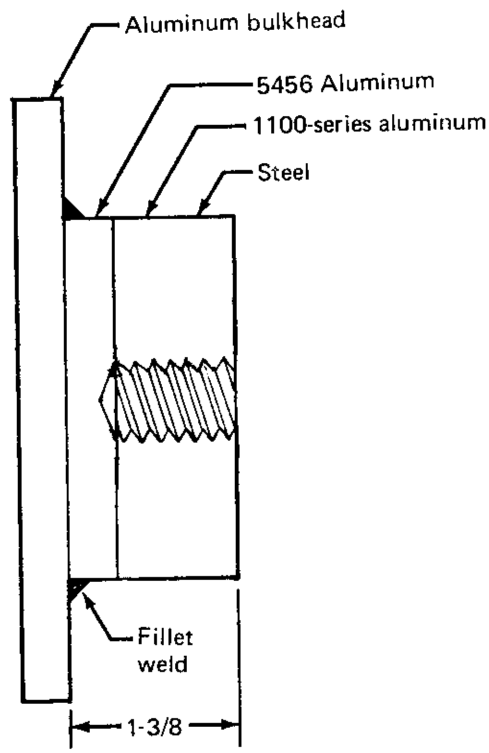
e) **Dissimilar Pipe Joints**



f) **Watertight Penetration—Aluminum Pipe Through Steel Bulkhead**



g) **Watertight Bulkhead Penetration—Steel Pipe Through Aluminum**



h) **Bulkhead Equipment Mount Utilizing Detacouple**

FIGURE 19 (CONCLUDED)

NTII also produces chill bars used for welding thin-gage aluminum by explosively bonding copper and aluminum. Thinner copper blocks are used over the standard solid copper block, thus lowering the cost of the chill bars.

The current design and development effort by Pittsburgh-Des Moines Steel and General Dynamics to fabricate liquid natural gas tankers uses Detacouple in attaching the steel support skirt from the primary structure to the 25,000-cubic-meter aluminum LNG spheres (References (15) and (16)).

IIE. ADHESIVE BONDING

The demand for high-performance military aircraft, reliable commercial transportation, and strong lightweight space vehicles has hastened the development of lightweight, high-strength-to-weight-ratio honeycomb sandwich panels and structures. Bonded honeycomb sandwich materials are incorporated into aircraft as flight control surfaces (flaps, ailerons, and rudders), as acoustical attenuating structures on turbine inlet and exhaust ports, or as insulating walls of cyrogenic tanks of space vehicles.

Information on the thermal properties, structural limitations and applications, and fatigue resistance of adhesive-bonded structure is available through government agencies such as the Air Force and NASA. Sections of the Boeing Design Manual, Section 26, on adhesive bonding have been included with this report for reference (Appendix I).

The state of the art in adhesive bonding in the aerospace industry has progressed significantly in the past 20 years. Advances in polymer chemistry have made possible the development of new adhesive systems with high strengths, good environmental resistance, excellent manufacturing properties, and moderate costs. The ultimate performance of the adhesive systems are highly dependent on the surface preparation process of the materials to be bonded. Materials such as wood, GRP, or glass may be prepared for bonding by a simple solvent wipe and/or light abrasion. Consistent, high-quality bonds in metal surfaces normally require a chemical-immersion-type prebond treatment. The state of the art of surface preparation for aluminum is far more advanced than for other metals such as steel, titanium, or magnesium. (The highest percentage of adhesive-bonded structures in aerospace applications involve aluminum alloys.) New full-curing chromated adhesive primers allow long-time storage (up to 12 months) and handling of parts to be bonded before final curing; they also provide much improved environmental resistance in the bond faying surfaces. Although bonding directly to a steel surface is not generally considered a good adhesives application, bonding to a chromated primer on an abraded steel surface should provide acceptable results for secondary structural applications.

Adhesive bonding of steel has not received as great an emphasis because of its lower strength-to-weight ratio as compared to aluminum or titanium. In general, low-carbon steels are normally sand-blasted or vacu-blasted with aluminum oxide particles to remove lubricants and scale prior to bonding. As indicated above, a good chromated primer may then be applied or if the adhesive system to be used has a primer system of its own, it should be applied. The more common adhesives like the epoxies, phenolics, nitrile-phenolics, etc., normally have primer systems that provide better wetting of the surfaces to be bonded. Considerable evaluation of chemical treatment of steel to prepare the surface for bonding has been performed recently, primarily on AISI 300-series stainless steel, but also on low- and high-carbon steels and high-strength alloy steels. Most of the treatments are satisfactory for bonding where the stress levels are quite low and are pointed primarily at nonstructural applications such as rub strips and fire shields. To bring the confidence level in bonded steel up to the level that prevails for aluminum, an extensive test program would be necessary. Such a program must consider surface treatment and long-term exposures (15-20,000 hours) in high humidity and salt spray and also at intended operational temperatures. The bonded specimens should be exposed to the various environments while under stress to obtain the most meaningful results. This type of testing necessarily is expensive an(requires an extended test schedule.

Adhesive bonding can be considered as a fastening technique for noncritical, structural applications, especially on the newer type ships such a hydrofoils and surface-effect vessels where aluminum structures are more common. Even on steel struc tures, however, adhesive bonding can be used to an advantage over classical welding c mechanical fastening techniques, especially where dissimilar materials are involved. The adhesive provides an excellent barrier between the dissimilar materials to preven galvanic corrosion. Two-part adhesive systems can be used to provide very short cure cycles--as short as 2 minutes--or thermosetting materials can also be used with short applications of heat in the 300°-400° F range for cure. Bonding pressure can be supplied through mechanical clamping devices, simple vacuum bagging techniques, or through clamp-up pressure supplied through the use of bolt-type fasteners that can be removed after the adhesive is cured or be retained in the assembly. For example, the flanges on noncritical duct work or piping can be bonded together when they are installed. Either two-part or thermosetting adhesives can be used. If a thermosetting adhesive is used, heat lamps or an electric blanket or heated pads on mechanical clamps can be used to cure the adhesive. Pressure can be supplied through clamps or fasteners through the flanges. The fasteners can be removed after the adhesive is cured or left in place unless dissimilar materials are involved and then could still be used if some dielectric jacket material were used to separate the dissimilar materials. Bond strengths from 1,000 to 5,000 psi in shear or flatwise tensile can be developed, depending on the specific adhesive materials used and/or the particular means of cure and pressure application.

Generalized statements on adhesive applications cannot be made. Each particular type of structure, material combination, fabrication sequence, etc., requires individual consideration to obtain the optimum physical properties from the materials as well as the most economical cost.

With the exception of the chemical processing requirement for surface preparation of aluminum, most two-part adhesives and the fast-curing thermosetting adhesives can be handled and applied in normal shipyard conditions. Personnel working with the adhesive materials must be trained in their handling, application, and curing. Written instructions alone should not be considered adequate.

Another consideration for adhesive bonding as a fastening technique is the joining of noncritical structural parts rather than welding or using mechanical fasteners. For example, nonstructural bulkheads fabricated as skins with welded or riveted stiffeners could be changed to adhesive-bonded stiffeners or have honeycomb sandwich structure substituted in their place. In addition to bulkheads, modular-type divider panels in crew quarters or office spaces on large ships, partitions in heads, galley cabinets, decorative interior panels, and some types of floor structure all lend themselves to bonded sandwich-type structures. This is especially true in aluminum structure. It is also assumed that the newer surface-effect ships or hydrofoil ships are more weight-critical than some of the larger, steel-hulled ships, and the higher strength-to-weight ratio of bonded sandwich structure could prove advantageous.

Since many of the newer ship designs are powered by gas turbine engines, sonic fatigue of the structure closely adjoining the powerplants can be a problem. Bonded structure is often superior in sonic fatigue resistance compared to conventional structure. Interior paneling, whether decorative in nature or as nonwatertight bulkheads, can be fabricated from bonded sandwich and be both light in weight and low in cost. Also associated with the gas turbine powerplants is consideration of acoustical treatment of both the inlet and exhaust areas to lower the powerplant noise level as much as possible. Bonded acoustical sandwich panels have not become very widely used on commercial jet aircraft in structural areas due to the permeability of adhesives to moisture. Here again, generalized statements about the overall applicability of the bonded structure is usually not feasible from a cost standpoint, since more tooling is normally required than would be needed for welded or riveted structure. An exception would be the application of standard module sizes for bonded partitions, but if some amount of duplicate production is involved, then tooling costs of bonded structure can be amortized. Consideration of each structure must be analyzed on an individual basis.

If studies show definite cost or installation advantages for bonded structures, related studies should be made to determine whether subcontracting the fabrication is more cost effective than equipping existing shipyards to fabricate on site. The decision to make or buy finished honeycomb sandwich structure is one of economics. The size and quantity of parts will determine the physical plant dimension required to fabricate bonded structure. In addition to this, the personnel needed to provide finished parts are of skills not commonly found in shipyards and would have to be trained. In-process controls and the necessary nondestructive test equipment will have to be included in the final analysis. The equipment required for a typical bonding facility for aluminum structures is shown in Appendix D.

IIF. WELDING

The advancements made in the art of welding ships are historical and well documented. It is sufficient to say that advances in welders, automated panel fabricators, and welding equipment and improvement of flame cutting techniques have advanced the state of shipbuilding severalfold. Numerous publications on cost and time savings studies have been conducted to establish the merit and economics of the aforementioned equipment, so further elaboration on these advancements will not be made here.

DISTORTION

One problem causing considerable difficulty and expense to shipbuilders is distortion caused by the welding of thin plate in secondary structure. Some shipbuilders design for heavier plate than structurally needed to reduce distortion problems. This practice may prevent some of the distortion, but its effect of adding additional weight, fabrication, and material costs would seem to open considerations of alternate approaches. Proposals for using riveted points in thin plate have been discussed in the mechanical fastening section of this report and will not be reiterated here.

FRICTION WELDING

Interest has been expressed in using friction-welding techniques to projection-weld studs in aluminum structures. As a result of investigation, the friction-welding techniques are not recommended. The required thrust value to friction weld a 1-inch-diameter bar of 6061 aluminum is approximately 7,000 pounds. This is in addition to the torque parameter also required. Such forces could not be exerted by manual application; however, friction welding has proved to be a satisfactory method of joining dissimilar metals with machine application.

DISSIMILAR METAL JOINTS

Several methods of joining dissimilar metals have been advanced. Generally, the research and development that went into these methods was aimed at satisfying particular needs such as tanks and vessels for corrosive and cryogenic propellants and fluids.

The Space and Information Systems Division of North American Aviation has advanced the field of dissimilar metal joining. Their primary interest is oriented toward large boosters and space vehicles. Their studies indicate that, while entirely feasible and practical, many combinations joined by welding or brazing result in brittle phases that are sensitive to shock and exhibit inferior mechanical properties. Aluminum-to-steel brazed joints are examples of this characteristic.

Table 16 lists a number of dissimilar materials that have been joined by several different techniques and processes. Again, these examples reflect the aerospace application and are included as information only.

STUD WELDING

In addition to fusion welding, the resistance-projection-stud-welding technique affords the contractor a flexible method of systems installation and attachment in steel structure. Projection-stud welding offers the most cost-effective method of installing support bracketry. To attempt to replace this system today with a mechanically fastened joint would not be cost effective.

Advancements in stud-welding techniques are available on a commercial basis. For example, the Nelson Electric Company produces marine cable and pipe-changer supports for a range of pipe and cable sizes as well as the necessary stud welder. Once the stud is welded into position, the cable clamp is threaded on the stud and crimped around the cable. The pipe hanger is welded directly to the bulkhead and is available in various lengths, or a channel stud is welded in position with an adjustable strap and carriage bolt. The pipe hanger uses a rubber insert between clamp and pipe for vibration dampening. Once the pipe is installed, a locking tab is inserted and bent over, retaining the pipe and insert. This system would facilitate adding or subtracting pipes of different sizes.

RECENT DEVELOPMENTS

In recent years, both shipbuilding and aerospace industries have expressed continued interest in processes such as plasma arc, electron beam, and laser applications. The need has been generated by specific product applications such as heavy plate welding for deep submersibles and titanium airframe structure.

TABLE 16

NAA DISSIMILAR-METAL BONDING PROCESSES

Union	Procedure
Aluminum to stainless steel	Dip-braze after tin-coating the stainless steel.
Aluminum to stainless steel	Solder after nickel-plating the aluminum.
Aluminum to stainless steel	Diffusion-bond after interface coating application.
Stainless steel to molybdenum	Vacuum-braze.
Titanium to aluminum	Solder after nickel-plating nickel on titanium and aluminum.
Copper to nickel	Diffusion-bonding after tin soldering.
Aluminum to stainless steel	Dip-braze after silver-plating of stainless steel.
Aluminum to beryllium	Direct dip-braze.
Stainless steel to beryllium	Vacuum-braze.
Columbium to moybdenum	Diffusion-bond honeycomb sandwich
Columbium to stainless steel	Inert-gas braze.
Tungsten to titanium Tungsten to copper Tungsten to stainless steel Tungsten to aluminum Titanium to aluminum	Tungsten-ARC inert-gas braze with aluminum brazing alloy.
Titanium to stainless steel	Resistance-weld-machine braze.
Tungsten to molybdenum	Electron-beam weld
Molybdenum to columbium	Electron-beam weld
Molybdenum to stainless steel	Electron-beam weld
Nickel wire to copper wire	Capacitor-discharge-resistance microweld
Stainless steel to low-alloy steel	Percussion-stud weld.

IIG. MECHANICAL BONDING

Mechanical bonding is a general term that is applied to three separate processes. These being diffusion bonding, deformation bonding, and roll bonding.

The diffusion bonding process essentially takes place in two stages: (1) microscopic plastic deformation results in intimate metal-to-metal contact and (2) diffusion completes the bond and ultimately eliminates the interface. Stage 1 plastic deformation is due to the limited metal-to-metal contact caused by surface roughness and contaminations, as no real surfaces are atomically flat. Applied bonding loads are borne by the "high" point of the surface irregularities. Sustained loading causes continued plastic deformation until the net area of surface contacts approaches the gross bonding area and bonding occurs, stage 2.

Deformation bonding involves gross plastic flow (30% to 60%, depending on alloys and temperatures), which promotes intimate contact and breakup of surface oxides. Plastic flow is accomplished by mechanically rolling the sheets to be bonded. The rollers supply the forces necessary to achieve plastic flow. Deformation bonding is conducted at room temperatures.

As aluminum alloys form tenacious refractory oxides, the usual and most successful methods of static diffusion bonding use a eutectic material between the aluminum sheets. These bonding processes require consideration of surface conditions, alloy compositions, temperature, prior coldwork, crystallographic orientation, post-heat treatments, and joint design.

Roll bonding is similar to diffusion bonding but does not employ a eutectic material as is used in diffusion bonding.

Both diffusion and roll bonding are time, temperature, and pressure controlled. Roll bonding requires higher pressures and temperatures and a shorter time for processing than the diffusion process.

At cyrogenic temperatures (-423° F), the bond becomes stronger due to shrinkage, but when raised to elevated temperatures (960° F) and quenched, the irregularities holding metals together shear, thereby reducing the shear properties of the overall joint.

For shipyard applications, these bonding processes would not represent a cost-effective approach to dissimilar metal-to-metal joints. This is partly due to the limited applications available, limited quantities produced, and the cost of equipment necessary to complete the processes.

III. CONCLUSIONS AND RECOMMENDATIONS

1. Mechanical fastener systems have had and will have continued application in ship construction. Their major areas of application have been in secondary structure and system attachments. The modern fastener systems available today have demonstrated their performance in structural, fatigue-critical, and fuel-tight joints and other special applications. The merits of some of the newer fastener systems

in shipbuilding applications remain to be demonstrated. Families of high-strength, corrosion-resistant, fatigue-rated fasteners are available for implementation into ship designs as well as for special applications such as those required for use with honeycomb sandwich panels.

Conventional rivets can be employed in some areas to replace welding of thin sheet and plate. Flush-head rivets can be used to attach thin-sheet aluminum panels to stiffeners and stringers and can be installed in drag-critical areas where flushness control is mandatory.

The welding of thin plate (less than 3/8 inch) creates distortion problems that can be reduced by conventional riveting, which is also one of the most cost-effective methods of joining, where necessary. Rivets are easily removed and replaced with simple pneumatic drilling and riveting equipment.

2. Explosion-bonded metals have much to offer in the design and construction of ships, particularly those with mixed aluminum/steel structure where galvanic incompatabilities occur.

   Bimetallic and trimetallic materials can be formed or machined into various shapes and configurations and offer good corrosion resistance, as shown by 5 years of continuous sea-water tests. Physical-property tests and structural testing have verified the integrity of explosion-bonded joints. Tests conducted by the Naval Ship Research and Development Center led to their recommending the use of these materials in the construction of naval combatant vessels.

   Comparative installation tests conducted by Hunter's Point Naval Ship yard and private shipbuilding yards have shown the explosion-bonded materials to be a cost-effective method of making dissimilar metal joints (superstructure to deck).

3. The current method of systems installation in steel structure is projection stud welding. Currently, there is not a more cost-effective method of attaching equipment supports. Projection stud welding equipment and related bracketry are available commercially.

   Stud welders for welding aluminum studs are commercially available for studs up to 1/2-inch diameter. Due to weight considerations of support equipment and the lower yield strengths of aluminum, the use of this type of equipment is somewhat limited. An alternate process to aluminum stud welding (as recommended by Nickum and Spaulding of Seattle and as presented in the explosive bonding section of this report) uses the bimetallic strip welded with the aluminum to aluminum and the steel stud projection welded to the steel side of the bimetallic strip. While more expensive, the reliability of the bimetallic-stud weld joint should reduce later repair or replacement costs.

   Some questions arise concerning the effects of localized degradation in the structure caused by stud welding. The effects of the primer (often applied before welding) and other impurities as well as residual stresses in and adjacent to the weld area are causes for concern. The latter will become increasingly pertinent as operating stress levels approach design limits.

4. Adhesive bonding, as applied in aircraft, has been limited primarily to aluminum and titanium, due to weight considerations. Aircraft contain a wide range of

bonded material applications, ranging from control surfaces to galleys and decorative panels. These applications do not include primary structure nor would they be recommended for primary structure in shipbuilding. However, adhesive bonding can be applied to some nonstructural applications. The areas of potential application include interior bulkheads, kitchen and toilet facilities, low-pressure piping and ducting, acoustic insulation for sonic fatigue, or areas of high-frequency vibration.

Adhesive bonding and sandwich panel construction lend themselves to modular construction and have been used as deckhouses on patrol craft produced by foreign nations. Adhesive-bonded sandwich panels and construction offer a high strength-to-weight ratio for numerous applications.

IV. RECOMMENDED AREAS FOR FURTHER STUDY

It is anticipated that those interested in ideas or concepts presented in this report will conduct the necessary qualification tests before incorporating them into their design and construction efforts. The following are delineated as areas for further study:

1. Compile a fastener matrix and preferred fastener list based on fastener types approved for use in ship design. Develop design allowables and add to the list and matrix, as required, to accommodate new applications. Take care to avoid excessive fastener proliferation.

2. Investigate the use of conventional riveting for attachment of thin sheet in secondary structure and application of high-strength fasteners to primary structure.

3. Continue to develop the full potential of the explosive-bonded bimetallic and trimetallic sheet. This effort should include tube cladding techniques for rudder stock and stern-tube installations, bulkhead penetrations, pipe flange connections for dissimilar pipes, and deck pads for equipment mounts.

4. Investigate cost-effective approaches to installing mixed materials for pipe systems that would satisfy necessary regulations.

5. Study potential applications for the electromagnetic riveting process, particularly in areas where large rivets may replace more expensive fasteners. The portability of the equipment and quality of EMR-installed rivets make large rivets more attractive than they have been in the past. The process is usually cold but can be supplemented by resistance heating of the rivet.

6. Consider possible applications for items in Appendix E such as in-place tube welder, laser alignment, and new bulkhead penetrations.

7. The logical step to follow a study of this type is a developmental activity encompassing the design and fabrication of selected joint hardware to assess and validate the comparative advantages of different joining methods. For example, welded versus mechanically fastened joints for a given application should be compared, each designed for use with its unique joining process.

8. Similarly, material trades in selected applications can be evaluated with the design of a selected joint for steel, aluminum, and combinations using explosive-bonded strips as the interface. Again, each should be designed to take advantage of the properties of the particular materials being compared.

9. Following the successful validation of some of the alternative fastening methods in test hardware, selected ships (or portions thereof) undergoing modification or those of a new design should be selected for incorporation of these concepts.

   In-service experience can be monitored to validate the projected performance of the new designs and fabrication methods.

10. Based on the feedback from the foregoing (items 7 through 9) an integration program, including the incorporation of alternative joining methods into regulatory documents, should be pursued.

11. A study of current maritime regulations and specifications and their relation to bonded structure should be made to determine where bonded nonstructural components can be applied.

APPENDICES

The topics listed in the appendices, while not related directly to the main scope of the report, have been included and commented upon as information that may be of interest to those functioning in these fields.

Piping systems, which include bilge, ballast, and weather deck drains, as well as water, oil, and air systems, involve high costs for materials, initial installation, and subsequent maintenance. The ideas and suggestions are presented for consideration, and the cost effectiveness of these systems over a period of operating time remains to be established.

The adhesive-bonding equipment shown, represents typical equipment found in the aircraft industry. It is not necessarily optimum for shipbuilding applications. The economics of purchasing completed parts should be considered before making a capital expenditure.

The in-place tube welder described and shown in Appendix E was developed to weld high-pressure stainless steel and titanium tubing in limited-access areas where conventional welding techniques could not be applied. High-quality welds are obtainable on a production basis.

Electrical systems encountered in shipbuilding range from electric lights to radar installations. Combatant vessels are equipped with a variety of complex electronic systems outside of the regular ship electrical facilities. Hookup of these various systems often requires multiple watertight bulkhead penetrations as well as connections between components in close proxity to each other. Compartments and passageways are often cramped and crowded, presenting additional problems.

The use of Multi-Cable Transit units for tubing, pipe, and wire connections eliminates stuffing-tube arrangements and the necessity of potting and sealing to maintain the watertight integrity of each compartment. These processes add to the cost of ships, are time consuming to install, and make modification of systems difficult.

Flat cable affords the fabricator the opportunity for additional flexibility when installing instrumentation systems, especially those involving multiple connections between components. Flat cables can be used efficiently in limited-access areas such as passageways and along framing.

Laser optics, even though remote from the subject of fastening or outfitting, remain pertinent nonetheless. Laser optics have found increasing use each year. Critical alignment of major jigs and components have been possible with laser equipment. The application of laser alignment techniques to shipbuilding is evident when you consider its being applied to alignment of stern-tube boring equipment or to placement of deck machinery or keel and side plates. It is, therefore, included in the appendices of this report for information as to the current state of the art and the joint sharing of this technology between the different industries.

APPENDIX A

PIPING SYSTEMS

Piping systems currently installed on commercial and military shipping use steel pipes, both Schedule 40 and 80, and steel pumps with bronze bushings and fittings. Large gate and globe valves can become expensive without considering compatible systems made for use with aluminum (Table 17).

Current design practices call for waste washers to be installed when it is necessary for pipes to penetrate bulkheads for overboard discharges and pump connections. This practice causes higher costs for initial construction and subsequent operation in the electrolytic environment of seawater.

Regulations currently restrict the use of any nonsteel/iron pipe and pump systems in such areas as fire protection and control. Extensive tests are now being conducted by the Naval Ship Systems Command, Annapolis, Maryland, to verify new materials such as the intumescent coatings on glass-reinforced plastic piping. While these hold some promise for future use, the current regulations are explicit.

There are possibilities of using a mixed tubing materials system such as plastics for bilges, ballast, and weather deck drains; aluminum and/or stainless steel for potable water, compressed air, and engine oil; and alloy steel and 90-10 copper nickel for fire-control systems. The merits of these systems would have to be determined from cost-effectiveness and reliability standpoints.

While these systems may save weight and installation costs, the fluid prime mover will be predominantly the steel pump due to availability and cost considerations. Again, galvanic incompatibilities can occur, especially in nonferrous ships. Since the pump can be isolated by the same method as the deck machinery, the problem lies in connecting the pump systems to dissimilar pipe systems.

TABLE 17

COST COMPARISON FOR ALUMINUM ALLOY AND STAINLESS STEEL VALVES[a]

Size IPS (in.)	Pressure service (lbs)	Type	304, 316, and 25 nickel-20 chrome stainless steel ($/each)	356-T6 aluminum alloy ($/each)
3 flanged	150	Gate	263.00	268.00
4 flanged	150	Gate	376.00	389.00
6 flanged	150	Gate	610.00	622.00
8 flanged	150	Gate	—	809.00
3 flanged	150	Globe	407.00	273.00
4 flanged	150	Globe	478.00	512.00
6 flanged	150	Globe	809.00	891.00

[a]Information taken from SSC report 281, p. 75.

TABLE 18

MATERIAL COSTS—BILGE SYSTEM IN BALLAST TANKS (U.S. DOLLARS)[a]

Item	Aluminum	Black steel	Galvanized steel	Fiberglass-reinforced plastic	PVC lined
Specification	6061-T6	A53	A53	Bondstrand or equal	Resistoflex
Thickness	Schedule 40	Schedule 80	Schedule 80	—	—
2440 feet of 4-inch pipe	$5,967	$5,630	$6,750	$10,248	$16,104
Aluminum bulkhead penetration (50)	5,967	5,630	6,750	10,248	—
Aluminum spools (40)	—	1,800	1,800	—	—
Flanges (70)	1,376	506	760	539	Included
Ells (150)	3,420	1,014	1,402	2,520	8,295
Couplings (36)	—	—	—	194	—
Valves (10)	←	Not included			→
Cathodic protection	—	1,720	1,720	—	—
Total cost	$10,763	$10,670	$12,432	$13,681	$24,399

[a]Information taken from SSC publication 218, p. 78.

Several suggested methods of pipe-to-pump attachments, bulkhead feedthroughs, and pipe tapoffs fabricated from bimetallic stock are shown in Figure 19.

While an interested party would have to develop the necessary rupture and fatigue data, the concepts are practical and offer an attractive cost-savings potential. This process could eliminate the costs of waste washers and gaskets and minimize related maintenance, corrosion, and rust allowances made for steel pipes. Hence, thinner-gage pipes could be used. Limited use of the glass-reinforced plastic and PVC pipe has been recommended by the Coast Guard, predominantly in bilge and ballast systems. Cost analyses from SSC Publication 218, *Design Considerations for Aluminum Hull Structure*, are shown in Tables 18 and 19 for bilge and ballast systems.

Nondestructive test (NDT) procedures are available commercially for in-process controls of explosion-bonded materials. These included X-ray technique and dye-penetrant inspection of the bond join and weld bead.

APPENDIX B

WATER SYSTEMS

Two water systems are in common use for ship operation. These are the fresh potable water system for sanitary engine cooling and consumption purposes and a saltwater system for ballast. The potable water is from two primary sources: (1) on-board desalinization and (2) shore supplied. The salt system is ocean supplied.

For steel structure, there is no inherent problem with either water system other than rust. Black schedule 80 steel pipe is used predominantly. However, with aluminum structure, different problems arise--some chemical and some regulatory. If aluminum pipe systems are used for both freshwater and saltwater systems, corrosion problems will occur due to the various differences in fresh water found in different ports. Minerals and free ions can contribute to the corrosion of the aluminum freshwater system.

The installation of aluminum piping in aluminum structure would simplify construction and eliminate the necessity of galvanic isolation techniques that would be required for a steel-pipe system. The aluminum pipe would be lighter than steel due to differences in density and would not have the heavy-duty (schedule 80) wall-thickness requirement as does steel pipe.

Fiberglass-reinforced plastic, on one hand, offers several advantages. Cost studies indicate the GRP system to be the least expensive of eight systems studied (see Table 19), would be chemically inert to most substances, and would not produce galvanic incompatibilities. "Sailor proofing" GRP pipe would be more difficult. Unlike heavy-duty steel pipe, the GRP could not be used as a "chinning bar." Allowances for reinforcing and protecting piping in passageways and overheads must be considered.

Difficulties encountered in a GRP system include fabrication because GRP is not bendable. Bulkhead penetration techniques would have to be developed, and regulatory agencies do not consider GRP with intumescent coatings to afford adequate fire protection.

TABLE 19

MATERIAL COST—BALLAST SYSTEM (U.S. DOLLARS)[a]

Item	Material							
	Aluminum	Black steel	Galvanized steel	Fiberglass reinforced plastic	Steel pipe PVC coated and lined	Stainless steel	Stainless steel	90-10 copper nickel
Specification	6061-T6	A53	A53	—		AISI 304	AISI 304	MIL-T-16420
Schedule	40	80	80	—		10	40	Type 200
Type	Seamless	Butt weld	Butt weld	Bondstrand or equal	Resisto-flex PP	Seamless	Seamless	Seamless
400 feet of 8 inch pipe	2,940	2,962	3,554	3,180	7,900	4,744	12,732	8,372
2000 feet of 12 inch IPS pipe	31,585	22,893	27,442	29,000	59,500	41,740	124,600	108,000
Bulkhead penetration connections	31,585	22,893	27,442	29,000	59,500	41,740	124,600	108,000
8 inch aluminum spool (waster piece)	—	3,000	3,000	—		—	—	—
12 inch aluminum spool (water piece)	—	12,600	12,600	—		—	—	Complete information not available
8 inch flanges (92)	4,048	3,220	3,551	1,509	Included in pipe	5,300	5,300	
12 inch flanges (38)	5,168	2,280	2,557	1,638	Included in pipe	6,250	6,250	
8 inch valve (23)	—	—	—	—	—	—	—	
12 inch valve (1)	—	—	—	—	—	—	—	
8 inch ells (37)	3,330	1,338	1,769	2,566	6,384	2,295	4,101	
12 inch ells (82)	21,320	8,282	10,783	8,930	28,700	22,796	35,424	
12 inch tees (20)	20,320	3,380	4,280	7,248	9,200	15,000	18,180	
Cathodic protection	—	3,400	3,400	—		—	—	
8 inch couplings (4)	—	—	—	58	—	—	—	
12 inch couplings (18)	—	—	—	445	—	—	—	
Total cost	88,711	63,405	72,936	54,574	111,684	98,125	207,587	

[a]Reprinted from SSC publications 218, p. 77.

Stainless steel pipe systems have been included in smaller craft such as patrol boats and hydrofoils. These systems are costly when compared to a similar system manufactured from black steel or GRP. However, stainless steel offers good corrosion resistance, is galvanically compatible with steel and aluminum structures, and is formable. In small diameters, welding or mechanical couplings can be used effectively.

The cost analysis for several ballast systems in a ship similar to the 632-foot M.V. Challenger are shown in Tables 17, 18, 19.

For economic and regulatory reasons, future ship construction will probably use an integrated pipe system composed of different materials. The cost involved with a mixed system must be determined to decide at what point there is an economic tradeoff.

APPENDIX C

OIL AND AIR SYSTEMS

Oil systems aboard ship can be lumped into three general categories: fuel oil for propulsion systems, lube oil for deck and propulsion machinery, and bulk cargo in the case of petroleum tankers.

Current regulations explicitly require fuel and engine lube lines to be manufactured from black steel due to the nonconductive characteristics of fuel oil and fire prevention requirements. The introduction of aluminum or plastic pipe should be considered for future use. As new materials and design allowables become available, regulatory agencies should consider their implementation after appropriate testing has been completed. The installation of black-steel fuel lines in aluminum structure will create galvanic corrosion problems if isolation procedures are not adequate.

The installation of stainless steel fuel and lubricating oil systems would eliminate the need for isolation protection. Bulkhead penetrations would have to be incorporated to maintain watertight compartments. These penetrations could be either mechanical or welded connections. Aircraft-type AN fittings and the in-place tube welder would facilitate pipe system installation and connection for modular construction and jumboizing. Design and fabrication techniques used in aircraft use modular construction and systems installation for preinstallation of many of the electrical systems, hydraulic tubing, and actuator cables.

Bulk cargo transfer to shore facilities or other ships will require an extensive pipe-and-pump network within a tanker structure. Cost considerations will be a major factor in deciding what type of system will be used. Safety experience gained with mobile aluminum truck tankers should make an all-aluminum pipe system a major contender for ship service, due to their impressive safety record.

Compressed-air systems involve two major areas of ship operation. They are a 400-psi engine-start system and a 100-psi ships-service system. Current design practices call for high-strength steel for each system. For an aluminum ship, a schedule 40 aluminum low-pressure system has been previously recommended. High-pressure stainless steel could be implemented for engine-start, eliminating galvanic couple problems associated with penetrations of steel pipe through aluminum bulkheads. This, used in

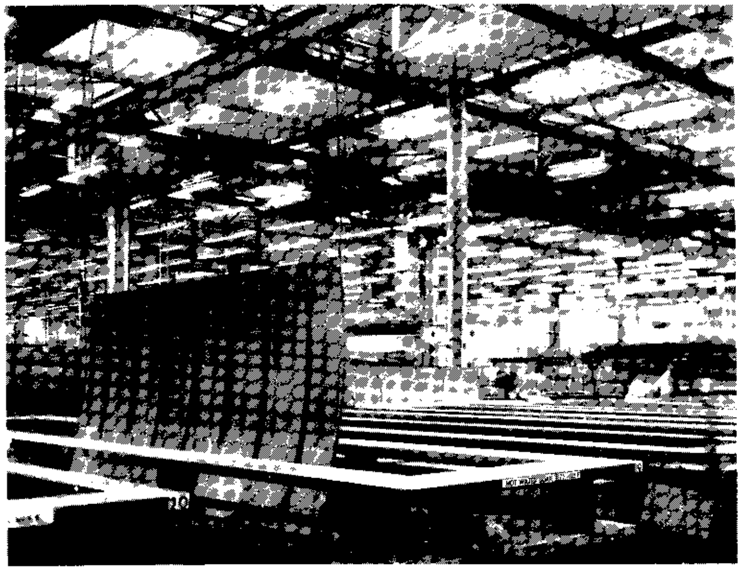


FIG. 20 - TYPICAL CHEMICAL PROCESSING LINE

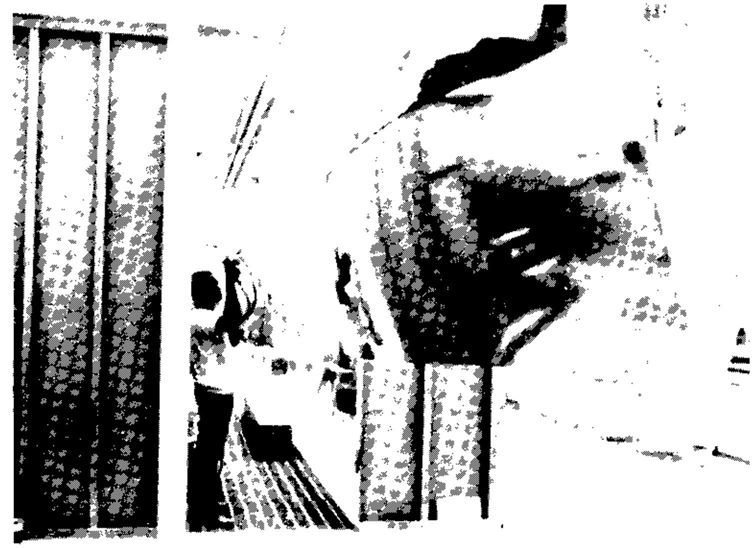


FIG. 21 - TYPICAL SPRAY BOOTH FOR APPLYING ADHESIVE PRIMER

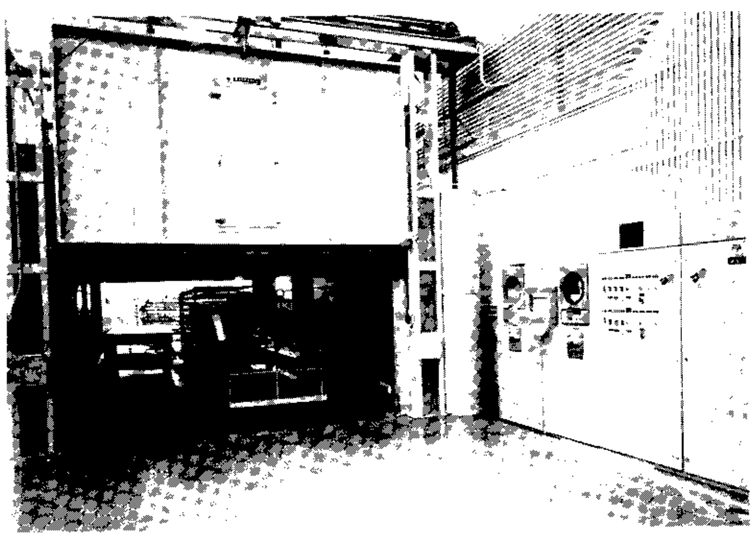


FIG. 22 - TYPICAL OVEN FOR PROCURING ADHESIVE PRIMER

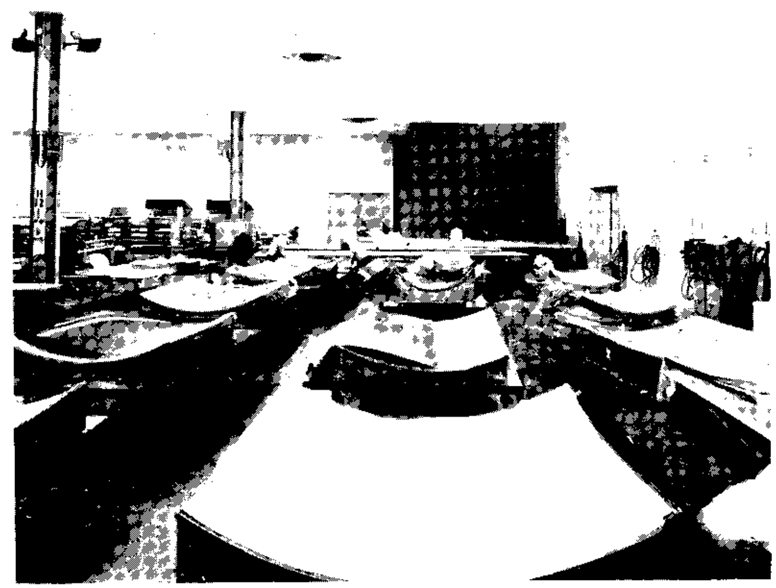


FIG. 23 - CLEAN ROOM FOR ASSEMBLY OF PARTS TO BE BONDED

conjunction with pressure reducers and regulators, could be reduced to a single high-pressure system, with the regulators and reducers supplying the low-pressure ships service.

