FASTENING ON THE F-14A
FOR COST EFFECTIVE FATIGUE RESISTANCE

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Introduction

Advancements in the state of the art continually challenge the airframe designer to cost effectively meet the requirements that arise with each new aircraft and its ever more demanding missions. The Grumman designed F-14A is a classic example of this fact, generated around the severest performance parameters.

To enumerate:

- The Navy posture for the 1970's requires an air superiority aircraft second to none
- Interchangeable multi-mission role capability was essential to broad spectrum cost effective carrier operations
- Greatly increased fatigue life over previous models
- Severely increased fatigue spectrums
- Minimum practicable structural maintenance
- Broad speed range variation from low subsonic to high supersonic

Preliminary design studies dictated a variable geometry wing to meet these design objectives. Experience with the F-111 Aircraft and the early study versions of the Boeing Supersonic Transport, made it clearly apparent that success in such a design would require weight optimization, maximum working stress levels and minimized fatigue concentration factors particularly in the moveable wing.

An extensive development program to guarantee these goals was conceived and activated at Grumman, and resulted in three major decisions.

- Extensive use of titanium as a structural material was essential
- Electron beam welding would be most effectively and selectively employed
- Interference fit fastening techniques were to be the principal mechanical joining means for the structure

Mr. Robert Witt in his paper on Tuesday, discussed Electron Beam Welding accomplishments. This presentation will, therefore, be addressed to the development and use of the interference fit systems as they contribute to cost effectiveness and reliability for the F-14A.

Discussion

For historical perspective, designing for interference fit fastening in aircraft is not new. In 1961, tapered fasteners in interference fit were installed in limited quantities in the RA-5C Vigilante, to obtain some extended fatigue life. With the passage of years, use of these fasteners increased, but it was not until the present family of aircraft that the interference fit concept was adopted as a major overall approach to structural joining. This discussion will be limited to its application on the F-14A aircraft.

Properly used, interference fit fastening provides an effective means for accomplishing two very desirable airframe design objectives. It makes possible a structure which is both optimized for weight, and yet fatigue resistant beyond normal life expectancy. In the past, this was a contradiction, since increasing fatigue resistance usually meant adding mass to the structure to reduce the operating stresses.

But the secret of interference fit fasteners is their unique ability to reduce the stress concentrations inherent in and around fastener holes by the generation of residual circumferential tensile stresses at the edge of the hole and radial compressive stresses in the wall of the hole.[1]

This stress concentration factor due to the fastener hole is the major contributing element in establishing the required thickness of a mechanically fastened structural joint. It therefore follows that the thickness can be reduced as the concentrations are minimized. The resulting weight reduction thus produced by interference fit fastening becomes obvious.

Today, many different fastening systems can produce variations of this end product with some degree of success. However, this paper offers no comparisons other than those affecting the selection of the F-14A fastening systems. Furthermore, theoretical analysis and critique of these systems is not included. Grumman has, from design to implementation, resolved the problem on the basis of function, performance, cost effectiveness and repairability, with cost effectiveness as the principal target for the development effort. Definite economic limits were the forcing constraints on any fastening system chosen.

With titanium wing structure to be joined by interference fit fastening, Grumman was in a difficult position. Despite some previous industry use of interference fastening in titanium structure, Grumman was breaking new ground with an entire wing design committed to such a combination, which emphasized the intense concentration required on cost. A mind open to new approaches was essential if a satisfactory conclusion was to be reached.

This immediately opened the field for screening fastening systems beyond those commercially available at that time. Entirely new approaches had to be devised and considered to assure that the most cost effective end product would be found. All Engineering and Manufacturing disciplines concerned participated in the design, evaluation and ultimate selections.

After considerable research and development, two different interference fit fastening systems resulted for the F-14A to meet the high and low load transfer joint requirements. Although, in both types, the end product is similar, each system performs a specific function within the limits of its own unique application. Because of these differences each system will be presented separately. We will start with the case of medium to high load transfer applications, such as beam to wing cover attachments.

For this, a <u>two piece straight shank interference fit fastening system</u> is used. Initial ground rules required any satisfactory interference fit system to provide all of the mechanical and physical properties available in conventional fasteners, and in addition be capable of installation in titanium structure with thicknesses varying to triple the fastener diameter. Fastener Material galvanically compatible with the titanium structure was mandatory since normally acceptable protective finishes would not survive in this application.

The then generally accepted tapered fastener gave rise to serious concern over its ability to meet all these objectives within the required cost limits. Manufacturing capability required to produce these sensitive tapered holes on a production basis to Grumman specification requirements was Concern #1. Because titanium is a much less forgiving material than alumimum, tapered holes on the F-14A demanded three coincident qualities for acceptance:

- Taper
- Roundness
- Diameter

With no known proven quality control method available to inspect these requirements economically, no guarantee that the benefits displayed by tapered fasteners in laboratory tests could be substantiated for production. At this point, investigation of straight shank fastening became a mandatory alternative.

Conventional titanium HiLok fasteners from HiShear Corp. of Torrance, Calif., in early functional installation tests when coated with commonly used molybdendum disulfide (MoS_2) dry film lubricant, first indicated a possible successful path to pursue. With minor variations, this fastening system was baselined at the best available starting point for the formidable task ahead. The development of a finishing system to permit installation of titanium pins into titanium structure, without the characteristic material galling during the insertion of the fastener into the hole was clearly Task #1. Task #2 required effective use of standard portable impact tooling on installation for use where squeezing access to both faces is unattainable.

