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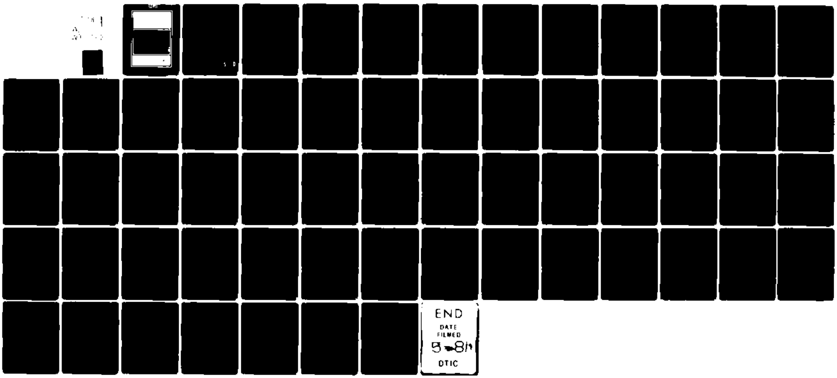

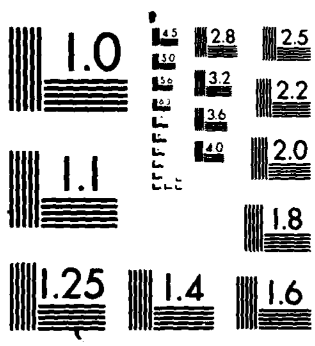

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AGARD REPORT No. 678

Critically Loaded Hole Technology Pilot Collaborative Test Programme

Final Technical Report

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.678

CRITICALLY LOADED HOLE TECHNOLOGY PILOT COLLABORATIVE TEST PROGRAMME

Final Technical Report

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- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
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PREFACE

The Structures and Materials Panel of AGARD has realised that substantial costs are involved in the procurement, installation, inspection and maintenance of fatigue rated fastener systems in high performance military aircraft. It has been widely quoted that the total cost of fastening assemblies in one C-5 cargo aircraft is equivalent to the cost of one C-130 airframe. In addition to high initial installation/assembly costs, fastening systems account for a disproportionate number of structural failures experienced by the operational aircraft fleet.

In 1975, the subject of aerospace fasteners and fastener holes was formally discussed by the SMP and an AGARD programme was sought to effectively deal with the growing problem of structural fatigue, particularly the influence of hole quality and subsequent fastener installation on the initiation and propagation of mechanical fatigue in mechanically fastened joints. Following National Reviews and the presentation of pilot papers in 1975 and 1976, a single unified cooperative test programme was agreed by all potential participants and the AGARD/SMP Subcommittee on Critically Loaded Hole Technology provided its endorsement to the proposed pilot programme. This report contains the results of that pilot programme. All the objectives of the pilot programme were met, mainly that the ability exists to generate consistent and acceptable data in a complex fatigue test environment and that the data generated was useful to all participants.

It was indeed fortunate that the subcommittee had available the services of individuals who could provide valuable input and who were dedicated to the success of this programme. Individuals sought out to provide service to this programme went beyond the NATO-AGARD Community; Dr Lars Jarfall of Sweden was invited and accepted as an active participant. This programme would not have been possible without the fine efforts of the two coordinators and technical leaders, Dr Tom Coombe of the UK and Mr Bob Urzi of the USA.

The Critically Loaded Hole Pilot Programme has spawned off a further subcommittee of the SMP. This group has been formed to more fully investigate fatigue rated fastener systems in an environment of cooperation and mutual acceptance and data exchange. This report is presented to the reader as an example of an SMP pilot cooperative effort which can effectively deal with an ever-increasing problem area affecting all member nations: a programme in which all interested parties can actively participate and each participant obtain gains which could not have been realized by any one individual working alone.

George P Peterson
Chairman
Critically Loaded Hole
Technology Subcommittee
AGARD Structures and
Materials Panel

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CRITICALLY LOADED HOLE TECHNOLOGY PILOT COLLABORATIVE TEST PROGRAMME

FINAL TECHNICAL REPORT OCTOBER 1976 - OCTOBER 1979

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SUMMARY

This final technical report contains the results of a pilot cooperative experimental programme which investigated the interaction of fastener hole quality and resulting fatigue lives of low load transfer structural joints when subsequently utilizing fatigue rated and non-fatigue rated fastener systems. These fastener systems were primarily loaded in shear. The report also discusses the potential and desirability for an AGARD follow-on activity in the area of fatigue rated fastener systems.

The fatigue data generated in this pilot programme indicated that there clearly was the ability to generate consistent data in complex fatigue testing between the participating countries. A load level verification was made during 1979 and it was established that there were few differences, within the range of testing frequencies used in this pilot programme, in the accuracy of loading or comparability of data between participants. Higher test frequencies, however, could present a different picture and should be checked to ensure the accuracy of loadings between participating countries.

Highlights of the data indicated that interference fit fasteners may be relatively insensitive to effects of surface finish and hole quality with the exception of dimensional tolerance which is important because it affects interference fit. Interference fit fasteners gave better results than clearance fit.

The general conclusions drawn from the pilot programme are as follows:

a. Fatigue data can be generated in a collaborative programme which is useful and acceptable to all participants.

b. The data generated could be useful to designers for initial fastener selection. It also could be used by manufacturers to justify relaxation of certain factors associated with hole quality.

c. Follow-on activities to generate design data and cost assessment should be undertaken using the pilot programme as the basis for the ability to generate and use this data across the participating countries with high confidence.

1. INTRODUCTION AND BACKGROUND

Fatigue life enhancement is of major concern to both designers and users of military aircraft. Since most fatigue cracks which result in structural failures in aircraft propagate from fastener holes in highly stressed areas, a number of fatigue fighting fastener systems have been developed. The cost of installing them, however, is high, in large part because of the manufacturing expense associated with the production and inspection of precision holes. By studying the relationship of hole quality parameters to the fatigue life of these joints, it may be possible to focus attention on the most important of these parameters, increasing productivity and reducing costs. These studies, however, are time consuming and expensive because of the number of hole parameters, materials, and fastener types involved.