Should an inert-gas fire-control system be adopted, aluminum tubing would facilitate systems installation in aluminum structure.

Cost effectiveness of incorporating various systems into ship construction should be investigated. A particular system, whether single or mixed, will have to meet regulatory approval, and therefore any hard-and-fast recommendations cannot be made without knowledge of ship's purpose, current state-of-the-art information, regulatory revisions, allowances or standards, system type (oil, water, fuel, etc.,), pump pressures, safety allowables, etc.

APPENDIX D

BONDING FACILITIES EQUIPMENT

A typical bonding facility for aluminum structures would require the following:

a) A chemical processing line with the following tanks (Figure 20):

1) Trichloroethylene degreasing tank

2) Alkaline cleaning tank

3) Warm water rinse tank, either immersion or spray

4) Sodium dichromate-sulfuric acid deoxidizer tank

5) Cold water spray rinse tank

6) Dryer tank

The sizes of the above tanks would have to be determined by the maximum part sizes to be run through the surface preparation process.

b) Closely adjacent to the chemical processing line should be a clean room. Operations to be included in the clean room and required special facilities are:

1) Spray booths and spray application equipment for applying adhesive primers (Figure 21).

2) Ovens to precure the adhesive primer--the sizes of both the spray booths and the precure ovens would be determined by the maximum size of parts to be processed (Figure 22).

3) Assembly area with adequate work space large enough to accommodate the tooling, parts, and associated assembly operations (Figure 23).

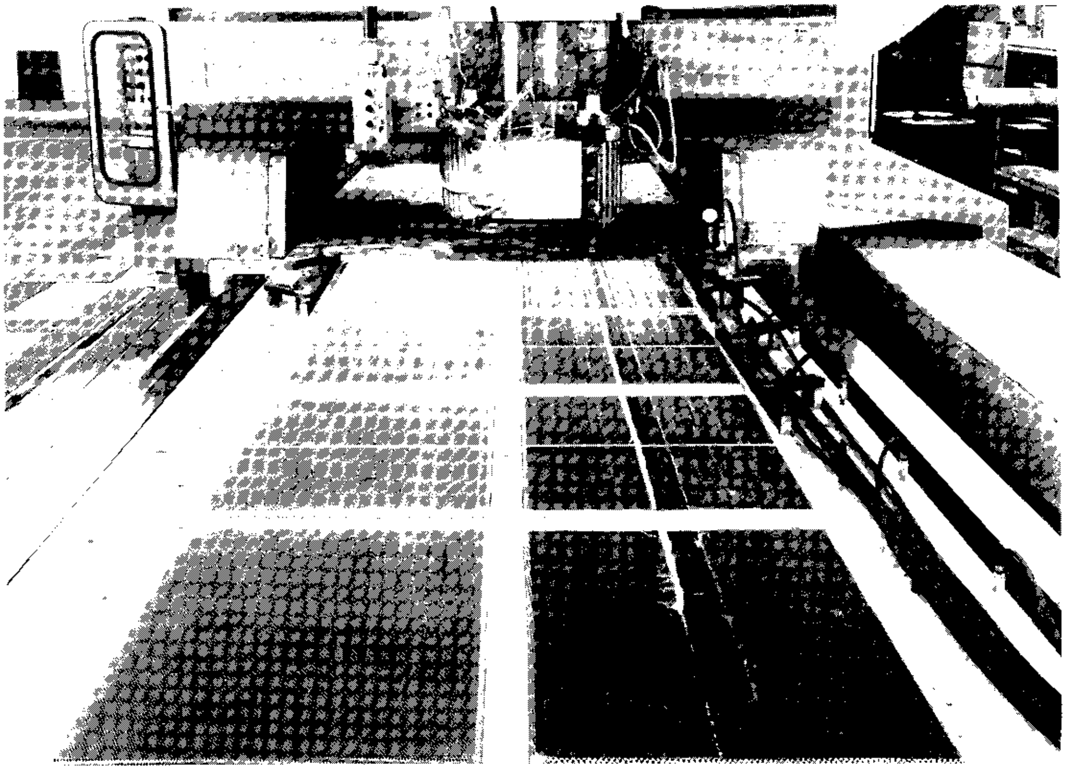


FIG. 24 - ALUMINUM HONEYCOMB CORE MACHINING EQUIPMENT

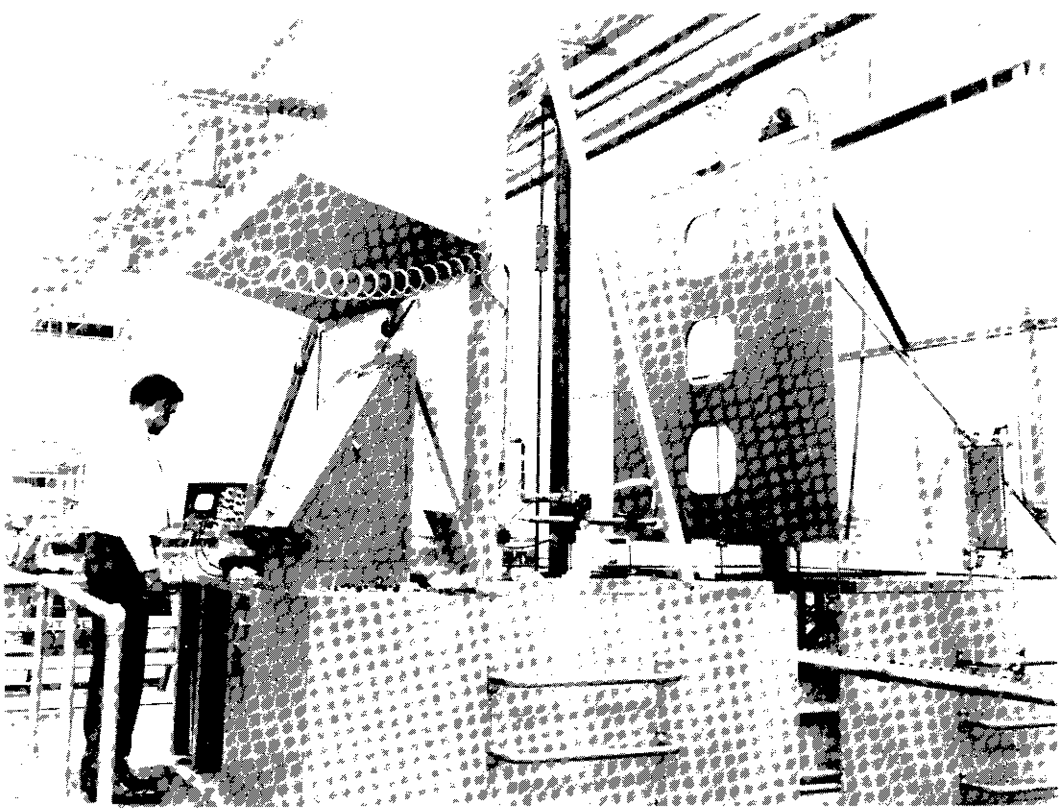


FIG.25 - ULTRASONIC NONDESTRUCTIVE TESTING EQUIPMENT

The clean room should have filtered incoming air and should be pressurized from 1/2 to 1 psi, in relation to adjacent areas, to be sure all air movement is outward from the clean-room area. The primary purpose of the clean room is to provide a segregated area for the special handling required for the "clean" part during the priming, precuring, and assembly operation.

c) A curing facility to supply heat and pressure for the final cure of the adhesive is required. The most common curing facility now in use is an autoclave. Here again, the size of the autoclave is determined by the maximum size of the largest bonded assembly and also the total volume of bonded parts. The autoclave requires area and handling equipment for staging and handling the bonding tools in and out. There is considerable experience in the design and fabrication of autoclaves for adhesive bonding in the aerospace industry.

As indicated above, the total bonding facility would be sized in relation to the maximum size of parts to be bonded and the volume of parts to be fabricated. In addition, consideration should be given to the sheet-metal and machining equipment for honeycomb core (Figure 24), machining equipment required to fabricate the detail parts required for the bonded assemblies, and the required nondestructive testing equipment (Figure 25) for inspection of assemblies in process and after the final bonding operation. In-process controls are also required to maintain bond quality and reliability and reinforce confidence level.

APPENDIX E

IN-PLACE TUBE WELDING

The in-place tube welder (Figure 26) was developed for in-place production welding of stainless steel and titanium high-pressure hydraulic systems and is a commercially available product.

Alignment of the tubing and fitup of the abutting ends at the weld joints are major factors in consistently producing an acceptable weld joint. Auxiliary bridge tools are used to support the tubing during the weld operation and are shown in Figure 27. The space envelope dimensions required for a typical head and auxiliary bridge tool are shown in Figures 28 and 29. Depending upon the application, various types of weld joint configurations have been used successfully. Several of the more popular and practical joints are shown in Figure 30.

For those heavy-wall tube joining applications requiring the addition of filler wire, suitable miniature crawler-type weld heads are available. Due to the additional mechanisms to handle wire feed, these heads are substantially larger than the nonfiller wire adding-type head. A representative head available at this time is shown in Figure 31, with its space requirements in Figure 32.

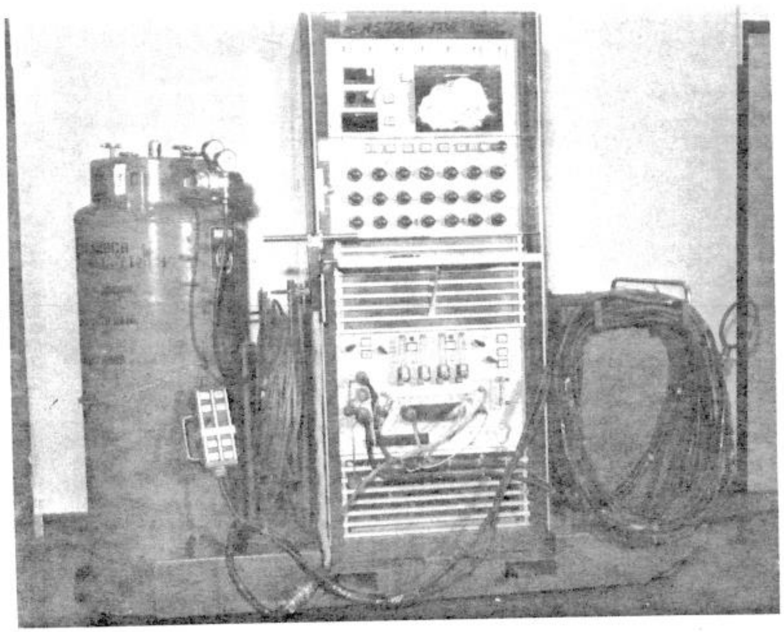


FIG.26 - TYPICAL COMMERCIAL INPLACE GTA TUBE WELDING POWER SUPPLY/PROGRAMMER AND WELD HEAD

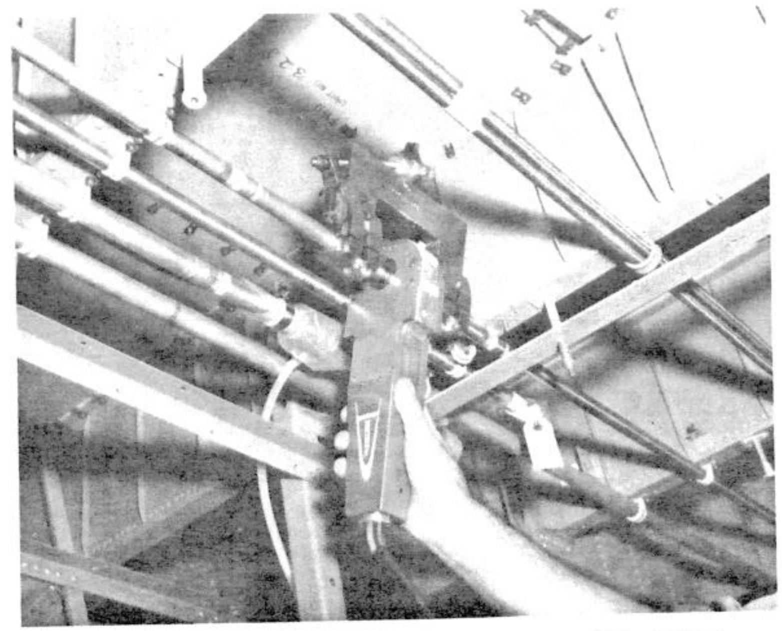


FIG.27 - TYPICAL COMMERCIAL INPLACE GTA TUBE WELDING HEAD WITH AUXILIARY BRIDGE TOOL

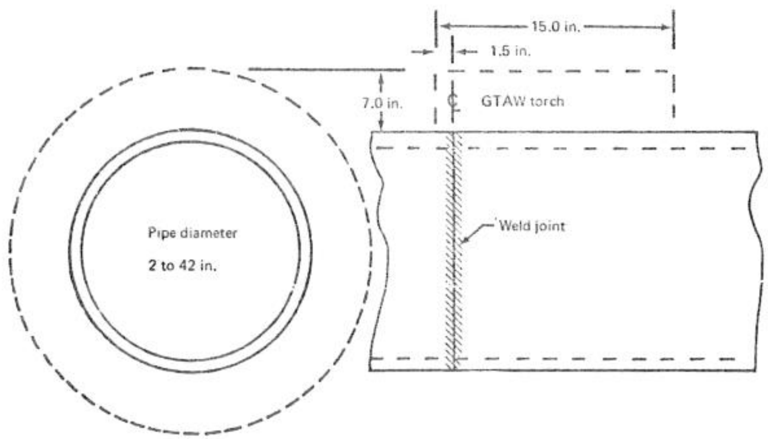


FIG.28 - CLEARANCE ENVELOPE FOR TYPICAL GTA PIPE WELDING CRAWLER HEAD

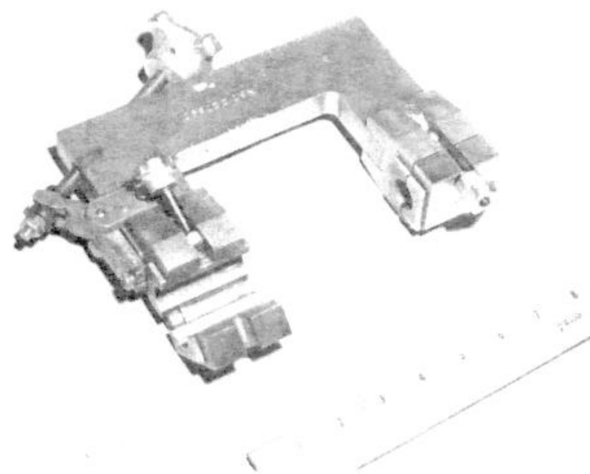


FIG.29 - AUXILIARY BRIDGE TOOL

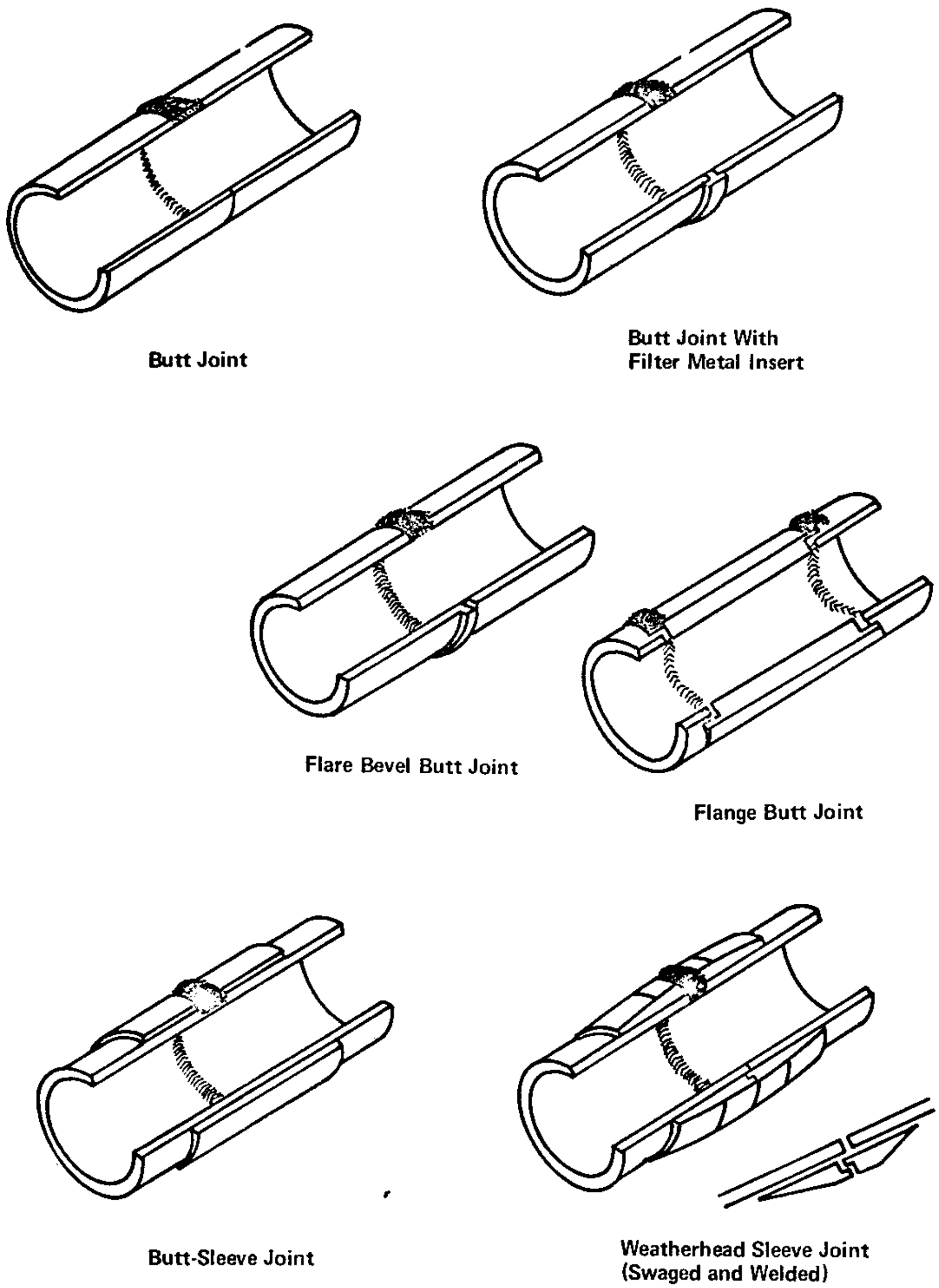


FIGURE 30

TUBING WELD JOINT CONFIGURATIONS
FOR GTA TUBE WELDER

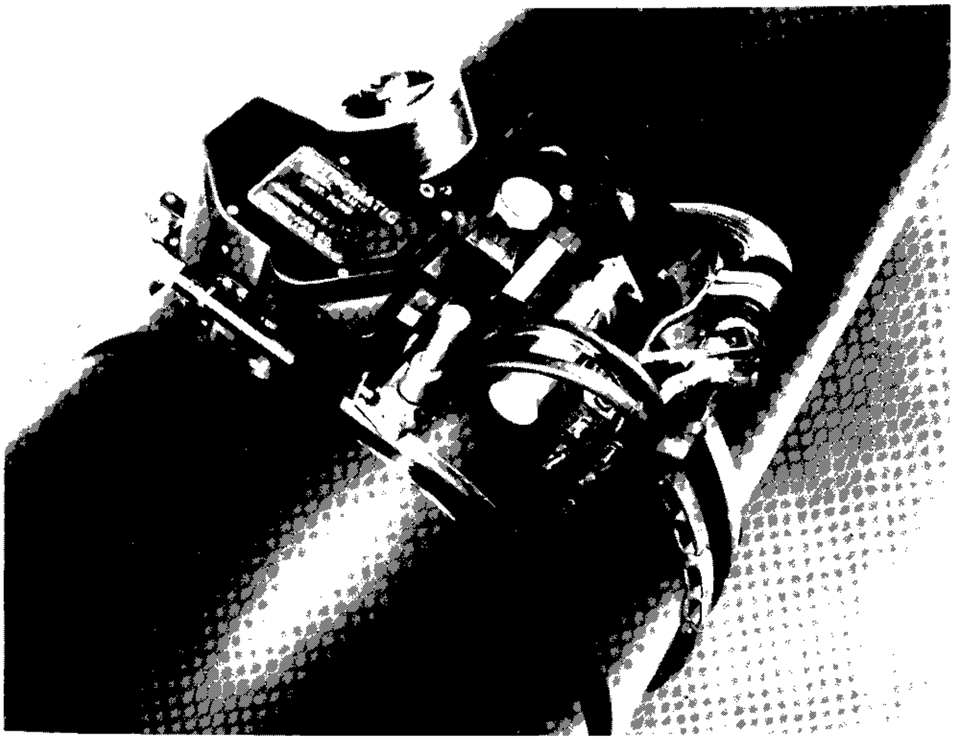


FIG.31 - TYPICAL COMMERCIAL MINIATURE GTA TUBE WELDING CRAWLER UNIT WITH AVC, TORCH OSCILLATION, AND WIRE FEEDER

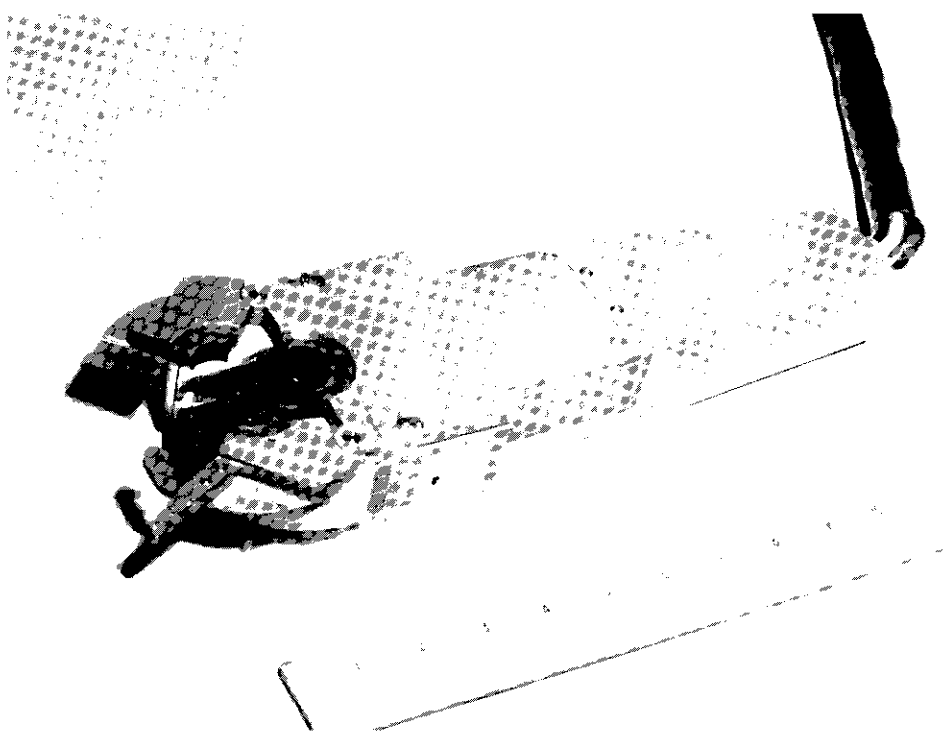


FIG.32 - TYPICAL GTA TUBE WELDING HEAD

APPENDIX F

ELECTRICAL SYSTEMS AND THEIR ATTACHMENTS

The installation of electrical systems and connections between components has presented numerous problems to the design and fabrication contractor of both steel and aluminum ships.

Regulations require many of the connecting compartments to be isolated from each other in the event of fire, flooding, or other contamination. Since control systems necessary for ship operation cannot be installed externally to the structure, it is required that bulkhead penetrations into adjoining compartments maintain the integrity of each compartment, should an emergency situation occur.

The penetration of steel piping through a steel structure, or aluminum piping through an aluminum structure, afford the opportunity for contaminants to enter adjoining compartments. This condition can be eliminated by fillet welding the pipe and bulkhead at the point of penetration. Suggestions and recommendations for dissimilar metal penetration of steel pipe through aluminum bulkheads are contained in the explosive-bonding section of this report and will not be elaborated upon here.

Electrical systems present a more difficult problem in that most of the wiring and cables are armored. Even when conduits are used, a stuffing tube arrangement must be fabricated to ensure each compartment's integrity. This process creates additional outfitting difficulties and higher costs, both in material and labor, and is not conducive to visual inspection or postservice modifications.

MULTI-CABLE TRANSIT

A commercial product, Multi-Cable Transit (MCT) bulkhead penetration, such as that marketed in recent years by Nelson Electric, offers the designer and fabricator a new method of maintaining compartment integrity when installing control systems (Figure 33).

Multi-Cable Transit bulkhead penetrations have frames made from aluminum or steel, measure approximately 2-3/8 inches in depth, vary from 5-1/4 to 5-1/2 inches in width, and have lengths of 4-3/4 to 9-3/8 inches, depending on model. The MCT uses cable modules made from Tecron, a DuPont neoprene compound that expands when heated.

The installation procedure is relatively simple. An oblong hole is cut in the bulkhead to accept the MCT frame which is then welded into position (Figure 34). Electrical cables or tubing are then run to their respective positions where they can be connected for a system check. The predrilled Tecron block, conforming to the respective cable dimensions, is installed with a slight coating of lubricant on the block. Armored cables have G.E.'s RTV-102 or 106 sealer applied in the grooves of each block to seal the space between the armor and cable sheath. A compression plate is installed, along with the end packing to seal against fire, water, and air leaks. MCT will accommodate cables or pipe ranging in outside diameter from 5/32-inch to 3-3/4 inches. These units may be purchased in gang or group mountings. Additional cables or tubing may be installed by adding the necessary insert blocks. Cables may be removed in the reverse manner. An added advantage of MCT installation is that fabricated

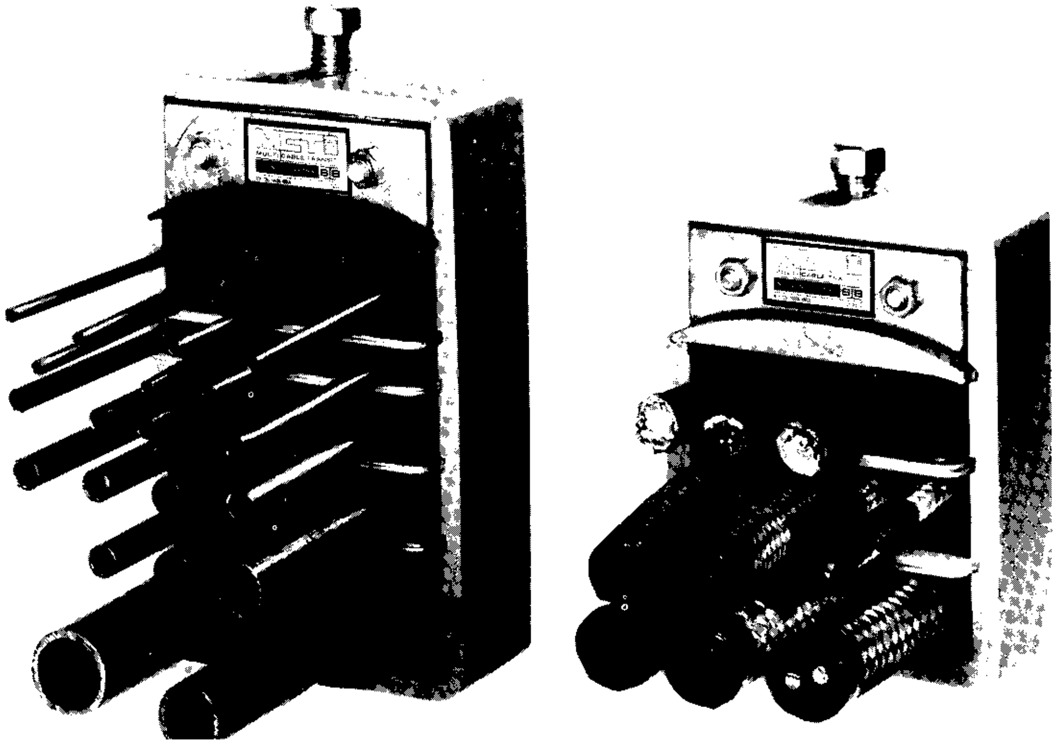


FIG. 33 - TYPICAL MCT CABLE & TUBE ASSEMBLIES

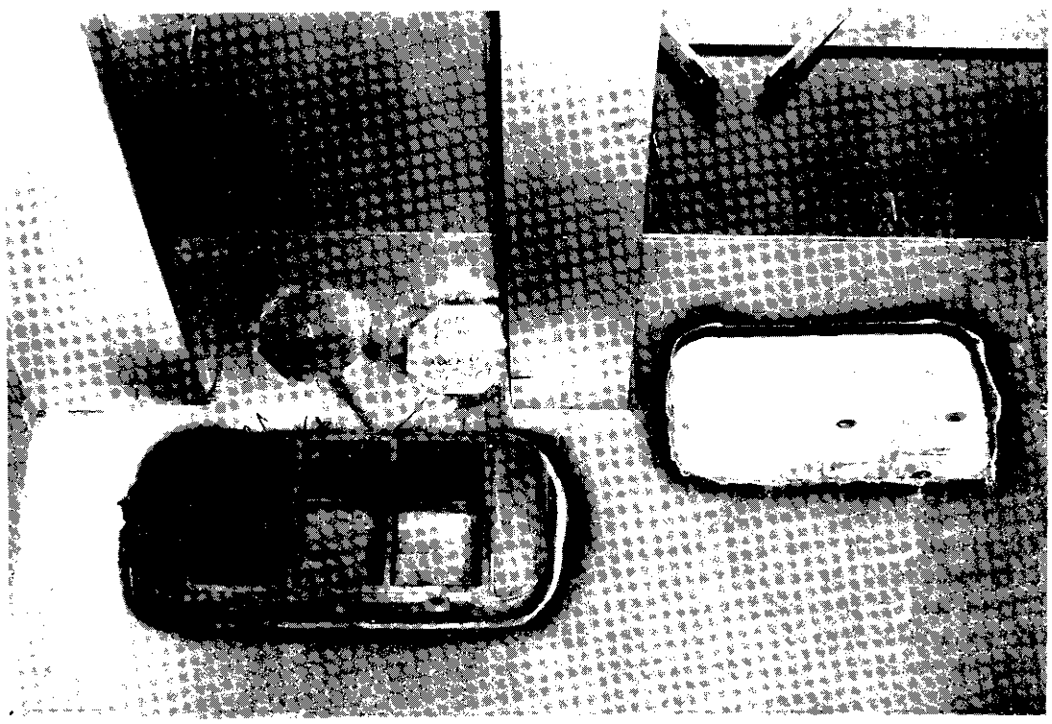


FIG. 34 - INSTALLATION OF MULTICABLE TRANSIT FRAME

cabling with connectors attached can be passed through the MCT. For rf and high-frequency applications where signal leakage and grounding are important, MCTs with conductive rubber blocks are available.

Fire tests conducted at the Lockheed Electronics Environmental Test Laboratory demonstrated that MCT could withstand 1715° F for 1-1/2 hours, when attached to a 1/4-inch steel test panel. The rear side of the MCT and cables remained relatively intact during the test. MCT inserts are not subject to attack from liquid chemicals or hydrocarbons. MCT is reputed to comply with Mil-P-16685C, U. S. Military Standard 167, Mil-S-901C, Mil-Std-108D, ASTM-E119-61, and the JCSLS fire-test standard.

Cost comparisons indicate the MCT units will save 50% of the installation costs over the cable-tray or conduit-and-sealing-compound methods of cable installation.

FLAT CABLE

Scotchflex, a family of flat cable produced by the 3M Company, currently is under study for possible introduction into commercial aircraft electrical systems connections.

The use of flat cable would provide additional advantages in ship outfitting and systems installations.

Flat cable can be installed in space-critical areas such as passageways, overheads, and bulkheads (Figure 35). This type cable is designed for hookup of connecting components, especially those using printed circuit boards in their assembly.

Transitions from flat cable to conventional round-wire connectors can be accomplished by any of several methods such as splices or junction boxes (Figures 36 and 37). Flat cable offers a decisive weight-savings advantage as well as ease of fabrication and installation. It can be prefabricated for modular construction or systems installation.

With more emphasis being placed on preassembly and modularization, implementation of the flat cable concept would be beneficial.

APPENDIX G

OPTICAL LASER APPLICATIONS

The Manufacturing Research and Development Department of Boeing is currently involved with developing a manual for using optical lasers in shipbuilding. This program is being conducted in conjunction with Todd Shipyards Corporation of Seattle.

The objective of this research program is to apply alignment state-of-the-art knowledge and experience to shipbuilding with special emphasis on hull erection and machinery installation. Although accuracy is the main criterion for using lasers in aircraft alignment, it is not the only criterion. There are more advantages that are not readily seen. A few of them are:

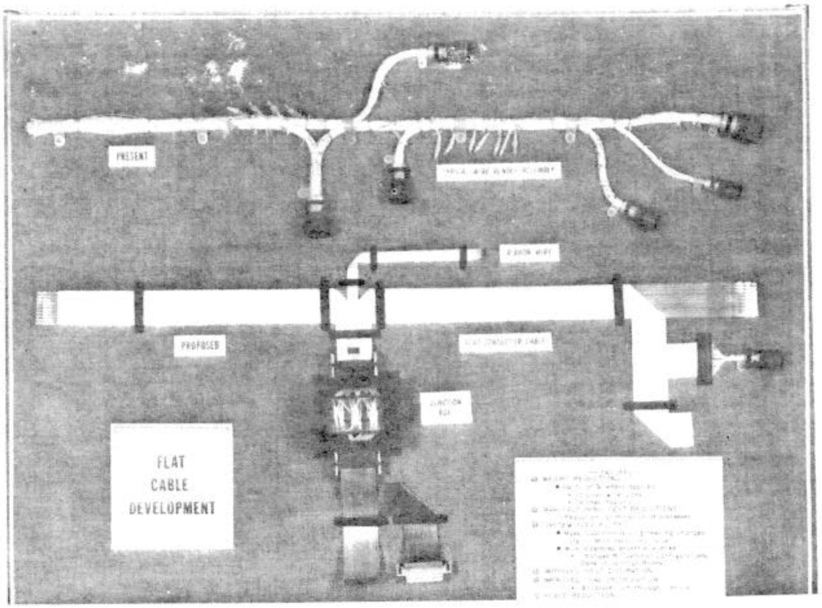


FIG. 35 - FLAT CABLE ASSEMBLY COMPARED TO ROUND WIRE BUNDLE

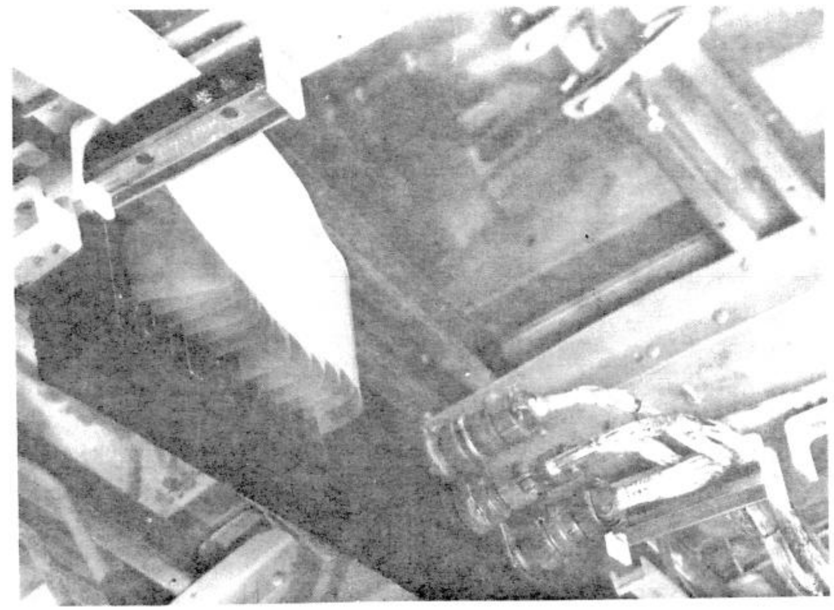


FIG. 37 - FLAT CABLE/ROUND WIRE JUNCTION BOX

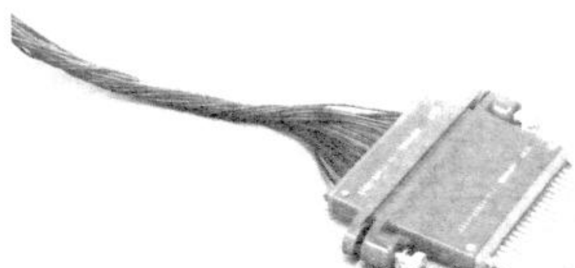


FIG. 36 -- FLAT CABLE TO ROUND WIRE TRANSITION

a) Optical instruments require experienced personnel. Lasers do not.

b) The accuracy of optical instruments depends on resolution, definition, proper certification, removal of parallax, pointing (dependent on physiological and psychological characteristics of individual operators), and proper targeting and target lighting. Lasers depend primarily on certification. Human interpretations would be eliminated for machinery and other precise alignment applications.

d) Once set up, one man can interrupt a laser beam anywhere and take a measurement much the same way as he would with a strung-out wire. The laser beam would be a precision straightedge. A piano wire, no matter how taut, still must be corrected for a perceptible catenary.

e) The laser beam can be detected visually as well as electronically. Optics normally require two men for this operation.

f) The laser is much more simple to buck into a line and considerably more simple to buck into a plane than is the telescope and transit under most fabrication conditions.

g) The laser does not require initial focusing to find the target and refocusing to achieve final alignment.

h) Unlike optics, the laser field of view is the entire field of view of the operator and any other observer. Thus, the laser can be used as a long pointing stick.

i) Collimation or autocollimation of the laser is not limited to mirror size as it is on the telescope.