Early test soon established an achievable interference level of .0045 for 1/4 inch diameter pins. By combining the expected hole tolerance of .0020 with normal ground shank fastener tolerance of .0005, the resultant interference spread for the fastening system was set at .0025. An empirical percentage of diameter concept for determining larger size interference levels was next derived. Figure 1 illustrates the interferences established for such a straight shank fastening system. The minimum interference level of .002 for 3/16 and 1/4 inch fasteners was confirmed by fastener fatigue tests to a minimum level of .0015 with the additional .0005 supplying the probability insurace for reliability in the system. Element fatigue testing of interferences below .0015 produced some inconsistencies making the absolute minimum guarantees essential. Figure 2 presents partial results of F-14A spectrum fatigue testing of this fastening system with both .0015" and .0040" interference levels in unloaded joint configuration.$_2$ Note that the improvement in fatigue life provided by straight shank interference fit fastening techniques is clearly evident.

Completion of this early testing led into efforts to improve the dry film lubrication. With the wing structural materials of Ti6AL4V and Ti6AL6V 2 Sn alloys, the initial fastener materials investigated were A-286 stainless steel and 6AL 4V titanium for reasons of galvanic compatibility. Very shortly, the A-286 material was discarded for lack of a finishing system capable of meeting all installation parameters. With the full concentration centered on titanium fasteners, numerous lubrication systems were tried and found wanting. It became apparent, however, that the ultimate finish would consist of an anodic coating base for some molybdenum disulfide dry film lubricant.

A finishing system developed and produced by Tiodize Corp. of

Burbank, Calif. successfully permitted reliable nongalling installations for titanium fasteners ranging through 5/16 inch diameter in all anticipated conditions. Proper lubrication of these fasteners is vital for two obvious reasons:

- Ease and repeatability in the installation of nondamaging fasteners
- Removal of fasteners if necessary, without hole damage

Structural repair or modification requiring removal of so called permanent fasteners had to be anticipated. The possibility always exists for an apparently properly installed fastener to gall the hole if inadequate finish is used, making normal removal impossible.

Accordingly, an acceptance requirement has been generated wherein sample test pins from each lubricated production run are installed in maximum interference and then removed from a titanium test plate. Lack of shop problems to date has validated this in-process lubrication control. Figure 3 compares the relative drive forces required to install a straight pin into three different materials.[3] Also of interest is the obvious modulus ratio of 1:1 with use of titanium fasteners and structure, which demands maximum efficiency of the finishing system in the fastener/hole interface.

Interference fit fasteners in diameters as great as three quarters of an inch next appeared as a probable requirement raising new concern over the relationship between the compressive strength of the 6AL 4V titanium already selected as the fastener material, and the obviously high installation forces they would require. Another material was accordingly sought to meet the existing requirements and yet provide the added installation strength necessary to meet all conditions.

Maximum galvanic compatibility along with corrosion resistance became an essential requirement in choice to preclude any stress corrosion potential because of aircraft carrier environmental conditions.

The winner, one of the few candidate alloys was Multiphase 35N which might well have been conceived specifically for the F-14A. It is a quartenary base material (35Ni 35 Co 20 CR 10 Mo) exhibiting extremely high resistance to straight corrosion and unsusceptible to stress corrosion cracking when tested in a 3.5 percent Na Cl solution for 180 days.[4] Strength levels in excess of 260 K.S.I. Ftu are achievable exceeding the F-14 requirement of 132 K.S.I. Fsu (228 K.S.I. Ftu). MP35N offers other advantages as a bolting material, giving further emphasis to its selection. After cold work and aging the material meets the following minimum properties:[5]

Tensile Strength	260,000 PSI
Yield Strength at .2% offset	230,000 PSI
Elongation in 4 diameters	8%
Reduction in Area	35%

This high yield and ductility is the basis for a fastener with the excellent bending and fatigue strength essential for inboard joints of a fighter type wing.

Standard Pressed Steel Co., of Jenkintown, Pa., the producer of these fasteners, supplied prompt resolution of the lubrication problem with a molybdenum disulfide coating of their own development.

All interference parameters for this two material fastening system, except materials, strengths and finishes were held constant. MP35N is utilized in 3/8 inch dia., through 5/8 inch dia. pins (representing ten percent of the two system total), with 6AL 4V titanium used in all the smaller diameters.

Figure 4 shows the configuration of this fastener. Although it is commercially known as HiLok/HiTigue, observe that the bead commonly associated with this fastener type has been revised to a transition radius proven more adaptable for titanium use. There is also an enlarged shank, for installation in standard size holes, thus preventing thread damage to the hole during installation.

To fully guarantee minimum interference fit in production with total repeatability and reliability, the fastener shank grinding and the hole production in the structure are rigidly controlled.