The programme reported herein had its genesis at the 40th AGARD SMP Meeting in April 1975. During that meeting, Dr. Michael Field of METCUT Research Assoc (US) presented a paper entitled "Surface Integrity and Tolerance Technology Can Be Combined to Reduce Costs and Insure Reliability in Aerospace Manufacturing". A significant portion of that paper dealt with drilling and reaming of fastener holes and fastener technology. Dr. Field strongly recommended in his paper that a cooperative test programme should be established on hole/fastener technology. A cooperative AGARD programme concentrating on specific fastener systems of concern in the participating NATO nations would be an extremely effective way of generating and sharing information that would otherwise not be generally available. As a result of Dr. Field's presentation and subsequent discussion came the idea of a cooperative test programme involving some or all of the nations represented on the Structures and Materials Panel. At this discussion, consideration was given to the type and extent of work required to investigate the influence of hole quality, and hence manufacturing cost, on fatigue performance. The discussion established that there was a widespread interest in the problem, that some nations already had some related work in hand, and that a complete study of the problem would be time-consuming and expensive because of the number and complex interaction of the parameters involved. It was therefore concluded that the topic was one which could best be tackled by a cooperative effort involving all the interested nations within the Structures and Materials Panel. Accordingly it was decided to set up an ad hoc Working Group whose first tasks would be to study possible future cooperative activities in more detail, having listed and taken account of all the related national programmes already existing.

The Working Group met at the 41st SMP Meeting (September 1975), and considered National Reviews of the topic from Belgium, France, Germany, Norway, UK and USA. Following suggestions made in a presentation by Mr. L.P. Clark of the US, the group decided that proposals for a limited cooperative programme should be requested to be given as pilot papers at the 43rd Meeting of the SMP (September 1976). It was intended that the proposed programme should have two objectives: to generate useful data and also give information on the feasibility of conducting such a cooperative programme. At the 42nd Meeting the pilot paper presenters were identified, and the items to be covered by the pilot papers were listed. It was also decided that, after the presentation of the pilot papers at the 43rd SMP, a meeting would be scheduled at which the content of a single cooperative programme would be agreed.

Three pilot papers were accordingly presented at the 43rd SMP from Germany, UK, and the US. A working session was then held at which a pilot programme was drafted. This programme was split into three phases, and so arranged that additional participants could join within the first three months of operation. This programme formed the basis of the work covered in this report. It must be emphasised that this work was set up only as a pilot exercise to prove the feasibility of a joint investigation of this type and while it should give useful and relevant data, in no way was it expected to give a complete answer to the critically loaded hole problem.

2. PROGRAMME DESCRIPTION

At the 43rd Panel Meeting (Fall 1976) pilot programme papers were presented by the US, UK and Germany. These pilot papers were followed by much discussion and comment. Immediately following these discussions a cooperative pilot programme plan was drafted by the technical experts attending the meeting and accepted by the SMP ad hoc group. At this point in the programme the US committed to provide all the necessary programme specimen material and made available to all AGARD nations the pilot programme description for the purpose of soliciting additional AGARD participation.

The original concept of the programme as defined at the 43rd SMP has been retained although some changes have been found desirable. It was found necessary to double the time interval allowed for the completion of each phase, to allow sufficient time to set up the programme, establish the participants and provision the material, and to cater for additional work features found necessary as the programme proceeded.

The following countries participated in all three phases of the programme:

France — Netherlands
Germany — Sweden
Italy — United Kingdom
United States

The details of their participation are given in Table I. Additionally Belgium and Turkey were associated with the programme although they were unable to take part in the experimental work.

From the onset it had been decided to use variable amplitude loading to make the tests correspond as closely as possible to the in-service environment. The FALSTAFF spectrum derived in Europe was adopted as typical of a fighter aircraft loading spectrum, even though this made the task more difficult for some participants because they had little or no previous experience of running FALSTAFF.

The material chosen for all phases of the programme was 5 mm (.196 in) thick aircraft quality rolled unclad sheet to specification 7050-T76. Material sufficient for all participants for all phases of the programme was ordered and delivered as one lot in order to eliminate material variability from the programme as much as possible. The material was procured by the USAF Materials Laboratory as the net yield of two ingots from ALCOA, Pittsburgh, Pennsylvania, USA, and delivered as sheets 5 mm x 1.2 m x 2.4 m. The chemical composition and mechanical properties, as supplied by the production facility (Aluminum Company of America), are given in Table II.

Since the specimens were tested in the as-received or as-milled condition, the sheets of aluminum alloy were procured with protective coating on each side to prevent scratching or other surface blemishes during shipment. The three phases of the programme were defined to run sequentially and designed such that an unsatisfactory outcome from any phase would lead to the cancellation of the remainder of the programme. The three phases comprised:

Phase 1. Fatigue testing by all participants of notched coupon specimens completely manufactured in the US. Additionally, some tensile tests were included.

Phase 2. Fatigue testing by all participants of notched coupons the blanks of which were manufactured in the US. Into these blanks each participant put holes of two selected qualities. Concurrently with these tests each participant tested six additional notched coupon specimens completely manufactured in the US identical in configuration to those tested in Phase 1.

Phase 3. Testing by each participant of his choice of a fatigue rated fastener assembled in a low load transfer specimen using both hole qualities selected in Phase 2, together with specimens containing standard or nonfatigue rated fasteners in low quality holes. In Phase 3, each participant fabricated his own test specimens completely from material supplied. Each phase of the programme is described in more detail in the following subsections.

2.1 Phase 1

The aim and purpose of Phase 1 was to substantiate the thesis that in spite of idiosyncrasies in fatigue testing occurring in widely separated mechanical testing laboratories, fatigue testing of identical specimens, utilizing similar testing parameters, eg load history, physical/chemical environment, etc, would lead to mutually agreeable conclusions. The thesis was stated with the stipulation that all test samples would be identical in physical, mechanical, and geometric properties.