A summary of applications of the optical laser includes, but is not limited to, the following:

a) Alignment of ways and blocks prior to laying keel

b) Alignment of keel and panels

c) Stiffener location and alignment for preassembly technique development

d) Checking levelness during hull erection

e) Hull-section alignment for modular or "jumboizing" assemblies

f) Stern-tube and shaft alignment

g) Hatch-coaming and guide installation

h) Lash-rail alignment

i) Superstructure-to-hull and deck alignments

APPENDIX H - BOEING DESIGN MANUAL

SECTION 17

FASTENERS, GENERAL

SECTION 17

FASTENERS, GENERAL

17.1 INTRODUCTION

A. Fastener information is presented in three sections:

1. Section 17 contains callout instructions for all fasteners and holes, hole sizes, sealing information and usage charts.

2. Section 18 provides strength data, edge margins and spacing requirements.

3. Section 19 contains descriptions of fastener installation tools and related information which must be considered in design.

B. The installation of fasteners is controlled by process specifications:

1. BAC5004 for rivets, lockbolts and blind fasteners.

2. BAC5009 for bolts and nuts.

Drawing forms contain references to these specifications in the title block area.

C. In addition, where applicable, additional process specifications should be called out on drawings. For example:

1. BAC5018 for installation of cotter pins and similar safetying devices.

2. BAC5047 for installation of fasteners which must be fluid tight.

3. BAC5049 for dimpling and countersinking.

4. BAC5085 for installation of metallic sandwich spacers.

17.11 RIVETING—GENERAL

Joint design and associated fastening concepts shall continue the practices used on previous commercial models with exceptions to provide increased reliability, weight and cost reductions. A brief resume of the major current practices and recommended changes follows:

Riveting

For structural fluid tight riveting, the use of NACA and modified countersink automatic riveting in accordance with BAC5047 shall be continued. Avoid the use of rivets where the material thicknesses add up to more than 2.5 D.

Avoid use of dimpled rivet installations in exterior and aerodynamic surfaces. Flush rivets shall be of the shear head type (BACR15CE) in thin skin applications.

Conventional 100° flush head and protruding head aluminum alloy rivets for interior structure, sub-structure and attachments shall be in accordance with MS standards 20426 and 20470.

For nutplate attachment use hollow pull-stem rivets (BACR15DR), except in seal areas, unless prohibited by customer specifications. In blind riveting applications requiring structural strength and fatigue resistance use the Cherrylock and bulbed Cherrylock locked spindle aluminum alloy rivets (NAS1398 and BACR15DJ).

For high temperature service the monel Cherrylock (NAS1398) shall be used.

17.2 SYMBOLS AND CALLOUT

17.21 FASTENER SYMBOLS

17.211 NAS SYMBOLS

The NAS523 Symbol System is used to call out permanent type fastener units on drawings. The fastener units shown in 17.2112, Basic Rivet Code, can be called out with the NAS Symbol System. A threaded bolt that is used with various nuts, pins, metal stiching, and miscellaneous special fasteners cannot be included in the NAS Symbol System.

A. The NAS Type Symbol is basically a cross with the intersection at the center of the fastener in the plan view. Fastener identity, size and installation instructions are indicated by letter-numeric coding within the quadrants of the cross. For convenience the four quadrants are referred to as shown below regardless of rotation.

Figure 17.211-1

B. Basic Code. The fastener is identified by a non-significant two-letter code in the NW quadrant, which defines all features except diameter and grip or length. It also includes the collars for lockbolts and Hi-Shears. When inclosed in a box, installation per BAC5047 is required. For code letters, see the usage charts. Code letters to be used by the entire aircraft industry are added to NAS523 and then to the Design Manual. Code letters for individual company use begin with X. Consult Seattle Standards Unit for assignment of new code letters.

C. Diameter and head location are indicated by a number and letter in the NE quadrant. The number is the same as the diameter dash number of the part or the last one or two digits of part numbers which express the nominal diameter by these digits, the letter N or F refers to NEAR SIDE or FAR SIDE of the manufactured head. If the head location is optional, or is clearly shown by the drawing the letter may be omitted.

D. Rivet length and spotweld optional are shown in the SE quadrant by a number and letter. The number is the dash number for the length or grip of the part; it is omitted for conventional rivets except in modification kit drawings per PM, D-4900. The letter W, if used, permits spotwelding instead of riveting.

E. Countersinking and dimpling instructions are shown in the SW quadrant as follows:

1. Dimpling is indicated by a D followed by a number indicating the number of sheets to be dimpled, if more than one.

2. Countersinking is indicated by the letter C. No number is used with countersinking.

3. Flush both sides is shown by placing the letters and number (as applicable) on two lines. The upper line applies to the manufactured head, and the lower line to the driven head. The angle of the driven head shall be the same as that of the manufactured head except as noted in paragraph F below.

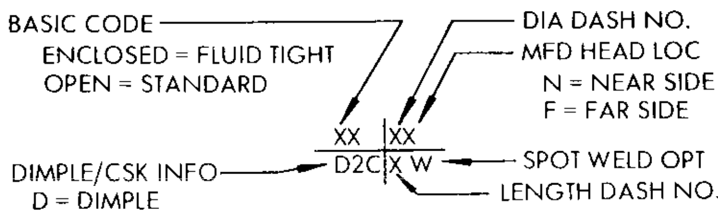
F. Fluid tight riveting (per BAC5047), is shown by enclosing the basic code in a square in the NW quadrant. Place 82 below the countersink code in the SW quadrant when an 82° driven head angle is required (NACA style).

G. Rivet symbol blocks as shown below will be printed on drawing forms stocked at the supply counters, or upon request to the Reproduction Unit. Several blank spaces are provided for listing the rivets used on the drawing and the code for each. More spaces may be added by the draftsman if required.

17.211 NAS SYMBOLS (Continued)

BK = MS20470B	CE = P (CKL)
BA = MS20426A	XLP = BACB30LA
DZ = SAL100-T & 6LC-C	NAS 528
XPC = BACB30MB*A**U & BACC30X	XC = BAC-R15BB-AD
┼ˣ HOLE LOCATION FOR X DIAMETER RIVET	

INSTALLATION:
STD, PER BAC 5004; FLUID TIGHT, PER BAC 5047



D = DIMPLE
2 = NO. SH DIMPLES
C = CSK INSTRUCTURE
2 LINES: TOP = MFD HD; BOTTOM = DRIVEN HD

NOTE: PROTRUDING HD RIVETS DRIVEN FLUSH
D/C INFO (2 LINES) APPLIES TO DRIVEN HD ONLY.

RIVET SYMBOL CODE

Figure 17.211-2

NOTE: The Basic Fastener Code and the equivalent part number(s) that are noted the Rivet Symbol Code box, shall be the same as those listed in 17.2112 and D590. These include codes for material, finish, etc., as required.

Example: XPC = BACB30MB*A**U & BACC30X

Where: BACB30MB = Basic Part Number
"A" code = A286 material
"U" code = Unplated

17.2111 EXAMPLES OF NAS SYMBOLS

Symbol	Description
BK 4 / W	MS20470B4, UNIVERSAL HEAD, 5056-F RIVET, 1/8 DIAMETER. HEAD DIRECTION OPTIONAL. SPOTWELD OPTIONAL.
BA 6N / C	MS20426A6, 100° HEAD, 1100-F RIVET, 3/16 DIAMETER. COUNTERSINK 100° NEAR SIDE FOR MANUFACTURED HEAD.
BA 6F / DC / DC	MS20426A6, 100° HEAD, 1100-F RIVET, 3/16 DIAMETER. MANUFACTURED HEAD FAR SIDE. DIMPLE OUTER SHEET AND COUNTERSINK INSTRUCTURE 100° BOTH SIDES.
DZ 6F / C 5	SAL100-T6-5 (BAC-B30P-6-5), 100° HEAD, STEEL, SHEAR LOCKBOLT, INCLUDING 2024-T4 COLLAR 6LC-C6 (BAC-C30A-C6). 3/16 DIAMETER, 5/16 MAXIMUM GRIP. COUNTERSINK 100° FAR SIDE FOR MANUFACTURED HEAD.
XLP 6 / C 3	BACB30LA6-3, 100° HEAD, BLIND BOLT HUCKBOLT, 3/16 DIAMETER, 3/16 NOMINAL GRIP. COUNTERSINK 100° FOR MANUFACTURED HEAD (Direction assumed to be obvious).
CE 6 / D	P6D (BAC-R15AP-6-147), BRAZIER HEAD, 5056-F BLIND RIVET (HUCK CKL), 3/16 DIAMETER, .129 - .165 GRIP RANGE. (The use of letter D for grip is an exception to the standard code). Head Direction Obvious.
XC 6F	BAC-R15BB-6AD, 2117-T3, 3/16 DIAMETER, UNIVERSAL HEAD RIVET. MANUFACTURED HEAD FAR SIDE. FLUID TIGHT PER BAC 5047.
XC 6F / C / 82	BAC-R15BB-6AD, 2117-T3, 3/16 DIAMETER, UNIVERSAL HEAD RIVET. MANUFACTURED HEAD FAR SIDE, COUNTERSINK 82° FOR FLUID TIGHT DRIVEN HEAD PER BAC 5047.
6	HOLE LOCATION FOR A 3/16 DIAMETER RIVET. (The number signifies rivet diameter in thirty-seconds.)

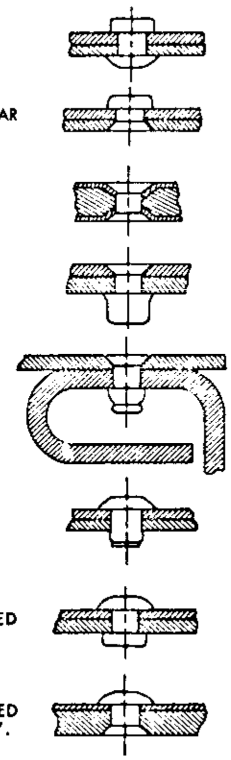


Fig. 17.2111-1

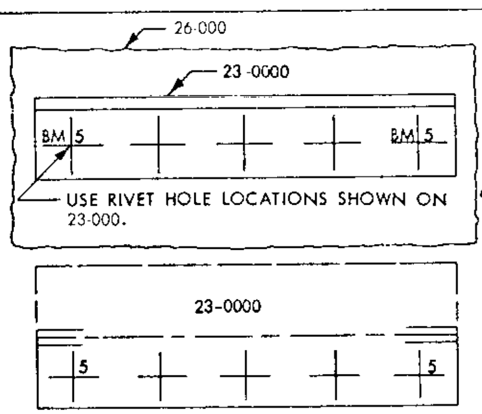
17.23 (Continued)

2. The assembly or installation drawing shall locate the parts, indicate the fastener and associated parts such as nuts, washers, etc., and show the hole size per 17.25.

Where hole patterns are duplicated on other drawings a note shall be added stating which drawing shall be used as a pattern. Drawings showing holes which are not to be used for patterns shall show the note:

USE RIVET (BOLT) HOLE LOCATIONS SHOWN ON XX-XXXX

This note should also be shown on assembly drawings not used as hole patterns.



A flag and flag note may be used when space is limited.

Figure 17.23-1

17.24 MATCHING HOLES

See DM 81, Section 13.

17.241 HOLES TO MATE WITH STANDARD PARTS

When holes in a detail part or assembly must mate with holes in a purchased or government furnished item the sizes and locations shall be completely dimensioned and toleranced to assure fit if assembly is on a higher drawing. The note, "LOCATE TO MATCH" shall not be used. If a G.F.E. part is brought together with Boeing parts for assembly, use note "USE HOLE LOCATIONS SHOWN ON -----------" (GFE PART).

17.242 COORDINATING HOLES

Coordinating holes shall be used in accordance with DM 81, 1.532.

17.243 IDENTICAL PARTS EXCEPT FOR HOLES

Parts which are identical except holes or hole locations require different part numbers. This applies to parts drawn as separate details or called out by dash number on an assembly or installation.

A. When a standard part is drilled for installation, it shall be given a new number and treated as a MAKE FROM part--see PM 94B1, Section 5.034.

B. Boeing detailed blank parts which are used in two or more assemblies having different hole patterns shall be treated as in A above.

17.25 HOLE SIZE CALLOUT

A. HOLE SIZES NOT SPECIFIED ON THE DRAWING. Hole sizes for conventional rivets and Cherry, Olympic, Huck, Dupont chemically expanded blind rivets, are controlled by BAC 5004 or BAC 5047 and shall not be shown on the drawing.

B. HOLE SIZES SPECIFIED ON THE DRAWING. All fastener holes not included in A above must have the size and tolerance clearly specified in decimal dimensions on the drawing. These include, bolts, screws, swaged collar fasteners, blind lockbolts, Jo-Bolts, and Deutsch Blind rivets.

Hole sizes may be specified in various ways, such as by note at the fastener location, or by a general note near the title block for each size and type of fastener used, or by a combination of such notes.

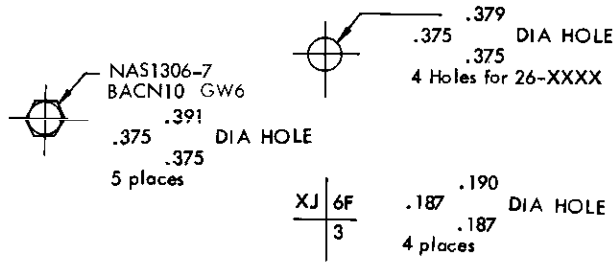
If the purpose of a hole is not readily apparent a note shall be added to reference its use. This also applies to blank holes.

When a clearance hole is one bolt size larger than the bolt, Manufacturing assumes the drawing is in error. To avoid misunderstanding and delay, a special note should be added. For example, if a .313 hole is required for a 1/4 bolt the following note may apply:

.313 $^{.317}_{.313}$ DIA. OVERSIZE HOLE FOR NAS 1304 BOLT

The method used to produce a hole will not be included in the drawing callout; the size and tolerance will indicate the required method.

Holes may be called out with or without the fasteners as shown:



NOTE: Solid ℄ for .5 diameter or less.

17.251 SELECTION OF HOLES FOR STANDARD FASTENERS

The precision required in drilling holes for bolted structural joints carrying shear loads is determined by the nature of the loads and by the number of bolts in the joint. See Figure 17.251-1.

SELECTION OF HOLES FOR FASTENERS

Joint Condition or Loading		Fastener Type	Recommended Hole Type	
Joint transmits large portion of load carried by airplane component (wing empennage, etc.).	Less than four fasteners in joint.	Close Tolerance Bolt	Close Ream ①	
Joint subject to frequent load reversal (buffeting or vibration).		Lock Bolt	Transition Fit ②	
Joint subject to rapidly applied loads as a result of high acceleration of large masses.	Four or more fasteners in joint.	Close or nonclose Tolerance Bolt, or Lock Bolt	Class I ③	
Joint in fluid tight structure.		All	Close Ream ①	
Joint in secondary structure.		All	Class II ③	R
Joint in primary structure: A. Not subject to reverse and/or rapidly applied loads. B. Over-strength (margin of safety greater than 25 per cent in shear and greater than 50 per cent in bearing). NOTE: Where resulting allowable motion in joint will tend to overload adjacent structure, use Class I hole.				
Joint in which tension only is applied to fastener with no reversed loads.		All	Class III ③ ④	R
Joint where close fit is obviously not required, and alignment of predrilled holes is difficult. Examples: Clamps, fairleads, instrument and equipment support brackets, junction boxes, lining trim, miscellaneous supports and brackets.				

① Close tolerance bolts may be installed in close reamed holes in all materials.

② Lock bolts in transition fit holes shall be restricted as follows (not for blind lock bolts):

A. Material single thickness next to collar shall be at least .25 times nominal fastener diameter.

B. Total material thickness shall not exceed 4 times nominal fastener diameter.

③ Hole sizes for blind bolts are shown in 17.253.

④ Class III holes do not necessarily provide the largest clearance advised for all designs. Where the design allows, and either fabrication or assembly is more economical with larger clearances, larger holes may be specified with sizes in accordance with 7.411.

Figure 17.251-1

17.252 STANDARD HOLES FOR STRUCTURAL FASTENERS

A. Hole size for bolts, screws, lockbolts, pins and other similar structural fasteners are given in Figure 17.252-1.

B. Manufacturing practices for hole preparation and fastener installation for all but extreme design requirements are specified in Process Specifications BAC5004 (for lockbolts and blind fasteners) and BAC5009 (for both screws and nuts). The requirements of BAC 5004 and BAC5009 are specified by a note silk screened on drawings near the title block. Special installation requirements, where necessary, must be clearly specified in detail on the drawings. In such cases, it must be established that the requirements are within manufacturing capabilities and are economically justified: consultation with the applicable divisional staff is recommended.

Some provisions of BAC5004 and BAC5009 are as follows:

1. Fastener holes are required to be within 2° of normal to:

   a. The surface under the head of protruding head fasteners.

   b. The surface surrounding the top of countersunk fastener.

   c. The surface in contact with the washer face of nuts.

NOTE: "within 2° of normal" is intended as a shop tolerance, in cases where design is such that the surface under the bolt head or nut is not nominally perpendicular to the hole with 1/2°, the drawing shall call for a spotface (per DM Book 81, 7.4132) as optional.

2. The perpendicularity of installed fasteners is also controlled by limiting the permissible gap under fastener head and nuts. This gap is influenced by hole abnormality, cocking of fasteners heads, lack of fastener straightness, abnormality of nut threads in relation to the washer face of nut, surface irregularities under nuts or heads of fasteners, bending of the fastener and compression of the clamped material.

C. Aluminum collars swaged on lockbolts can accommodate more slope than nuts on bolts. The permissible slopes given in Figure 19.34-1 include the 2° deviation from normal allowed for shop hole preparation.

17.252 (Continued)

STANDARD HOLE LIMITS PER NAS 618 ① ②

Nominal Diameter Fastener	Close Ream Min	Close Ream Max	Transition Fit In Alum and Mag Min	Transition Fit In Alum and Mag Max	Transition Fit In Steel Min	Transition Fit In Steel Max	Class I Min	Class I Max	Class II Min	Class II Max	Class III Min	Class III Max
0									.062	.067	.081	⑤ .090
1									.075	.080	.093	⑤ .103
2									.088	.093	.106	⑤ .118
3					Use close ream diameters for standard fasteners				.101	.106	.120	.131
4									.114	.119	.136	.147
5 or 1/8									.127	.132	.147	.158
6									.140	.145	.161	.172
③ 8 or 5/32	.1635	.1645	.161	.164			.164	.168	.166	.171	.192	.203
10 or 3/16	.1895	.1905	.187	.190			.190	.194	.190	.199	.218	.229
1/4	.2495	.2505	.247	.250			.250	.254	.250	.261	.279	.291
5/16	.3120	.3130	.309	.313			.312	.316	.313	.327	.342	.354
3/8	.3745	.3755	.371	.375			.375	.379	.375	.391	.404	.416
7/16	.4370	.4380	.434	.438			.437	.442	.438	.457	.467	.479
1/2	.4995	.5005	.496	.500			.500	.505	.500	.521	.529	.541
9/16	.5620	.5630	.559	.563			.562	.567	.563	.583	.591	.610
5/8	.6245	.6255	.621	.625			.625	.630	.625	.645	.653	.672
3/4	.7495	.7505					.750	.757	.750	.773	.778	.797
7/8	.8745	.8755					.875	.882	.875	.898	.903	.922
1	.9995	1.0005					1.000	1.010	1.000	1.026	1.028	1.047
1 1/8	1.1245	1.1260					1.125	1.135	1.125	1.155	1.153	1.172
1 1/4	1.2495	1.2510					1.250	1.260	1.250	1.280	1.278	1.297
1 3/8	1.3745	1.3760					1.375	1.385	1.375	1.405	1.403	1.422
1 1/2	1.4995	1.5010					1.500	1.510	1.500	1.530	1.528	1.547

① Class II holes and #0 thru 6 holes are not shown in NAS 618.
② Oversize fasteners are for repair work only and shall not be used in design.
③ Transition fit for 5/32 B30DX, B30DY, B30GP and B30GQ is .162 - .165, not per NAS 618.
④ For holes with larger tolerances see note ④ in Figure 17.251-1.
⑤ Washer required under fillister screw head.

Figure 17.252-1

17.253 HOLE SIZES FOR BLIND FASTENERS GROUP I

Holes listed in Figure 17.253-1 are for high strength blind fasteners (Huck Blind Bolt).

HOLE SIZES FOR HUCK BLIND BOLTS
BAC B30LA & BAC B30LB

Nominal Size	Hole Diameter Minimum	Hole Diameter Maximum
5/32	.164	.167
3/16	.199	.202
1/4	.260	.263
5/16	.312	.315
3/8	.374	.378

Figure 17.253-1

17.3 FLUSH REQUIREMENTS

The selection of countersinking or dimpling, and the flushness tolerance that must apply, shall be in accordance with this section.

17.31 TOLERANCES

A. The normal fastener flushness tolerance of $^{+.010}_{-.005}$ is included in BAC 5004 and 5009. Drawings which require compliance with these specifications need not call out normal tolerances. However, if tolerances smaller than $^{+.010}_{-.005}$ are necessary they shall be selected from Figure 17.31-1 and called out on the drawing by symbol or note as shown by example.

B. These tolerances are mandatory for dimpled structure to permit the use of standard dies. The same (or larger) tolerances are preferred for countersunk structure. However, countersinking tools can be adjusted to satisfy special requirements.

C. Drawing callout examples of an individual tolerance included with a symbol as a general note:

BE / D — ALL MS20426 RIVETS INSTALLED FLUSH $^{+.005}_{-.000}$ (IN AREA INDICATED).

XFV / D — ALL BACB30GY RIVETS INSTALLED FLUSH $^{+.005}_{-.002}$ (IN AREA INDICATED).

17.31 (Continued)

FASTENER ①	DRAWING NUMBER	FLUSHNESS TOLERANCE (TO BE SPECIFIED ON DRAWING)	REMARKS
Aluminum Rivets	MS20426 BACR15BA	+.005 -.000	1. Preferred. Requires practically no shaving.
Aluminum Lock-bolts	BACB30GQ	+.002 -.000	2. For critical aerodynamic areas. Requires shaving.
Blind Rivets Group 11	NAS1399 BACR15DD BACR15DF BACR15DJ	+.002 -.004 Maximum stem protrusion above skin .020	1. Usual, as driven. 2. Normal stem retention.
		+.002 -.004 Maximum stem protrusion above skin .002	1. For critical aerodynamic areas. 2. Requires shaving. 3. Normal stem retention.
Shear Lockbolts	BACB30GY		1. Cannot be shaved. 2. Cannot be installed in below-flush applications which require aerodynamic smoother.
Tension Lockbolts Tension Lockbolts Stumps	BACB30DX BACB30HG	+.002 -.005	1. Cannot be shaved. 2. Cannot readily be installed in below-flush applications which require aerodynamic smoother except with specialized dimple tooling.
Steel Bolts	BACB30LU NAS583-590	+.005 -.005	
Huck blind bolt	BACB30LA	+.005 -.005	1. May be shaved. 2. Must be corrosion protected after shaving.
Huck blind bolt	BACB30LB	±.005	1. Must be corrosion protected.

① Contact applicable divisional staff unit for data on fasteners not included.

Figure 17.31-1

17.32 COUNTERSINKING AND DIMPLING

On a direct cost-per-fastener basis, countersinking a hole is cheaper than dimpling. However, when the increased shear strength of dimpling joints is considered, the smaller quantity of fasteners required with dimpling may occasionally make the dimpled joint less expensive than one using countersinking. In addition, limitations such as thickness, material condition, accessibility, etc., apply to both processes and will, in part, influence choice.

17.321 COUNTERSINKING

Countersinking is necessary where sheet thickness is too great to use dimpling or in applications where the size or shape of an assembly does not permit access to dimpling equipment. Countersinking and dimpling are controlled by BAC 5049.

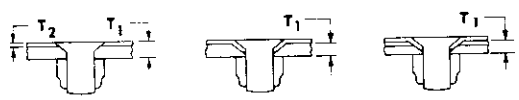
17.3211 MINIMUM SHEET THICKNESS

The minimum material thicknesses which are recommended for countersinking are shown in Figures 17.3211-1 and 17.3211-2. Sheets thinner than those listed must be dimpled. Sheets whose thickness is sufficient to countersink, may be dimpled if within the limits of Figure 17.322-2. These limits are not valid where integral fuel tank sealing is a requirement - see 17.5.

The minimum sheet thicknesses are based on the minimum practical limitation including tolerances that would provide a satisfactory installation. Countersinking resulting in a sharp edge is poor design practice where service life is a factor. Consult Stress Unit for information regarding sheet thickness, fit and spacing that will insure satisfactory fatigue life for a specific design.

A. For use with manufactured countersunk rivets.

MINIMUM SHEET THICKNESS FOR COUNTERSINKING ①



T_1 = Thickness of sheet or sheets countersunk.
T_2 = Thickness of top sheet held in place by flush head.

Fastener Diameter		3/32	1/8	5/32	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8
Rivets, Blind Rivets, Alum. Lock Bolt	T_1	.040	.051	.064	.081	.125	.125	.156				
	T_2	.032	.040	.040	.050	.063	.063	.063				
BAC-R15CE Shear Head Rivet	T_1		.051	.064	.081	.125						
	T_2		.032	.040	.050	.063						
Shear Lock Bolt, Deutsch Rivet	T_1				.052	.066	.073	.093	.102	.112	.121	.131
	T_2				.049	.049	.049	.049	.057	.057	.066	.066
Bolt Tension Lock Bolt, Jo-Bolt, Hi-Strength Blind Fasteners	T_1				.085	.110	138	167	.195	.222	.249	.279
	T_2				.057	.057	.057	.057	.066	.066	066	.066

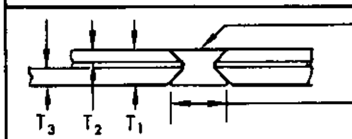
① Values apply to any combination of fastener and fastened material, and are based upon zero flushness. Where fastener head is permitted below flush, values of T_1 and T_2 shall be increased by an amount equal to the maximum permitted below flushness.

Figure 17.3211-1

B. For use with shop driven flush heads.

Figure 17.3211-2 T_3 values apply to both countersink and protruding head rivets whose shanks are driven flush in a countersink sheet to a diameter of 1.5 times the shank diameter.

MINIMUM SHEET THICKNESS FOR COUNTERSINKING



T_1 = Combined thickness of sheets.

T_2 = Sheet thickness at the surface in contact with the manufactured countersunk head.

T_3 = Sheet thickness at the surface in contact with the shop driven head.

Rivet Size	T_1	T_2	T_3
1/8	.080	.040	.040
5/32	.110	.040	.050
3/16	.140	.050	.071
1/4	.190	.063	.090
5/16	.220	.063	.100

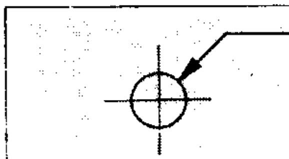
Figure 17.3211-2

17.3212 CALLOUT

A. NAS CODE FASTENERS. Countersinking is called out by the letter "C" in the SW quadrant. See 17.211.

B. OTHER. Countersunk holes for flush head fasteners, such as bolts and screws, which are not covered by symbol callout described in 17.21, shall be specified as follows:

1. For exterior (aerodynamic) surfaces and parts countersunk on assembly, do not dimension countersink. Callout as shown:

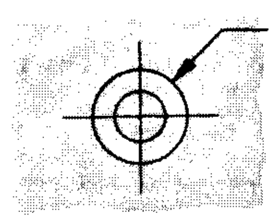


BACB30LU6-20
BACN10 GW6
$.279\ ^{.291}_{.279}$ DIA.
CSK 100° NEAR SIDE 4 PLACES

NOTE: Drawing or BAC 5009 will control flushness.

Figure 17.3212-1

2. Completely dimension the countersink on the drawing (see Figure 17.3212-2 if the holes must be pre-countersunk. This callout necessitates the inspection of countersink size instead of fastener fit. Controlled interchangeable items are examples of this requirement. For countersink diameters and limits see Figure 17.3212-3.



$.279\ ^{.291}_{.279}$ DIA.
CSK 100° x $.515\ ^{.525}_{.515}$ DIA.
4 PLACES

Figure 17.3212-2

17.3212 (Continued)

COUNTERSINK DIAMETERS FOR 100° FASTENERS NAS514, NAS583-590, BACB30LU, BACB30AB, BACB30BF		
Fastener Diameter	Countersink Diameter ①	Theoretical Flushness Limits - For Reference Only; Do not specify on drawing ②
No. 4	$.225^{.233}_{.225}$	+.000 -.009
No. 6	$.280^{.288}_{.280}$	+.000 -.009
No. 8	$.335^{.345}_{.335}$	+.000 -.012
3/16	$.390^{.400}_{.390}$	+.001 -.013
1/4	$.515^{.525}_{.515}$	+.001 -.015
5/16	$.645^{.657}_{.645}$	+.001 -.018
3/8	$.775^{.787}_{.775}$	+.001 -.020
7/16	$.905^{.920}_{.905}$	+.001 -.021
1/2	$1.035^{1.050}_{1.035}$	+.001 -.026

① A change of .001 in countersink diameter will affect flushness by approximately .00042.

② These limits are approximate because head sizes and tolerances for various fasteners are not identical. They represent variations of head diameter, head angle, countersink diameter and countersink angle.

Figure 17.3212-3

17.322 DIMPLING

Dimpling is used where sheet thicknesses are too small for countersinking and where the higher shear strength of a fastener in dimpled sheet will permit the use of fewer fasteners in a given joint.

Dimpled joints are either a combination of dimpled sheet and countersunk instructure or of multiple thicknesses of dimpled sheet as shown in Figure 17.322-1.

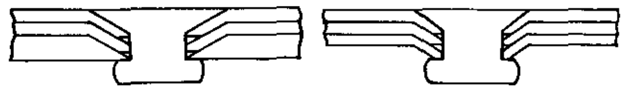


Figure 17.322-1

A. Extruded, forged or machined sections shall not be dimpled.

B. Dimpled parts subject to fatigue and heavy vibration should be made from 2024-T3 in preference to 7075-T6 provided strength and other considerations permit.

C. Warpage of sheet during dimpling, due to metal expansion during forming, can be minimized by observing the requirements of 17.3221.

D. Warpage of dimpled joints due to rivet shank expansion can be minimized by use of countersunk instructure and/or by non-expanding shank fasteners.

E. Thickness limits and allowables for simultaneous dimpling of multiple thicknesses may be obtained from the applicable staff unit. In such cases, the total thickness of sheets to be dimpled at one time is considered as a single thickness in Figure 17.322-2; drawing notes shall clearly designate areas which may be multiple dimpled.

MATERIAL THICKNESS LIMITS FOR DIMPLING

MAXIMUM ①

		ALUMINUM		MAGNESIUM		CORROSION RESISTANT STEEL ②			
						Portable		Stationary	
	Dia	Portable	Stationary	Portable	Stationary	Annealed	1/4 H	Annealed	1/4 H
CONVENTIONAL RIVETS (Except BAC-R15CE)	3/32	.050	.050	.050	.050	.050	.040	.050	.050
	1/8	.063	.063	.063	.063	.063	.040	.063	.063
	5/32	.071	.071	.071	.071	.071	.040	.071	.063
	3/16	.071	.090	.090	.090	.090	.040	.090	.063
	1/4	.063	.090	.125	.125	.100	.040	.125	.050
	5/16	.063	.090	.125	.140	.091	.032	.125	.050
BLIND RIVETS	1/8	.050	.050	.050	.050	.050	.040	.050	.050
	5/32	.063	.063	.063	.063	.063	.040	.063	.063
	3/16	.071	.080	.080	.080	.080	.040	.080	.063
	1/4	.063	.090	.125	.125	.100	.040	.125	.050
SHEAR HEAD FASTENERS	3/16	.050	.050	.050	.050	.050	.040	.050	.050
	1/4	.071	.071	.071	.071	.071	.040	.071	.063
	5/16	.063	.080	.080	.080	.080	.040	.080	.050
	3/8	.063	.090	.100	.100	.090	.040	.100	.050
TENSION HEAD FASTENERS	#8	.071	.080	.080	.080	.080	.040	.080	.063
	#10	.071	.100	.100	.100	.100	.040	.100	.063
	1/4	.063	.090	.100	.140	.090	.040	.140	.050
	5/16	.050	.080	.100	.160	.080	.032	.125	.050
	3/8	.040	.063	.080	.125	.063	.025	.090	.040

MINIMUM

	Dia	.010	.016	.020	.025	.032	.040	.050
CONVENTIONAL RIVETS (Except BAC-R15CE)	3/32	CAM						
	1/8	CA	M					
	5/32	CA	M					
	3/16	C	A	M				
	1/4		C	A	M			
	5/16		C	A		M		
BLIND RIVETS	1/8	CA	M					
	5/32	C	AM					
	3/16		CA	M				
	1/4			C	A	M		
SHEAR HEAD FASTENERS	3/16	CA	M					
	1/4	C	A	M				
	5/16		CA	M				
	3/8		C	A		M		
TENSION HEAD FASTENERS	#8	C	A	M				
	#10		C	A	M			
	1/4			C	A	M		
	5/16				C	A	M	
	3/8					C	A	M

① Above the heavy line is the maximum material thickness for obtaining a structural advantage over countersinking. Below the heavy line is the maximum material thickness within the dimpling machine forming capacity.

NOTE: Clearances for the stationary machine (CP-450 EA) and a typical portable dimpler are shown in Section 19. For other portable yokes see Standard Tools, Volume III.
Consult applicable C.A.D. staff unit for:

(a) Limits for dimpling titanium, or materials other than those shown.
(b) Limits when simultaneously dimpling multiple thickness of materials.

② Austenitic Group which includes 301, 302, 321, 347.

C - Corrosion Resistant Steel
A - Aluminum
M - Magnesium

Figure 17.322-2

17.3221 EDGE MARGIN

Where a dimple is sufficiently coined to assure proper nesting a radial stress remains around the hole. The greater (less restricted) expansion between the hole and the edge causes distortion. This can be minimized by:

A. Adding 50 per cent to the design edge margin. For design edge margin see Section 18. Thicknesses less than .050 need only the design edge margin.

B. Adding a stiffening flange. The minimum flange heights shoul agree with DM 81, Section 1 , or as listed for formed sections in th BAC standard pages. The flange must have sufficient flat surfac for dimpling die contact.

The use of butt straps without a flanged edge is not recommende where no other stiffening member is present. Waviness in the ski splice will result because of sheet stretch due to dimpling and rivet ing unless stiffening restricts the waviness.