Grumman's cost effectiveness for this straight shank fastening system can best be defined at this time in terms of the following comparison relative to other systems:

- Standard Fastener configuration - low unit cost
- Conventional straight hole (one shot)
- Standard off the shelf cutting tools
- Completely simple hole inspection
- Conventional installation equipment(squeezing or impact driving)
- Reduced installation forces
- Minimum workforce indoctrination

Moving to the second fastening system, <u>controlled squeeze force riveting</u>, a brief resume of the F-14A wing design is in order. The titanium pivot fitting is electron beam welded to the wing cover. To compliment this configuration, and reduce machining operations, 'Z' and built up 'Y' section stringers are mechanically fastened to the wing covers. This structural arrangement of the upper and lower wing cover assemblies is illustrated in Figures 5 and 6.

A fastening system selection for the low load transfer joint characteristics of skin/stringer attachments was again based on the most cost effective method achievable. After an in depth analysis of the wing geometry and loading, an upsetable fastener type inserted in a clearance hole appeared feasible if production installation techniques could be developed to produce a reliable, repeatable interference fit system. Only with the proper controls, however, could such an installation be accomplished while having most of the advantages of the conventionally riveted joint, such as a very inexpensive fastener in a drilled .005 tolerance hole.

The initial functional tests clearly showed the need for a rivet material with upset ductility, yet having a modulus sufficient to overcome titanium's elastic resistance and produce the necessary interference fit. Material galvanic compatibility with titanium was again mandatory. Review of the available alloys resulted in selection of fully aged A286 stainless steel. It offers the required mechanical properties, is notably low in strain rate sensitivity, is reasonably priced and has a well known usage history. Possible alternate use of titanium beta alloys was not pursued at the time because of a low confidence level in repeatability of the published properties, and the slight improvement in the strength to weight ratio did not justify the increased cost.

In the finally derived process, the rivet is installed under application of a controlled squeeze force of approximately 500 K.S.I., hence giving the system its name. A more commonly known title, however, is the oversqueezed riveting system because of the obviously high installation forces involved. Figure 7 shows the installation of these rivets on Grumman's automated riveting equipment. Repeated tests have shown that, with the allowable geometric condition limits, this force consistently produces a minimum interference fit of .0015 between rivet and hole. Unloaded joint configuration spectrum fatigue test results of this fastening system as shown in Figure 8 compares with open hole testing in a common type specimen.[6] This direct comparison illustrates the fatigue life improvement offered by this concept. Testing of loaded joints, though also conducted, will not be discussed in this paper since any advantages in load transfer have not been incorporated in the F-14A design.

The intended goal, achieved in both of these systems, yields a structure statically rather than fatigue critical, derived through the stress concentration factor reduction at all fastener holes.

Installation of this rivet, as shown in Figure 9 obviously required floor mounted squeezing equipment to guarantee the necessary controls. Though desirable, a portable installation was not realized, however, until the Grumman developed stress wave riveter was introduced. The technical specifics of this remarkable device were the subject of a presentation on Tuesday by Mr. Basil Leftheris, another Grumman colleague. However, at the risk of duplication, discussion of its use in this application is pertinent. Although the apparent benefit from the stress wave riveter is portability, illustrated in Figure 10, resoundingly significant improvement in the end product resulted in two areas.

Against a trapezoidal fit of the installed oversqueezed rivet, (much greater interference fit at the upset tail than at the manufactured head), the stress wave riveter produces a more uniform fit from head to tail, because the speed at which the stress wave travels through the rivet to create interference fit and upset results in a rivet less sensitive to joint thickness. The stress wave riveter surpasses all other forms of upsetting because of their basic limitation in that they form the rivet tail before shank expansion. Therefore, since the energy produced is more efficiently used, the stress wave riveter can and does more consistently produce a greater and more evenly distributed interference fit.

Another fallout of this method is effective coining of the surface of the fastener hole by the inertia forces generated under the high speed stress wave mechanism. The cost effectiveness of this fastening system is best demonstrated by a comparison of riveted and bolted joints:

	Oversqueezed Rivet	Conventional Riveting	Conventional Bolting
Hole Tolerance	.005	.005	.002
Fastener Shank Tolerance	.001 (clearance .002/.008)	.005	.0005
Configuration	One Piece	One Piece	Two Pieces
Installation Method	Squeezing/ Stress Wave	Squeezing/ Bucking	Torque Wrenches