2.1.1 Specimen Configuration

2.1.1.1 Specimen Design

For the purpose of conducting the evaluation tests required to substantiate the thesis described above, a plain, flat, centre notched coupon specimen was tested. This coupon specimen contained a theoretical net stress concentration factor of approximately 2.4, with the centre notch being of the same quality and condition for all specimens and containing no initial flaws. The coupon configuration agreed upon (SMP working group - 43rd Meeting), is defined by Figure 1. The test specimen geometry for static tensile tests conformed to Figure 6 (50 mm gauge length) of ASTM Standard E8-69.

2.1.1.2. Specimen Fabrication

Manufacture of all specimens required for Phase 1 was accomplished by Metcut Research Assocs. of Cincinnati, Ohio, under the direction of the USAF Materials Laboratory under Contract F33615-75-C-5173. The facility manufacturing the test specimens was chosen on the basis of experience, reputation, and knowledge of utilizing material removal techniques resulting in uniform quality of mechanical surfaces. Fatigue and static test specimens were free of all nicks, scratches, blemishes, etc, and all fatigue specimens were individually wrapped to prevent specimen damage in handling and shipping.

2.1.1.2.1 A sketch showing the layout of the specimens used in the programme is presented in Figure 2. The blanks were cut out per the sketch using a Grob bandsaw cutting at approximately 300 ft per minute. After cutout, the edges, both length and width, were milled using the conditions given in Table III. This was followed by contouring of the gauge section per the conditions in Table IV. The hole located in the centre of the gauge section was produced in a three-step operation:

Step 1 - Drill at 660 rpm, .002 in per revolution, 7/32 in dia hole

Step 2 - Ream at 660 rpm, hand feed, .243 in dia hole

Step 3 - Ream at 660 rpm, hand feed, .251 in dia hole

2.1.1.2.2 After drilling, the edges of the hole and the edges of the gauge area were radiused using a carbide form cutter having a 1/32 in radius. This operation was followed by longitudinal polishing of the gauge area and was accomplished by use of 180 grit aluminum oxide paper.

2.1.1.2.3 In order to ascertain that the specimens used by all participants in Phase 1 were as similar as possible, residual stress determinations by the X-ray diffraction method were required on the circumference of three holes that had been drilled and double reamed in a 7050-T76 aluminum test coupon. The determinations were made at a point at the mid-thickness of the coupon in the tangential direction with respect to the hole periphery. In order to make these measurements, a wedge containing approximately 120 degrees of the hole periphery was sectioned from each coupon.

2.1.1.2.4 The size of incident X-ray beam used to measure the stresses was approximately 0.1 x 0.1 inches. The value of the elastic constant E/(1+v) in the direction normal to the (311) plane was obtained previously by calibration for 7075-T6 aluminum, an alloy similar to 7050-T76 in chemical composition and mechanical properties. Determination of the single crystal elastic properties for 7050-T6 aluminum alloy was outside the scope of this investigation.

2.1.1.2.5 Residual stresses measured in the three holes are listed below. Compressive stresses are reported as negative values.

Hole Number	Residual Stress (MPa)
10	-40.0
50	-64.8
90	-38.6

Due to the limited scope of this stress analysis, the stress relaxation resulting from the sectioning of the test coupons was not monitored. Because of general systematic errors, the large beam size and the lack of stress relaxation data, the measured stresses do not necessarily represent the total residual stress present in the holes before sectioning. However, since the same measurement procedures were used on each sample, a relative comparison of results is considered to be meaningful.

2.1.1.3 Specimen Requirements

Six fatigue plus two spares (one spare supplied without centre notch) and three tensile specimens were randomly selected and provided to each AGARD participant for fatigue and static testing. The total of eleven (11) specimens were packaged and shipped to each participating member country as specified in Table V. Each country received the specimens, a letter and a packing slip identifying their specimens.

2.1.1.4 Tensile Data Generation and Reporting

Tensile tests were conducted on a universal test machine using the guidelines given in ASTM E8-69. Individual data sheets were kept for each specimen tested. Data sheets for tensile test coupons contained the following information:

Date & location of testing
Manufacture/model of test machine
Test temperature (^{o}C)
Relative humidity (%)
Specimen identification
Rate of loading (MPa/min)
Ultimate tensile strength (MPa)
Yield strength (MPa)
Percent elongation (2 inch gauge)

2.1.2 Fatigue Testing

2.1.2.1 Test Machines

Fatigue tests were conducted in programmable servo-hydraulic axial loading fatigue test machines. Initial alignment of the test specimen gripping mechanism was treated as absolutely essential and extreme caution was taken to eliminate imposed bending stresses on fatigue test specimens. The unnotched fatigue specimens were strain gauged and cycled while monitoring strain gauges to verify minimisation of bending stresses, substantiate machine head alignment, and assess the requirement for providing buckling restraints.

2.1.2.2 Applied Load Definition

For purposes of fatigue testing specimens for all three phases of the pilot programme, the FALSTAFF spectrum was chosen. FALSTAFF, Fighter Aircraft Loading STAndard for Fatigue, it a standardized fatigue spectrum which was developed by a joint international programme sponsored by the Air Force authorities of three European countries. Some of the stated applications of the spectrum include fatigue evaluation of materials and fatigue evaluation of fabrication processes. Used as the basis for the spectrum were recorded load factor/time histories obtained from four different fighter aircraft types which were flown by those European Air Forces. Five different aircraft/Air Force combinations were used. The flight load recording was separated into three mission-type groups, i.e. Type 1 missions exhibited severe repetitive manoeuvring, Type 2 missions had nonrepetitive severe manoeuvring, and Type 3 missions exhibited moderate manoeuvring. Once classified by mission-type, the load/time histories were evaluated for their peak and trough (valley) values and the resultant data incorporated into three matrices.

The FALSTAFF spectrum consists of 200 flights composing approximately 36,000 completely randomised end points (peaks or troughs) or approximately 18,000 cycles. Each flight starts with a series of taxiing/take off loads which reflect one of two aircraft configurations, i.e. clean or with pylon tanks. Flight manoeuvring loads are then applied which reflect a particular type of mission. This is done by a random-draw process that is made on one of the three mission-type matrices. The flight ends with a series of landing/taxiing loads. One time through the 200 flights is referred to as a "pass". Each pass applies the same randomized loads in the exact same sequence.