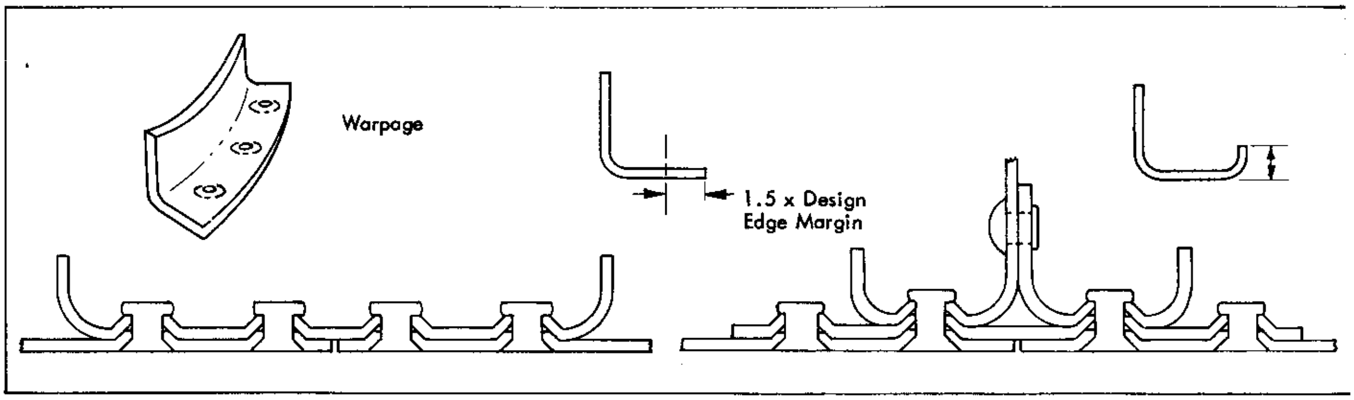


Figure 17.3221-1

17.3222 CALLOUT

A. NAS CODE FASTENERS. Dimpling is called out by the letter D in the SW quadrant. See 17.211.

B. OTHER. Dimpled holes for flush head fasteners such as bolts and screws which are not covered by NAS symbol callout shall be specified as follows:

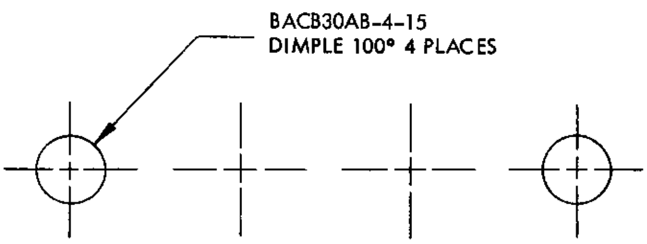


Figure 17.3222-1

C. DRAWINGS. Projects shall issue sealing installation drawing to define sealing requirements for each model airplane.

17.5 SEALING

Fastener sealing information is found in:

A. BAC Process Specifications:

1. BAC 5000 Sealing (in general)
2. BAC 5047 Fastener Installation; Fluid Tight
3. BAC 5504 Integral Fuel Tank Structure Sealant
4. BAC 5732 Integral Water Tanks.

B. Documents as specified by Projects:

1. D-15248 integral fuel tanks.

17.51 CALLOUT

The Project sealing installation drawings shall be referred to by note SEAL PER DRAWING 29-00000 on all Project drawings re quiring sealing provisions. Reference to BAC 5000, Process Speci fication for Sealing, shall be made as applicable on the seali installation drawing. In addition, these drawings shall complete describe or illustrate all sealing requirements not included in BA 5000.

17.52 TYPES

Type and levels are per BAC 5000.

17.53 MAXIMUM SPACING

See 17.5B.

17.6 FASTENER USAGE CHARTS

The following usage charts provide convenient reference and com parative data for fasteners in common use. The BAC Standard (D-590) should be consulted for complete information.

17.61 NAS SYMBOL FASTENERS

In this classification those fasteners appear which are shown on drawings by NAS symbols.

17.611 SOLID SHANK STRUCTURAL RIVETS

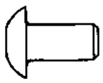
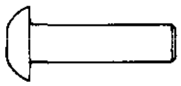
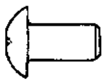
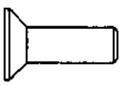
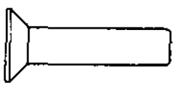
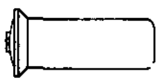
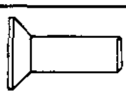
SOLID SHANK STRUCTURAL RIVETS					
ILLUSTRATION	PART AND PAGE NUMBER		MATERIAL	SIZE RANGE	DESCRIPTION
	MS20470 80.90.1.2.1		AL 1100, AL ALLOY 5056, 2117, 2024, 2017	1/16 THRU 3/8	UNIVERSAL HEAD
	BACR15BB 80.90.6.8		2024, 2117, AL ALLOY	1/8 - 7/16	CLOSE TOLERANCE SHANK UNIVERSAL HEAD
	MS20615M 80.91.1.3.1		MONEL	1/16 - 7/16	CLOSE TOLERANCE CORROSION AND HEAT RESISTANT UNIVERSAL HEAD
	MS20426 80.90.1.1.1		AL 1100, AL ALLOY 5056, 2117, 2024, 2017	1/16 THRU 3/8	100° FLUSH HEAD
	BACR15BA 80.90.6.7		2117, 2024 AL ALLOY	1/8 - 7/16	CLOSE TOLERANCE SHANK 100° FLUSH HEAD
	BACR15CE 80.90.6.9		5056, 2017 AL ALLOY MONEL	3/32 - 1/4	SPECIAL LOW HEIGHT 100° SHEAR HEAD
	MS20427M 80.91.1.1.1		MONEL		CLOSE TOLERANCE SHANK CORROSION AND HEAT RESISTANT 100° FLUSH HEAD

Figure 17.611-1

17.612 LOCK BOLTS & HEX DRIVE BOLTS

These fasteners are recommended for use when a reduction in cost and weight is desired on permanent installations, provided the tensile loads do not exceed the values listed in 18.21. If the joint requires the high shear strength of these fasteners they are recommended in lieu of rivets because of greater rigidity and better clamp-up. The shear *type has a head and* collar of minimum size for use where loads are primarily shear; the tension type has a heavier head and collar.

The diameter tolerances for lockbolts (.0015 in.) with swaged coll are per NAS618, while closer tolerances (.0005 in. and .0010 in.) c offered with Hi-Lok fasteners (threaded collar). However, there i higher cost associated with the Hi-Loks as compared to lockbolts. *pull-type* lockbolts have a 1-inch pin tail. See 18.21 for allowabl

Pull-type shear lockbolts and Hi-Loks are intended for shear applic tions where tool clearance is adequate. They offer excellent clamp action and good sealing properties. *Pull-type tensile lockbolts* prov good residual tension and sealing properties. Stump-type tensile c shear lockbolts and Hi-Loks are recommended for applications wh there is not sufficient tool clearance for pull-type lockbolts.

LOCK BOLTS & HEX DRIVE BOLTS - TENSION TYPE

ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	STRENGTH 70°F (RATED) Fsu	MATERIAL	FINISH	MAX. TEMP. °F	MATING COLLAR	
	BAC B30DX 80.81.6.15	5/32 - 1/4 5/16 - 3/8 5/32 - 3/8	95	ALLOY STEEL	CADMIUM	250° 250° 450°	NAS 1080 NAS 1080P NAS 1080R	80.80.5.5 80.80.5.5 80.80.5.5
	BAC B30DX ( ) A 80.81.6.15	5/32 - 1/4 5/16 - 3/8 3/16 - 1/4	95	A286	CADMIUM BARE	250° 250° 900°	NAS 1080 NAS 1080P BAC C30Q	80.80.5.5 80.80.5.5 80.80.6.30
	BAC B30OP 80.81.6.23	5/32 - 3/8	44.5	ALUMINUM	ANODIZE	250°	NAS 1080D	80.80.5.5
	BAC B30DY 80.81.6.16	5/32 - 1/4 5/16 - 3/8 5/32 - 3/8	95	ALLOY STEEL	CADMIUM	250° 250° 450°	NAS 1080 NAS 1080P NAS 1080R	80.80.5.5 80.80.5.5 80.80.5.5
	BAC B30DY ( ) A 80.81.6.16	5/32 - 1/4 5/16 - 3/8 3/16 - 1/4	95	A286	CADMIUM BARE	250° 250° 900°	NAS 1080 NAS 1080P BAC C30Q	80.80.5.5 80.80.5.5 80.80.6.30
4	BAC B30GQ 80.81.6.24	5/32 - 3/8	44.5	ALUMINUM	ANODIZE	250°	NAS 1080D	80.80.5.5
	BAC B30HC 80.81.6.30	3/16 - 5/16 3/8 3/16 - 1/4 3/16 - 1/4	95	ALLOY STEEL	CADMIUM DIFF.CD.NI.	250° 250° 450° 900°	NAS 1080 NAS 1080D NAS 1080R BAC C30L	80.80.5.5 80.80.5.5 80.80.5.5 80.80.6.27
	BAC B30GR 80.81.6.25	3/16 - 3/8	44.5	ALUMINUM	ANODIZE	250°	NAS 1080D	80.80.5.5
	BAC B30HD 80.81.6.31	3/16 - 5/16 3/8 3/16 - 1/4 3/16 - 1/4	95	ALLOY STEEL	CADMIUM DIFF.CD.NI.	250° 250° 450° 900°	NAS 1080 NAS 1080D NAS 1080R BAC C30L	80.80.5.5 80.80.5.5 80.80.5.5 80.80.6.27
4	BAC B30GS 80.81.6.26	3/16 - 3/8	44.5	ALUMINUM	ANODIZE	250°	NAS 1080D	80.80.5.5
	BAC B30JC 80.85.6.30	5/32 - 1/2	95	ALLOY STEEL	CADMIUM	450°	BAC C3CX	80.85.6.28
	BAC B30JC( ) A 80.85.6.30	5/32 - 1/2	95	A286	CADMIUM OR BARE	450° 800°	BAC C30X BAC C30Z	80.85.6.28 80.85.6.31
5	BAC B30NY 80.85.6.40	5/32 - 1/2	95	6AL-4V TITANIUM	CADMIUM	450°	BAC C30X( )M	80.85.6.28
	BAC B30MB ( )A 80.85.6.22	5/32 - 1/2	95	A286	CADMIUM OR BARE	450° 800°	BAC C30X BAC C30Z	80.85.6.28 80.85.6.31
	BAC B30NX 80.85.6.39	5/32 - 1/2	95	6AL-4V TITANIUM	CADMIUM	450°	BAC C30X( )M	80.85.6.28
	BAC B30HA 80.85.6.8	3/16 - 3/8	44.5	ALUMINUM	ANODIZE	250°	BAC C30P	80.80.6.29
	BAC B30ND 80.85.6.36	5/32 - 1/2	95	A286	CADMIUM OR BARE	450° 800°	BAC C30X BAC C30Z	80.85.6.28 80.85.6.31
5	BAC B30NZ 80.85.6.41	5/32 - 1/2	95	6AL-4V TITANIUM	CADMIUM	450°	BAC C30X( )M	80.85.6.28

4 MS 20426 HEAD STYLE   5 AN 509 HEAD STYLE

Figure 17.612-1

17.612 LOCKBOLTS & HEX DRIVE BOLTS (Continued)

LOCKBOLTS & HEXDRIVE BOLTS - SHEAR TYPE									
	BAC B30GW 80.81.6.28		3/16 - 3/8	95	ALLOY STEEL	CADMIUM	250° 450°	BAC C30K NAS 1080E	80.80.6.26 80.80.5.5
	BAC B30GW ( ) A 80.81.6.28		3/16 - 3/8 3/16 - 1/4	95	A286	CADMIUM BARE	250° 900°	BAC C30K BAC C30L	80.80.6.26 80.80.6.27
	BACB30GP 80.81.6.23		5/32 - 3/8	44.5	ALUMINUM	ANODIZE	250°	NAS 1080D	80.80.5.5
	BAC B30GY 80.81.6.29		3/16 - 3/8	95	ALLOY STEEL	CADMIUM	250° 450°	BAC C30K NAS 1080E	80.80.6.26 80.80.5.5
	BAC B30GY( ) A 80.81.6.29		3/16 - 3/8 3/16 - 1/4	95	A286	CADMIUM BARE	250° 900°	BAC C30K BAC C30L	80.80.6.26 80.80.6.27
	BAC B30LD 80.81.6.37		3/16 - 3/8	44.5	ALUMINUM	ANODIZE	250°	BAC C30K( ) F	80.80.6.26
	BAC B30FM 80.85.6.1		5/32 - 1/2	95	ALLOY STEEL	CADMIUM	250°	BAC C30M	80.85.6.15
	BAC B30FM( ) A 80.85.6.1		5/32 - 1/2	95	A286	CADMIUM OR BARE	250° 800°	BAC C30M BAC C30AB*P	80.85.6.15 80.85.6.33
	BAC B30GZ 80.85.6.7		3/16 - 3.8	44.5	ALUMINUM	ANODIZE	250°	BAC C30P	80.85.6.16
	BAC B30MY 80.12.6.101		5/32 - 1/2	95	6AL-4V TITANIUM	CADMIUM	250°	BAC C30M	80.85.6.15
	BAC B30FN 80.85.6.2		5/32 - 1/2	95	ALLOY STEEL	CADMIUM	250°	BAC C30M	80.85.6.15
	BAC B30FN( ) A 80.85.6.2		5/32 - 1/2	95	A286	CADMIUM OR BARE	250° 800°	BAC C30M BAC C30AB*P	80.85.6.15 80.85.6.33
	BAC B30HA( ) R 80.85.6.8		3/16 - 3/8	44.5	ALUMINUM	ANODIZE	250°	BAC C30P( ) R	80.85.6.16
	BAC B30NW 80.85.6.38		5/32 - 1/2	95	6AL-4V TITANIUM	CADMIUM	250°	BAC C30M	80.85.6.15

4 MS 20426 HEAD STYLE

Figure 17.612-2

17.613 BLIND FASTENERS

Blind fasteners are used primarily where one side of the assembly is inaccessible for the installation of conventional fasteners. For high corrosion areas, see A286 self-plugging rivets. For clearances and typical installations see Section 19.

Drawing callouts shall be per 17.22.

Hole size callout for Group I shall be per 17.25.

Hole size for Group II and Group III shall be per BAC5004 and need not be specified on drawing.

Blind fasteners are divided into three groups according to their limitations.

A. GROUP I. These are high strength steel structural blind fasteners which may be used with weight savings in place of bolts and plate nuts in permanent lockout areas. Fasteners in this group are BACB30LA and BACB30LB blind lockbolts (See Fig. 17.613-1). They are subject to the following limitations:

1. Use primarily in shear.
2. Use where the fastener is a part of the permanent structure and is not subject to removal.
3. Use only where standard fasteners are not suitable.
4. Do not use where failed fasteners could fall into air intakes.
5. Design allowables not listed must be substantiated by test data.
6. With joints of unequal sheet thicknesses, the stress allowable shall be the one that applies to the sheet with the lower allowable.

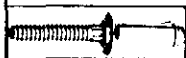
STRUCTURAL BLIND FASTENERS– BOLTS							
	BAC B30LA 80.70.6.16.1		5/32 - 3/8	ALLOY STEEL	CADMIUM	450°	HIGH STRENGTH NON-HOLE FILLING
	BAC B30LB 80.70.6.17		5/32 - 3/8	ALLOY STEEL	CADMIUM	450°	

Figure 17.613-1

B. GROUP II. These are lower strength aluminum alloy and monel blind fasteners which may be used in areas and for applications where conventional rivets cannot be used. They are subject to the same limitations as Group I fasteners and to the following restrictions taken from MS33522:

1. Do not use on control surface hinge brackets; wing or control surface attachment fittings; landing gear fittings.
2. Do not use for fluid tight joints.
3. Chemically expanding (explosive) blind rivets may be used only in all-metal or non-inflammable areas.

C. GROUP III. These are non-structural blind fasteners which may be used for lightly-loaded applications. They are subject to the same limitations as Group II fasteners.

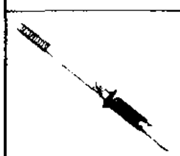
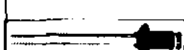
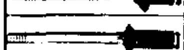
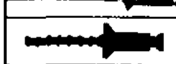
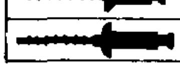
BLIND FASTENERS – RIVETS							
ILLUSTRATION	PART & PAGE NUMBER		SIZE RANGE	MATERIAL	FINISH	MAX TEMP °F	DESCRIPTION
	NAS 1398B 80.71.5.1.1		1/8 - 1/4	5056 ALUMINUM	ANODIZE	250	The minimum blind side sheet thickness allowed when using NAS 1398 or NAS 1399 blind rivets is D/4, where D equals the hole diameter. Hole filling and locked stem
	NAS 1398D 80.71.5.1.1		1/8 - 1/4	2017 ALUMINUM	ANODIZE	250	
	NAS 1398MW 80.71.5.1.1		1/8 - 1/4	MONEL	CADMIUM BARE	450 900	
	NAS 1399B 80.71.5.2.1		1/8 - 1/4	5056 ALUMINUM	ANODIZE	250	
	NAS 1399D 80.71.5.2.1		1/8 - 1/4	2017 ALUMINUM	ANODIZE	250	
	NAS 1399MW 80.71.5.2.1		1/8 - 1/4	MONEL	CADMIUM BARE	450 900	
	BAC R15EB-P 80.71.6.50		1/8 - 3/16	5056 ALUMINUM	ANODIZE	250	Non-hole filling locked stem - for thin sheet installations
	BAC R15EB 80.71.6.50		1/8 - 3/16	5056 ALUMINUM	ANODIZE	250	
	BAC R15DR 80.71.6.49		3/32	CARBON STEEL	CADMIUM	450°	Non-structural Hollow rivet used only for nut plate attachment
	BAC R15DF-P 80.71.6.49		3/32	CARBON STEEL	CADMIUM	450°	

Figure 17.613–2

17.62 THREADED FASTENERS

17.621 BOLTS

The fastener index charts (Figs. 17.6211-1 thru -4) give comparative information on usage of recommended standard bolts. For complete part numbers and dimensions see the BAC Standards, D-590. Other information may be found in the following references:

Handbook 28 Screw Thread Standards for Federal Services, 1944 plus 1950 Supplement and 1957 Amendment

MIL-S-7742 Military Specification for Screw Threads (Synopsis of H-28)

MIL-B-7838 Bolt, Internal Wrenching, 160ksi FTU

MIL-S-8879 Screw Threads, Controlled Radius Root with Increased Minor Diameter; General Specification

DM Book 81 Section 7 Thread Design Specifications

DM Book 81 Section 18 Rated Strength Data

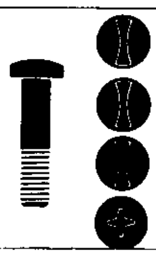
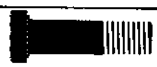
Threaded Fasteners are available in alloy steel corrosion resistant steel, and titanium.

Alloy steel bolts shall be used whenever possible in structural applications. Tensile strengths of 160 to 180 ksi and 220 ksi are available in standard bolts.

In primary structural applications, alloy steel bolts smaller than 1/4 inch diameter shall not be used unless approved by the applicable divisional staff.

Cadmium plated alloy steel bolts are limited to temperature exposures up to 450°F. High-strength alloy steel bolts are also available with platings that will withstand temperatures up to 900°F.

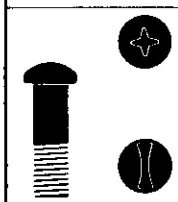
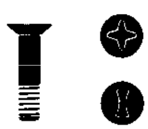
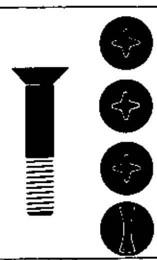
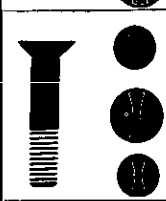
Corrosion resistant bolts are available with cadmium plated finish and passivated. CRES bolts are used in exposed areas through aluminum (plated bolts) for high temperature areas up to 1200°F (passivated finish). CRES bolts are about twice as costly as alloy steel bolts. They are presently available in strength levels up to 200ksi FTU.

Illustration	Part, Page Number and Class	Strength (Rated) 70°F Fsu	70°F Ftu	Max. Temp. °F	Size Range	Shank: Drilled	Shank: Undrilled	Head: Drilled	Head: Undrilled	Thd. Length: Long	Thd. Length: Short	Finish: Cadmium	Finish: Passivated	Finish: Dif Cad N	Finish: Cadmium Fluoborate	Material	Mating Nuts
PROTRUDING HEAD STRUCTURAL BOLTS-ALLOY STEEL																	
	BAC B30NE 80.1.6.120 ▷3 160T	95	125 / 160	450°	10-32 THRU 1-1/4	X	X	X	X	X		X				ALLOY STEEL	GROUP II GROUP III GROUP IV GROUP V
	BAC B30NF 80.1.6.121 95S	95	160	450°	10-32 THRU 1-1/4	X	X	X	X		X	X				ALLOY STEEL	GROUP II
	BAC B30NK 80.10.6.32 ▷2 156S	156	125	450° / 600°	10-32 THRU 2-12	X	X		X		X			X		MARAGING STEEL	GROUP II GROUP II (CRES)
	BAC B30NJ 80.1.6.122 ▷2 125S	125	125	450° / 800°	10-32 THRU 2-12	X	X		X		X			X		H-11 STEEL	GROUP II GROUP II (CRES)
	BAC B30FD 80.1.6.89 180T	108	180	450°	10-32 THRU		X	X	X		▷1				X	ALLOY STEEL	GROUP V
	BAC B30MT 80.1.6.119 220T	125	220	450° / 800°	10-32 THRU 1-3/4		X	X	X		▷1			X		H-11 STEEL	GROUP VII GROUP VII (CRES)
	BAC B30NG 80.1.6.123 260T	156	260	450°	10-32 THRU 1-3/4		X	X	X		▷1			X		MARAGING STEEL	GROUP VIII
	NAS 1217 80.1.5.29 ▷4 95S	95	125	450°	8-32 THRU 3/8		X		X		X	X				ALLOY STEEL ONLY	GROUP II
	NAS 1218 80.1.5.30 ▷4 160T	95	160	450°	4-40 THRU 3/8		X		X	X		X				ALLOY STEEL ONLY	GROUP V
	BAC B30EM 80.1.6.83 ▷4 160T	95	160	900°	10-32 THRU 5/16		X		X	X				X		ALLOY STEEL	BAC N10MD 80.60.6.33
	NAS 623 80.1.5.22 95S	95	125	450°	8-32 THRU 3/8		X		X		X	X				ALLOY STEEL	GROUP II
PROTRUDING HEAD STRUCTURAL BOLTS - CORROSION RESISTANT & ANTI-MAGNETIC																	
	BAC B30LJ 80.10.6.26 ▷2 95S	95	80 / 125	450° / 800°	10-32 THRU 1-1/4	X	X	X	X		X	X	X			A-286	GROUP I GROUP II (CRES)
	BAC B30LM 80.10.6.28 ▷2 ▷3 160T	95	160	250° / 450° / 600°	10-32 THRU 1-1/4	X	X	X	X	X		X	X			A-286	SELF-LOCKING BOLT GROUP V GROUP V (CRES)
	BAC B30NM 80.12.6.12 160T	95	160	450°	10-32 THRU 3/4		X		X	X		X				6AL-4V TITANIUM	GROUP V ▷5
	BAC B30NR 80.12.6.13 ▷2 95S	95	80 / 125	450°	10-32 THRU 1		X		X		X	X				6AL-4V TITANIUM	GROUP I GROUP II ▷5
	BAC B30LT 80.10.6.30 ▷2 110S	110	125	450° / 800°	10-32 THRU 3/4	X	X		X		X	X	X			A-286	GROUP II GROUP II (CRES)

▷1 FATIGUE RATED ▷2 LIMITED BY NUT CAPABILITY ▷3 AVAILABLE IN SELF-LOCKING SERIES ▷4 USE IN PERMANENT INSTALLATIONS ONLY ▷5 USE ONLY NUTS WITH DRY FILM LUBRICANT WITH TITANIUM FASTENERS

Figure 17.621-1

17.621 BOLTS (Continued)

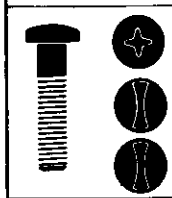
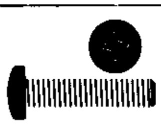
ILLUSTRATION	PART, PAGE NUMBER AND CLASS	STRENGTH (RATED) 70°F Fsu	STRENGTH (RATED) 70°F Ftu	MAX. TEMP °F	SIZE RANGE	SHANK DRILLED	SHANK UNDRILLED	HEAD DRILLED	HEAD UNDRILLED	THD. LENGTH LONG	THD. LENGTH SHORT	FINISH CADMIUM	FINISH PASSIVATED	FINISH DIF CAD N	FINISH CADMIUM FLUOBORATE	MATERIAL	MATING NUTS
PROTRUDING HEAD STRUCTURAL BOLTS - CORROSION RESISTANT & ANTI-MAGNETIC (CONTINUED)																	
	BAC B30LE 80.10.6.24 ▷2 200T	110	200	450° 800°	10-32 THRU 3/4		X	X	X	▷1		X	X			A-286	GROUP VII GROUP VII (CRES)
	BACB30MF 160T	95	160	450°	10-32 THRU 3/4		X		X	▷1		X				6AL-4V TITANIUM	GROUP V ▷5
	BAC B30LK 80.10.6.27 ▷2 95S	95	80 125	450° 800° 450° 800°	4-40 THRU 3/8	X	X		X		X	X X	X X			A-286	GROUP I GROUP I (CRES) GROUP II GROUP II (CRES)
	BAC B30NT 80.12.6.15 ▷2 95S	95	80 125	450°	4-40 THRU 3/8		X		X		X	X				6AL-4V TITANIUM	GROUP I ▷5 GROUP II ▷5
	BAC B30LN 80.10.6.29 ▷2 ▷4 160T	95	160	450° 800°	1/4 THRU 3/8		X		X	X		X	X			A-286	GROUP V GROUP V (CRES)
	BAC B30NS 80.12.6.14 160T	95	160	450°	1/4 THRU 3/8		X		X	X		X				6AL-4V TITANIUM	GROUP V ▷5
FLUSH HEAD STRUCTURAL BOLTS - ALLOY STEEL																	
	BAC B30LU 80.2.6.48 95S	95	125 160	450°	8-32 THRU 1	X	X		X	X		X				ALLOY STEEL	GROUP II AND III GROUP V
	BAC B30EL 80.2.6.30 ▷2 ▷4 95S	95	80	450°	10-32 THRU 3/4		X		X		X	X				ALLOY STEEL	GROUP I GROUP II
FLUSH HEAD STRUCTURAL BOLTS - CORROSION RESISTANT & ANTI-MAGNETIC																	
	BAC B30LR 80.11.6.23 ▷2 ▷3 95S	95	160	250° 450° 800°	8-32 THRU 1-1/4		X		X	X		X	X			A-286	Self-locking bolt Group V Group V (Cres)
	BAC B30LH 80.11.6.20 ▷2 95S	95	80 125	450° 600° 450° 800°	8-32 THRU 1-1/4	X	X		X		X	X	X			A-286	GROUP I GROUP I (CRES) GROUP II GROUP II (CRES)
	BAC B30NN 80.13.6.9 95S	95	160	450°	10-32 THRU 3/4		X		X	X		X				6AL-4V TITANIUM	GROUP V ▷5
	BAC B30LP 95S 80.11.6.22 ▷2 ▷3 ▷4	95	160	250° 450° 800	10-32 THRU 1-1/4		X		X	X		X	X			A-286	SELF-LOCKING BOLT GROUP V GROUP V (CRES)
	BAC B30LL 80.11.6.21 ▷2 ▷4 95S	95	80	450° 800°	10-32 THRU 1-1/4		X		X		X	X	X			A-286	GROUP I, GROUP II GROUP I, GROUP II (CRES)
	BAC B30MS 80.13.6.5 ▷4 95S	95	160	450°	10-32 THRU 3/4		X		X	X		X				6AL-4V TITANIUM	GROUP V ▷5
	BAC B30NU 80.13.6.10 ▷2 ▷4 95S	95		450°	10-32 THRU 3/4		X		X		X	X				6AL-4V TITANIUM	GROUP II ▷5

▷1 FATIGUE RATED. ▷2 LIMITED BY NUT CAPABILITY ▷3 AVAILABLE IN SELF-LOCKING SERIES ▷4 USE IN PERMANENT INSTALLATIONS ONLY

▷5 USE ONLY NUTS WITH DRY FILM LUBRICANT WITH TITANIUM FASTENERS

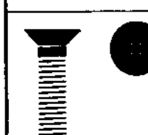
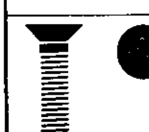
Figure 17.621-2

17.621 **BOLTS** (Continued)

ILLUSTRATION	PART, PAGE NUMBER AND CLASS		STRENGTH (RATED) 70°F Fsu	70°F Ftu	MAX. TEMP. °F	SIZE RANGE	SHANK DRILLED	SHANK UNDRILLED	HEAD DRILLED	HEAD UNDRILLED	THD LENGTH LONG	THD LENGTH SHORT	FINISH CADMIUM	PASSIVATED	DIF CAD N	CADMIUM FLUOBORATE	MATERIAL	MATING NUTS
PROTRUDING HEAD SCREWS - ALLOY STEEL																		
	MS 16998 80.1.1.13 125T		—	125	450°	6-32 THRU 5/8 PLUS 0-80		X		X	THESE FASTENERS HAVE NO GRIP	AND ARE CONSIDERED FULL THREADED	X				ALLOY STEEL	GROUP VI GROUP II
	MS 24678 80.1.1.17 160T		—	160	450°	6-32 THRU 5/8		X	X				X				ALLOY STEEL	TAPPED HOLES
	MS 21262 80.1.1.8 160T		—	160	250°	4-40 THRU 5/8		X		X			X				ALLOY STEEL	TAPPED HOLES SELF-LOCKING
	BAC S12CB 80.1.6.97 125T		—	125	450°	4-40 THRU 10-32		X		X			X				ALLOY STEEL	GROUP II
	NAS 563 SERIES 80.1.5.17 160T		—	160	450°	10-32 THRU 3/4		X	X	X			X				ALLOY STEEL	TAPPED HOLES AND INSERTS
	NAS 600 SERIES 80.1.5.18 125T		—	125	450°	4-40 THRU 3/8		X		X			X				ALLOY STEEL	GROUP II
	BAC S12BE [4] 80.1.6.81 125T		—	125	450°	2-56 THRU 3/8		X		X			X				ALLOY STEEL & CRES	GROUP II
	160T BAC S12BG [4] 80.20.6.18		—	160	250°	2-56 THRU 3/8		X		X			X				ALLOY STEEL & CRES	TAPPED HOLES SELF-LOCKING
PROTRUDING HEAD SCREWS - CORROSION RESISTANT & ANTI-MAGNETIC																		
	MS 16996 80.1.1.11 80T		—	80	700°	10-32 THRU 3/8 PLUS 0-80		X		X				X			CRES	GROUP II(CRES) GROUP VI(CRES) (0-80 only)
	MS 24673 80.1.1.14 80T		—	80	700°	10-32 THRU 3/8		X	X					X			CRES	TAPPED HOLES AND INSERTS
	MS 21295 80.1.1.9 80T		—	80	250°	4-40 THRU 3/8		X		X				X			CRES	TAPPED HOLES SELF-LOCKING
	BAC S12BE [4] 80.1.6.81 125T		—	75 / 125	700° / 800°	2-56 THRU 3/8		X		X				X			CRES	GROUP VI(CRES) (2-56 only) GROUP II(CRES)
	160T BAC S12BG [4] 80.20.6.18		—	75	250°	2-56 THRU 3/8		X		X				X			CRES	TAPPED HOLES SELF-LOCKING
	125T BAC S12CK 80.20.6.29		—	125	800°	4-40 THRU 3/8		X		X				X			CRES	GROUP II (CRES) GROUP III(CRES)

[2] LIMITED BY NUT CAPABILITY [4] USE IN PERMANENT INSTALLATIONS ONLY [5] USE ONLY NUTS WITH DRY FILM LUBRICANT WITH TITANIUM FASTENERS

Figure 17.621--3

ILLUSTRATION	PART, PAGE NUMBER AND CLASS		70°F Fsu	70°F Ftu	MAX. TEMP. °F	SIZE RANGE	SHANK DRILLED	SHANK UNDRILLED	HEAD DRILLED	HEAD UNDRILLED	THD LENGTH LONG	THD LENGTH SHORT	CADMIUM	PASSIVATED	DIF CAD N	CADMIUM FLUOBORATE	MATERIAL	MATING NUTS
FLUSH HEAD SCREWS - ALLOY STEEL																		
	NAS 514 80.2.5.2 125T		—	125	450°	4-40 THRU 3/8		X		X			X				ALLOY STEEL	GROUP II
FLUSH HEAD SCREWS - CORROSION RESISTANT & ANTI-MAGNETIC																		
	125T BAC S12ER 80.20.6.30		—	125	450°	4-40 THRU 3/8		X		X			X				6AL-4V TITANIUM	GROUP II [5]

[4] USE IN PERMANENT INSTALLATIONS ONLY [5] USE ONLY NUTS WITH DRY FILM LUBRICANT WITH TITANIUM FASTENERS

Figure 17.621-4

17.621 BOLTS (Continued)

ILLUSTRATION	PART AND PAGE NUMBER		SIZE RANGE	STRENGTH 70°F (RATED) Fsu	MATERIAL	FINISH	MAX. TEMP. °F	MATING COLLAR
TAPERED BOLTS - SHEAR TYPE								
	BAC B30KD 80.2.6.42		3/16 - 1	108 110	ALLOY STEEL A 286	CADMIUM PASSIVATED	450° 800°	BACN10HY(M) 80.60.6.50 BAC N10HY(A) 80.60.6.50
	BAC B30MU 80.13.6.6		3/16 - 1	95	6AL-4V TITANIUM	CADMIUM	450°	BAC N10HY(M) 80.60.6.50
	BAC B30PB 80.2.6.51		3/16 - 1	108 110	ALLOY STEEL A 286	CADMIUM PASSIVATED	450° 800°	BACN10HY(M) 80.60.6.50 BAC N10HY(A) 80.60.6.50
	BAC B30MW 80.12.6.9		3/16 - 1	95	6AL-4V TITANIUM	CADMIUM	450°	BAC N10HY(M) 80.60.6.50
TAPERED BOLTS - TENSION TYPE								
	BAC B30PD 80.2.6.53		3/16 - 1	108	ALLOY STEEL	CADMIUM	450°	BACN10RD 80.60.6.57.1
	BAC B30PD(A) 80.2.6.53		3/16 - 1	110	A 286	Cadmium Silver	450° 900°	BACN10RD(AM) 80.60.6.57.1 BACN10RD(A) 80.60.6.57.1
	BAC B30PE 80.1.6.126		3/16 - 1	108	ALLOY STEEL	CADMIUM	450°	BACN10RD 80.60.6.57.1
	BAC B30PE(A) 80.1.6.126		3/16 - 1	110	A 286	Cadmium Silver	450° 900°	BACN10RD(AM) 80.60.6.57.1 BACN10RD(A) 80.60.6.57.1

Figure 17.621-5

17.6211 TITANIUM FASTENERS

R A. Comparison of titanium and steel

TITANIUM-- STEEL COMPARISON		
Item	Titanium	Steel
Weight	.163 Lbs/Cu in	.284 Lbs/Cu in (74% heavier)
Corrosion Resistance	Equal to CRES	Cadmium plated steel not as good as titanium
Galvanic Corrosion	Equal to Cadmium plate	Cadmium plate - Fair
Magnetic Permeability, μ	1.00005	Alloy Steel = High 302 CRES = 1.003 304 CRES = 1.020 A286 = 1.007
Alloy	6AL-4V	See procurement specs.
Temp Limits	450° (Limit of Cadmium Plate)	450°F (Limit of Cadmium plate)
Quality Control	Equal to steel plus fatigue tests	See procurement specs for requirements.

Figure 17.6211-1

B. 1. General Information

1. Drawings shall show fastener installation per Boeing process specifications BAC 5004, BAC 5009 and BAC 5054 as applicable. Drawings should specify that the torque for nuts used on titanium bolts be in accordance with BAC 5009.
2. Titanium, rubbing or sliding against itself or many other materials, such as alloy steels and corrosion resistant steels, will gall readily. This results in the creation of severe stress risers tending to early fastener failure. Avoid designs which result in motion on the bolt surface.
3. Titanium bolts shall not be used in close reamed holes in steel or composite steel-aluminum structure where tightening from the bolt head side is required. Galling of the fastener shank usually results in these installations and creates stress risers leading to early bolt failure.

C. Usage R

Titanium fasteners are primarily used where weight is the prime consideration (see Figure 17.6211-1 for weight comparison). Their use is subject to the following limitations:

1. Only titanium fasteners shown in Figure 17.621-1, 2, 4, and 5 shall be used. These range from .19 inch diameter through 1 inch diameter.
2. Fasteners of .19 inch diameter shall be used only if the cost/lb. conforms to the specific requirement of the Project involved.
3. The rated ultimate strengths for titanium fasteners shall be in accordance with 18.21 and 18.22.
4. The joint strength and edge margin tables in 18.23-1, 18.23-3, and 18.23-4 shall be used for titanium fastener designs as applicable.
5. BACB30MR, titanium tension fasteners, from .25 inch diameter through .75 inch diameter, may be used in primary tension applications.
6. The use of titanium in contact with liquid oxygen is prohibited since either the presence of fresh surface, as produced by tensile rupture, or impact may initiate a violent reaction. Impact of the surface in contact with liquid oxygen may result in a reaction at energy levels as low as 10 ft-lb. In gaseous oxygen, and from temperatures of -250°F and above, a partial pressure of about 50 psi is sufficient to ignite a fresh titanium surface.
7. Titanium fasteners shall not be used for single joint connections such as control rod and attachment, structural pin joints, or applications where the fastener is subjected to rotating or sliding motion because of potential fretting or galling of the titanium bolt.
8. Titanium bolts shall be used only in conjunction with steel nuts that are lubricated with a molybdenum disulfide dry-film meeting the requirements of BMS 3-8. The proper nut combinations are tabulated in Figure 17.621-1, 2, 4, and 5.
9. Collars for shear type and tension type titanium hex drive bolts are prescribed in Figure 17.612-1 and 2.
10. Nuts for Taperlok fasteners are prescribed in Figure 17.621-5.