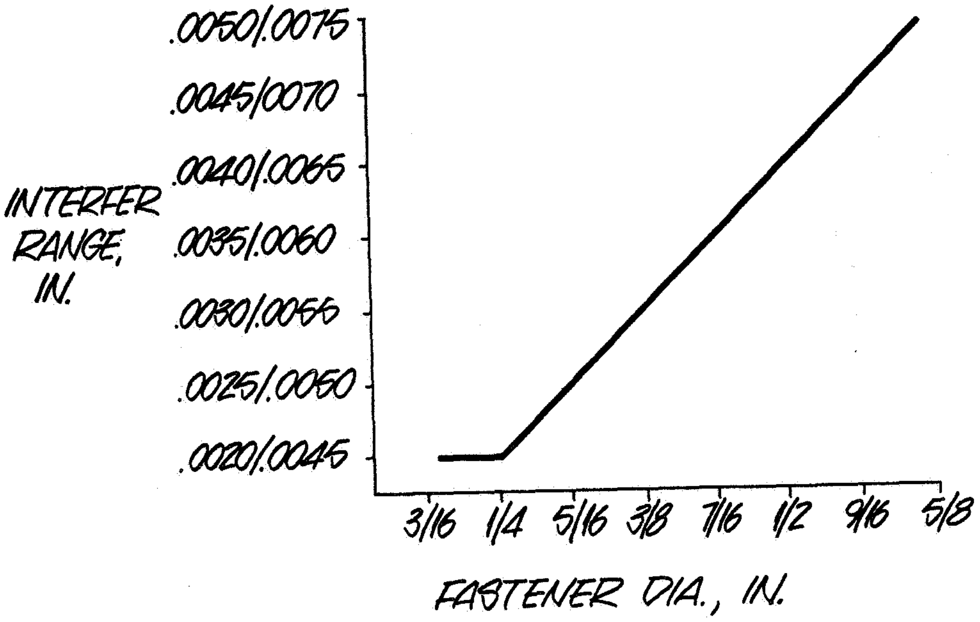
In summation, the benefits derived from interference fit fastening techniques produced under laboratory conditions for aerospace structures have been amply demonstrated many times. Grumman Aerospace, however, as all others, must build vehicles in the real world, not in laboratories.

For this reason, development of the F-14A systems was based on hard rate application in reality, the Production Shop. Only here can proven ultimate cost effectiveness and reliability of such systems be attained.

The high level of success achieved in reaching these much sought after goals has been most rewarding to this time. The few minor difficulties encountered to date in implementation indicate that the correct selections were made. Surely, the valuable, practical experience gained on the F-14A has provided the firm foundation to build the future advances in this state-of-the-art essential to the better, more complex and sophisticated vehicles of tomorrow.

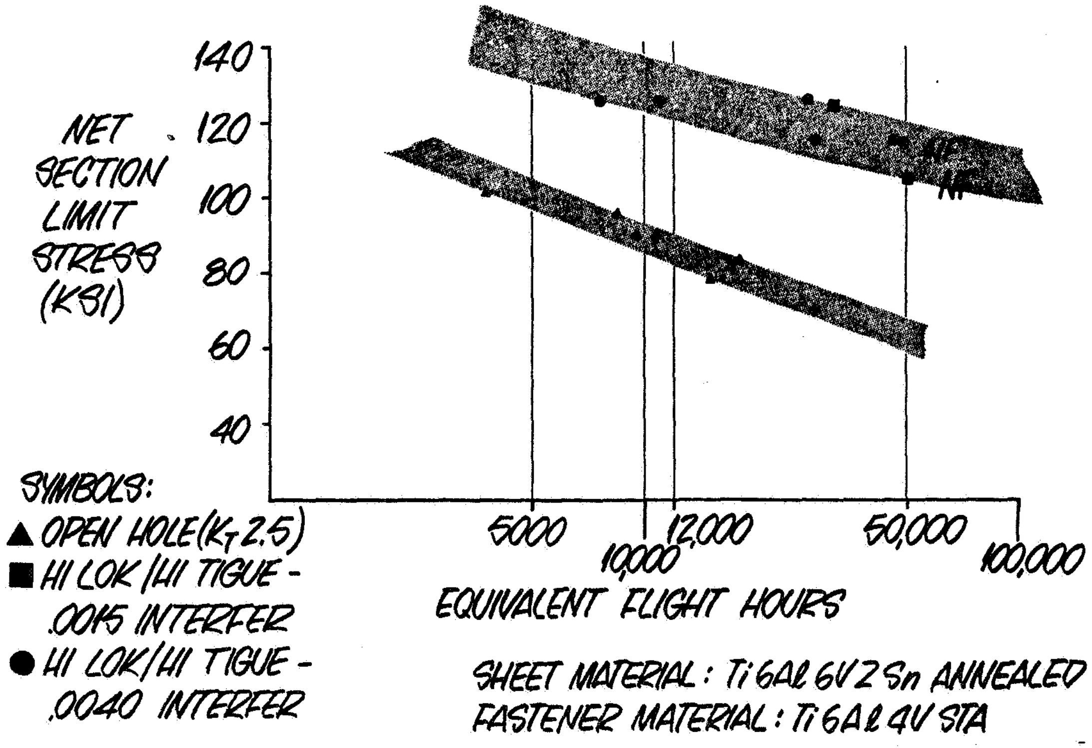
BIBLIOGRAPHY

1. Smith, Clarence R., "Preventing Fatigue Failures", Assembly Engineering, April 1968.
2. Wolfman, A., "Effects of Salt Water Exposure and Relaxation of Installation Stresses of Interference Fasteners in Ti6AL 4V and Ti6AL 6V2Sn Annealed Alloys", August 1969.
3. Gill, Frank, "Recent Developments in Structural Airfram Fasteners", Hi Shear Corp., Torrance, Calif.
4. Montano, J.W., "A Mechanical Property and Stress Corrosion Evaluation of MP35N Multiphase Alloy", National Aeronautics and Space Administration, Washington, D.C., May 1971.
5. Aerospace Material Specification (AMS) 5758, Society of Automotive Engineers, New York, May 1971.
6. Wolfman