The total stress/load range from tension to compression consists of 32 distinct values. The end points (peaks or troughs) are stored as a series of integers ranging from 1 to 32 with the 1-level representing the maximum compressive load and the 32-level representing the maximum tensile load. These integer values are multiplied by the appropriate scaling factor to obtain loads to apply to a test coupon. Zero stress/load is equivalent to level 7.5269 (which is not an integer and does not appear in the spectrum).

The intensity/severity of the spectrum is usually identified by referencing the stress/load that a test specimen sees at the highest load level in the spectrum i.e. load level 32, which appears twice in the 200 flights. In this report the same convention is used.

For Phase 1 testing, all participants used a reference stress level of 234.4 MPa gross area stress at a test frequency compatible with the fatigue test machine used. This stress level was selected after preliminary tests were run by the US developing a plot of gross area stress vs number of flights to failure utilizing the K_t=2.4 centre notch coupons. Based on these preliminary tests, a stress level of 234.4 MPa was selected to give a mean test life of 10,000 flights.

2.1.2.3 Test Procedures

As an initial step in the test procedure all specimens were cleaned in standard solvent prior to insertion in a test machine. This operation removed any surface contamination incurred during prior handling. Utilizing standard testing procedures, fatigue tests were conducted in servo-hydraulic test equipment under normal ambient conditions (room temperature and laboratory air). All abnormal conditions were avoided, eg unusually high or low humidity, unusually high or low room temperature, any corrosive gases and contact between specimen and salt, acids, or electrical current. Dummy specimens were used in the initial set-up of the test machine and controls. Overload/underloads were avoided. Any deviation from normal operations was required to be noted on the test operation/data sheet.

Prior to beginning the fatigue tests on the centre notched specimens, an unnotched (no hole) fatigue specimen was strain gauged and the test machine alignment verified in accordance with Paragraph 8.2 of ASTM E466-76, Constant Amplitude Axial Fatigue Tests of Metallic Materials.

After the test machine alignment had been verified, the maximum spectrum compressive load was applied to the strain gauged specimen. A check of fatigue test machine alignment was accomplished by using unnotched, strain-gauged specimens. The vertification process used and the results obtained by each participating organisation is documented in the individual participant's technical report. (See references 2 through 8). Specimen buckling strain was determined statically and dynamically. If the buckling strain exceeded 5%, an anti-buckling restraint would have been designed and utilized. In fact, no participant exceeded this buckling limit.

A dummy fatigue specimen was installed in the test machine to check set-up procedures and loads application. A simultaneous recording of programmed load and applied load was obtained for at least one complete pass through the spectrum. This recording was checked to ensure that proper loads were applied to the specimen.

Fatigue tests were conducted on the six specimens provided by the US. The loads applied in all portions of the programme were those defined by the FALSTAFF spectrum dated March 1976. Dynamic loads were applied at a rate such that the mean cyclic frequency did not exceed 100 Hz. Observations were made during testing in an effort to determine the number of flights required to initiate a visible crack in the specimen. The number of flights to crack initiation have not been reported in this report; however, several countries did document these data and crack initiation life figures and some crack propagation data are given in the individual reports. (See references 2 through 8).

2.1.2.4 Data Sheets

Data sheets for fatigue test specimens contained the following information (all data were reported in both Imperial and Metric (SI) units).

Date and location of testing
Manufacture/model of fatigue test machine
Test temperature
Relative humidity
Reference (gross) stress level of FALSTAFF spectrum
Specimen identification
Percent specimen bending at minimum load (if applicable)
Percent specimen bending at RMS mean load (if applicable)
Average cyclic frequency
Number of flights to initial visible crack
Size of initial visible crack
Number of flights to complete failure
Fatigue-crack initiation site (with photo)
Record of abnormalities
Description of buckling restraint (if used)

2.1.3 Phase 1 Schedule

The static and dynamic tests described for the Phase 1 portion of the pilot programme were accomplished prior to the Fall 1977 meeting of the SMP. The schedule and milestones for the Phase 1 activity are shown in Figure 3.

2.2 Phase 2

From the data submitted on Phase 1 and preliminary analysis of the data, a major restructuring of the Pilot Test Programme took place. Added to the programme was a complete replication of the Phase 1 test effort which took place concurrent with the Phase 2 test activity. Phase 2 was modified as to content and level of effort required. Retained from the original programme was the definition of two levels of hole quality (cost) reflecting the practice of each participant's aerospace industry. Taking advantage of the Phase 1 results and with the replication of the Phase 1 testing, the concept of round-robin testing was no longer required for the Phase 2 activity. It was felt that the homogeneity of variance exhibited in Phase 1 further densified by repeating the Phase 1 tests would enable each country to work independently in Phase 2. However, common materials and a single source of specimen blanks were again used in Phase 2. Each participant made, from specimen blanks provided by the US, six specimens containing a high quality (cost) hole and ten specimens containing a low quality (cost) hole. Concurrently with the tests on the sixteen specimens, six repeat specimens, identical to Phase 1 specimens, were also tested. The hole manufacturing processes selected by each participant are indicated in Tables VI through XII.

2.2.1 Specimen Configuration

2.2.1.1 Specimen Design

Specimen configuration used in Phase 2 was a centrally located, open hole coupon, having overall dimensions exactly as that used in Phase 1 testing. However, these specimens were received by each participant containing a single centrally located 1/16 inch (1.58 mm) diameter pilot drill hole. Each participant then finally conditioned these specimen "blanks" by drilling 1/4 inch (6.35mm) diameter holes to his definition of "low or high" hole quality (cost). The specimen then appeared identical to those tested in Phase 1 (see Figure 1).