17.6212 SELF-LOCKING BOLTS

Self-locking bolts shall be used in installations which do not allow the use of self-locking or castellated nuts (tapped holes, etc.).

A. The locking action of self-locking bolts may be achieved by two methods:

1. A plastic insert installed on the threaded portion of the bolt (the use of this type is limited to temperature environments upto 250°F).

2. Mechanical displacement of the thread pitch diameter (the temperature limitations of this type are controlled by the bolt material or finish).

Both types of self locking bolts obtain the locking action from friction created by the interference between the mating threads. Locking torque and other performance requirements are subject to conformance to MIL-F-18240.

B. Self Locking Externally Threaded Fasteners shall be Subject to the Following Limitations:

1. Fasteners shall be selected and used in a manner that will permit functional and dimensional interchangeability with a part that has only the attributes described and defined by the applicable standards and specifications.

2. Fasteners shall be used only in applications that permit engagement with complete internal threads over the minimum external thread.

3. Self-locking externally threaded fasteners shall not be used as follows:

   a. At joints in control systems, at single attachments, or where loss of the fastener would affect safety of flight.

   b. As an axis of rotation for another part unless the fastener is held by a positive locking device that requires shearing or rupture of material before torsional loads would be applied to the fastener in such a manner as to relieve the initial stresses of the assembly or turn the fastener loose.

   EXAMPLE: Bearings, Bushings, Clamp-up bushings, Pulleys, Cranks, Levers, Linkages, Hinge pins, Axles, Shafts, Spindles, Gears, Cams, Cam Followers, Sliding mechanisms, and Pivot points.

   c. At any single bolted structural joint which serves as a primary load path, the failure which would endanger the safety of personnel or would render the equipment inoperative or cause its destruction.

   EXAMPLE: Fixed joints, Tie rods, Struts (fixed length members) Wing attachments to fuselage, Stabilizer surface attachments, Longeron joints, Alighting gear joints, and Engine mounts.

4. Fasteners that contain a self locking element design which incorporates an insert or part that is non-metallic shall not be used in parts where the locking element will encounter keyways, slots, cross-holes or thread interruptions.

5. Fasteners shall not be used in assemblies which require that fasteners be removed for routine servicing purposes more times than the number of removals specified in the approved locking element or fastener specification or standard.

6. Fasteners shall not be used on jet engine aircraft in locations where a loose fastener could fall or be drawn into the engine air intake scoop.

7. Fasteners that have had the locking element reworked or reprocessed by other than an approved manufacturer shall not be used by contractors or field maintenance personnel of the services.

8. Self-locking elements classified as 250°F are intended for use at ambient temperature conditions (-65°F to 250°F) and are designed to function satisfactorily at temperatures thru that range.

9. When fasteners are used in applications requiring controlled torque, such as clamping molded gaskets in fuel cells, consideration must be given to the maximum and minimum locking torque permitted by the locking element or fastener specification or standard approved for use.

17.6212 SELF-LOCKING BOLTS (Continued)

10. For the self-locking element designs that incorporate an insert or part that is non-metallic the entering end of threaded holes used in conjunction with self-locking externally threaded fasteners shall be countersunk 90 to 110 degrees. This countersink shall have a minimum diameter .015 in. larger than the major thread *diameter of fastener*. This is to prevent first thread from cutting the self-locking element.

11. Unthreaded holes or portions of holes thru which the locking device of fastener *must pass shall have a minimum* diameter sufficient to clear the locking element if the specifications of the fastener permit the locking device to protrude beyond the maximum major diameter of the thread.

12. Self-locking externally threaded fasteners shall not be used with plain nuts, castellated nuts, or self-locking nuts.

17.6213 NON-STANDARD THREADED FASTENERS

A. DEFINITION

Bolts, screws and threaded pins which are unavailable under MS, NAS or BAC standards because of one or more distinguishing features are classified as non-standard.

B. USAGE

1. Avoid the design of special fasteners for the following reasons: Compared to standard fasteners, higher costs are normally incurred in procuring and using non-standard items because of low volume, special identification and inspection procedures and *possible requirements for customer approval*. In some instances, development and qualification testing are necessary.

   Customer procurement of replacement parts becomes more complex and costly.

2. When usage of non-standard fasteners is necessary, their design shall be directed toward achieving the maximum degree of similarity to their standard counterparts to take advantage of existing supplier facilities and technology available from the production of similar standard parts.

   Prudent selection of the part characteristics and manufacturing options allowed will usually result in higher quality parts at the minimum cost.

C. DESIGN PRACTICE

Non-standard bolts, screws and pins shall be designed in accordance with the following considerations:

1. Specifications

   Bolts, screws and pins which are similar in function, strength, performance rating and geometry to standard bolts shall, to the extent practical, be designed to utilize the corresponding procurement specification for standard bolts selected from Figure 17.6213-1. Where MIL-S-7742 threads are called out, show threads in accordance with MIL-B-7838 as allowable option. It is not permissible *to substitute MIL-S-7742 threads for MIL-B-7838* threads. For processes which must vary from the bolt specification (heat treatment, plating, etc.), call out a specification in accordance with Procedures Manual 9481 Section 10.092. See Section 18.21 for description of various thread forms.

2. Highly reliable bolts and pins

   All ferromagnetic bolts and pins, which are used in areas where the failure of such a part would endanger personnel or would become a hazard to the functional operation of the vehicle, are *classified as "highly reliable"* and must undergo magnetic particle inspection per BAC 5424, Class A. A special note on the drawing is necessary to indicate such a requirement.

   Avoid hollow shank fuse bolt design because *it has proven im*practical to control processing (particularly heat treatment) to ar adequate leve' to maintain failure strength of fuse within narrov design limits. Whenever possible, use conventional bolt desigr as fuse bolts. Allow a minimum tensile strength variation o ± 15,000 psi.

3. *Materials*

   Although some of the specifications listed in Figure 17.6213- provide a larger schedule of materials, it is desirable to stan ardize and limit the materials selection to only those shown i the Figure 17.6213-1. See item 7.c for drawing requirement

17.6213 NON-STANDARD THREADED FASTENERS (Continued)

4. Forged and rolled features

   Forged heads, rolled head to shank fillet radius, and rolled threads are required for high strength and fatigue applications. The use of headed blanks is preferred. Where strength and/or fatigue considerations permit, allow machining from bar stock. A note allowing for optional machining should appear on the drawing.

5. Standard wrenching

   Design permitting, non-standard bolts should utilize standard wrenching by specifying head dimensions which conform to the latest bolt standards. This will avoid added fabrication and maintenance costs.

6. Marking

   Non-standard bolts shall be marked in accordance with PM 94B1, Section 5.011. On fasteners, head marking is normally raised or depressed on protruding heads and depressed on flush heads. Head marking shall include manufacture's identification.

7. Drawings

   a. Separate drawings

   Non-standard bolts shall be detailed on separate drawings per PM 94B1 Section 1.031. All differences from the standard shall be detailed on the drawing.

   b. Drawing type

   Non-standard bolts whose variation from a standard is completely designed by Boeing, may be released by the project on a production release drawing.

   Non-standard bolts with some features which are vendor designed should be released on specification control drawings (see PM 94B1 section 10 and 11.

   Non-standard bolts with a requirement that absolute control of replacement bolts (after delivery of end product to customer) be from specified sources, should be released on a source control drawing.

   c. Material column

   For non-standard bolts which are essentially modified standard bolts, the material column should only show materials selected from Figure 17.6213-1, whereas highly reliable parts are limited to H-11 (AMS 6485) or 4340M (BMS 7-26).

   d. Stock size

   It is preferable to make non-standard bolts from headed blanks with an option for machining from bar stock. It is therefore desirable to indicate a "suggested stock size" for the optional machining process in the stock size column.

   e. Source control

   If it is required to limit the sources for reasons of special manufacturing processes, qualification tests, etc., a note should appear on the drawing as follows:

   Procure from XYZ Bolt Company, Address; City, State.

OUTLINE FOR THE DESIGN OF SPECIAL BOLTS AND PINS

H.T. Range (ksi)	Material ②	Application	Procurement Spec.	Thread Spec.	Type of Finish ①
160 - 180	④ 4340, 8740	Tension or Shear	BPS-F-69	MIL-S-7742 MOD	QQ-P-416 Type II, Cl.3
180 - 200	④ 4340, 8740	Tension or Shear	BPS-F-69	MIL-S-8879 MOD	Cad. Fluob. per NAS672 or AMS2416
220 - 240	H-11	Tension or Shear	BPS-F-69	MIL-S-8879 MOD	
270 - 300	4340M	Tension or Shear	③	MIL-S-8879 MOD	BAC5804
160 - 180	A - 286 CRES	Tension or Shear	BPS-F-69	MIL-S-7742 MOD	QQ-P-416 or Passivated
200 - 220	A - 286 CRES	Tension or Shear	BPS-F-69	MIL-S-8879 MOD	

NOTE: The use of headed blanks is preferred.

Where strength and/or fatigue considerations permit, allow machining from bar stock.

① Temperature limitation 450°F. For temperatures up to 900°F use AMS 2416 finish. Other finishes may be specified if needed.

② Materials Specifications: 4340 per MIL-S-5000, 8740 per MIL-S-6049, AMS6322, 4340M per BMS 7-26Cl.2. A-286 per AMS5737, H-11 per AMS6487

③ Consult Staff Unit for recommendations.

④ Use AISI 8740 or 4340 for bolt sizes through 5/8 and AISI 4340 only for sizes over 5/8.

Figure 17.6213-1

17.6214 SPECIALLY SURFACED STEEL BOLTS

Specially surfaced steel bolts, pins and studs shall be used for applications where galling would occur with standard cadmium plated steel bolts. See Book 81, Section 14 for recommended surface treatments.

17.6215 BOLTS WITHOUT COTTER HOLES

Bolts without cotter holes shall be called for when used with self-locking nuts. See the code or example of part number on NAS and BAC standard pages for proper designation of bolts without cotter holes.

17.6216 OVERSIZE BOLTS

See BAC 5004 and BAC 5009 for a list of oversize bolts, lockbolts, hi-shear rivets and hole sizes.

Oversize bolts shall be used for repair work only. They shall not be used in new design, and shall not be called for on drawings. However, fittings should be designed large enough to permit the use of oversize bolts in the shops or replacement by the next larger size standard bolt in service repair. Clearance and edge margin for the next larger size standard bolt must be considered in order to avoid replacement of an entire fitting due to damage of a bolt hole.

17.6217 RADIUS CLEARANCE

Due to the large head to shank radii on some protruding head fasteners, (e.g., NAS 1303 Series, BACB30MT, BACB30LM Series, etc.), a clearance problem exists. Radius clearance may be obtained by countersinking the structure or adding a washer under the head (preferred).

For structural reasons a clearance shall be provided for Class I and Close Ream holes as described below. Radius clearance for Class II and Class III holes is not a structural problem, however the design should provide ample clearance.

Approximately .008 chamfer can be obtained by noting:

> BREAK SHARP EDGES OF FASTENER HOLES
> ON ENTERING SIDE PER BAC 5300

Where washers are used to provide clearance:

Use an .063 thick aluminum washer (AN 960) if loss of preload is of no concern. Use a countersunk steel washer MS 20002C, BAC W10AK-C) if loss of preload is of concern. Drawing notes shall specify the direction of countersink face to mate with the fastener radius.

BACW10BP washers may be used under the head of BACB30MT bolts.

17.6218 BOLTED SLOPLING SURFACES

Self aligning washers (BAW10BT) shall be used on bolted sloping surfaces. The maximum slope is 8° from perpendicularity with the axis of the bolt hole.

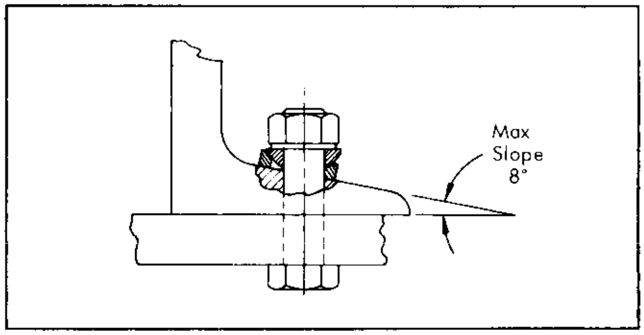


Figure 17.6220-1

17.622 SCREWS

17.6221 TAPPING SCREWS

A. LIMITATIONS for Use per AND 10087 (Airborne Application) Tapping Screws Shall Not be Used Under the Following Conditions:

1. As fasteners for the fabrication of primary structure.
2. Where the joint is subject to rotation which would tend to loosen the screw.
3. As fasteners for structure or accessories where failure might result in danger or damage to the airplane or personnel.
4. Where loss would permit the opening of a joint to air flow or leakage.
5. Where required to cut their own threads and are subsequently subject to replacement without increase in diameter size.
6. Where subject to corrosive mediums, such as exhaust gases, salt spray, etc.

B. CLEARANCE HOLES.

Clearance holes are used as necessary to permit parts to be drawn together and to allow tolerances for matching hole patterns. See Figure 17.6221-1.

17.6221 (Continued)

SIZE	MAJOR DIAMETER	CLEARANCE HOLE	PROTRUDING LENGTH	
			THREAD FORMING SCREW	THREAD CUTTING SCREW
No. 2	.086	$.106^{.111}_{.106}$	①	.16
No. 4	.112	$.128^{.133}_{.128}$	.27	.21
No. 6	.138	$.157^{.167}_{.157}$	.32	.25
No. 8	.164	$.182^{.192}_{.182}$	.38	.25
No. 10	.190	$.209^{.219}_{.209}$	.46	.32
No. 12	.216	$.234^{.244}_{.234}$	.49	①
No. 14	.242	$.261^{.276}_{.261}$	.55	①
1/4	.25	$.261^{.276}_{.261}$	①	.37
① SCREWS NOT AVAILABLE IN THIS SIZE				

Figure 17.6221-1

C. LENGTH.

The length of tapping screws installed in sheet assemblies shall be such that at least two complete threads of the grip extends beyond the assembly. Select standard lengths by adding the "protruding lengths" shown in Figure 17.6221-1 to the material thicknesses. These "protruding lengths" include allowance for minus tolerances on the screw. Standard screw lengths are: .250, .312, .375, .50, .62, .75, .875, 1.00, 1.25, 1.50, 1.75, and 2.00. Both length and diameter are indicated by the MS dash number. In MS 24618-21, "21" indicates a diameter of .138 (No. 6 screw) and a length of .75.

D. MATERIAL AND CORROSION PREVENTION.

Steel screws are cadmium plated. Corrosion resisting steel screws are passivated. Tapping screws used in aluminum alloys shall be installed with a phenolic or aluminum washer. The washer and screw shall be coated with zinc chromate paste before insertion so as to completely seal the connection.

17.62211 THREAD FORMING SCREW

A. TYPE.

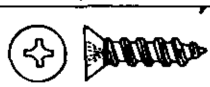
① TYPE A (STD PAGE NO. 80.30.1)			
MS24615	STEEL	82	
MS24616	CRES	CSK	
MS24617	STEEL	Round	
MS24618	CRES	Head	
① SPACED THREAD WITH GIMLET POINT			

Figure 17.62211-1

B. RECOMMENDED USES.

1. In place of wood screws.
2. In light non-structural assemblies to reduce cost and weight.
3. In wood or plastics and in combinations of wood, plastics and metals.

C. HOLE SIZES.

1. Interference hole sizes, which are sufficiently undersize to secure the screw, are listed in MS24631 (80.30.1.9). These are similar to drill sizes and should be shown in the callout as the nominal size. Fixture drilling tolerances per DM Book 81, Section 7.411 shall be added to obtain the plus tolerance. An example for a No. 8 Type A screw in .032 aluminum alloy sheet is $.116^{.118}_{.116}$
2. Clearance hole sizes are shown in Figure 17.6221-1.

17.62212 THREAD CUTTING SCREW

A. TYPES. Thread cutting screws have ends of Type D, F, G, or T, at the manufacturer's option. Do not specify.

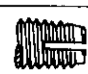
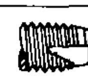
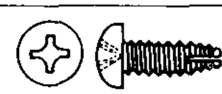
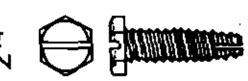
① D 	F 	G 	T 
MS24627 (80.30.1)			
MS24627	STEEL	82° CSK	
MS24628	CRES		
MS 24629	STEEL	PAN	
MS 24630	CRES		
BAC S12BN (80.30.6.16)	STEEL	HEX SLOT OPT'N	
① MACHINE SCREW THREADS WITH FLUTED ENDS			

Figure 17.62212-1

B. RECOMMENDED USES

1. For attachment of name plates, etc., where rivets are impractical due to removal and replacement of plates. Replacement of screws requires the use of the next larger diameter screw.
2. For attachment of name plates in blind holes.

C. HOLE SIZES

1. Interference hole sizes are listed in MS24634 (80.30.1.10). These are similar to drill sizes and should be shown in the callout as the nominal size. Fixture drilling tolerances, per Book 81 Section 7.411 shall be added to obtain the plus tolerance.

   An example for No. 6 Thread Cutting Screw in .063 aluminum alloy sheet is $.110^{.112}_{.110}$
2. Clearance hole sizes are shown in Figure 17.6221-1.

17.6222 DRIVE SCREWS

MS21318(80.50.1.1)is a round head, carbon steel, cadmium plated screw. Insertion is by driving without wrenching.

A. RECOMMENDED USES: Drive screws may be used to attach nameplates not subject to repeated removal and replacement.

B. LIMITATIONS. Do not drive in metals too thin to resist damage. Sheet thickness equal to screw diameter is considered minimum.

C. SIZE. The recommended size for use with name plates is No. 4 which has a maximum diameter of .114

The available lengths are as follows: MS21318-19(.12), -20(.19), -21(.25), -22(.31), -23(.38).

Interference holes are .104 $^{.109}_{104}$

For other drive screw sizes see MS21318

17.6223 WOOD SCREWS

Wood screws are obsolete for new design. Use Type A Thread Forming Screws.

17.6224 SET SCREWS

Figure 17.6224-2 shows headless set screws with hex socket and with three point types. Screws with hex socket are preferred for Boeing design to standardize installation tools. The point types are illustrated and described below.

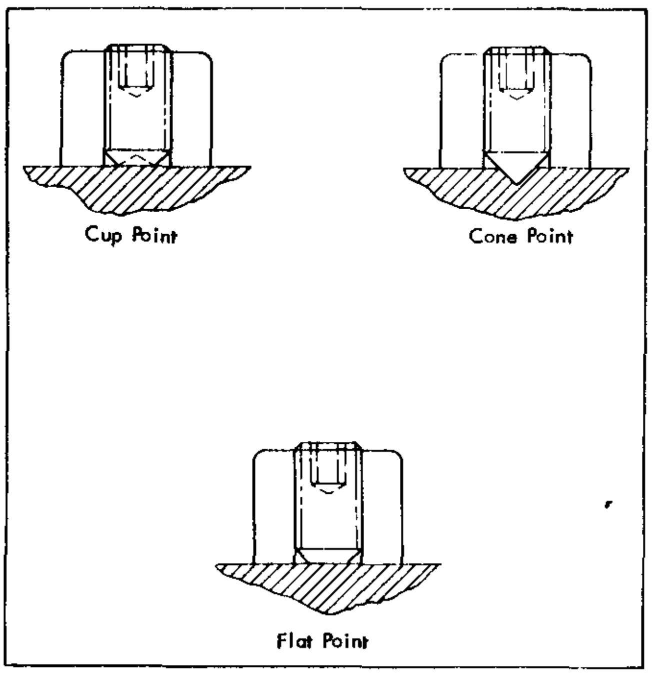


Figure 17.6224-1

NAS 1081 provides self-locking set screws with flat or cone point.

A. CUP POINT. The cup point is the preferred point for general use. This point is the easiest to procure from commercial sources. It may be used for permanent or simi-permanent location of machine parts where cutting of the shaft by the sharp point is not objectionable. It should not be used against hardened shafts and is seldom spotted in.

B. CONE POINT. The cone point is especially adapted for permanent location of a machine part. It may be used against hard or soft shafts and should always be spotted in. The included angles of the spot and point should be the same.

C. FLAT POINT. The flat point is to be employed where frequent resetting of the point is required with the least possible damage to the surface against which the point bears. It may be used against hardened shafts but is not suitable for spotting in.

17.6224 **SET SCREWS** (Continued)

ILLUSTRATION	PART & PAGE NUMBER		SIZE RANGE	MAX TEMP°F	FINISH	DESCRIPTION
SET SCREWS — ALLOY STEEL						
	MS 51966 80.20.1.12.1		0-80 THRU 1/2	450	CADMIUM	FLAT POINT
	MS 51974 80.20.1.14.1		2-64 THRU 1/2	450	CADMIUM	CONE POINT
	MS 51963 80.20.1.9.1		2-56 THRU 1/2	450	CADMIUM	CUP POINT
	MS 51965 80.20.1.11.1		2-56 THRU 1/2	450	CADMIUM	FLAT POINT
	MS 51973 80.20.1.13.1		2-56 THRU 1/2	450	CADMIUM	CONE POINT
	MS18063 80.20.1.28.1		4-40 THRU 1/2	250	CADMIUM	CUP POINT SELF-LOCKING
	MS18065 80.20.1.30.1		4-40 THRU 1/2	250	CADMIUM	FLAT POINT, SELF-LOCKING
	MS18067 80.20.1.32.1		4-40 THRU 1/2	250	CADMIUM	CONE POINT, SELF-LOCKING
SET SCREWS-CORROSION RESISTANT & ANTI-MAGNETIC						
	MS 51023 80.20.1.5.1		0-80 THRU 1/2	350	PASSIVATED	CUP POINT
	MS 51038 80.20.1.8.1		0-80 THRU 10-32	350	PASSIVATED	CONE POINT
	MS 51021 80.20.1.4.1		2-56 THRU 1/2	350	PASSIVATED	CUP POINT
	MS 51029 80.20.1.6.1		2-56 THRU 1/2	350	PASSIVATED	FLAT POINT
	MS18064 80.20.1.29.1		4-40 THRU 1/2	250	PASSIVATED	CUP SELF-LOCKING
	MS18066 80.20.1.31.1		4-40 THRU 1/2	250	PASSIVATED	FLAT POINT, SELF-LOCKING
	MS18068 80.20.1.33.1		4-40 THRU 1/2	250	PASSIVATED	CONE POINT, SELF-LOCKING

Figure 17.6224-2

17.623 NUTS

A. CONTROL SYSTEM APPLICATION

1. CLAMP UP. Use only all metal self-locking nuts on bolts that are used:

    a. To clamp up on the inner races of bearings and/or bushings.

    b. Throughout the power plant control systems in all clamp up applications.

NOTE: On steel alloy bolts use steel alloy nuts such as, BACN10JC or BACN10GW; and, on CRES bolts use only CRES nuts such as, BACN10JC*C or BACN10GW*A (* dash number).

2. UNCLAMPED. Use non-self-locking nuts with a separate locking feature such as castellated nuts and cotter pins on bolts for unclamped static or rotary joints with bushings or bearings.

B. LIMITATIONS APPLICABLE TO SELF-LOCKING NUTS

1. Nuts of the No. 10 and 1/4 sizes shall be used only with bolts, screws, or studs that have not been drilled for cotter pins.
2. Corrosion-resistant steel self-locking nuts shall be used only with corrosion resistant steel bolts or screws.
3. Round or chamfered end bolts, studs, or screws must extend at least the full round or chamfer through the nut. Flat end bolts, studs, or screws must extend at least 1/32 inch through the nut.
4. Plate nuts shall be installed with rivets, screws, or projection spotwelding. If projection spotwelding is used, control shall be maintained in order that removal, by drilling out the welds, permits replacement with standard drilled plate bolts.
5. Nuts which are attached to the structure shall be attached in a positive manner to eliminate the possibility of their rotation or misalignment when tightening is to be accomplished by rotating the bolts or screws. The manner of attachment shall permit removal without injury to the structure and permit replacement of the nuts.
6. All self-locking nuts that have had the locking element reworked or reprocessed by other than a nut manufacturer shall not be used by contractors or field maintenance personnel of the services.
7. Special nuts, which depend on friction for their anchorage and torsional rigidity, such as clinch nuts, single-rivet plate nuts, and similar devices, are not acceptable for use in aircraft structural applications. They may be used on aircraft equipment and component parts, such as instrument mountings and electrical equipment.
8. Self-locking nuts shall not be used in conjunction with bolts or screws on jet engine aircraft in locations where the loose nut, bolt, or screw could pull, or be drawn into the engine air intake scoop.

17.6231 NUT USE CHARTS

The following charts of nuts are divided into nine groups. These groups are determined by thread height, material, and strength.

See Figures 17.621-1 through 17.621-4 to determine nut usage for particular bolts.

17.6231 NUT USE CHARTS (Continued)

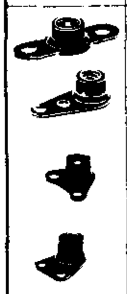
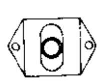
ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	ALLOY STEEL	CRES	DESCRIPTION
GROUP I 80 KSI - SHORT THREAD					
	BAC N10JD 80.60.6.53.	10-32 THRU 1-1/4 - 12	X	X	CASTELLATED, HEX 450° AND 900°
	BAC N10JC 80.60.6.52.	1/2-20 THRU 2-12	X	X	HEX, SELF-LOCKING LOW HEIGHT 450°, 900°F
GROUP II 125 KSI - SHORT THREAD					
	BAC N10JC 80.60.6.52	4-40 THRU 7/16-20	X	X	HEX, SELF-LOCKING LOW HEIGHT 450°, 900°F
	BAC N10HY 80.60.6.50	10-32 THRU 1-12	X	X	12 POINT SELF-LOCKING CAPTIVE WASHER
	BAC N10JP 80.62.6.122	4-40 THRU 5/6 - 24	X	X	MINIATURE NON-FLOAT TWO LUG 450°F, 800°F
		4-40 THRU 5/16 - 24	X	X	ONE LUG 450°, 800°F
		4-40 THRU 5/16 - 24	X	X	CORNER TYPE 450°F, 800°F
		10-32 THRU 5/16 - 24	X	X	SHORT LUG TYPE 450°F, AND 800°F
	BAC N10JY 80.62.6.129	6-32 THRU 1/4 - 28	X	X	TWO LUG FLOATING CAPPED 450°F, 800°F
	BAC N10KA 80.62.6.131	10-32 THRU 3/8 - 24	X	X	TWO LUG PLAIN BASE CAPPED 450°F AND 800°F
		6-32 THRU 3/8 - 24	X	X	TWO LUG FLOATING BASE CAPPED 450°F AND 800°F
		10-32 THRU 3/8 - 24	X	X	ONE LUG FLOATING BASE CAPPED 450°F AND 800°F
	BAC N10JN 80.62.6.121	4-40 THRU 5/16 - 24	X	X	MINIATURE - FLOATING PLAIN BASE 450°F, 800°F
	BAC N10JR 80.62.6.124	4-40 THRU 3/8 - 24	X	X	NON-FLOATING TWO LUG PLAIN BASE 450°F AND 800°F
		4-40 THRU 3/8 - 24	X	X	FLOATING TWO LUG 450°F, 800°F
		8-32 THRU 5/16 - 24	X	X	NON-FLOATING TWO LUG 100° C'SINK 450°F AND 800°F
	BAC N10MX 80.62.6.113	1/4-28 & 5/16 -24	X		.250 LATERAL FLOAT FROM CENTER .020 MINIMUM LONGI-TUDINAL FLOAT 450°

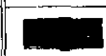
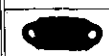
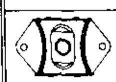
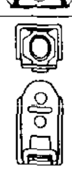
ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	ALLOY STEEL	CRES	DESCRIPTION
GROUP II 125 KSI SHORT THREAD (CONTINUED)					
	BAC N10KB 80.62.6.132	6-32 THRU 3/8 - 24	X	X	NON-FLOAT ONE LUG PLAIN BASE 450°F AND 800°F
		4-40 THRU 3/8 - 24	X	X	FLOATING ONE LUG 450°F AND 800°F
		8-32 THRU 5/16 - 24	X	X	NON-FLOAT ONE LUG 100° C'SINK 450°F AND 800°F
	BAC N10KF 80.62.6.135	6-32 THRU 3/16 - 20	X	X	NON-FLOAT CORNER PLAIN BASE 450°F AND 800°F
		8-32 THRU 5/16 - 24	X	X	NON-FLOAT CORNER 100° C'SINK 450°F AND 800°F
	BAC N10JQ 80.62.6.123	10-32 THRU 5/16 - 24	X	X	MIN-FLOATING TWO LUG DEEP C'BORE 450°F AND 800°F
	BAC N10KD 80.62.6.133	1/4 - 28	X	X	LARGE AXIAL FLOAT TWO LUG PLAIN AND DEEP BORE 450° AND 800°F
	BAC N10KH 80.62.6.137	10-32	X	X	FLOATING ONE LUG SIDE BY SIDE RIVET HOLES 450°F AND 800°F
	BAC N10JU 80.62.6.125	10-32	X	X	FLOATING TWO LUG CURVED BASE 450°F, 800°F
	BAC N10JS 80.65.6.76	10-32 THRU 5/16 - 24	X	X	FLOATING ONE LUG AND TWO LUG DEEP C'BORE 450°F, AND 800°F
	BAC N10JT 80.65.6.77	10-32 THRU 5/16 - 24	X	X	SELF-ALIGNING TWO LUG FLOATING 450°F AND 800°F
	BAC N10PD 80.65.6.52	10-32 THRU 1/2 - 20	X		SELF-ALIGNING SPHERICAL BASE 250°F AND 450°F
	BAC N10MT 80.65.6.60	10-32 THRU 3/8 - 24	X		SELF-ALIGNING SPHERICAL BASE 450°F
	BAC N10KC 80.65.6.78	10-32 THRU 3/8 -24	X	X	NON-FLOAT ONE LUG, TWO LUG AND CORNER DEEP C'BORE COLOR CODED 200°F WITH ALUMINUM SHELL 450°F WITH STEEL SHELL
	BAC N10FX 80.67.6.13	6-32 THRU 1/4 - 28	X		CLIP ON NUT FOR PLAIN AND DIMPLED HOLES. DIMPLE PART AVAILABLE IN 10-32 SIZE ONLY 450°F
	BAC N10GF 80.62.6.64	10-32 THRU 1/4 - 28	X		NUT PLATE SELF-LOCKING, FLOATING, SPRING LOADED 450°F
	BAC N10KJ 80.66.6.44	6-32 THRU 10-32	X	X	MINIATURE, RIGHT ANGLE, FLOATING 450°F, 800°F
	MS 21209 80.100.1.2	4-40 THRU 1 - 12		X	HELICOIL INSERT 450°F

Figure 17.6231-1

17.6231 NUT USE CHARTS (Continued)

GROUP III 125 KSI - LONG THREAD

ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	MATERIAL ALLOY STEEL	MATERIAL CRES.	DESCRIPTION
	BAC N10R 80.60.6.3	6-32 THRU 1/2 - 20	X		CAP NUT 250°F OR 450°F
		10-32 THRU 5/16 - 24	X	X	TWO LUG FLOATING REMOVABLE NUT VARIABLE C'BORE 450°F AND 800°F
	BAC N10KE 80.62.6.134	10-32 THRU 1/4 - 28	X	X	ONE LUG FLOATING REMOVABLE NUT VARIABLE C'BORE 450°F AND 800°F
		10-32 THRU 5/16 - 24	X	X	CORNER FLOATING REMOVABLE NUT 450°F & VARIABLE C'BORE 800°F
	BAC N10JV 80.62.6.126	6-32 THRU 3/8 - 24	X	X	NON-FLOAT CAPPED TWO LUG 450°F AND 800°F
	BAC N10JW 80.62.6.127	6-32 THRU 5/16 - 24	X	X	NON-FLOAT CAPPED ONE LUG 250°F, 450°F AND 800°F
		10-32 THRU 7/16 - 20	X	X	FLOATING CAPPED SELF-SEALING-FUEL RESISTANT TWO LUG 250°F
	BAC N10JZ 80.62.6.130	10-32 THRU 5/16 - 24	X	X	FLOATING CAPPED SELF-SEALING NON-FUEL RESISTANT CORNER STYLE 450°F
		10-32 THRU 5/16 - 24	X	X	FLOATING CAPPED SELF-SEALING, FUEL RESISTANT TWO LUG LOW MAGNETIC 250°F
	BAC N10JX 80.62.6.128	6-32 THRU 5/16 - 24	X	X	NON-FLOAT CAPPED CORNER 250°F, 450°F AND 800°F
	MS 21209 80.100.1.2	4-40 THRU 1-12		X	HELICOIL INSERT 450°F

GROUP IV 160 KSI - LONG THREAD

ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	MATERIAL ALLOY STEEL	MATERIAL CRES.	DESCRIPTION
	BAC N10KG 80.62.6.136	1/4 - 28 THRU 9/16 - 18	X	X	NON-FLOATING TWO LUG 250°F 1/4 - 28 THRU 1/2 - 12 CAN BE CODED FOR 450°F & 800°F
	BAC N10JD 80.60.6.53	10-32 THRU 1-1/4 - 12	X	X	CASTELLATED, HEX 450°F 800°F
	BACN10RD 80.60.6.57.1	10-32 THRU 1-12	X	X	12 POINT, CAPTIVE WASHER 450°F, 600°F 900°F
	BACS13BE 80.100.6.23	8-32 THRU 1/2-20	X		THREADED INSERT LIGHT WEIGHT 450°
	BACS13BF 80.100.6.24	8-32 THRU 1-12	X		THREADED INSERT HEAVY DUTY 450°

GROUP V 180 KSI - LONG THREAD

ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	MATERIAL ALLOY STEEL	MATERIAL CRES	DESCRIPTION
	NAS 577 80.65.5	1/4 -28 THRU 1-1/2 -12	X		BARREL NUT FLOATING 450°F
	BAC N10GW 80.60.6.47	10-32 THRU 1-1/2 -12	X	X	12 POINT EXTERNAL WRENCHING 450°F AND 800°F
	BAC N10JZ 80.62.6.130	1/2 -20	X	X	FLOATING CAPPED SELF-SEALING TWO LUG FUEL RESISTANT 250°F

GROUP VI MISCELLANEOUS NUTS

ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	MATERIAL ALLOY STEEL	MATERIAL CRES	DESCRIPTION
	AN 315 80.61.2.2	6-40	X	X	Hex Non-Selflocking Carbon Steel, Cres and Aluminum 250°, 450° & 700°
	NAS 671 80.61.5.2	0-80 AND 2-56	X	X	Hex Non-Selflocking Carbon Steel & Cres 450° & 700°
	AN256	6-32 THRU 10-32			PLATE, SELF-LOCKING RT. ANGLE, ALUM. OR STEEL NUT ALUM. BRACKET 250°F

GROUP VII 220 KSI - LONG THREAD

ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	MATERIAL ALLOY STEEL	MATERIAL CRES	DESCRIPTION
	BAC N10HC 80.65.6.74	10-32 THRU 1-1/2 -12	X		BARREL NUT NON-FLOAT PART CAN BE CODED FOR EITHER 250° OR 450°F
	BAC N10HR 80.60.6.51	10-32 THRU 1-1/2 - 12	X	X	12 POINT EXTERNAL WRENCHING FATIGUE RATED 450°F & 800°F

GROUP VIII 260 KSI - LONG THREAD

ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	MATERIAL ALLOY STEEL	MATERIAL CRES	DESCRIPTION
	BAC N10JG 80.60.6.56	10-32 THRU 2 - 12	X		12 POINT EXTERNAL WRENCHING-FATIGUE RATED 450°F

GROUP IX BEARING RETAINER NUTS

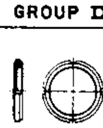
ILLUSTRATION	PART AND PAGE NUMBER	SIZE RANGE	MATERIAL ALLOY STEEL	MATERIAL CRES	DESCRIPTION
	MS 19068 80.66.1.6	.391 THRU 7.847	X		SPANNER WRENCHING NON-SELF LOCKING
	BAC N10GR 80.60.6.42	1.173 THRU 10.565	X		SPANNER WRENCHING SELF-LOCKING
	NAS509 80.61.5.1	1/4-28 THRU 2 1/4-12	X		DRILLED JAM NUT FOR ROD ENDS

Figure 17.6231-2

17.624 PLATE NUTS AND GANG-CHANNEL NUTS

Plate nuts and gang channel nuts of aluminum alloy of any type shall not be used in primary structure for tension applications.

Steel plate nuts and gang-channel nuts may be used for tension applications.

The restrictions of 17.623 also apply to self-locking plate nuts and gang-channel nuts.

The specifications for nut plates with NAS numbers are referenced only on the BAC Standards pages with which they are grouped.

17.6241 GANG-CHANNEL NUTS - DRAWING CALLOUT

Gang channel nuts shall be called out by BAC Commercial part number as specified on the applicable pages of the BAC Standard Book, D-590, unless the stock strip must be cut other than midway between two adjacent nuts. The gang nut strip must be detailed to show the end dimensions of special cuts, and it shall be called out in the drawing parts list as follows:

A. An individual dash number of the drawing shall be assigned to each gang nut channel and placed in the PART NUMBER column.