INTERFERENCE LEVELS vs FASTENER DIAMETER

FIGURE 1



TWO PIECE STRAIGHT SHANK INTERFERENCE FIT FASTENER - SPECTRUM FATIGUE

SHEET MATERIAL: Ti 6Al 6V 2Sn ANNEALED
FASTENER MATERIAL: Ti 6Al 4V STA

FIGURE 2

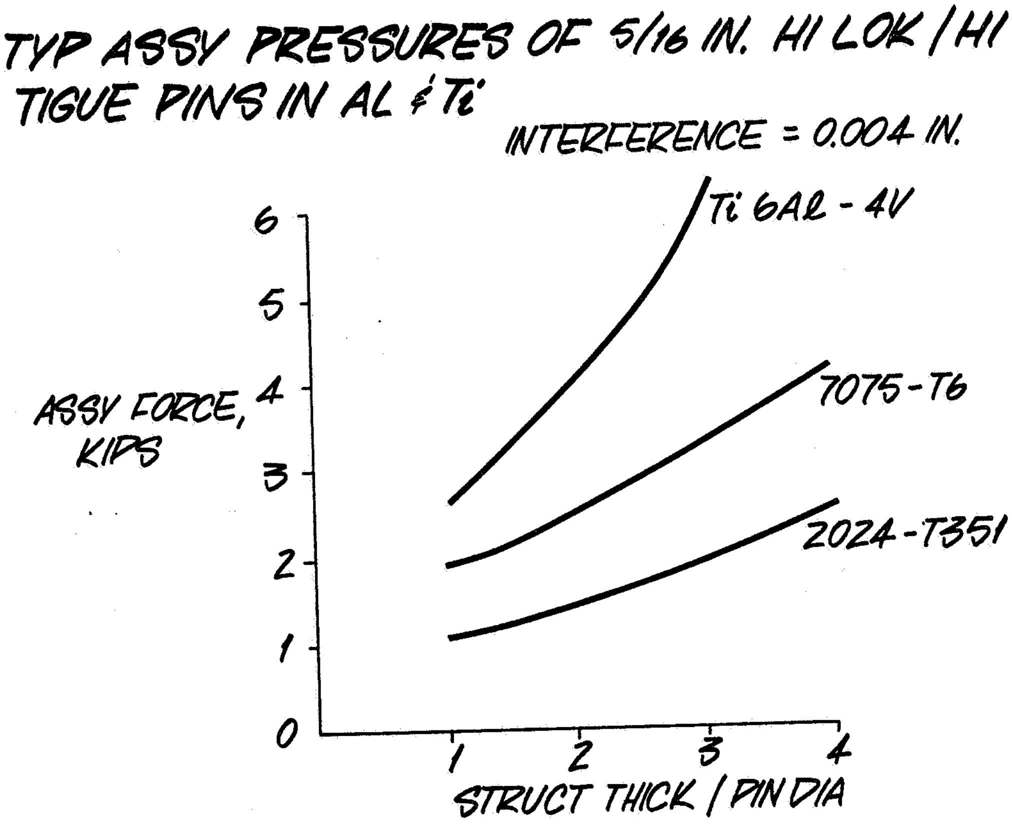


FIGURE 3

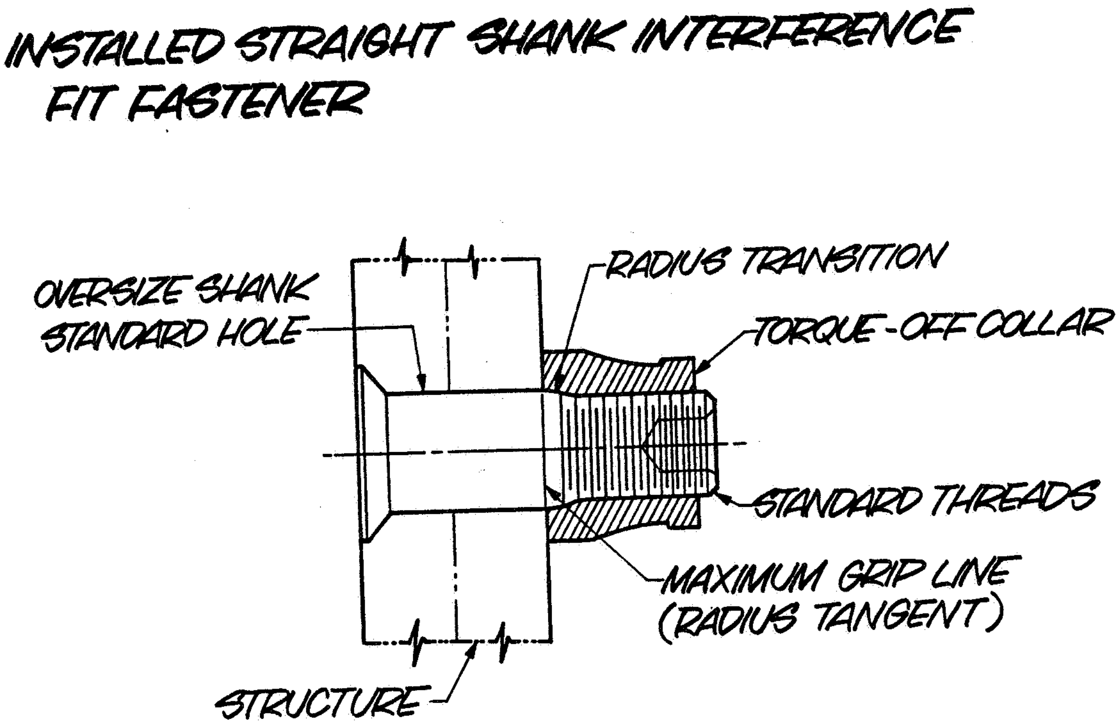


FIGURE 4

UPPER WING COVER ASSY

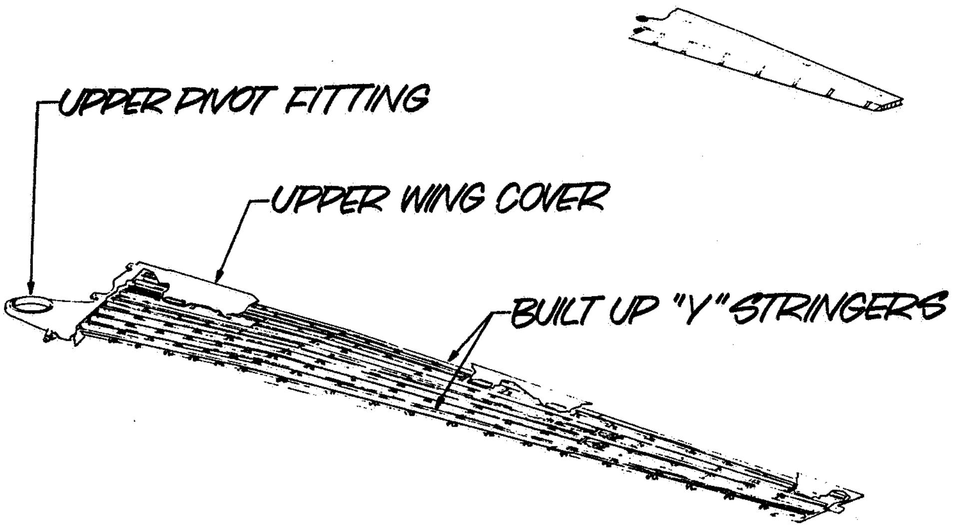


FIGURE 5

LOWER WING COVER ASSY