2.2.1.2 Specimen Material and Fabrication

The specimen material for Phase 2 was taken from the same heat/lot/shipment as those specimens produced for Phase 1 (ALCOA 7050-T76 bare aluminum alloy plate 0.196 inch (5 mm) stock thickness). Specimen blanks were manufactured at a single source within the US by Metcut Research Associates under USAF Contract F33615-78-C-5030 and then randomly selected for shipment to each participant for final machining (centre hole fabrication). Ten of the specimen blanks provided subsequently received the participant's process for producing "low" (cost) quality holes and six specimen blanks received the treatment leading to the participant's definition of "high" (cost) quality holes. For the purposes of the pilot programme, the term "low" quality implied a minimum cost but acceptable hole (to the participant's standards), produced by standard shop practices to a specification allowing a relatively wide variation in geometric tolerances. This type of hole could have visual surface blemishes and might or might not contain a burr. However, the production of this type of hole should not have altered the physical/mechanical properties of the material being drilled. The term "high" quality referred to a fastener hole produced in the aircraft structure where fatigue considerations would be of paramount importance. This type of hole would reflect relatively much higher production costs than the "low" quality hole, with the geometric consideration being much narrower in scope than the low quality hole.

2.2.1.3 Hole Fabrication Documentation

In order to obtain maximum utilisation of the subsequent fatigue test data it was required that each participant listed in logical sequence the detailed steps taken in the production of his "high and low" hole quality specimens. This information is given in Tables VI through XII. Each participant also recorded all pertinent factors such as hole size, surface finish, hole straightness, bell mouthing, rifling, chatter marks and out-of-roundness, peculiar to each specimen. This information can be obtained from the individual test report (see References). Figure 4 gives the data sheet requirements on production variables for "low and high" quality holes.

2.2.2 Fatigue Testing

2.2.2.1 Participant Testing

Each participant tested six of his own "high" level of hole quality open hole specimens and ten of his own "low" quality specimens. Concurrent with these sixteen specimens he also tested six repeat specimens from Phase 1. He randomly inserted the repeat Phase 1 fatigue specimens in his Phase 2 test sequencing. He tested all specimens in an identical manner to that employed during Phase 1 testing. The FALSTAFF spectrum and reference stress level used during Phase 1 were not modified in any manner, except to ensure that the gross area nominal stresses experienced by the test specimens tested in Phase 2 were identical to those utilised by the other participants. Care was required to be taken that the test environment (humidity and temperature) was at standard conditions. All specimens were fatigue tested to complete failure.

2.2.2.2 Data Generation and Reporting

Individual data sheets were kept for each specimen tested. The data sheets for fatigue test specimens tested in Phase 2 contained the same information as the data sheets required for Phase 1.

2.2.3 Analysis of Data

Inspection of Broken Specimens

After testing, the fracture surfaces were inspected to locate crack initiation sites. Attempts were required to correlate these crack locations to significant hole metrology. The failed specimen was examined and a record made of any pertinent features which might provide correlation to other data generated before or after the subject programme.

2.2.4 Phase 2 Schedule and Milestones

2.2.4.1 Schedule

The completion of Phase 2 testing was accomplished prior to the Fall '78 (47th) meeting of the SMP. Testing procedures and test specimens used in Phase 2 were identical to those used in Phase 1, thus enhancing more rapid execution of the tests. The schedule for Phase 2 and Phase 1 repeat is shown in Figure 5.

2.3 <u>Phase 3</u>

In this phase the work developed into separate programmes, each programme being undertaken by one participant and being complete in its own right. Each programme determined the fatigue performance of one structural fatigue enhancement fastener system in high and low quality (cost) holes. For comparative purposes each participant also determined the fatigue performance of a standard nonfatigue rated fastener in his low quality hole. The fatigue resistant and nonfatigue resistant fastener systems selected by each of the participants are listed in Tables XIII and XIIIa.

2.3.1 Specimen Configuration

2.3.1.1 Specimen Design

The selection of the joint configuration for evaluation of fastener fatigue life has historically been left to the discretion of the airframe designers. This has led to a multiplicity of specimen configurations. Work conducted in the US sponsored by the USAF and USN in 1969 - 1975 has studied the problem, surveyed the industry, determined the types and configurations in use and evaluated those joints. Joint configurations break down into four basic types: no-load, low-load, medium load, and high-load transfer. Comparative testing indicated that one configuration of each of the types of joints noted was sensitive to the fatigue resistance of the fastener installed in it. For the low load transfer type specimen, the reverse "dogbone" specimen was shown to exhibit the greatest sensitivity to the fastener system variables. In the US, MIL-STD-1312, "Fastener Test Methods", Test Number 21 defines the specimen geometry for a standard low load transfer specimen to be used for fastener system development work under government/ military contracts. The reverse dogbone (DRD) specimen design shown in Figure 6 corresponds to this definition for 1/4 inch nominal diameter fasteners, and transfers approximately 5% of the axial load at each fastener location if there is an interference fit between the (steel) fastener and the hole. Two fasteners are used in this configuration with both fastener head locations occurring on the same side of the specimen. The specimen geometry given in Figure 6 was common to all participants for Phase 3 testing.

2.3.1.2 Specimen Material

The 7050 sheet material to be used in Phase 3 was purchased as a single lot in Phase 1 and was furnished by the US to all participants as part of the Phase 2 activity. However, the sheet material used for Phase 3 testing was from a second ingot (heat) received from ALCOA. Tensile properties from this second heat were obtained and compared to the first heat by the US. The comparison is indicated in Table II. The material was shipped to each recipient in the same condition as received from the mill, namely 4 feet x 8 feet x 5 mm thick pieces. In Phase 3 each participant manufactured his own specimens completely.

2.3.1.3 Specimen Fabrication

Details of the fastener system chosen by each participant matched the standards associated with the system chosen. However, the fastener installation process, torque levels, hole size, amount of interference/clearance, fastener identification, etc, was documented by each participant. Common to all participants was the scheme of faying surface preparation and treatment and wet sealant installation of fasteners. Following the machining, hole production and indentification processes, all aluminum joint specimens tested in Phase 3 of this pilot programme received a faying surface treatment. This treatment consisted of cleaning (degreasing) with suitable solvent and spray painting with epoxy primer to a dry film thickness of .05 - .13 mm (.002 - .005 in). After curing the primer and upon assembly, the faying surfaces of the joint specimens were coated with Products Research and Chemical Corporation (PRC) PR-1431-G Type 1 Corrosion Inhibitive Sealant or equivalent. A supply of PR-1431-G sealant was furnished by the US to each participant. PR-1431-G is a two part dichromate cured, polysulphide sealant with an increased soluble chromate content to inhibit corrosion in areas subject to galvanic action. This sealant has a "pot" life of twelve (12) hours and cures at 54.4^{o}C for forty-eight (48) hours. The mixed material was applied using a standard short nap paint roller. In addition to faying surface treatment, all fasteners installed in the joint specimens were installed wet with sealant.