B. The BAC number minus the code for the number of nuts shall be placed with the name in the NOMENCLATURE column.

C. The commercial part number noted on the BAC page shall be shown in the STOCK SIZE column, together with the number of nuts in the strip.

D. The name and address of the vendor as shown in the illustrated callout on the BAC page shall be placed in the MATERIAL column.

NUT-GANG CHANNEL (NAS 689P6)	G1000-3-6 12 NUTS	1
NOMENCLATURE	STOCK SIZE (APPROX. NET)	MATERIAL

1 KAYNAR MANUFACTURING CO. INC, 820 EAST 18TH STREET, LOS ANGLES 21, CALIF (OR EQUIVALENT).

A separate detail drawing shall be made for each specially cut gang nut channel which is used on more than one drawing.

17.6242 PLATE NUT HOLE CLEARANCE - DRAWING CALLOUT

The screw hole size to be punched or drilled in material where a plate nut is to be attached shall be Class III (per Figure 17.252-1) and shall be specified at the part indicator for the plate nut, as shown below.

NAS 680A3

$.218^{.229}_{.218}$ DIA HOLES

To avoid excessive repetition on drawings which call out a great many plate nuts, the clearance hole size may be omitted from the plate nut part indicators, and the hole size information added to the general drawing notes as follows:

CLEARANCE HOLE SIZES FOR PLATE NUTS SHALL CORRESPOND TO THE SIZE OF THE PLATE NUT AS SHOWN:

No. 10-32	$.218^{.229}_{.218}$ DIA HOLE
Size Plate Nut	Clearance Hole Size

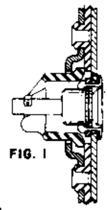
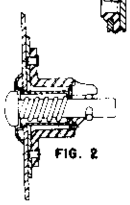
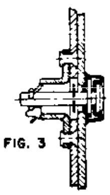
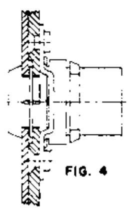
17.625 SHEET SPRING NUTS

Sheet Spring Nuts are light in weight and economical. Their use is controlled by MS 33538.

17.634 QUICK RELEASE FASTENERS

QUICK RELEASE FASTENERS

QUARTER TURN

ILLUSTRATION	STUD ASS'Y	STUD MAT'L & FINISH	HEAD STYLE FLUSH SLOT	HEAD STYLE FLUSH CROSS	HEAD STYLE PROTRUDING CROSS	HEAD STYLE PROTRUDING WING	HEAD STYLE PROTRUDING KNURL	NON-SEAL	SEAL	STRENGTH RATING TENSION	STRENGTH RATING SHEAR	GRIP RANGE	TEMP RANGE	MATING COMPONENTS WASHER BAC	SNAP RING BAC	SEAL RING BAC	GROMMET BAC	RETAINER BAC	SPACER BAC	RECEPTACLE BAC
 FIG. 1	BACS21X 90.21. 6.9.7 FIG. 1	Alloy Steel Cadmium Plate		X		X	X	X		700	700	.051 to .500	450°		R12X 90.22. 6.7		G20X 90.22. 6.5			R11X 90.20. 6.2
												.381 to 1.550		W10X 90.22. 6.14	R12X 90.22. 6.7		G20X 90.22. 6.5			R11X 90.20. 6.2
		CRES Passivate							X			.111 to .440	250°		R12X 90.22. 6.7	S11X 90.22. 6.17	G20X 90.22. 6.5			R11X 90.20. 6.2
 FIG. 2			X							350	350	.051 to .500	550°		R12X 90.22. 6.7		G20X 90.22. 6.5			R11X 90.20. 6.2
						X		X				.381 to 1.550		W10X 90.22. 6.14	R12X 90.22. 6.7		G20X 90.22. 6.5			R11X 90.20. 6.2
	BACS21Y 90.21. 6.10	Alloy Steel Cadmium Plate			X	X	X	X		200	200	.030 to 1.529	350°	W10X 90.22. 6.14			G20AA 90.22. 6.16			R11Y 90.20. 6.3
	FIG. 2			X	X	X	X							W10X 90.22. 6.14						R11Y 90.20. 6.3
 FIG. 3		Beryllium Copper Cadmium Plate			X	X	X	X		200	200	.030 to 1.529	450°	W10X 90.22 6.14			G20AA 90.22. 6.16			R11Y 90.20. 6.3
			X	X	X	X	X							W10X 90.22 6.14						R11Y 90.20. 6.3
 FIG. 4	BACS21Z 90.21. 6.11 FIG. 3	Alloy Steel Cadmium Plate		X	X	X	X			200 / 200 (1)	100 / 200 (1)	.000 to .719	450°	W10X 90.22. 6.14					S18X 90.22. 6.11	R11Y 90.20. 6.3
										100 / 200 (2)	50 / 200 (2)									R11AB 90.20. 6.6
	BACS21AE 90.21. 6.14 FIG. 4	Alloy Steel Cadmium Plate		X				X		1700	3580	.158 to 1.557	450°					R12AB 90.22. 6.9		R11AE 90.20 6.7
					X							.058 to 1.457								

(1) Strength is dependent on type of BACR11Y receptacle.

(2) Strength is dependent on type of BACR11AB receptacle.

MULTIPLE LEAD

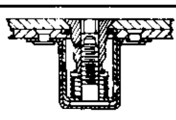
ILLUSTRATION	STUD ASS'Y	STUD MAT'L & FINISH	HEAD STYLE HEX SOCKET	NOM. DIA.	GRIP RANGE	MAX. TEMP.	STRENGTH RATING TENSILE	STRENGTH RATING DOUBLE SHEAR	MATING COMPONENTS RECEPTACLE	MATING COMPONENTS RETAINER RING
	BACF34B-B 90.20.6.32	Alloy Steel Cad Plate	Flush	.250	.125 to 1.062	450°	1000	5440	BACF34B-R4 90.20.6.32	BACF34SR 90.20.6.32
	BACF34C-B 90.20.6.34	Alloy Steel Cad Plate	Flush	.375	.188 to .999	450°	3800	15000	BACF34C6R 90.20.6.34	BACF34C6SR 90.20.6.34
	BACF34D-B 90.20.6.29	Alloy Steel Cad Plate	Flush Protruding	.250	.072 to 1.133		2000	4500		
				.3125	.173 to 1.172	450°	3500	9500	BACF34D-R__ 90.20.6.29	BACF34D-R 90.20.6.29
				.375	.148 to 1.147		6000	13000		

Figure 17.634-1

17.632 SHEAR PINS

Shear pins may be used as fasteners to relieve overstress, or to provide for intentional separation of mechanically mated parts. The shear pins are designed to shear when the shearing force reaches a predetermined value.

When the design requires these types of shear pins, the following criteria must be considered:

A. The shearing edges must be well defined and sharp. Clearances must be kept to a minimum so that failure of the shear pin is not appreciably influenced by bending stresses. Shear pins should be installed with a transition fit. The interface clearance between shearing edges should be in the order of that obtained when using DM 17.252 Class I holes (based on pin size), with a maximum interface clearance of 10 per cent of the shear pin diameter.

B. The minimum strength for shear pin materials, except for standard fastener application, is taken from the allowable strengths specified in Section 21. For critical shear tolerance limits, tests should be performed to verify analytical values.

1. The predictability or variability of minimum and maximum shear strengths are strongly influenced by the shearing edge condition and clearance.
2. Shearing edge material must be hard enough to insure that the edge will not break or deform during the shearing action.

C. Strength allowables that appear in Section 18 should not be used for undriven rivets used as shear pins, since these allowables depend on an increase in strength from work hardening during rivet installation.

D. If more than one pin is used all the directions of force applications must be known. For example, if two parts fastened by shear pins are designed to separate with application of an axial force, lateral forces (bending moments) that may be inadvertently applied must also be taken into account. Where warranted, a test program should be conducted to determine the dynamic shearing force on a specific part.

E. Shear pin applications should be designed so the pins can be readily inspected for structural integrity. Include indexing marks, where practical, for visual detection of partially sheared pins and for realignment of parts prior to removal of partially sheared pins. The use of check holes is also recommended for visual inspection. Avoid, where possible, use of shear pins in critical applications where periodic inspection of the pins and shearing edges is not possible.

F. For critical applications, a Specification Control Drawing or a Boeing Standard may be prepared to control minimum shear strength, maximum shear strength or both. If such a drawing is prepared, the requirements must include at least the following: Material, all dimensions, strength requirements and testing method. D2-2860, Procedures of Mechanical Testing of Aircraft Structural Fasteners is recommended for fasteners. Shear pin drawings should carry a note to the effect that material substitutions per BAC 5005 are not allowed without prior approval of Engineering.

G. Always use the largest margin possible for shear out over the maximum operating stress.

NOTE: Consult the applicable divisional staff for: Stress allowables, material recommendations for shear pins, shearing edges, inserts (when used) and dimensional limitations.

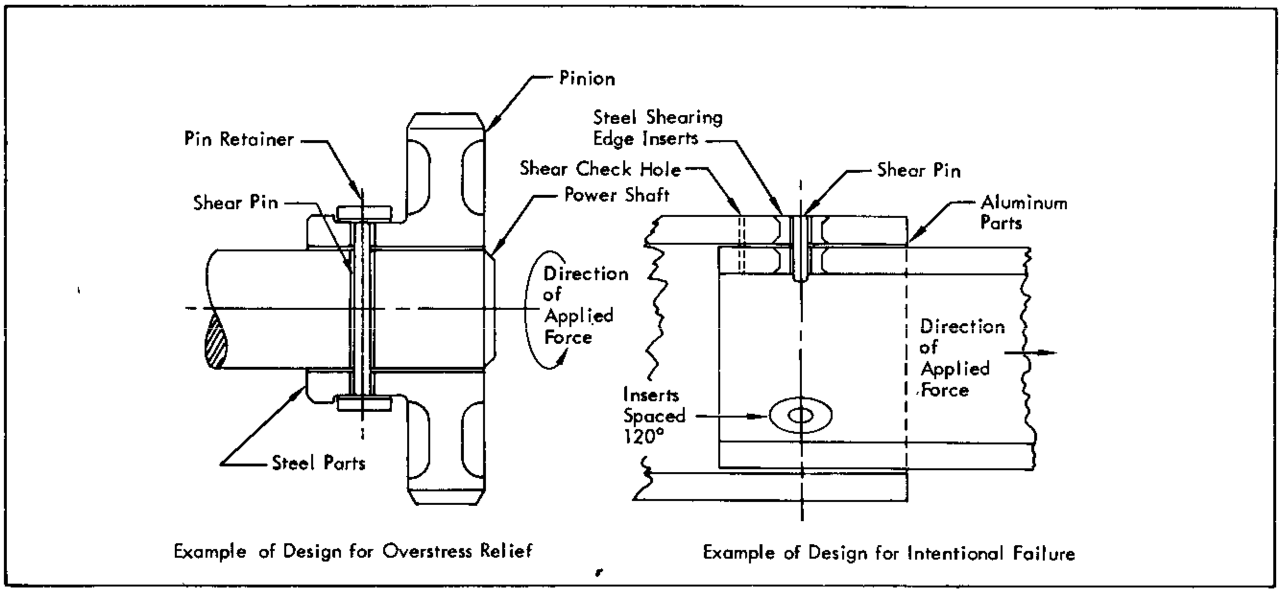


Figure 17.632-1

17.6332 (Continued)

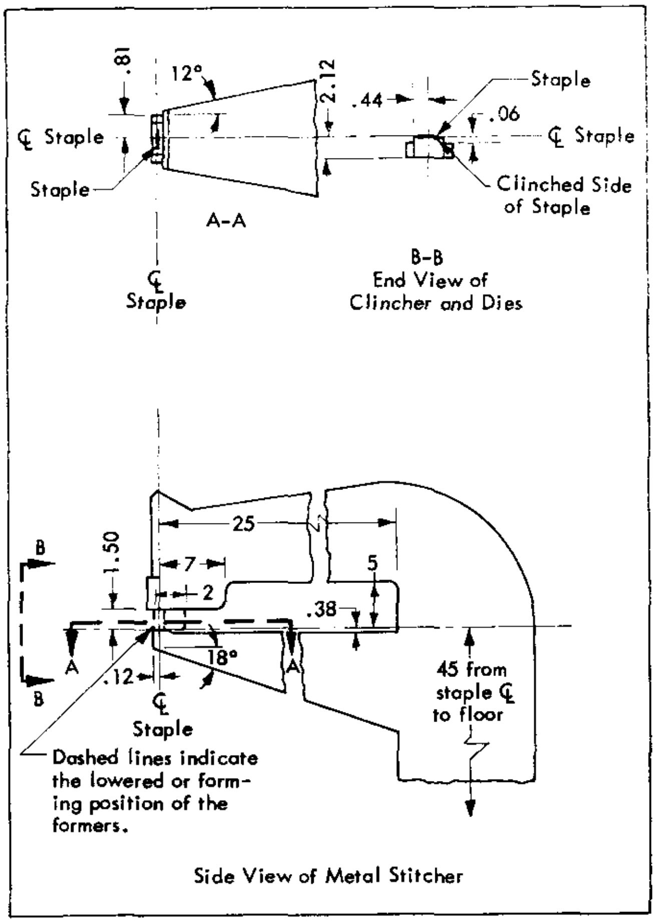
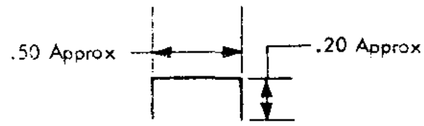


Figure 17.6332-2

17.6333 DRAWING CALLOUT

A drawing symbol shall be used to indicate metal stitches whenever they appear on drawings from either the driven or clinched side. The symbol may be made freehand using the approximate dimensions shown below. On a long row of stitches only two or three symbols on each end need be shown.



Typical Metal Stitch Drawing Symbol

The process specification shall be called for on the drawing by a general note with symbol, such as:

METAL STITCHES PER BAC 5404

Spacing for metal stitches may be indicated by adding to the general note above, the required information, such as:

SPACE APPROXIMATELY____INCHES or____EQUAL SPACES.

Otherwise, the spacing shall be dimensioned on the drawing.

Flush stitches in soft material shall be indicated by a note on the drawing. When it is desired to restrict clinching to a particular side, a note shall *specify:*

CLINCH FAR SIDE or CLINCH NEAR SIDE

Unless this is so noted on the drawing, the shop will usually clinch *against the harder or heavier material.*

The edge margin and starting point of each row of stitches must be dimensioned on each drawing as shown in Figure 17.6333-1. When it is required to place the stitch at an angle to the centerline of the row in order to prevent cracking of the material being stitched, the symbol shall be shown at an angle and dimensioned as shown.

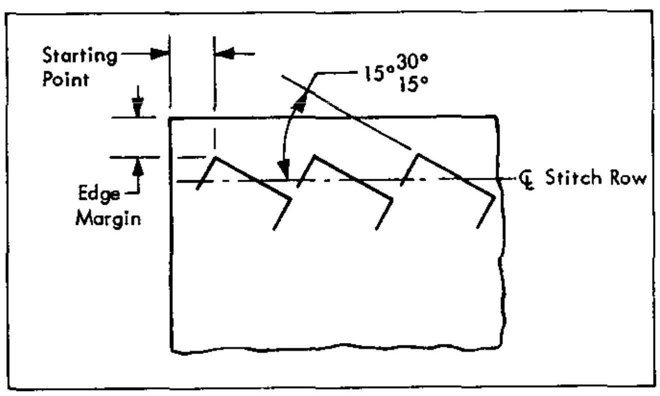


Figure 17.6333-1

17.633 METAL STITCHING

A. When designing minor, nonstructural assemblies involving the attachment of asbestos, fiber, rubber, felt, fabric-base laminated phenolics, cotton webbing, etc., to aluminum alloy, mild steel, annealed stainless steel, brass, or copper sheet metal, consideration should be given to metal stitching. In addition, minor thin gage, all-metal parts such as ammunition boxes, ducts, and chutes may be assembled by stitching with a possible saving in production time and cost.

B. Comparatively brittle materials such as methyl methacrylate, Tenite, paper-base laminated phenolic and magnesium alloy sheet, etc., cannot be stitched. Some relatively brittle materials, such as hard black asbestos, white fiber asbestos, and certain types of plastics can be successfully stitched by using a metal backing strip .25 by .020 under the crown of the stitches. For these materials, a note on the drawing should allow the optional use of a backing strip.

C. Stitches cannot be driven flush in sheet metal but their use in ducts, boxes, etc., is permitted at the discretion of the Project Engineer. Stitches can be driven flush in soft materials.

D. When stitching parallel to the grain would tend to cause cracking in wood or other material with a definite grain, the stitch shall be placed at an angle of from 15° to 30° to the centerline of the stitch row. The exact angle within this range is at the option of the shop.

E. Metal stitches use .051 diameter zinc-coated steel wire per specification MIL-W-6714 with a minimum tensile strength of 290,000 psi. The length of stitch is approximately .5 inch and is formed from a one-inch length of wire for work thicknesses up to .12 inch plus twice the extra thickness for work over .12 inch.

17.6331 EDGE MARGIN AND SPACING

Stitches can be located .12 inch from a flange on the side of the work against which the stitch is clinched and from .12 to .31 inch from a flange on the crown side of the work. The greater clearance is necessary on heavier work. The recommended minimum edge margin is .12 inch.

Suggested stitch spacings are as follows:

A. .75 inch approximately for a single row of stitches in ducts with light, internal pressure where minor leakage is not critical. This spacing is also considered the minimum design spacing for stitching. (The shop minimum row spacing of stitches is .70 inch.)

B. 1.00 inch for metal-to-metal joints taking light loads.
C. 1.25 inches for rubber, fiber, felt, or nonstressed metals.
D. 1.50 inches for asbestos, canvas, etc.

The above stitch spacings are in no way engineering standards and can be varied to suit particular requirements. Stitch patterns and sealing compounds for pressure-tight seams have not been determined.
The drawing minimum design stitch spacing in a row is .75 inch with .70 inch considered the shop minimum. The minimum row spacing for metal stitches is .19 inch. See Figure 17.6331-1 for application of these minimums. The drawing nominal dimensions for margins and spacings with the tolerances applied should not be less than the minimums given.

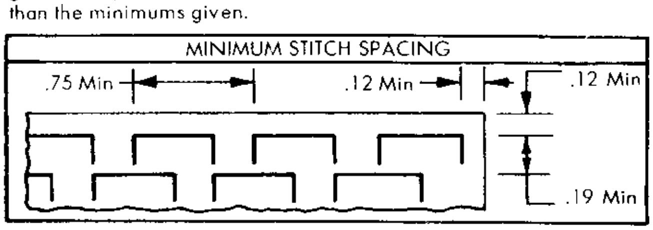


Figure 17.6331-1

End loops in cotton webbing strips 1 inch wide or less for attaching to cleats, rings, buckles, etc., may be made with metal stitching. A minimum of two stitches shall be used and spaced as shown in Figure 17.6331-2

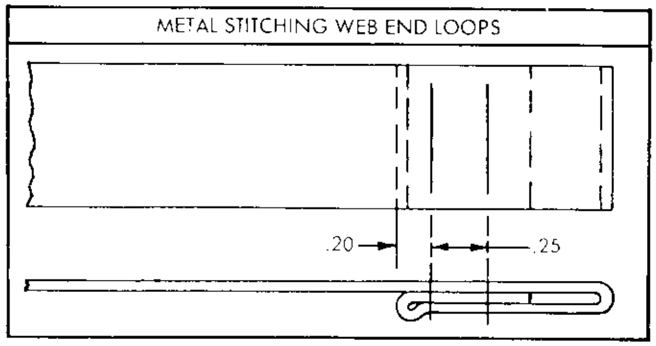


Figure 17.6331-2

17.6332 CAPACITIES AND DIMENSIONS

The maximum recommended material thickness values for satisfactory production stitching on present equipment are given in Figure 17.6332-1. The principal dimensions of present Boeing equipment are shown in Figure 17.6332-2.

STAPLING MACHINE CAPACITY FOR VARIOUS MATERIALS (2)

Material	Number of Sheets and Remarks (1)	Max Total Thick. (in.)	Max Single Sheet Thick. (In.)
Clad 2024-0, 3003	4 sheets of .040	.160	.102
Clad 2024-T3	2 sheets of .040	.080	.064
Type 302 Annealed Corr Resist. Steel	2 sheets of .020	.040	.032
Type 302 1/2 Hard Corr Resist. Steel	2 sheets of .016	.032	.020
18-8 Full Hard Stainless Steel	1 sheet of .020	.020	.020
Wood and Plywood, Rubber, Rubber-bonded Canvas, Canvas Cardboard and Asbestos	.75 possible on fine grained wood.	.75	--
Plastic, Hard Plywood (Compressed and Impregnated.)	Type of plastic and amount of compression are governing factors.	.38	--
Molded Phenolic, Hard Rubber, Procelains	Too brittle; cracking tendency does not permit stitching	--	--

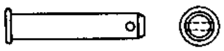
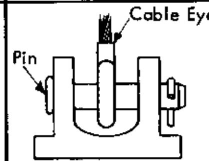
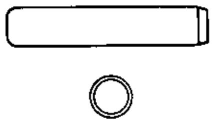
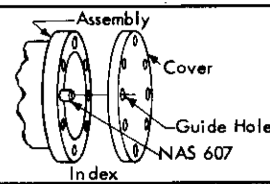
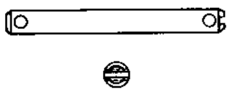
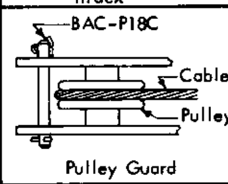
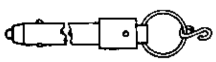
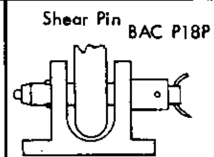
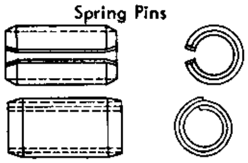
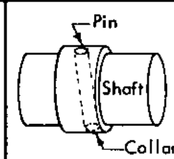
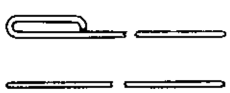
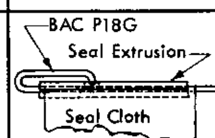
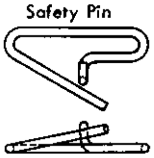
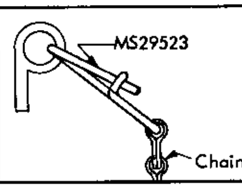
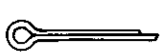
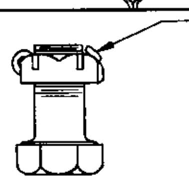
(1) Any combination of gages of any one metal, the sum of which does not exceed the maximum total thickness listed above, can be stitched, providing that no individual sheet of the combination exceeds the maximum single sheet gage listed for that material.

(2) Specific recommendations cannot be made for applications which use combinations of metal and soft non-metallic materials. In such cases, trial tests should be made; consult the applicable staff.

Figure 17.6332-1

17.63 SPECIAL FASTENERS

17.631 PINS USAGE CHART

PIN TYPE	PART NUMBER	MATERIAL	REMARKS
Flat Head Pin 	MS20392	STEEL	 Recommended Use: In shear applications where little or no tension load exists, such as fork and eye connections. Use in place of bolt and nut will save weight.
Dowel 	NAS 607	STEEL CASE HARDENED	 Recommended Use: As an alignment index in symetrical assemblies to avoid improper installation. Dowel pin and mating guide hole must have diameter larger than any bolt holes to insure pin can only fit in correct hole.
Two Hole 	BAC P18C	2024-T STEEL	 Recommended Use: In place of flat head pin when direction of removal is unknown at time of installation.
Quick Release 	BAC P18AL BAC P18AM NAS 1333-1346	4130 STEEL	 Recommended Use: Primarily in shear applications where quick disassembly is necessary. Handle types available: Ring (illustrated). "L", "T", or button. Available in drive out or non-drive out types.
Spring Pins 	MS16562	STEEL AND CRES	 Recommended Use: In shear applications when installed in drive fit holes. Design limits and hole sizes: Per MS33547.
Seal Retainer Pins 	BAC P18G	CRES	 Recommended Use: To attach seal cloth to BAC-1520-484 or BAC-1520-470 seal extrusion.
Safety Pin 	MS29523	CRES	 Recommended Use: To attach safety chain to structure.
Cotter Pin 	MS24665	STEEL CRES	 Cotter Pin Recommended Usage: As a safety retaining device. Cadmium plated steel pins may be used with cadmium plated fasteners in temperatures up to 450°F. CRES pins should be used in corrosive areas or in non-magnetic applications up to 800°F.

NOM BOLT SIZE		#10, 1/4, 5/16	3/8, 7/16, 1/2	9/16, 5/8	3/4, 7/8	1, 1-1/8	1-1/4
STEEL	MS24665 - DASH NOS.	134	287	357	359	360	362
CRES		153	304	374	376	377	379
NI-CU		191	338	408	410	411	413
NOM COTTER PIN SIZE		1/16 x 3/4	3/32 x 1-1/4	1/8 x 1-1/2	1/8 x 1-3/4	1/8 x 2	1/8 x 2-1/2

Figure 17.631-1

17.64 WASHERS, SPACERS AND SHIMS

17.641 WASHERS

Washers shall be selected from the following standards in the order of preference shown for the application needed:

To protect the surface of the structure during installation of a fastener by tightening, one standard washer may be used under either the bolt head or the nut (whichever is being turned).

A maximum of two additional washers may be used to allow for grip adjustment of the bolt.

For prevention of dissimilar metal corrosion between washer and structure see the finish document listed in DM Book 81, Section 14.

TYPE	STD PART DWG NO.	MATERIAL	RECOMMENDED USAGE
Plain	MS20002	Heat-Treated Alloy Steel	Per 1, 2, and 3
	BACW10BN		
	AN960	Al Alloy (Clad 2024-T3 or T4). Carbon steel, CRES and brass.	General usage 1, 2, 3, 4, 5, and 6
	BACW10AT	Steel and Alum Alloy	Large I.D. for use with tapered shank fasteners per 1, 2, 3, and 4.
	AN970	Steel	Large OD for use on wood.
	MS27183	Steel	Thicker and larger than AN960 per 1, 2, and 4.
	BACW10P		General usage for washers not found in other standards.
	NAS1197	5052 Al Alloy	Per 4 with magnesium.
Countersunk	MS20002	Heat-Treated Alloy Steel	To obtain a clearance with the large head-to-shank radii on high strength fasteners, in designs where stress will not approve the required countersinking in the material under the fastener head. Also 2 and 4.
	BACW10BN		
Lock-Split	MS35337	Steel CRES and Bronze	Where not restricted per AND10476.
	MS35338		
Lock-Tooth	MS35336		See Standard Page 70.7.1.0
	MS35790	Carbon Steel and Bronze	
Counter Bore	AN975	Steel	With AN386 Taper pins.
Self Aligning	BACW10BT	Steel	Concave and convex washers are used together.
Vibration Stop	AN8013	Steel and Al Alloy	With BAC-S14C vibration insulators (shock mounts per AND10405 and AND10407).
Bearing Retainer	MS19070	Steel	With MS19068 lock nuts to retain bearings.
	BACW10Q	Steel	With ball bearing, self-aligning rod ends to prevent bolt head from slipping through end in case of loss of balls.
Dimpled 100°	BACW10U	Steel and Al Alloy	Per 4 with 100° csk fasteners.
	BACW10Z	5052 Al	
Pre-Load Indicating	BACW10AM	Heat-Treated Alloy Steel	For 220 KSI Bolts — Used for accurate control of preload in bolt to obtain maximum fatigue life.
	BACW10AP		For 160 KSI Bolts
	BACW10AQ		For 125 KSI Bolts

1. Used under nut to compensate for difference in bolt grip length and material thickness per 19.512.

   In the interest of weight saving, two washers are recommended as a maximum for any one application. However, the use of more washers is preferred to the use of a bolt of special length or washer of special thickness.

2. To distribute bearing load over a greater area to prevent compression of material under bolt head, screw head or nut.

3. To prevent galling of aluminum or aluminum alloy sheets less than .051 thick and other soft materials when bolts, screws, or nuts are tightened, or by lock washers (per AND10476).

4. To insulate dissimilar metals against corrosion. Wherever possible, the washer material should be similar to the material upon which it rests rather than to the bolt or nut material so that corrosion, if it exists, is created between the replaceable bolt and washer instead of washer and fitting or sheet. Use 5052 aluminum alloy washers with magnesium alloy per DM, Book 81, Sect. 14.0323.

5. Where material next to nut is steel, use MS20002 steel washers. Use 2024-T3 or 2024-T4 washers (AN960 for sizes 1" and smaller; BACW10P for larger) if material next to nut is aluminum alloy.

6. Used next to plastic laminates to prevent crazing caused by driving solid rivets and swaged collars, see DM, Book 81 Sect. 24.311.

Figure 17.641-1

17. 642 SHIMS, PLATE NUTS

TYPE	PART NO.	MATERIAL	NUT SIZE	THICKNESS	REMARKS
Plain Plate Nut Shim Type W Type T Type F	NAS463 NAS463C NAS463D NAS463DD	1010 Steel or better Cres (301, 302, 321, or 347) 5052-H36 2014, 2024, 7075, or 5052	No. 6, 8 & 10 1/4, 5/16 & 3/8	.016, .032, .063 & .090	For general use with plate nuts.
	BAC-S18L (Type W only)	2024-T4	7/16	.072 & .156	
	BAC-S18M	Magnesium	No. 6, 8 & 10 1/4, 5/16 & 3/8		.125	
	BAC-S18U	2024-T4	1/4, 5/16 & 3/8	.125, .188, .250 & .312	
Floating Plate Nut Shim Type X Type Y	NAS463 NAS463C NAS463D NAS463DD	1010 Steel or better Cres (301, 302, 321, or 347) 5052-36H 2014, 2024, 7075	No. 6, 8 & 10 1/4, 5/16 & 3/8	.016, .032, .063 & .090	For general use with plate nuts.
Type B Type C	BAC-S18M	Magnesium	No. 6, 8 & 10 1/4, 5/16 & 3/8	.125	
Countersunk Plate Nut Shim Type W Type T Type F	NAS500- NAS500C NAS500D NAS500DD	1010 Steel or better Cres (301, 302, 321 or 347) 5052-36H 2014, 2024, 7075, 5052	No. 8, 10 & 1/4	.080, .090 & .125	For use with 100° dimpled sheet. Use of csk plate nuts preferred to use of shims.
Miniature Plate Nut Shim Type A Type B Type C Type D	NAS 1195	2014, 2024, 5052, or 7075	No. 2 thru .375	.032 and .063 See Standards Page	For use with miniature plate nuts.

Recommended Use: With plate nuts, to increase material thickness to accommodate grip of bolt. When attaching plates, panels, etc., which would be removed for maintenance in metals of varying thicknesses it is preferable to use shims so bolts may all be of some grip length to avoid installation errors. Use washers per 17.641 with hex nuts. Drawing Callout: Per PM, D-4900

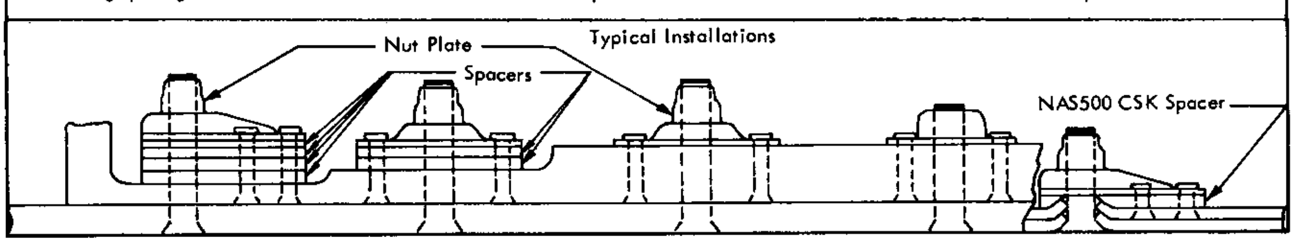
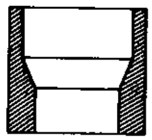
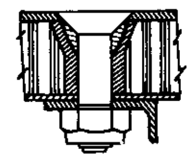
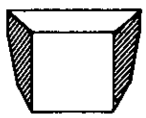
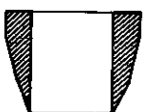
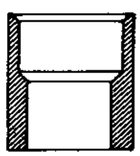
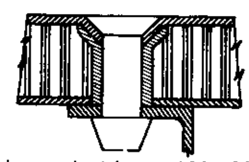
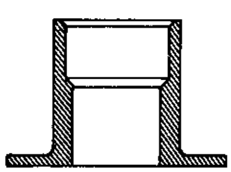
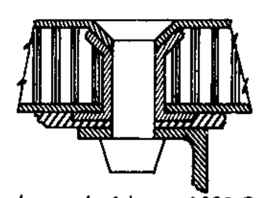


Figure 17.642-1

17.643 SPACER, SANDWICH BOARD

STYLE	PART NO.	MATERIAL	FASTENER NOM DIA	REMARKS ①	TYPICAL INSTALLATION ②
 Sleeve	BAC-S18AB	2024-T4 Sleeve 7075-T6 Plugs	No. 10 1/4 5/16	For use in primary aluminum structural sandwich with skins thicker than .040	 See Standards Page for applicable fasteners.
 Type A Plug for Countersunk Fasteners  Type B Plug for Protruding Head Fasteners	BAC-S18AB	CRES See Standards Page	No. 10 1/4 5/16	For use in primary steel structural sandwich with skins greater than .040	
	BAC-S18AC	2024-T4	No. 8 No. 10 1/4	For use in secondary aluminum structural panels with skins thinner than .040 or secondary structural load attachments in primary panels with skins thinner than .040 Dimple formed with hot dimpling dies.	 May be used with any 100° CSK fasteners which will fit the specified inside diameter except pull type lockbolts. See Standards page.
		416 CRES	No. 8 No. 10 1/4	As above in steel or titanium panels	
	BAC-S18AD	2024-T4	No. 8 No. 10 1/4	Especially designed for flooring attachment; skin thicknesses less than .040. May be used in any secondary loading & spacer application. Dimple formed with hot dimpling dies.	 May be used with any 100° CSK fasteners which will fit the specified inside diameter except pull type lockbolts. See Standards page.
		CRES See Standards Page		As above in steel or titanium panels.	

① Strength of these joints is dependent upon the sandwich construction. Consult the applicable divisional staff unit for information.

② The note, INSTALL PER BAC 5085, shall be added to applicable drawings.

Figure 17.643-1

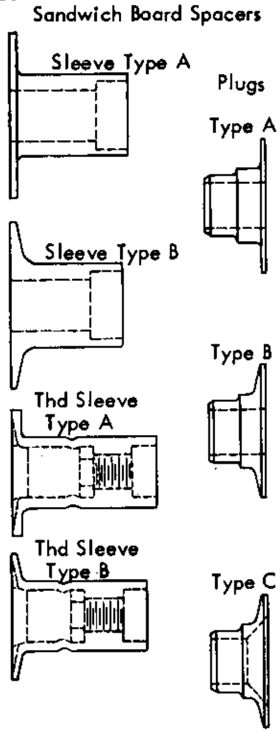
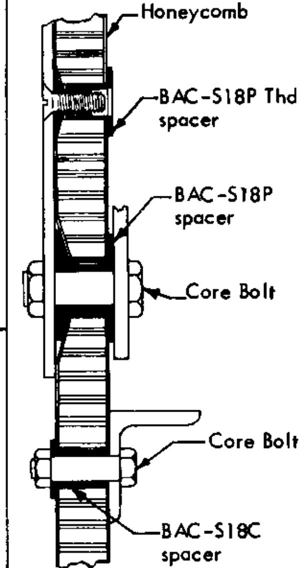
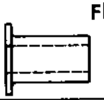
STYLE	PART NO.	MATERIAL	FASTENER NOM DIA	REMARKS	TYPICAL INSTALLATION
Sandwich Board Spacers  Sleeve Type A Plugs Type A Sleeve Type B Type B Thd Sleeve Type A Thd Sleeve Type B Type C	BAC-S18P	2024-T3 2024-T4 & 6061-T6	No. 8, 10 and 1/4	For use in sandwich board, balsa wood, etc. to prevent crushing of material. Type A, B, or C, plug may be used with either Type A or B sleeve. For installation data see Standards page.	 Honeycomb BAC-S18P Thd spacer BAC-S18P spacer Core Bolt Core Bolt BAC-S18C spacer
		2024-T4	10-32	For use as a self-locking tapped hole in sandwich board, etc. Type A, B, or C plug may be used with either Type A or B sleeve. See Standard page for installation data.	
Flanged Spacer 	BAC-S18C	2017-T4 or 2024-T4	1/8 & 5/32 Rivet No. 6, 8, 10 & 1/4	Stronger in shear than S18P. See BAC-S18D for installation data.	