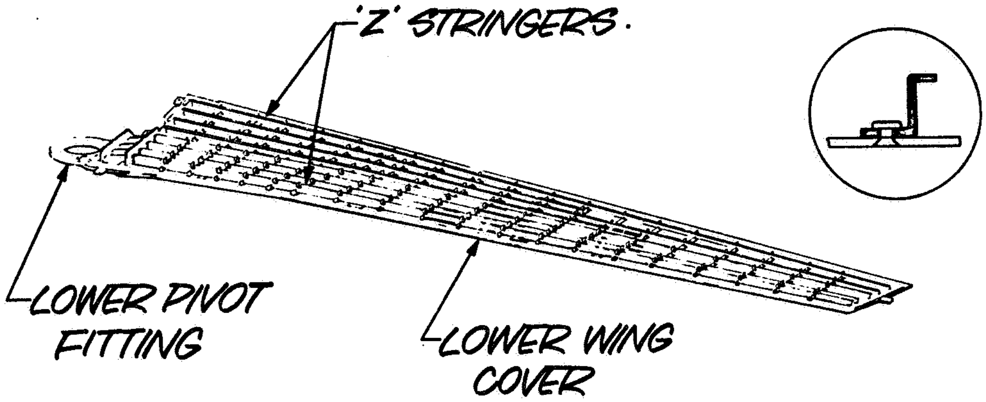


FIGURE 6

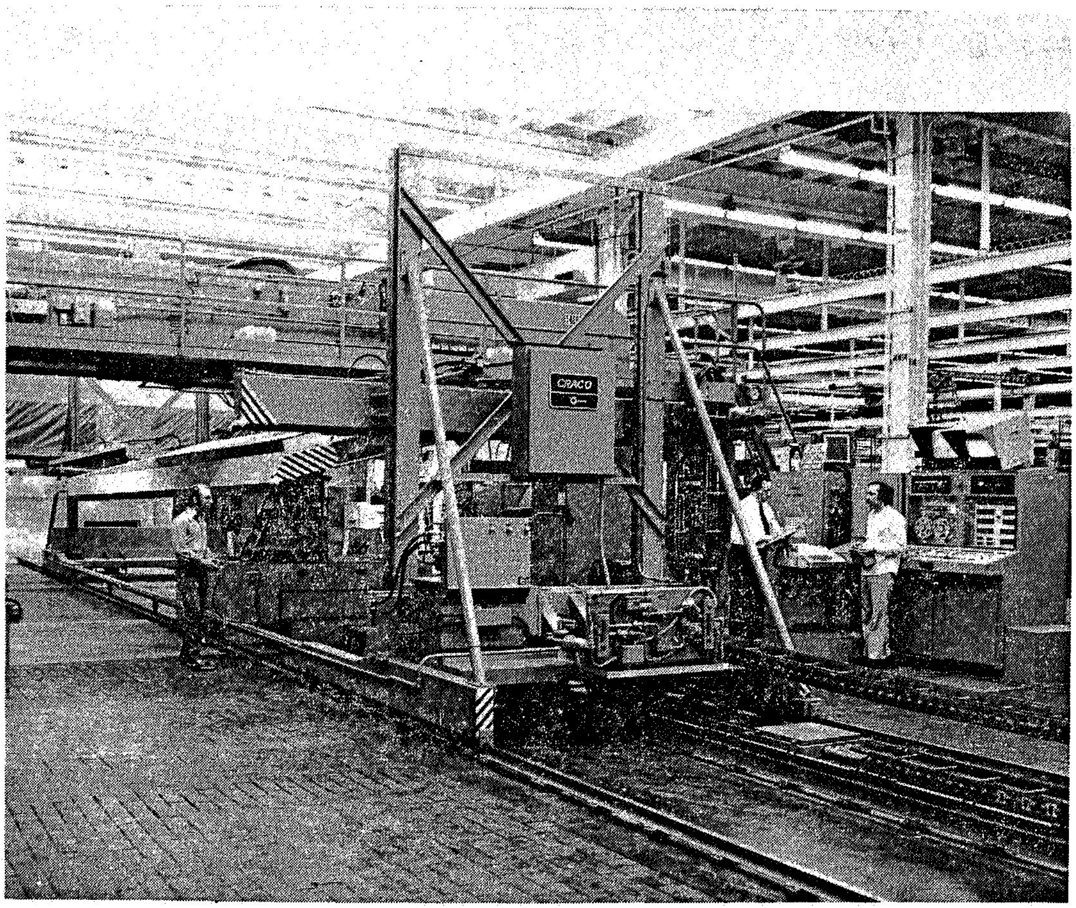


FIGURE 7
CRACO AUTOMATIC RIVETING MACHINE

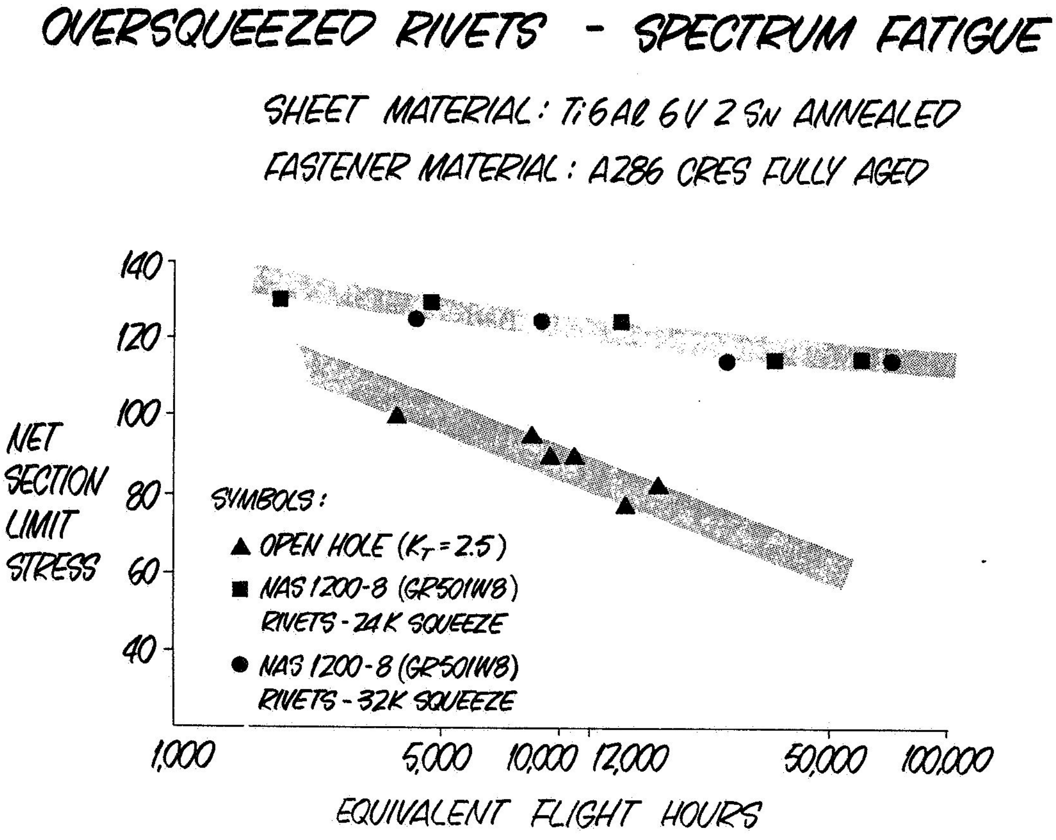


FIGURE 8

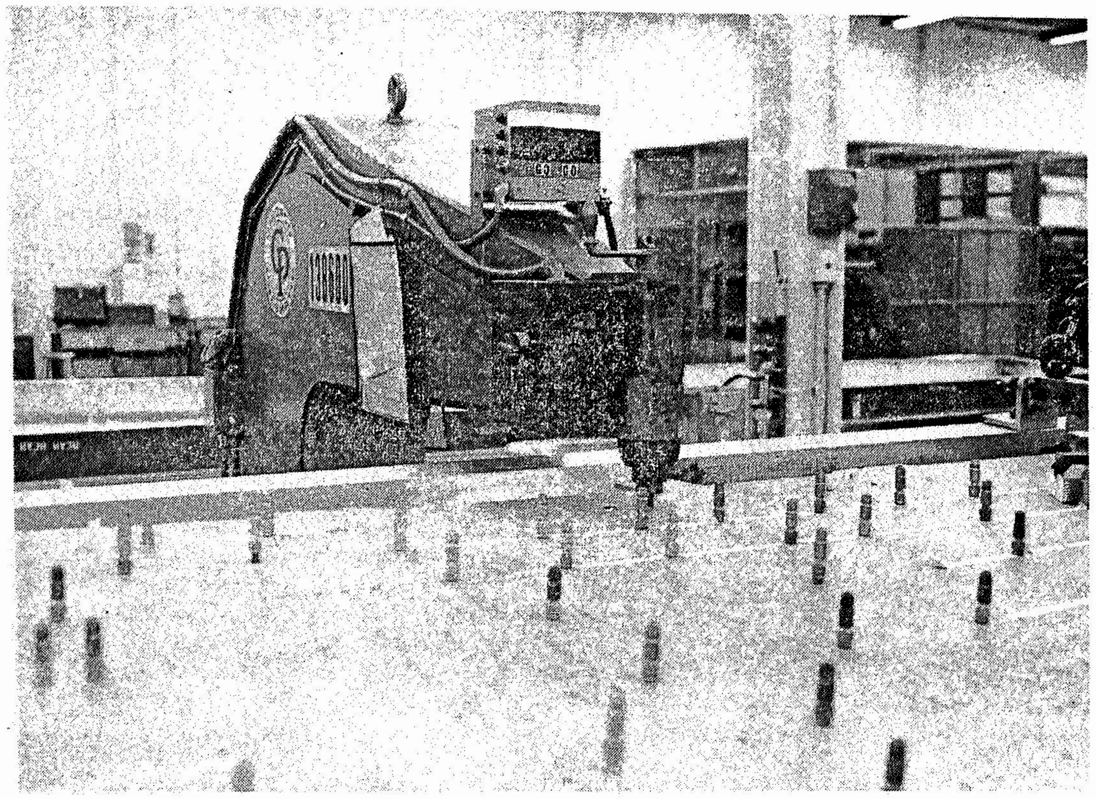