2.3.1.4 Specimens Required

Each participant fabricated eighteen low load transfer, reverse dogbone specimens as shown in Figure 6. Six of these specimens contained high quality holes, identical to those established in Phase 2. Six specimens contained low quality holes, identical to those established in Phase 2, and these twelve specimens were all assembled with the same selected fatigue enhancement fastener system. Six additional reverse dogbone joint specimens contained low quality holes and were assembled with a standard nonfatigue resistant fastener system of the participant's choosing. However, the Netherlands nonfatigue rated joint consisted of a double margin drilled hole (ie a high quality hole), assembled with Blind Huckbolt fasteners (clearance fit).

2.3.2 Fatigue Testing

2.3.2.1 Data Generation

Each participant tested all the specimens of his own manufacture. The loading spectrum used was identical to that used in Phases 1 and 2 (FALSTAFF). However, the reference stress level was changed from that used in Phases 1 and 2 to obtain a mean fatigue life of 10,000 flights. All participants used a reference stress level of 351.6 MPa established by the US to achieve the target life of 10,000 flights.

2.3.2.2 Documentation and Reporting

Data sheets were kept on each specimen, containing a detailed description of the fasteners installed plus all other pertinent testing details as described in Section 2.1.2.

2.2.2 Phase 3 Schedule

The construction of joint specimens was initiated when the Phase 2 test results had been assessed and it was decided that Phase 3 testing should proceed. This decision to continue the pilot programme was made at the 47th SMP Meeting. The construction of joint specimens was initiated after the 47th SMP when an assessment of the Phase 2 and the repeat Phase 1 results had shown it to be acceptable to proceed with Phase 3 of the programme. The schedule for Phase 3 is shown in Figure 7.

2.4 Load Level Verification

2.4.1 Purpose

This part of the total programme was added after the Phase 1 and Phase 1 repeat results obtained by all participants had been assessed. In these two series of tests with nominally identical specimens some participants achieved significantly different lives which it was considered may have been due to differences in applied load level. It was therefore considered desirable to determine whether the procedure followed by all participants would result in identical spectrum load levels at the selected reference stress levels on a common specimen.

2.4.2 Method

It was decided to set up a single team with a set of self-contained equipment whose task was to measure the load levels applied by each participant. The equipment was provisioned and the team contracted by the USAF Materials Laboratory, and the load measurement task was undertaken by a two-man team from the University of Dayton Research Institute. A master load cell was taken to and installed in the test machine used by each participant in turn, and peak and valley load levels measured for one pass (200 flights) of FALSTAFF and a separate measurement made for the loads applied during flight 173. A special purpose recorder was built which assembled the measured load levels into one of 128 band levels of load magnitude, thus allowing each of the 32 levels defined by FALSTAFF to be subdivided into four levels of achievement for the purpose of statistical analysis. Figure 8 indicates diagrammatically the component parts of the recording system.

2.4.3 Data Presentation

For each test machine used in the programme the following data were printed:

- Histograms of peak levels and valley levels
- Exceedance curves of peaks and valleys
- A histogram of the difference between the measured data and the FALSTAFF requirement.

These plots were produced for the assembled data for the 200 flights of one pass, and repeated for the flight 173 data.

2.4.4 Schedule

Load measurements in the participating countries were made as follows:

United States	7-8 May 1979	Netherlands	31 May, 1 June 1979
West Germany	21-22 May 1979	France	4-5 June 1979
Sweden	28-29 May 1979	Italy	7-8 June 1979
	United Kingdom	11-12 June 1979	

2.4.5 Verification of FALSTAFF Spectrum

The results of the University of Dayton's evaluation of the loading accuracy of the various participating laboratories are presented in the Appendix, but a brief summary of the results will be presented here. The results of this investigation are measured in terms of how nearly the magnitude of each stress reversal compared to the expected value of the peak or valley. This comparison is made by comparing the recorded histograms of the peaks and valleys with the expected histograms.

The expected histogram of the peaks and valleys (troughs) of the 200 flight spectrum is presented in Table XXI. The table also presents the tabular data for the exceedance curve (peaks at or above level) for the peaks and valleys as well as the level crossing count and the range count data.

Before saying anything about the results of the histogram recordings, some discussion of the recording equipment is necessary. During the visits to the various laboratories it was found that the functioning of the recorder was very dependent on the state of charge on the batteries. It was also discovered that the two digital microprocessors (which determined if a peak (or valley) had occurred) worked independently, and that the valley processor required a slightly larger range of load to define a valley than did the processor for the peaks. The fact that there were two processors made it possible for the recordings to show a different number of peaks than valleys. The battery voltage drop had the effect of causing extraneous counts to be added to the recorded data, particularly to the valley recorder. It also appears that only a limited number of load levels were affected so that whereas some load levels would have an incorrect number of counts other load levels would appear to be correct.

The recordings from four laboratories were such that there is no question that they applied the correct number of cycles and at the correct amplitude to match the FALSTAFF Spectrum for 200 flights. The recordings from the other three countries were such that one can state that the controlling computer was programmed to apply the correct number of loads and with the proper magnitude to match the FALSTAFF Spectrum for 200 flights. Also for two of these three laboratories it can be stated that the peaks of the stress reversals applied to the master load cell specimen were of the proper number and magnitude. The recordings for the valleys for the two laboratories were inconclusive at some load levels but indicated the correct magnitude and number for other load levels. The remaining laboratory had a servo valve failure during the visit and was unable to operate at the same frequency as was planned for the Phase 3 tests. The recordings from the laboratory also showed that they had the correct spectrum of loads and could apply the loads at the correct magnitude. However, there was some question about a high frequency component on the load cell signal at some load levels.