Figure 17.643-2

17.644 RIVET, SPACER HEAD, BLIND

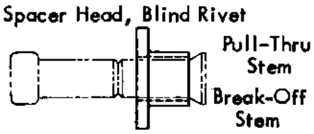
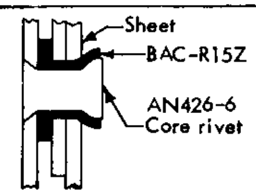
STYLE	PART NO.	MATERIAL	FASTENER NOM DIA	REMARKS	TYPICAL INSTALLATION
Spacer Head, Blind Rivet  Pull-Thru Stem Break-Off Stem	BAC-R15Z BAC-R15BY BAC-R15CC	5056-F	1/8, 5/32 & 3/16	Head used to space sheets. Installed with Cherry or Olympic rivet gun. Break-off type (preferred with blind rivets) limited to applications where the broken stem can be retrieved on blind side. See Std pg for installation.	 Sheet BAC-R15Z AN426-6 Core rivet

Figure 17.644-1

17.645 SPACER, RIVET AND BOLT

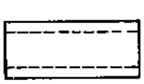
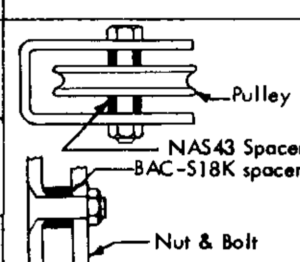
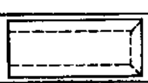
STYLE	PART NO.	MATERIAL	FASTENER NOM DIA	REMARKS	TYPICAL INSTALLATION
 Spacer	NAS42	2024-T & 4130 or 8630 Steel	3/32 thru 3/8 rivet	Gen Usage: Spacing sheets, wire bundle clamps, pulley guards, etc. with rivets.	 Pulley NAS43 Spacer BAC-S18K spacer Nut & Bolt
	NAS 43	2024-T & 4130 or 8630 Steel	No. 4 thru 1.00	Same usage as NAS42 with bolts & screws except not for pulley guards.	
 CSK Spacer	BAC-S18K	2024-T or 6061-T	No. 8, 10 and 1/4	For use with top sheet dimpled.	

Figure 17.645-1

17.646 SPACER, PLATE NUTS

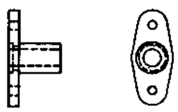
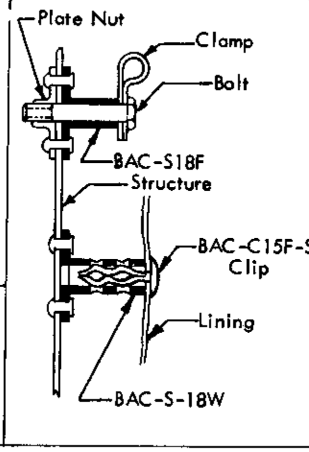
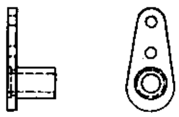
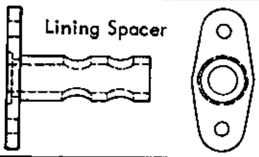
STYLE	PART NO.	MATERIAL	FASTENER NOM DIA	REMARKS	TYPICAL INSTALLATION
Plate Nut Spacers Two Lug Type 	BAC-S18F	Plate 2024-T	No. 10	For general stand-off spacer usage with nut plates. Two lug type preferred where space permits.	
	BAC-S18G	Tube 6061-T	1/4 & 5/16		
One Lug Type 	BAC-S18R	Plate 2024-T	No. 10		
	BAC-S18S	Tube 6061-T	1/4		
Lining Spacer 	BAC-S18W	Plate 2024-T Tube 6061-T		To attach lining with BAC-C15F-5 clips.	

Figure 17.646-1

17.647 NUT, SPACER PLATE

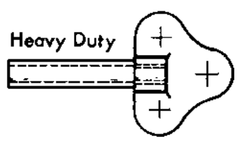
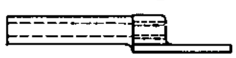
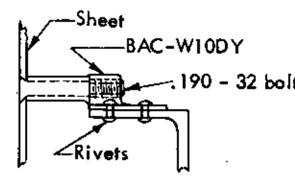
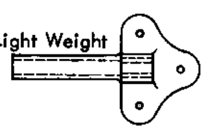
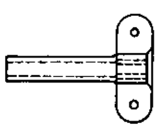
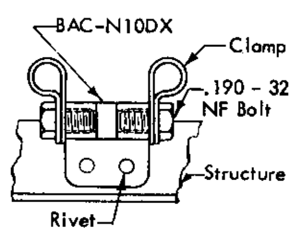
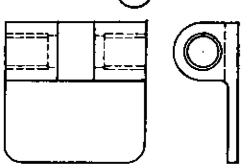
SPACER PLATE NUTS	STD NO.	MATERIAL	THREAD	TYPICAL USAGE	
Heavy Duty  	BAC-N10DW	Cast 356-T6 Forged 2014-T6	.10-32	For stand-off attachment of equipment etc. parallel to mounting surface	
Light Weight 	BAC-N10DY	2014-T6	.10-32		
Two Lug Light Weight 	BAC-N10DZ	2014-T6	.10-32		
	BAC-N10DX	2014-T6	.10-32		
Drawing Callout - Per PM 94B1 Section 10					

Figure 17.647-1

17.648 RADIUS FILLERS

Radius fillers are allowed a maximum gap of .040 per BAC 5300. When less maximum gap is required to obtain increased tension loads or reduce deflection, the allowable maximum gap should be noted on the drawings as follows:

MAXIMUM GAP BETWEEN RADIUS FILLER AND THE RADIUS OF FORMED PART (OR EXTRUSION) SHALL BE .XXX.

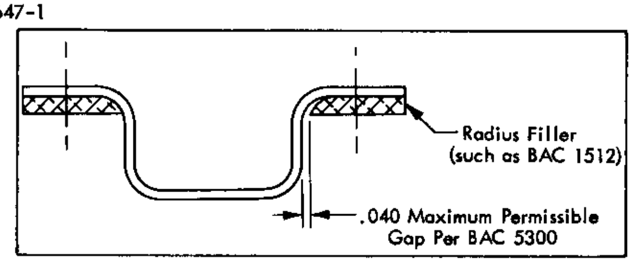


Figure 17.648-1

APPENDIX I - BOEING DESIGN MANUAL

SECTION 26

ADHESIVE BONDING

SECTION 26

ADHESIVE BONDING

26.01 GENERAL

This section contains information to aid in the selection of adhesives for structural and non-structural applications. It also presents guidance concerning typical joint configurations and data on strength and comparative cost.

26.02 REFERENCES

Documentation and specifications for structural bonding are quite different from non-structural bonding because of the rigid controls required for structural bonding, and consequently are listed separately.

26.021 STRUCTURAL ADHESIVES

A. BMS - BOEING MATERIAL SPECIFICATIONS

1. Sheet Stock

BMS 5-69	Laminated Aluminum Sheets - Structurally Bonded

2. Adhesive Systems

BMS 5-42	Structural Adhesives for Metal-to Metal Assemblies AF 9330 System.
BMS 5-51	Moderate Temperature Curing Structural Adhesive System.
BMS 5-70	Structural Adhesives for Metal to Metal Sandwich Assemblies FM61 System.
BMS 5-80	Moderate Temperature Curing Structural Adhesive System.
BMS 5-89	Corrosion Inhibiting Adhesive Primer
BMS 5-90	Structural Foaming Adhesives
BMS 8-30	Structural Foam-in-Place Adhesive

B. BAC - PROCESS SPECIFICATIONS

BAC 5452	Structural Foam Bonding
BAC 5514-542	Structurally Bonding Metal-to-Metal.
BAC 5514	Common Bonding Requirements for Structural Adhesives Systems.
BAC 5514-551	Structural Bonding with Moderate Temperature Curing Adhesives (BMS 5-51).
BAC 5514-570	Structural Bonding with BMS 5-70.
BAC 5514-580	Structural Bonding with Moderate Temperature Curing Adhesives (BMS 5-80).
BAC 5514-589	Application of Corrosion Inhibiting Adhesive Primer
BAC 5514-590	Structural Bonding with Foaming Adhesives

26.022 NON-STRUCTURAL ADHESIVES

The following specifications should be called out when applicable as indicated by Figures 26.711-1, 26.711-2 and Paragraph 26.714.

A. BAC SPECIFICATIONS

BAC 5010	Application of Adhesives
BAC 5038	Processing of Acrylic Plastics
BAC 5407	Structural Bonding of Metal to Wood or Plastics
BAC 5444	Bonding Shims and Fillers
BAC 5447	Processing of Thermoplastic Sheet Materials
BAC 5472	Bonding of Cork Composition Ablative Insulation Material.

26.1 ADVANTAGES OF ADHESIVE BONDING

A. An adhesive distributes stresses more uniformly throughout the bonded area than mechanical fasteners.

B. A bonded exterior joint in an airplane or aerospace vehicle presents a smooth aerodynamic surface to the elements, thus eliminating the drag caused by non-flush mechanical fasteners.

C. The use of an adhesive bond can reduce the weight of the system.

D. With the proper selection of the adhesive, the continuity of an adhesive-bonded joint reduces the probability of leakage, and therefore, can eliminate the need for extra gaskets or sealants. This is an important advantage over rivets where buckling of thin metal sheets takes place between rivets, making gasketing or sealing mandatory.

E. Adhesive bonding may be faster and less expensive than other fabrication techniques such as welding, brazing or mechanical fastening with rivets.

F. Galvanic action will not normally result from the bonding of dissimilar metals. The adhesive used is generally a good dielectric and thus can bond and insulate simultaneously.

G. With proper care to prevent warpage, the use of elastomeric adhesives permits the bonding of dissimilar materials with widely differing coefficients of expansion. This is primarily applicable to nonstructural bonding.

H. Bonded sandwich construction presently offers the optimum strength-weight ratio for certain structural applications. See Section 216 for design information.

I. As a result of the more uniform load distribution, structural adhesive bonding increases component fatigue life.

J. The visco-elastic characteristic of adhesives in laminated sheets improves resistance to sonic fatigue.

26.2 TYPES OF ADHESIVE BONDING

26.21 STRUCTURAL BONDING

Structural bonding is used in primary and secondary structural areas where bond integrity is required. Structural bonding requires designs that can be easily and reliably fabricated during processing. Greater control over materials and bonding techniques is required in structural bonding because of the load-carrying requirements the assembly must meet.

Design information on structural adhesive bonding is given in 26.6 and structural adhesive bonded honeycomb sandwich panels in Section 216.

26.22 NON-STRUCTURAL BONDING

Non-structural adhesives are considered those adhesives that may fail in service without endangering the safety of the aircraft. They are not used where structural integrity is required, as the bond strength reliability is of a lower order. Non-structural adhesives are used for joining rubber, foam, plastics, fabrics, leather and metals, while structural bonding mainly concerns metal-to-metal fastening. In general, the shear strength of non-structural adhesives is in the range of 200-1200 psi and the peel strength ranges from 10 to 30 lb-in. per inch width.

Non-structural bonding is generally faster and less expensive than structural bonding in those applications where structural integrity is not mandatory.

Design information on non-structural adhesive bonding is given in 26.7. Non-structural adhesive bonded sandwich panels are a unique system in themselves, not representing adhesive bonding as such; information may be found in Section 218 (new).

26.3 FORMS OF ADHESIVES

Adhesives are available in two basic forms: (1) dispersed in a fluidizing carrier solvent, either organic or aqueous; and (2) free of volatile carrier. The latter, includes films, solvent-free pastes, powders, and hot melts.

The first form of adhesive is most common because air drying can be employed in many cases to remove the carrier fluid for development of a good bond; also, common paint brushes or spray guns can be used to apply them, depending on the usage.

The carrier-free adhesives are rapidly gaining favor as the most practical for assembly line structural bonding. They provide the strongest adhesive bonds obtainable. In this class of adhesives are (1) adhesive films, unsupported or supported; (2) lump and powder adhesives which are heated and cured by heat or solvent reaction; (3) pastes, solvent free, which must be cured to develop cohesive strength. The epoxy resin based paste adhesives are among the most versatile adhesives available.

26.4 DESIGN OF ADHESIVE BONDED JOINTS

A. JOINT DESIGN. To realize maximum efficiency from adhesives, joints should be expressly designed for adhesive bonding. The detailed stress analysis of an adhesive-bonded joint is difficult, partly because of the nonlinear stress-strain characteristics of adhesives. Stress analysis has shown that stresses are not uniformly distributed across the adhesive joint, being greatest at the free edges of the glue line.

B. TYPES OF JOINTS. Selection of adhesive joint designs is a compromise between strength and joint preparation cost. The design of metal-to-metal joints is influenced by the magnitude and direction of the load the joint will have to bear. Figure 26.4-1 shows several possible joint configurations. In non-structural applications little more than selection of a desired joint configuration is required. However, in structural applications, more detailed consideration must be given to the effects of the individual joint on the part configuration and load distribution.

C. ANGLE JOINTS. The lower portion of Figure 26.4-1 presents an evaluation of angle joints for resistance to cleavage against four directions of stress application. When heavy sections are bonded, the parts should be designed so that the adhesive is in shear. Cleavage stresses should be avoided or minimized whenever possible.

D. BUTT JOINTS. Butt joints are easily fabricated but are impractical because of probable failure when loaded in tension. In cases where a butt joint must be made, a bonded shear component should exist along at least part of the bond line.

E. LAP JOINTS. Lap joints are the most commonly used adhesive joints. Peak stresses develop at the ends of the lap due to the eccentricity of loading resulting from the finite thickness of the joint and the differential strain induced between adherends and adhesive by the load.

F. SCARF JOINTS. Scarf joints are butt joints where the joint angle is less than 90°. The joint is relatively costly to produce. Because of machining requirements it can not be used on thin stock.

G. JOGGLE LAP JOINTS. Joggle laps are a means of lining up tensile forces in joining thin sheet or parts but should be avoided if complete sealing of the joint is required.

26.4 DESIGN OF ADHESIVE BONDED JOINTS (Continued)

H. STRAP JOINTS. The strap, double strap, recessed double strap, beveled double strap, half lap and double lap all provide good resistance to bending stresses.

I. STRESS CONCENTRATIONS. Stress concentrations at the ends of a lap joint tend to result in an apparent failing stress lower than the actual or theoretical value. (This apparent failing stress is defined as the observed breaking load divided by the lap area). It has been found that the failing stress is independent of the width of overlap but diminishes with increasing length of overlap. Figure 26.4–2 shows the effect of overlap length at room temperature.

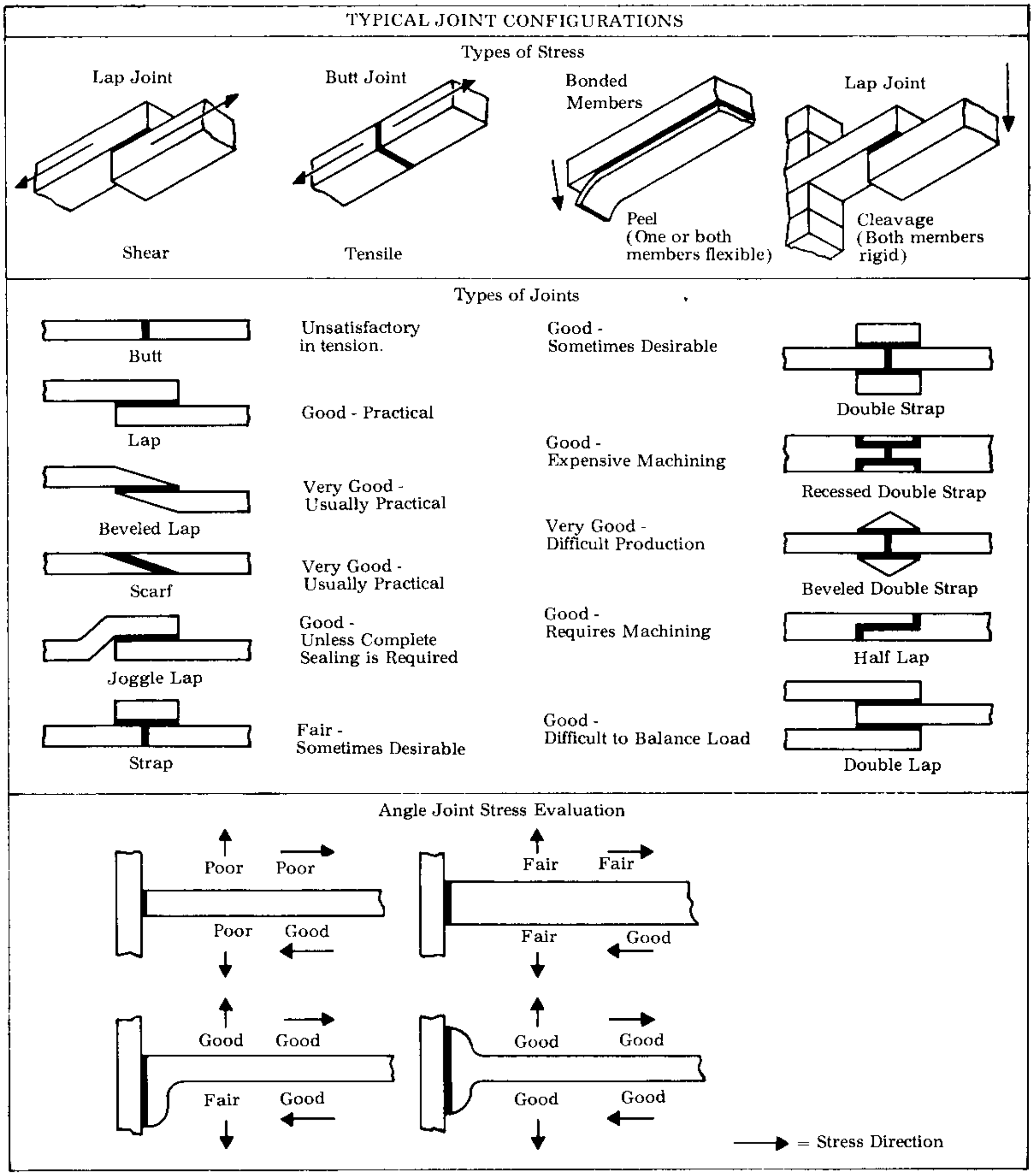
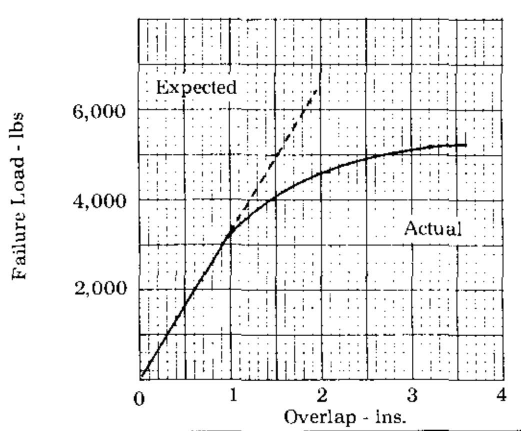


Figure 26.4–1

26.4 DESIGN OF ADHESIVE BONDED JOINTS (Continued)

TYPICAL ACTUAL FAILING STRESS - LAP JOINTS



NOTE: The bond strength of the overlap varies with the length of the lap, thickness of the material, and its yield strength.

Figure 26.4–2

26.5 DESIGN OF ADHESIVE BONDED PARTS

When designing parts for adhesive bonding, the following basic design guides should be followed if the maximum strength of the adhesive is to be achieved:

A. Stiffness and thermal expansion coefficients of the adherends should be as similar as possible.

B. Arrange the adhesive bond in shear or compression avoiding flatwise tension and peel.

C. Stress concentrations at edge of joints can be reduced in heavier structures by tapering the edge of adherends or using stepped doublers.

D. Make the bond area large enough to carry the required load.

E. Make the contours of mating structures as similar as possible to ensure uniform pressure application to all sections of the bondline.

26.6 STRUCTURAL BONDING DESIGN INFORMATION

26.61 DESIGN OF ADHESIVE BONDED STRUCTURES

A. LOAD DISTRIBUTION. Uniform load distribution is necessary to obtain optimum joint efficiency and fatigue life. Close coordination with both the materials technology organization and the tooling group is necessary in order to avoid excessive production costs. The following objectives apply for optimum adhesive bonding design:

1. Minimize any stress concentrations in the adhesive bond.
2. Provide efficient distribution of loading to the attached component.
3. Apply stresses in shear or compression.

B. CURING ESSENTIALS. Extensive processing is required in structural bonding. The bonding process requires:

1. Even pressure distribution to ensure proper contact during the flow and wetting stages of the cure, consequently dimensional tolerances are very critical. These tolerance problems can occur when nested parts having contour are bonded.
2. Temperature application as uniform as possible to provide even curing of all sections of the bond.

C. DESIGN OBJECTIVES. The above requirements make it necessary to design parts and details which can be easily fabricated.

D. DESIGN PRECAUTIONS. In the design of assembly or installation of bonded structures the following precautions should be taken:

1. Avoid locating fasteners in the vicinity of joggles.
2. Consider the effect of any possible corrosive attack.

26.611 METALS SUITABLE FOR STRUCTURAL ADHESIVE BONDING

Figure 26.611-1 lists metals that may be bonded.

MATERIAL	SERIES
Wrought Aluminum Alloy	2024 3003 5052 5456 6061 7075 7079 7178
Corrosion Resistant Steel	All
Magnesium	AZ31 HK31
Titanium	Ti-6Al-4V Ti-8AL-1Mo-1V Ti-C.P.

Figure 26.611-1

26.612 SELECTION OF AN ADHESIVE BONDING SYSTEM

A. CHOICE OF ADHESIVES. For structural bonding the class known as thermosetting adhesives is used. Two primary thermosetting types are the epoxy and phenol-formaldehyde (commonly called phenolic) resin systems. Modifiers are added to give desired properties. Other thermosetting resins are available but are not used to any great extent. Figures 26.6121-1 and 26.6121-2 present information for assisting in the selection of an adhesive system. DM84A3 Section 532 presents design allowable information for the various structural adhesive systems.

B. ENVIRONMENTAL CONSIDERATIONS. Service conditions or resistance to environmental factors that must be taken into account include the following:

1. Type of loading.
2. Operating temperature.
3. Fluid exposure - JP-4 fuel, BMS 3-11 Hydraulic Fluid, alt spray, etc.
4. Corrosion.

C. STRENGTH CONSIDERATIONS. Strength considerations that must be accounted for include:

1. Tensile shear strength.
2. Peel and fatigue strengths.
3. Creep strength.
4. Flexibility, stability, etc.

IMPORTANT NOTE: Elevated temperature bonding processes will cause a loss in the mechanical properties of the aluminum alloy sheet materials being bonded. For example, bonding per BAC 5514 of trailing edge assemblies with the BMS 5-70 adhesive system can subject the aluminum alloy material to temperatures in excess of 325°F for as much as 60 minutes. The loss in mechanical properties of the material is dependent on the temperature and accumulative time of exposure. Design Manuals 84A series, in the XX.X-3 subsections provide data on the resulting reduced values.

26.6121 SELECTION OF ADHESIVES

Figures 26.6121-1 and 26.6121-2 provide information on the selection and mechanical properties of structural adhesives.

ADHESIVE SELECTION CHART FOR STRUCTURAL BONDING

Process Specification BAC No.	Adhesive System BMS Number	Type of Structure	In-Service Temperature Limitations, °F	Remarks
5514-542	5-42	Metal-to-Metal (1) Structures	250	Specify for bonding of sheet, doublers, and stiffeners of aluminum alloy, magnesium alloy, or titanium.
5514-551	5-51	Metal-to-Metal Structure Aluminum Honeycomb Sandwich (1) (2)	180	Specify for machined honeycomb assemblies for laminated and square edge assemblies: For bonding of sheet doublers and stiffeners of aluminum and titanium.
5514-570	5-70	Aluminum Honeycomb Sandwich	300	Specify for machined honeycomb laminated edge and square edge honeycomb assemblies
5514-580	5-80	Metal-to-Metal Structure Aluminum Honeycomb Sandwich (1) (2)	180	Alternate to BAC 5514-551

(1) Laminated sheet is available as BMS 5-69. Typical drawing callout shall be by the note: TWO PLY .0XXX SHEETS LAMINATED PER BMS 5-69. The note shall refer to the applicable parts by flag in the stock size and material column of the parts list.

(2) See BMS 4-4 and 4-6 for honeycomb core drawing callouts.

Figure 26.6121-1

26.6121 **SELECTION OF ADHESIVES** (Continued)

MECHANICAL PROPERTY CURVES OF DIFFERENT BMS SPECIFICATIONS

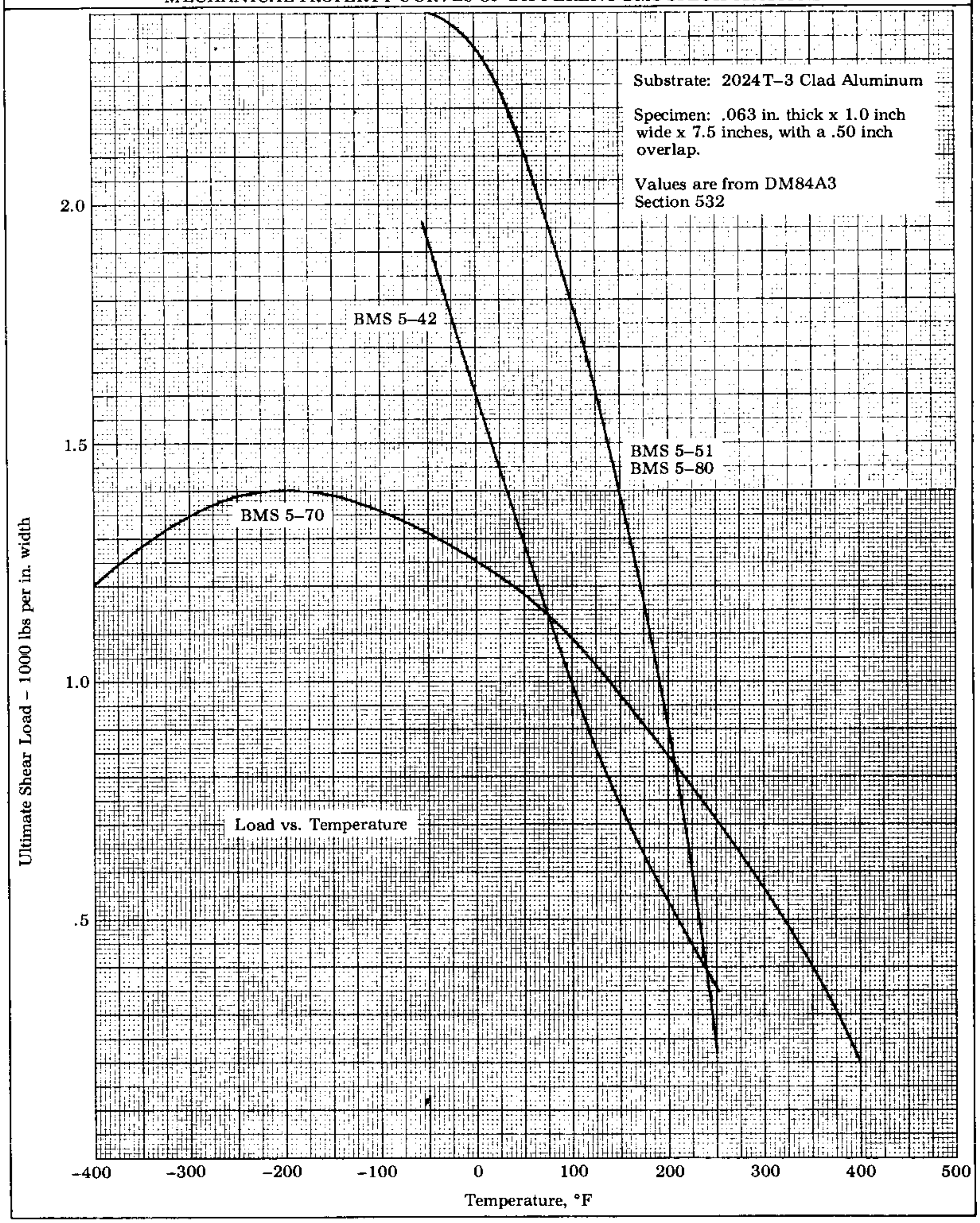


Figure 26.6121-2

26.613 CURED BOND LINE THICKNESSES

The cured nominal bond line thickness for structural adhesives varies, depending on the usage of the adhesive, curing pressure, width of the overlap and the chemical nature of the adhesive. The values given in Figure 26.613-1 are for typical wide area bonds (12" x 12") and would vary if the overlap was smaller.

CURED BOND LINE THICKNESSES AND WEIGHTS		
Adhesive	Cured Nominal Bond Thickness (inches)	Nominal Weight lb/ft
BMS 5-42 (1) Type 1 with		
Type 2, Grade A	.009	.055
Type 2, Grade B	.011	.07
Type 3, Grade C	.004	.03
BMS 5-51 (1) Type 1 with		
Type 2, Grade 5	.003	.03
Type 2, Grade 10	.008	.06
Type 3, Grade 15	.012	.08
BMS 5-70 (3) (Type 1 Liquid Adhesive with Type 2 Tape Adhesive) Bonded per BAC 5413	.01	.085
BMS 5-80 (1)		
Type 1, Grade A	—	—
or Grade B with	—	—
Type 2, Grade 5	.005	.03
Type 2, Grade 10	.010	.06
Type 2, Grade 15	.015	.08
	—	—
	—	—

(1) Cured bond line thickness will vary with pressure and width of overlap.

(2) Heavy scrim in the bond line keeps bond thickness fairly uniform regardless of pressure or length of overlap.

(3) This is a very high flow adhesive. Narrow bond overlaps (.50 to .625) will have a nominal .006 in. bond line. Wide overlaps with the same pressure will have .01 to .012 inch thick bond lines.

Figure 26.613-1

26.614 DRAWING CALLOUT

Drawings shall callout the adhesive system and process by the following:

BOND WITH BMS 5-xx PER BAC 54xx.

BAC 5514 "Common Bonding Requirements for Structural Adhesive Systems", collects and specifies all the common processes for all structural bonding adhesive systems. A BAC 5514 dash-numbered specification is used for each specific adhesive systems individual processing requirements. For ease of reference, the dash number will be the three digits of the BMS numbers. Therefore, the BMS will not need to be called out. The callout will then be:

BOND PER BAC 5514-551 (BAC 5514-580 OPTIONAL)

The callout shall be referred to by flags in the appropriate place on the field of the drawing and in the material column of the list of materials for both details and their assemblies.

NOTE: For drawing callout of specific processes and/or materials, see the references in 26.021.

26.62 ADHESIVE BONDED HONEYCOMB SANDWICH PANELS

Honeycomb sandwich structures consist of two high density faces or skins separated by a relatively light weight stabilized core. The function of the core is to stabilize and separate the faces and to resist transverse shear loads and local crushing loads normal to the faces. The selection of the core and face materials will depend upon the particular requirements the structure must meet.

The designations, structural and non-structural, are used to describe the two types of bonded sandwich construction. Non-structural sandwich panels are covered in Section 218.

Structural sandwich panels are covered in Section 216.

26.7 NON-STRUCTURAL ADHESIVE BONDING - DESIGN INFORMATION

26.71 SELECTION OF AN ADHESIVE SYSTEM

A. The following considerations should apply when selecting non-structural adhesive systems:

1. The materials to be bonded; their surface condition (rough or smooth, porous or non-porous); their susceptibility to "crazing" (acrylic and polystyrene plastics); flexibility; method of prebond treatment.

2. The environmental resistance of the adhesive bonded joint to moisture, oils and greases, BMS 3-11 Hydraulic Fluid, ozone, fuels and solvents, temperature (also cyclic temperature change), radiation, and fluids such as cleaning materials, coffee, urine, etc.

3. The type of loading to which the adhesive-bonded joint will be subjected, i.e., fatigue, shear, tension, peel, vibration, and their strength requirements.

4. The method of adhesive application, i.e., manual brush, extension gun, spray, dip, roller coat and trowel.

5. The assembly requirements, i.e., assembly location such as factory or field, the access of bonding tools such as spray guns, rollers, vacuum bagging equipment, bonding jigs, elevated temperature curing equipment (ovens and heat guns).

6. The curing requirements, i.e., *temperature (elevated or* room), pressure and cure time.

7. Special requirements such as color, electrical properties, and high frequency heating from nearby electronic equipment including radar and antenna systems.

8. The materials to be bonded must be resistant to corrosion resulting from the action of harmful substances present in, or produced from the adhesive used. Although this type of action is comparatively rare, it must be recognized and avoided.

Examples:

a. Some epoxy compounds react detrimentally with copper and brass.

b. Some neoprene adhesives react with moisture to release hydrochloric acid.

c. Some silicone adhesives react detrimentally with copper and brass.

9. Bonding cost considerations are heavily influenced by the labor involved in application. Figure 26.713-1 shows cost of bonding a one-foot square area. Even under these comparable conditions, the method of application can cause total costs to vary over 300%. For large areas, high production, or peculiar shapes, consult the Materials Technology organization for cost analysis and guidance.

B. When the design of non-structural joints approaches any of the limitations noted in Figure 26.711-2 consult the Materials Technology organization.

26.711 SELECTION OF ADHESIVES

A. The adhesives shown in Figure 26.711–1 are recommended for nonstructural bonding applications.

B. Thermosetting adhesives (i.e., Types 38, 54, 59, etc.) are relatively rigid and exhibit high tensile and shear strength (see Figure 26.711-2 whether the load be applied at a fast rate (dynamic), or a constant load (static). They also have good fatigue characteristics. However, rigid adhesives have relatively poor bonding qualities when stressed in peel or cleavage.

C. Some adhesives show high tensile and shear strength but have poor resistance to constant or vibrating stresses. The rubber-based adhesives (i.e., Types 40, 48, 53, etc.) have low tensile or shear strength, but because of film elasticity, develop high peel or cleavage strength.

SUGGESTED BAC 5010 ADHESIVE TYPES FOR VARIOUS COMBINATIONS OF SURFACES

	Acrylics	Cellulose	Cork	Fabrics	Felt	Glass, Ceramics	Leather	Melamine	Steel and Aluminum	Brass and Copper	Nylon
Acrylics	BAC 5038										
Cellulose	12	17 30 40 48									
Cork	12 44 59	30 40 48	12 38 40 48								
Felt	12 59	30 40 48	38 40 48	34 38 48	30 34 40 48						
Glass, Ceramics	12 59	30 40 48	12 38 40 48	12 38 48	38 40 48	38 40 44 48 54					
Leather	12 59	30 48	12 38 48	12 38 48	38 48	12 38 48	12 48 58				
Melamine	12 59	40 48	38 40 48 54	38 48	38 40 48	38 44 54	38 48 54	38 44 54 58			
Steel and Aluminum	12 38 44 59	40 48	38 40 48 54	38 48	30 40 48	38 40 44 48 54	12 38 48	38 40 44 48 54	38 40 44 48 54 68		
Brass and Copper	12 44 51	40 44 48 51	40 44 48 51	12 48	40 48	12 40 44 48	12 48	12 40 44 48	12 40 44 48	40 44 48	
Nylon	12 44 51 59	12 40 48 51	40 48 51	12 38 48 51	38 40 48 51	38 40 48 51 54	12 38 48 51	38 40 48 51	38 40 44 48 51	40 44 48 51	38 51
Paper, Cardboard	12 59	12 30 34 48	12 30 48	12 30 34 48	30 34 48	12 30 34 48	12 30 34 48	12 48	12 48	12 48	12 48
Phenolics	12 44 51 59	30 40 48	12 38 40 44 48	38 44 48	38 40 48	38 40 44 48 54	38 44 48	12 38 44	38 40 44 48	12 40 44 48	38 40 44 48 51
Polyester & Epoxy Laminates	12 44 51 59	30 40 48 51	38 40 44 48 51	38 44 48 51	38 40 48 51	38 40 44 48 51	38 48 51	38 44 51	38 40 44 48 51 68	40 44 48 51	38 40 44 48 51
Polystyrene A-B-S (1)	12 59	17 30 48	30 38 48	30 38 48	38 48	12 38 48 52	12 38 48	12 38 48	12 38 44 48	12 44 48	12 38 48 51
Polyurethane Foam	12	12 48	12 48	12 48	48	12 48	12 48	12 48	12 48	12 48	12 48
Polyvinyl Chloride, Flexible	12	48	48	48	48	48	48	48	48	48	48
Polyvinyl Chloride, Rigid	44	48	48 51	48	48	44 48	44 48	44 48	44 48	44 48	44 48
Rubber, Buna-N	12 59	40 48	40 48 59	48 59	40 48 59	40 48 59	48 59	40 48 59	40 48 59	40 48	40 48 59
Rubber, Butyl	44	44	44	44	44	44	44	14	44 49	44	44
Rubber, Neoprene	44	5 44 53 58	5 44 53 58	5 44 53 58	5 44 53 58	5 44 53 58	5 44 53 58	5 44 53 58	5 44 53 58	5 44 53 58	5 44 53 58
Rubber, Silicone	60 68	46 60 68	46 60 68	46 60 68	46 60 68	46 60 68	46 60 68	46 60 68	46 60 68	46 60 68	46 60 68
Teflon	12 59	30 40 48	38 40 48	12 34 38 48	30 40 48	38 40 44 48 54	12 48	38 44 54 58	38 40 44 48 54 56	38 48	51
Wood	12 59	30 40 48	12 30 38 40 48	12 38 48	38 40 48	19 38 40 48 59	12 30 38 48	12 38 40 48	12 38 40 48 54	12 40 44	5 38 40 48 51

Figure 26.711-1 (Continued)

26.711 SELECTION OF ADHESIVES (Continued)

SUGGESTED BAC 5010 ADHESIVE TYPES FOR VARIOUS COMBINATIONS OF SURFACES (Continued)

	Paper, Cardboard	Phenolics	Polyester and Epoxy Laminates	Polystyrene A-B-S (1)	Polyurethane Foam	Polyvinyl-Chloride Flexible	Polyvinyl-Chloride Rigid	Rubber, Buna-N	Rubber, Butyl	Rubber, Neoprene	Rubber, Silicone	Teflon	Wood
Paper, Cardboard	30 34												
Phenolics	30 34 38 48	38 40 44 48 54											
Polyester & Epoxy Laminates	12 38 48	38 44 51	38 44 51 54										
Polystyrene A-B-S (1)	12 30 34	12 38 48	12 38 44 48	12 38 48									
Polyurethane Foam	12 48	12 48	12 48	12 48	12 48								
Polyvinyl Chloride, Flexible	48	48	48	48	48	9 48							
Polyvinyl Chloride, Rigid	44 48	44 48	44 48	44 48	48	9 48	9 44 48						
Rubber, Buna-N	48 59	40 48 59	40 48 59	48 59	48			40 48 59					
Rubber, Butyl	44	44	44 49	44					44				
Rubber, Neoprene	5 44 53 58	5 44 53 58	5 44 53 58	5 53 58	5 58				44	5 53 58			
Rubber, Silicone	46 60 68	46 60 68	46 60 68	46 60 68	46	60 68	60 68				46 60 68		
Teflon	30 34	38 40 44 48 54	38 44 51 54	38 48	12 48	48	44 48	40 48 59	44	5 53 58	46 60 68	38 40 44 48 54	
Wood	12 30 34	5 38 54	5 38	5 38 48	12 48	38 48	38 44 48	40 48 59	44	5 53 58	46 60 68	19 38	19 38

(1) Bond Royalite and Boltaron ABS materials in accordance with the specification outlined in BAC 5447.