FIGURE 9

OVERSQUEEZED RIVETING ON
CHICAGO PNEUMATIC CP-4 MACHINE

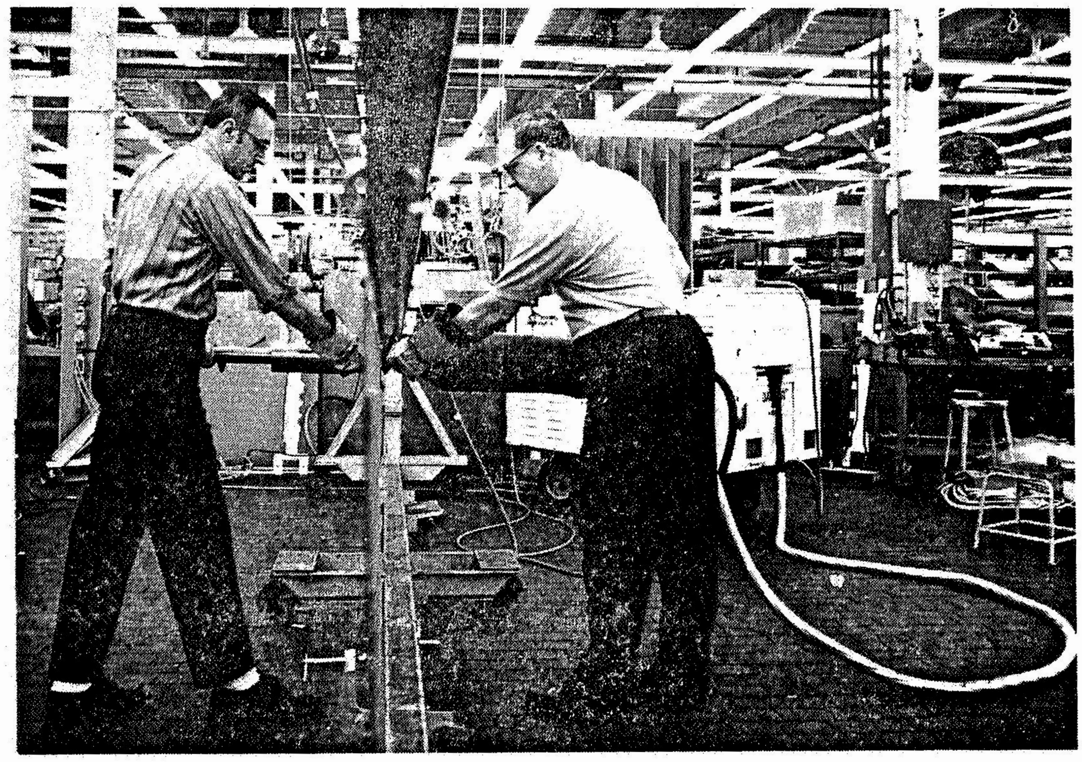


FIGURE 10

STRESS WAVE RIVETING

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