In general, the results of the verification study showed:

1. All participating laboratories had the correct histogram for the input to the servo system.

2. When operating under normal conditions, all participating laboratories were capable of applying the programmed loads to the master load cell specimen to within an accuracy of one-half a FALSTAFF load level for a great majority of the cycles. There were a few cycles where the magnitudes were incorrect by three-fourths of a FALSTAFF load level and a great number of cycles where the loads were accurate to within one-fourth of a FALSTAFF load level.

3. The static calibration of all load cells agreed with the calibration of the master load cell specimen.

4. The difference between the programmed load and the load recorded from the master load cell specimen was not proportional to the magnitude of the load but rather was a constant offset.

One final observation should be made about the visits to the various laboratories which is not exactly related to the verification programme. This is that the various laboratories each had a different wave shape and frequency for applying the loads. In some of these laboratories the frequency was a function of the load range and, therefore, spanned a spectrum of frequencies.

3. DISCUSSION OF RESULTS

Each participant has documented his own particular test observations and specimen construction detials as applicable to each phase of the pilot test programme. These detail accountings include photographs of failure surfaces, exact conditions of ambient conditions, and particulars of individual test equipment. A comprehensive listing of both formal and informal reports pertinent to this Critically Loaded Hole Technology Programme are given in References 2 through 8. Copies of report documents can be obtained through the principal investigator associated with each participating country listed in Table I. The comments on the results which follow have been agreed by all participants.

3.1 Single Source Coupon Tests

Because all the specimens used in Phase 1 and the repeat of Phase 1 were manufactured at one location in the US (see Section2.1.1.2) from one single common material source, the results from these parts of the programme were expected to give some indication of the similarity of test techniques among all the participants.

Static tensile results are given in Table XIV. From these results it is very apparent that each participant's tensile test techniques lead to comparable conclusions. However, this is to be expected since ASTM Tensile Standards for materials testing have been adopted universally for many years by the technical community at large.

The fatigue test results in Phase 1 did not exhibit the same similarity between participants as the tensile test results. Figure 9 shows the lives achieved in the Phase 1 testing by all participants plotted on Gaussian probability paper. The plot shows that all the results lie approximately on a straight line so they could possibly all belong to one population, but it can be seen that there is considerable banding of the results, so that there in fact is some doubt about them all belonging to a single population. Table XV lists the log mean lives and number of tests reported by each participant for the Phase 1 programme, and gives the value of the F statistic for all the results as F=20.314. This level of F statistic strongly suggests that the seven sets of results do not come from a common population. Figure 10 shows the lives achieved in the Phase 1 repeat testing by all participants, again plotted on Gaussian probability paper. Again the results lie reasonably on a single straight line, but the line is much steeper than the Phase 1 line, indicating a lower coefficient of variation. Also it can be seen that the results are not banded and all participants' lives are intermixed, suggesting that all seven sets of results could come from a single common population. Table XVI lists the log mean lives and the number of tests reported by each pariticipant and gives the value of the F statistic for all the results as F=3.468, which suggests quite strongly that all the results could come from a common population in the Phase 1 repeat tests.

Discussion by the participants of the scatter which had occurred in the Phase 1 results had focussed attention on the need to closely monitor testing procedures and check the accuracy of the achievement of FALSTAFF in order for all participantsto achieve a common result. The smaller variation and indication of a common population achieved in the Phase 1 repeat testing indicated that whatever improvements had resulted had been sufficient to commonise the testing practice. Table XVII lists the log mean lives achieved by each participant for Phase 1 and Phase 1 repeat tests. Also listed is the T statistic from the Student T test applied to each of the two sets of results from each participant. Only for Sweden, the US, and Italy, is the T statistic large enough to suggest that Phase 1 and Phase 1 repeat results were from different populations. For all the other participants the two sets of results appear to be from the same population. The Phase 1 and Phase 1 repeat specimens were machined on different occasions but according to identical specifications.

All participants considered that it was reasonable to conclude that a common standard of testing could be achieved providing that the total test process was adequately checked and monitored. More discussion on this aspect of the programme is presented in Section 4 of this report.

3.2 Hole Quality

Each participant tested centre-notched coupon specimens which were manufactured to the pilot hole stage by Metcut Associates, USA, and the notch completed by each participant finishing the central hole to either a low quality or high quality standard of his own selection. There was no intent to commonise the hole manufacturing process between participants. However, all the specimen blanks (containing the pilot hole) were fabricated at a single source (Metcut).

The details of each participant's high and low quality hole fabrication parameters are given in Tables VI through XII. The reader is again reminded that these hole quality standards were chosen independently by each participant and were not intended to be an object of comparisons between participants. For the purposes of the pilot programme, the term "low quality hole" implies a minimum cost but acceptable hole (to the participant's standards), fabricated by standard shop practices to a specification allowing a relatively wide variation in geometric tolerances. This type of hole has visual surface blemishes and may or may not contain a burr. The term "high quality hole" refers to a fastener hole produced in the aircraft structure where fatigue considerations are of paramount importance. This type of hole reflects relatively much higher fabrication costs than the "low" qualtiy hole.

The log mean lives for both hole qualities obtained by all participants testing at a reference gross stress level of 234.4 MPa (34 ksi) are listed in Table XVIII. The results obtained by all participants for each hole quality have been examined to see if they come from a common population, but the level of F statistic derived for both hole qualities, also quoted in Table XVIII, indicates that it is most unlikely that either the low or high quality hole results relate to a common base. This is not at all surprising as there was no intent that the manufacturing processes should be similar, and the techniques chosen varied widely, as can be seen from Table XIX which summarizes the "low and high" hole qulaity fabrication parameters chosen by each participant.