Figure 26.711-1

NOTE:

IMPORTANT

This table is intended for use in finding the possible BAC 5010 adhesive types suited for bonding various combinations of surfaces. Because of the variations in the nature of the materials listed and the varying criteria of usage, it is imperative that the designer strictly adhere to the 6 steps outlined here for proper adhesive selection.

Steps Necessary To Select The Correct Adhesive

1. Determine the nature of the materials to be bonded:
   a. Check the available vendor information.
   b. Consult the Materials Technology organization when unable to determine the nature of the substrates.
2. Check the process documents and specifications under 26.022. If your bonding job is covered by one of the documents or specifications, callout that particular document or specification. If your job is not covered by any document or specification, proceed to Step 3.
3. Select the possible adhesive types found in Figure 26.711-1 by matching the substrates.
4. Referring to Figure 26.711-2, select the proper adhesive for your job. Determine which (if any) of the possible adhesives meets the requirements for this job. See Figure 26.711-2 for important criteria to consider, i.e., BMS 3-11 Hydraulic Fluid, oil, fuel and water resistance, etc. Consult Figure 26.713-1 to compare costs of suitable adhesives.
5. For any applicable criteriaa not covered by Figures 26.711-2 and 26.713-1. consult the Materials Technology organization for recommendations.
6. Drawing callout for the adhesive you have selected is described in 26.714.

26.711 SELECTION OF ADHESIVES (Continued)

ADHESIVE PROPERTIES				
BAC 5010 Type No.	Manufacturer's Designation or BMS No.	Description	Visual Appearance	Physical Properties &Primary Uses
5	Bostik 1008A Bostik 1008B Accelerator Bostik 1007 Primer	A black two component, room temperature curing Neoprene base adhesive in a Toluene vehicle.	Black, brushable syrup.	Tough, flexible, contact type rubber cement used for bonding & splicing Neoprene rubber & Neoprene coated fabric to themselves. Not recommended for de-icing boots.
9	Cyclohexanone	Cyclohexanone vinyl solvent for bonding vinyl parts or films to themselves.	Very thin, clear, pale amber liquid.	Used for bonding vinyl parts or films to themselves.
12	BMS 5-55	A one part synthetic rubber base adhesive in a naphtha vehicle.	Brown, thin, brushable liquid.	A flexible contact cement. Provides immediate strength without clamping. Will not craze acrylics.
17	Lacquer-Thinner per Federal Specification TT-T-266.	A blend of solvents used for bonding Styrene & Cellulosic plastics to themselves.	A clear, water thin liquid.	A clear liquid used for bonding Polystyrene, A-B-S, & Cellulosic plastics to themselves.
19	Lauxite RF2905 2905 Hardener Cascophen RS-216 FM-60M Catalyst Catalin 726 Accelerator 30 Bostik 1007 Primer	A two component, resorcinol resin base, formaldehyde catalyzed, room temperature curing adhesive.	Black, medium, brushable syrup.	A rigid adhesive high in tensile & shear strength. Used for bonding wood to wood & wood to wood laminates. For flyaway & non-flyaway applications.
30	BMS 5-43	A one part, room temperature setting Nitrocellulose base adhesive in a Ketone & Ester vehicle.	Clear, pale yellow, medium syrup.	A transparent, rigid thermoplastic adhesive, which dries rapidly to give immediate strength. Will craze acrylics & other thermoplastics. Used for bonding wood, paper, felt & cork to themselves & to each other.
34	BMS 5-56	A one part, water dispersed rubber base adhesive.	Cream colored, thin paste.	A light amber flexible contact adhesive. Easy application, non-flammable, & possesses very little odor. Used for bonding paper, charts & placards, felt, fabric, & other porous materials to metal & wood.
38	BMS 5-29, Type 1 EC-776 Primer	A two part, Polyamide resin, Epoxy base adhesive.	Clear, light yellow, medium-heavy syrup.	A rigid general purpose Epoxy adhesive high in tensile & shear strength. Used for bonding Polyester & Phenolic fiberglass laminates & metals to themselves & each other. Not to be used on copper or brass.

Figure 26.711-2 (Continued)

26.711 SELECTION OF ADHESIVES (Continued)

ADHESIVE PROPERTIES (Continued)							
BAC 5010 Type No.	Resistance To Liquids	Application & Cure	Flash Point	180° Peel Strength	Shear Strength	Temperature Limitations	Drawing Callout
5	Resistant to water & oil. Poor resistance to fuel. Not BMS 3-11 resistant.	Brush application. Cures at room temperature.	40°F	MIL-W-5665, Type II, Class 3, (cotton webbing) bonded to 2024-T3 aluminum 8 lbs/in (2)	MIL-W-5665, cotton webbing bonded to aluminum: 539 psi (2)	200°F	BAC 5010 TYPE 5
9	Restricted only by the properties of the vinyl.	Brush or spray. by solvent evaporations.	93°F	Slightly less than material being bonded.	Slightly less than material being bonded.	Restricted only by the properties of the vinyl.	BAC 5010 TYPE 9
12	Resistant to water. Poor resistance to oils & fuel. Not BMS 3-11 resistant.	Brush or spray. Cures by solvent release. May by reactivated with naphtha.	54°F	MIL-W-5665, Type II, Class 3, (cotton webbing) bonded to 2024-T3 aluminum. 10 lbs/in (2)	MIL-W-5665 (cotton webbing) bonded to aluminum: 80 psi (1)	−30°F to 125°F	BAC 5010 TYPE 12
17	Restricted only by the properties of the plastics.	Brush or dip. Cures by solvent evaporation.	Below 60°F	Slightly less than material being bonded.	Slightly less or sometimes greater than the material being bonded.	Restricted only by the properties of the plastics.	BAC 5010 TYPE 17
19	Resistant to water, oil, & fuels.	Brush or spreader. Cure at room temperature or with aid of heat up to 130°F. Requires clamping during cure.	Resin 102°F Activator 177°F.	MIL-R-6855, Class 1, Grade 60, Buna-N rubber bonded to 2024-T3 aluminum 9 lbs/in (2)	Bond is stronger than wood where density is .76 or less.	300°F	(3)
30	Fair resistance to water, oils, & fuels. Cannot stand continuous immersion. Not BMS 3-11 resistant.	Brush or roller coat. Cures by solvent evaporation.	0°F	MIL-W-5665, Type II, Class 3, (cotton webbing) bonded to 2024-T3 aluminum. 6 lbs/in (2)	MIL-W-5665 (cotton webbing) to aluminum: 300 psi (1)	200°F	BAC 5010 TYPE 30
34	Fair resistance to water & oils. Poor resistance to fuels. Not BMS 3-11 resistant.	Brush, spatula or sprayed. Cures by solvent evaporation.	Above 80°F	MIL-W-5665, Type II, Class 3 (cotton webbing) bonded to 2024-T3 aluminum 1.5 lbs/in (2)	MIL-W-5665 (cotton webbing) to aluminum: 55 psi (1)	−20°F to 200°F	(4)
38	Resistant to fuel, oil, & BMS 3-11. Fair resistance to water.	Stiff brush, spatula, roller, or spreader. Cures at room temperature or with aid of heat up to 250°F. Requires contact pressure.	Part AB: 395°F Part CD: 468°F	2024-T3 aluminum (5) bonded to 2024-T3 aluminum 3.7 lbs/in (2)	Aluminum to aluminum 1000 psi (1)	160°F	(5)

Figure 26.711-2 (Continued)

26.711 SELECTION OF ADHESIVES (Continued)

ADHESIVE PROPERTIES					
BAC 5010 Type No.	Manufacturer's Designation or BMS No.	Description	Visual Appearance	Physical Properties & Primary Uses	Resistance To Liquids
40	BMS 5-14	A one part, Buna-N base, room temperature curing adhesive in a Ketone vehicle.	Light brown to dark amber, medium, brushable syrup.	A tough, flexible contact type adhesive with good peel strength. Provides immediate strength without clamping. Should be used where good fuel resistance is required & odor is not objectionable. Bonds fabrics, felt, cork, wood, Buna-N rubber, glass, metals, & vinyl plastics.	Resistant to water, oil, & fuels. Not BMS 3-11 resistant.
44	BMS 5-19	A two part, Polysulfide rubber base room temperature curing adhesive & sealant. 100% solids.	Thick, brown paste.	Cures to a tough flexible rubber, with good peel strength. Used for bonding nonporous materials such as phenolic & polyester laminate, & metals to themselves & to each other where a flexible adhesive with good peel strength is required. The gap filling properties of this adhesive are very good.	Resistant to fuel, water, & salt spray. Poor resistance to BMS 3-11.
45	BMS 5-58 A-4094 (7)	A two part, room temperature vulcanizing Silicone rubber.	Light brown, pourable paste.	Cures to a flexible rubber. Used for bonding Silicone rubber sheet and extrusions to metals & plastics or to themselves. Its use is limited to applications where bond strength is not critical.	Resistant to water. Poor resistance to oil & fuel. Fair BMS 3-11 resistance.
46	A-4000 Silicone Adhesive A-4000 Catalyst A-4014 Primer (7)	A two component, Silicone resin, room temperature curing adhesive.	Water clear, thin syrup.	A contact type Silicone adhesive. Cures to a resilient film. Used for bonding silicones to themselves or other materials. Its use is limited to applications where bond strength is not critical.	Resistant to water. Poor resistance to oil & fuel. Fair BMS 3-11 resistance.
47	BMS 5-57	A one part, Silicone base, room temperature curing, pressure sensitive adhesive.	Clear to milky, medium syrup.	Pressure sensitive adhesive. May be used for low strength applications up to 600°F such as bonding low density insulation material.	Resistant to water. Poor resistance to oil & fuel. Not BMS 3-11 resistant.
48	BMS 5-30	A one part Buna-N base adhesive in an ester solvent.	Tan to amber, brushable, medium syrup.	A tough, flexible, low odor, contact type adhesive with good peel strength. Should be used in areas where passenger comfort is a consideration. Bonds fabrics, felt, cork, wood, Buna-N rubber, glass, metals, & vinyl plastics.	Resistant to water, oil, and fuels. Not BMS 3-11 resistance.
49	BMS 5-34	A two component Polysulfide-Epoxy, room temperature curing adhesive.	Off-white, brushable syrup.	A tough rigid adhesive. Used where BMS 3-11 resistance is required.	Resistant to BMS 3-11, oil, and fuels. Poor water & salt spray resistance.
50	BMS 5-36	A one part, non-solvent, rapid setting, room temperature curing adhesive.	A colorless, slightly milky, low viscosity liquid.	Tough, quick setting adhesive for soft rubber (BMS 1-28) & for bonding strain gauges. Very expensive. Use on small parts only.	Poor resistance to water & salt spray. Resistant to BMS 3-11, oil, and fuels.

Figure 26.711-2 (Continued)

26.711 SELECTION OF ADHESIVES (Continued)

ADHESIVE PROPERTIES (Continued)						
BAC 5010 Type No.	Application & Cure	Flash Point	180° Peel Strength	Shear Strength	Temperature Limitations	Drawing Callout
40	Brush or spray. Cure by solvent evaporation. May be reactivated with methyl ethyl Ketone up to 24 hours after application.	30°F	15 lbs/in; MIL-W-5665 (cotton webbing) to aluminum. (1)	175 psi; MIL-W-5665 (cotton webbing) to aluminum. (1)	300°F	BAC 5010 TYPE 40
44	Knife, spatula or pressure gun. Cures by vulcanization at room temperature or at temperatures up to 180°F. Requires contact pressure during cure.	Above 80°F	20 lbs/in; see BMS 5-19 (1)	278 psi; aluminum to aluminum. (2)	200°F	BAC 5010 TYPE 44
45	Knife or spatula. Cures by vulcanization at room temperature. Requires contact pressure during cure.	Above 80°F	Very low peel strength.	135 psi; aluminum to aluminum. (1)	- 70°F to 300°F	BAC 5010 TYPE 45
46	Brush. Cures by polymerization at room temperature. Does not require clamping.	60-90°F	BMS 1-22 bonded to 2024-T3 aluminum. 7.8lbs/in (2)	MIL-W-5665 Type II, Class 3, (cotton webbing) bonded to 2024-T3 aluminum. 281 psi (2)	- 65°F to 400°F	BAC 5010 TYPE 46
47	Brush or spray. Becomes tacky by solvent evaporation.	70°F-100°F	1.5lbs/in; MIL-W-5665 to aluminum. (1)	2024-T3 aluminum to aluminum 10 psi. (1)	- 65°F to 600°F	BAC 5010 TYPE 47
48	Brush or spray, Cures by solvent evaporation. May be reactivated with methyl ethyl Ketone up to 24 hours after application.	30°F	MIL-W-5665, Type II, Class 3, (cotton webbing) bonded to aluminum 17 lbs/in (2)	100 psi; MIL-W-5665 to aluminum. (1)	300°F	BAC 5010 TYPE 48
49	Knife or spatula. Cures by polymerization at room temperature. Requires clamping during cure.	Part A, 472°F Part B, 277°F	Rigid adhesive. Very low peel strength.	200 psi; MIL-W-5665 to aluminum. (1)	160°F	BAC 5010 TYPE 49
50	Brush or swab. Cures at room temperature by moisture absorption.	176°F	BMS 1-11, Grade 40, Neoprene rubber bonded to 2024-T3 aluminum 30.6 lbs/in (2)	BMS 1-11, Grade 40, to aluminum. Also aluminum to aluminum. 100 psi (1)	180°F	(6)

Figure 26.711-2 (Continued)

26.711 SELECTION OF ADHESIVES (Continued)

ADHESIVE PROPERTIES (Continued)					
BAC 5010 Type No.	Manufacturer's Designation or BMS No.	Description	Visual Appearance	Physical Properties & Primary Uses	Resistance To Liquids
51	BMS 5-31	A two component poly-sulfide base room temperature curing adhesive.	A translucent, brownish-green paste.	A tough flexible adhesive. Used primarily to bond Nylon & Mylar to themselves & other materials. Should be used when resistance to vibration and fuel is a factor.	Resistant to water, fuel, & oils. Poor resistance to BMS 3-11 & salt spray.
52	BMS 5-60	A two component Epoxy, low viscosity, quick setting, room temperature curing adhesive.	Clear amber, low viscosity liquid.	Quick setting. Good electrical properties. Used for bonding phenolic, laminated sheet & metal-clad.	Resistant to BMS 3-11, oil, & fuel. Poor resistance to water & salt spray.
53	Gaco N-29 Cold bond Gaco N-39 Accelerator Gaco N-15 Primer	A two component, Neoprene base, room temperature curing adhesive.	Medium viscosity syrup. Olive drab to black color.	A tough, flexible contact adhesive. Used for bonding and splicing Neoprene rubber and Neoprene rubber coated fabrics to themselves & with a primer to metals.	Resistant to water and oil. Poor resistance to fuels. Not BMS 3-11 resistant.
54 Grade 1	BMS 5-25 Grade 1	A two component, aluminum filled, room temperature curing, Epoxy resin base adhesive.	Red paste	A rigid adhesive high in tensile & shear strength, but poor in peel strength. Used for bonding metal to metal in non-structural applications where high strength is required. Bonds metals, plastics, wood, glass and fiberglass laminates to themselves & to each other. Do not use for bonding copper & brass. Good filling properties.	Resistant to BMS 3-11, oil, and fuel. Poor resistance to water and salt spray.
54 Grade 3	BMS 5-25 Grade 3		Gray paste		
56	Epon 828 Pyromellitic Dianhydride Accelerator	A two component, high temperature curing, Epoxy resin adhesive.	Canary yellow syrup.	A rigid adhesive high in tensile and shear strength, but poor in peel strength. Used for bonding Teflon to metal. Good at high temperatures.	Resistant to water and oil. Poor resistance to fuels. Not BMS 3-11 resistant.
58	EC-880	A one component, room temperature setting synthetic rubber adhesive.	Light tan, brushable syrup.	Synthetic rubber contact cement. Good flow resistance, heat resistance. Synthetic rubber to metal, wood, & most other surfaces.	Resistant to water and oil. Poor resistance to fuels. Not BMS 3-11 resistant.
59	Epon 913	A two component room temperature or heat curing Epoxy resin base adhesive.	Dark gray paste	A rigid Epoxy resin system, high shear strength. Bonds metal, Buna-N rubber, acrylics, wood, & glass to themselves & to each other. Good bond strength to oily metals.	Resistant to fuel, oil, BMS 3-11, & water. Not resistant to salt spray.
60	Q-3-0121 RTV 1200 Primer (1)	A one component room temperature vulcanizing Silicone rubber.	Creamy, white paste.	Cures to a white rubbery solid. Excellent peel strength and good electrical insulating properties. Good adhesion to Silicone rubber and most other materials.	Resistant to water and ozone. Poor resistance to oil. Fair resistance to BMS 3-11. Not fuel resistant.
68	93-046 RTV 1200 Primer (1)	A two component room temperature vulcanizing Silicone rubber adhesive.	Heavy black paste.	Cures to a tough black rubbery solid. Very high peel strength. Adheres well to glass, cured Silicone rubber, cork, phenolic, Epoxy, Silicone resin laminates and most metals.	Resistant to water and ozone. Poor resistance to oil. Fair resistance to BMS 3-11. Not fuel resistant.

Figure 26.711-2 (Continued)

26.711 SELECTION OF ADHESIVES (Continued)

ADHESIVE PROPERTIES (Continued)						
BAC 5010 Type No.	Application & Cure	Flash Point	180° Peel Strength (1)	Minimum Shear Strength (1)	Temperature Limitations	Drawing Callout
51	Knife or spatula. Cures by polymerization at room temperature. Requires contact pressure during cure.	Above 150°F	10 lbs/in Mylar to aluminum. 5 lbs/in, Nylon to aluminum. (1)	90 psi Mylar to aluminum. 150 psi, Nylon to aluminum. (1)	- 65°F to 160°F	BAC 5010 TYPE 51
52	Brush. Room temperature curing Requires contact pressure during cure.		Rigid adhesive - very low peel strength.	500 psi, BMS 8-20 (phenolic (1) laminate) to BMS 8-20.	250°F	BAC 5010 TYPE 52
53	Cures upon solvent evaporation by room temperature vulcanization.	Base, 34°F; Activator, 83°F.	MIL-W-5665, Type II, Class 3 (cotton webbing) bonded to 2024-T3 aluminum (2) 12.9 lbs/in	MIL-W-5665, Type II, Class 3 (cotton webbing) bonded to 2024-T3 aluminum. (2) 267 psi	200°F	BAC 5010 TYPE 53
54 Grade 1	Knife or spatula. Cures by polymerization at room temperature or at temperature up to 200°F. Requires contact pressure during cure.	150°F	Rigid adhesive - very low peel strength.	1000 psi, aluminum to aluminum. (1)	160°F	BAC 5010 TYPE 54 GRADE 1
54 Grade 3	Knife or spatula. Cures by polymerization at a temperature of 200°F to 350°F. Requires contact pressure during cure.	150°F	Rigid adhesive - very low peel strength	1100 psi, aluminum to aluminum. (1)	300°F	BAC 5010 TYPE 54 GRADE 3
56	Knife or spatula. Cures by polymerization at 350°F under 5 to 15 psi.		Rigid adhesive - very low peel strength.	2024-T3 aluminum bonded to aluminum 1863 psi (1)	350°F	BAC 5010 TYPE 56
58	Brush or spray. Cures upon solvent evaporation at room temperature		MIL-W-5665 Type II, Class 3 (cotton webbing) bonded to aluminum 36 lbs/in (2)	MIL-W-5665 Type II, Class 3 (cotton webbing) bonded to aluminum 410 psi (2)	- 20°F to 250°F	BAC 5010 TYPE 58
59	Knife or spatula. Cures by polumerization at room temperature or at temperature up to 180°F. Requires contact pressure during cure.		Rigid adhesive very low peel strength.	2024-T3 alumimum to aluminum 404 psi. (2)	180°F	BAC 5010 TYPE 59
60	Knife or spatula. Cures at room temperature by moisture absorption. Requires contact pressure during cure.		BMS 1-22 Silicone rubber bonded to 2024-T3 aluminum. 30 lbs/in	BMS 1-22, sandwiched between 2024-T3 aluminum lap shears. 234 psi (2)	- 85°F to 400°F	BAC 5010 TYPE 60
68	Spatula, trowel, or sealant gun. Cures at room temperature.				- 70°F to 500°F	BAC 5010 TYPE 68

Figure 26.711-2 (Continued)

26.711 SELECTION OF ADHESIVES (Continued)

(1) Refer to minimum BMS requirement.

(2) Refer to the average test results of T6-3133.

(3) 1. Wood flyaway application: BAC 5010, TYPE 19, METHOD I.

2. Wood non-flyaway application: BAC 5010 TYPE 19, METHOD II.

3. Bonding wood & Buna-N rubber to metals: BAC 5010, TYPE 19, METHOD III.

(4) 1. General application: BAC 5010, TYPE 34, METHOD I.

2. Bonding vinyl or polyurethane foams to metal: BAC 5010, TYPE 34, METHOD II.

(5) 1. General application: BAC 5010, TYPE 38.

2. Bonding to metal surfaces: BAC 5010, TYPE 38, SPECIAL METHOD I.

3. Nonstructural metal to metal bonding. Using glass scrim: BAC 5010, TYPE 38, SPECIAL METHOD II.

(6) 1. General application: BAC 5010, TYPE 50, METHOD I.

2. Primer application only, for bonding thin rubber gaskets, complicated parts and where one highly plasticized surface is involved: BAC 5010, TYPE 50, METHOD II.

(7) Required on non-silicone rubber surfaces.

NOTE: When the design of nonstructural joints approaches any of the limitations shown here, consult the Materials Technology organization for recommendations.

Figure 26.711-2

26.712 SURFACE REQUIREMENTS FOR NON-STRUCTURAL BONDING

A. ALODIZED ALUMINUM SURFACES. No bonding restrictions when alodized per BAC 5719.

B. ANODIZED ALUMINUM SURFACES. No bonding restrictions when anodized per BAC 5019.

C. CHROMADIZED CLAD ALUMINUM SURFACES. No bonding restrictions when chromadized per BAC 5798.

D. BMS 10-11, TYPE I, PRIMER OR BMS 10-53 PRIMER. No bonding restrictions when BMS 10-11, Type I Primer or BMS 10-53 Primer is applied per BAC 5736 or BAC 5745.

E. ZINC CHROMATE PRIMED SURFACES. Bonding to zinc chromate primed surfaces is allowed only:

1. When the bonded parts are completely and mechanically supported by means other than adhesives. (Note - mechanical holding waived for overhaul and repair).
2. Where batts, lining materials, paper, or felt are to be bonded.
3. Where the adhesive is used primarily to facilitate assembly.

Zinc chromate primer should be omitted from bonding areas on the original design or may be removed prior to bonding, whichever is more feasible.

F. ORGANIC PAINT FINISHES. Bonding is allowed, but not desirable, over epoxy enamel. Bonding is not allowable over:

1. Alkyd Enamel
2. Acrylic Enamel
3. Vinyl Paint
4. Nitrocellulose Lacquers

All organic finishes should be omitted from bonding areas (including epoxy enamel) in the original design or they may be removed later if this is more feasible.

G. CADMIUM PLATED STEEL. No bonding restrictions on cadmium plated steel which meets the requirements of Federal Specification QQ-P-416, Type II or BAC 5718 and BAC 5701 which specify chromate post-plate treatment. See the applicable model finish specification for proper finish callout. Where the chromate post-plate treatment is not allowed, contact the Materials Technology organization for bonding instructions.

H. CADMIUM PLATED TITANIUM. No bonding restrictions on cadmium plated titanium which meets the requirements of BAC 5804 and specifies chromate post-plate treatment. See the applicable model finish specification for proper finish call-out. Where the chromate post-plate treatment is not allowed, contact the Materials Technology organization for bonding instructions.

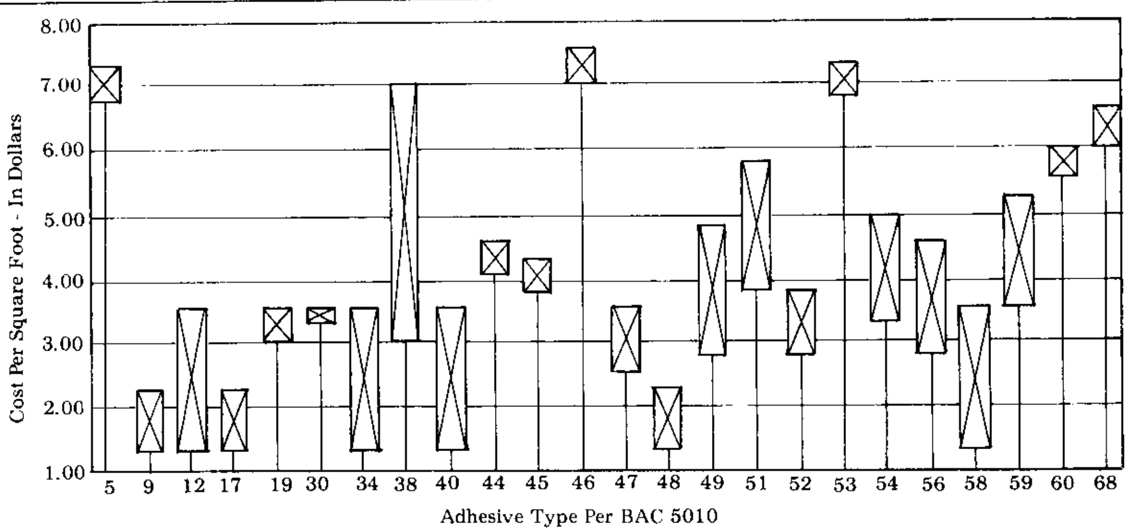
I. POLYTETRAFLUOROETHYLENE (TFE - TEFLON). Teflon must be surface treated prior to bonding. There are no bonding restrictions on surface treated Teflon (purchased as "bondable" one side) or on Teflon etched per BAC 5481 or BAC 5550 (1)

(1) Where etching facilities exist.

26.713 COST INFORMATION

Comparative costs of adhesive bonding are given in Figure 26.713-1.

COST OF NON-STRUCTURAL ADHESIVE BONDING



Costs are for bonding two flat, non-porous surfaces one foot square and include all manufacturing costs, including primer where necessary. Material, labor and overhead costs were included. Data re-verified in August 1966.

Figure 26.713-1

26.714 DRAWING CALLOUT

To obtain the proper drawing callout for nonstructural adhesive bonding follow the steps outlined in the footnote to Figure 26.711-1 and use the appropriate BAC 5010 Type number as indicated in Figure 26.711-2. The callout shall appear on the drawing as:

BOND PER (Drawing callout from Figure 26.711-2).

Example: BOND PER BAC 5010, TYPE 38, SPECIAL METHOD 1.

The callout shall be referred to by flags in the appropriate place on the field of the drawing and in the material column of the list of materials for both details and their assemblies.

NOTE: For drawing callout of specific processes and/or materials, see the references in 26.022.

LIST OF REFERENCES

1. "The Fastener Population Bomb," *American Machinist Magazine*, April 17, 1972.

2. *Assembly Directory and Handbook*, Hitchcock Printing Company, Wheaton, Illinois, 1969.

3. Walter Schwenk, *Fabrication Techniques for Rivet Fasteners Utilizing 55-Nitinol*, Interim Technical Report IR-85R-2 (IV), Air Force Materials Laboratory, March-May 1973.

4. C. R. McKenney and J. G. Baker, "Explosion-Bonded Metals for Marine Structural Applications," *Marine Technology*, July 1971.

5. V. D. Linse, R. H. Wittman, and R. J. Carlson, *Explosive Bonding*, DMIC Document 225, Battelle Memorial Institute, Columbus, Ohio.

6. F. R. Baysinger, "Welding Aluminum to Steel Using Transition Insert Pieces," *Welding Journal*, February 1969.

7. H. E. Otto and S. H. Carpenter, "Explosive Cladding of Large Steel Plates With Lead," *Welding Journal*, July 1972.

8. R. H. Whittman, "The Explosive-Bonding Process: Applications and Related Problems," ASTME AD67-177, April 1967.

9. Private Correspondence with C. R. McKenney, Marketing Representative, Metal Classing Section, E. I. du Pont de Nemours and Company, February 28, 1973.

10. L. Farbo, Boeing Laboratory Test Report LSR-2852, New Oreleans Test Facility, November 26, 1969.

11. L. A. Becker, *Evaluation of Bimetallic Couple for Use on Naval Combat Ships*, Naval Ship Research and Development Center Report 3634, May 1971.

12. *Marine Technology Magazine*, July 1971.

13. R. S. Koogle, "Fabrication Cost Comparison Study--Welded Aluminum/Steel, Bimetallic Strip Versus Mechanical Fastening," Project Order 2-0094.

14. Robert Yearick, "Shipshape for a Big Catch, "*Du Pont Magazine*, July-August 1972.

15. F. E. Hamren, "Liquid Natural Gas Ships--A New Construction Approach," *Maritime Reporter and Engineering News*, February 1, 1973.

16. Personal Communication with C. R. McKenney, E. I. du Pont de Nemours and Company, April 1973.

ADDITIONAL SOURCES OF INFORMATION

1. Altenburg, C. J. and R. J. Scott, *Design Considerations for Aluminum Hull Structures,* Gibbs and Cox Ship Structure Committee Report 218, USCG, 1971.

2. "American Shipbuilders Turn to Automated Welding to Compete," *Welding Engineer,* April 1969.

3. Cantrell, D., *Bonding Metal-to-Metal Riveted Structure With Room Temperature Curing Adhesive,* D6-7132, Boeing Commercial Airplane Company, September 1961.

4. Cline, C. L., "An Analytical and Experimental Study of Diffusion Bonding," *Welding Journal Supplement,* November 1966.

5. DeLollis, N. J., "Adhesives for Metals--Theory and Technology," *Industrial Press,* 1970.

6. *Establishment of Parameters and Limitation of Explosive Welding,* Pratt & Whitney Aircraft Report PWA-FR-1528, August 27, 1965.

7. "Friction Welding: Versatile Joiner of Dissimilar Metals," *Welding Engineer,* December 1970.

8. Gatsek, Leo F., *Bonding and Welding of Dissimilar Metals,* NASA Publication SP-5018.

9. Hawkins, S., G. H. Levine, and R. Taggart, *A Limited Survey of Ship Structural Damage,* Ship Structure Committee Report 220, USCG, 1971.

10. Holtyn, C. H., "Aluminum--The Age of Ships," Presented to the Society of Naval Architects and Marine Engineers, New York, November 10, 1966.

11. Holtyn, C. H., *Shipbuilding Guide to Aluminum Construction,* Reynolds Metals Company, 1963.

12. Lowenberg, A. L., and P. D. Watson, *Recommended Emergency Welding Procedure for Temporary Repair of Ship Steels,* Ship Structure Committee Report 195, May 1969.

13. *Machine Design Magazine,* Fastener reference issue, 1972.

14. Roderick, Robert L., *American Machinist Magazine,* McGraw-Hill, December 28, 1970.

15. Scott, R. J., and J. H. Somella, *Feasibility Study of Glass-Reinforced Plastic Cargo Ship,* Gibbs and Cox Ship Structure Committee Report 224, USCG, 1971.

16. Turner, M. J., "Manual Vs. Machine Welding in Shipbuilding," *Welding Engineer,* August 1972.

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13. ABSTRACT

This report is aimed at defining fastening processes and techniques that are not widely used in ship construction today in terms of their applicability and potential for improving cost, construction, reliability, and maintenance of hull structures and attachments. The study includes similar and dissimilar metal-to-metal and metal-to-nonmetal joints, a generic fastener matrix of typical fasteners, fastener installation equipment and processes, proposed applications of explosion-bonded materials, and cost comparisons of various fabrication techniques. Fusion welding, diffusion bonding, friction welding, and adhesive bonding are discussed. Several fastener standards and vendor proprietary fasteners are included as figures. Extractions from Boeing Design Manual sections on mechanical fastening and adhesive bonding are included as reference attachments. Fastening systems and techniques that merit further study or verification are identified.

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Prof. A. Mansour, *Dept. of Ocean Engineering, Massachusetts Inst. of Technology*
Prof. R. H. Owens, *C'man, Dept. of App. Mathematics & Computer Science, University of Virginia*
Dr. P. Van Dyke, *Principal Research Scientist, Hydronautics, Inc.*
Prof. G. A. Wempner, *School of Eng. Science & Mechanics, Georgia Inst. of Technology*

The SR-207 Project Advisory Committee provided the liaison technical guidance, and reviewed the project reports with the investigator:

SHIP STRUCTURE COMMITTEE PUBLICATIONS

These documents are distributed by the National Technical Information Service, Springfield, Va. 22151. These documents have been announced in the Clearinghouse journal U.S. Government Research & Development Reports (USGRDR) under the indicated AD numbers.

SSC-251, *A Study of Subcritical Crack Growth In Ship Steels* by P. H. Francis, J. Lankford, Jr., and F. F. Lyle, Jr. 1975. AD-A013970.

SSC-252, *Third Decade of Research Under the Ship Structure Committee* by E. A. Chazal, Jr., J. E. Goldberg, J. J. Nachtsheim, R. W. Rumke, and A. B. Stavovy. 1976. AD-A021290.

SSC-253, *A Guide for the Nondestructive Testing of Non-Butt Welds in Commercial Ships - Part One* by R. A. Youshaw and E. L. Criscuolo. 1976. AD-A014547.

SSC-254, *A Guide for the Nondestructive Testing of Non-Butt Welds in Commercial Ships - Part Two* by R. A. Youshaw and E. L. Criscuolo. 1976. AD-A014548.

SSC-255, *Further Analysis of Slamming Data from the S.S. WOLVERINE STATE* by J. W. Wheaton. 1976. AD-A021338.

SSC-256, *Dynamic Crack Propagation and Arrest in Structural Steels* by G. T. Hahn, R. G. Hoagland, and A. R. Rosenfield. 1976. AD-A021339.

SSC-257, *SL-7 Instrumentation Program Background and Research Plan* by W. J. Siekierka, R. A. Johnson, and CDR C. S. Loosmore, USCG. 1976. AD-A021337.

SSC-258, *A Study To Obtain Verification of Liquid Natural Gas (LNG) Tank Loading Criteria* by R. L. Bass, J. C. Hokanson, and P. A. Cox. 1976.

SSC-259, *Verification of the Rigid Vinyl Modeling Technique: The SL-7 Structure* by J. L. Rodd. 1976.

SL-7 PUBLICATIONS TO DATE

SL-7-1, (SSC-238) - *Design and Installation of a Ship Response Instrumentation System Aboard the SL-7 Class Containership S.S. SEA-LAND McLEAN* by R. A. Fain. 1974. AD 780090.

SL-7-2, (SSC-239) - *Wave Loads in a Model of the SL-7 Containership Running at Oblique Headings in Regular Waves* by J. F. Dalzell and M. J. Chiocco. 1974. AD 780065.

SL-7-3, (SSC-243) - *Structural Analysis of SL-7 Containership Under Combined Loading of Vertical, Lateral and Torsional Moments Using Finite Element Techniques* by A. M. Elbatouti, D. Liu, and H. Y. Jan. 1974. AD-A 002620.

SL-7-4, (SSC-246), *Theoretical Estimates of Wave Loads on the SL-7 Containership in Regular and Irregular Seas* by P. Kaplan, T. P. Sargent, and J. Cilmi. 1974. AD-A 004554.

SL-7-5, (SSC-257) - *SL-7 Instrumentation Program Background and Research Plan* by W. J. Siekierka, R. A. Johnson, and CDR C. S. Loosmore, USCG. 1976. AD-A02133

SL-7-6, (SSC-259) - *Verification of the Rigid Vinyl Modeling Technique: The SL-7 Structure* by J. L. Rodd. 1976.