The results obtained by each participant for his high and low quality holes have also been compared to see if the lives differ significantly by using the Student T test. The T values derived are listed in Table XX where it can be seen that for three participants, Germany, Netherlands and UK, there was no significant difference (or improvement) in fatigue life obtained with the high quality hole as compared to the low quality ones. This could be taken to suggest that there is no point in incurring the extra manufacturing cost associated with the high quality holes selected by these participants. However, it should be remembered that while every possible care was taken to make the quality of the holes in the specimens typical of that likely to be obtained in a normal production environment, the experiments did not investigate the spread of fatigue performance over the total probable quality range of each process in production. It seems likely that this range of quality could give a corresponding range of fatigue performace which would be different for the two hole qualities. It is also generally true that in practice there is more interest in the performance of holes containing a fastener.

Table XX shows that the results of four participants suggest a significant difference between their high and low quality holes, based on the derived T value. However, for two of those four, France and Italy, it can be seen that the so-called "low" quality hole is significantly better than the "high" quality one. Figure 11 indicates diagrammatically the relation between the log mean lives for the two quality holes and the Phase 1 repeat life obtained by each participant. Figure 11a shows diagrammatically the log mean lives for the two hole qualities and the repeat Phase 1 hole quality in relation with the different hole preparation techniques used. Figure 11a indicates a relatively large scatter between the countries' results for each hole preparation classification, especially for the reamed and broached holes. The scatter for the drilled and double margin drilled holes is of the same order as the scatter for the Phase 1 repeat fatigue lives. There is no obvious correlation between the fatigue performance obtained and the quality (i.e. cost) of the hole manufacturing process. The high quality hole processes chosen by all participants were all processes which aimed at good geometrical properties, close tolerance and good surface finish, but the relative fatigue performance obtained suggests that these properties are not the ones which primarily determine fatigue behaviour. There could be others, such as residual surface stresses after final machining, which are equally important in these open holed specimens, but of course geometry and tolerance could have a very different significance when the hole contains a fastener, particularly if an interference fit is required. The effect of the fastener system and resulting joint fatigue life was addressed by the test effort in Phase 3, where the fastener hole quality chosen by each participant was identical to that chosen and tested in Phase 2.

3.3 Installed Fastener Tests

It was during the Phase 3 activity (joint fatigue tests) that the load verification exercise performed by the University of Dayton Research Institute took place (see paragraph 2.4.5). The results of this survey indicated that a high level of accuracy was obtained by each participant during the Phase 3 spectrum fatigue testing. In light of the survey results, each participant's test data must be considered valid and meaningful for analysis.

It must be re-emphasized that the fastener hole quality (a residue of Phase 2) and the fastener system selected by each participant were the only variables investigated during the Phase 3 activity. Except for clamping of the specimens and the use of anti-buckling guides, all other test and joint parameters were kept constant for all participants. Each participant had the identical objective, namely to generate joint fatigue data using a common specimen configuration but containing fastener holes of different qualities (by his own standards) and containing fatigue rated or non-fatigue rated fastener systems, again by his own standards, so that the data generated would be acceptable to all the other participants. This objective was met in the pilot programme.

The data generated by each participant whether viewed independently or in concert with all other data generated by all participants can be considered very useful to the airframe designer. These data, however, cannot and should not be considered as design allowable "values". The type data presented can prove useful in providing guidance to the airframe designer, especially a designer not well acquainted with structural fastener systems and performance. The validity of the aircraft joint design is the responsibility of the structural analyst, and the data generated cannot be construed to infringe on his responsibility or on his analytical methods.

The particular details of each participant's choice of fastener hole quality and hole fabircation parameters can be found in Tables VI through XII. In the Pilot Programme the non-fatigue rated joint is described as a joint with a low quality hole assembled with a "rivet" system which would give the same static strength of the joint as the fatigue rated joints. However, the Netherlands non-fatigue rated joint consists of a double margin drilled hole (i.e. a high quality hole), assembled with Blind Huckbolt fasteners (non-fatigue rated fasteners) with a unique clearance fit. The fastener system selected by each participant is presented in Tables XIII and XIIIa. The individual joint fatigue test results obtained by each participant are tabulated in Table XXII and diagrammatically shown in Figures 12 and 13. The detail test results are fully presented in each participant's final technical report. (See References 2 through 8). The individual reports give an accurate assessment of the fatigue performance achieved by the fastener system selected in conjunction with the level of hole quality selected by each participant.

4. CONCLUSIONS

The data generated in all three Phases of the programme exhibited beyond all doubt that there was the ability to generate consistent data in complex fatigue testing between the participating countries. The data generated substantiated the notion that flight-by-flight complex fatigue spectrum data can be generated in a collaborative programme which is useful. More important is the fact that all the data generated at different laboratories were accepted by all participants.

In reviewing all the data generated by the participants, the following corporate view can be taken. The total data generated indicated that interference fit fastener systems may be relatively insensitive to effects of surface finish and hole quality with the exception of dimensional tolerance, which is important because it affects interference fit. Figures 12 and 13 show clearly the better fatigue performance of the interference fit fastener systems regardless of the hole quality. In Figure 13, results are given for the fastener systems utilising Hi-Lok fasteners. Both Figures 12 and 13 show the relatively small scatter within the hole preparation classification except for the UK-reamed-Hi-Lok-interference case. In France the use of the same interference fit fastener, the Hi-Lok "Bull Nose" fastener in both the high and low quality holes, leads to the same fatigue lives. In the French tests, however, fatigue failures initiated from fretting between faying surfaces. Other participants did not experience any problems with surface fretting, although all the UK Hi-Lok interference fit failures initiated at sites other than the fastener hole bore, usually from a 'clamped' surface, but in one case (Specimen No. FP G2) from the corner of a free surface. This behaviour is in contrast to the clearance fit cases, where all failures initiated from the surface of the bore and where Hi-Loks had significantly lower test lives. The Netherlands data indicated that interference fit and clamp-up had greater significance, in terms of flights to failure of the bolted joint, than hole quality. However, the influence of each separate parameter cannot be quantified. The German data indicated higher interference fit resulted in longer test lives regardless of hole quality. The United States data, having essentially the same interference fit in both low and high quality holes, resulted in equivalent joint fatigue lives regardless of hole quality. The Swedish data showed that the same standard hex head bolt with slight interference fit gave a significant increase in fatigue lives when compared to clearance fit. However, when Sweden used the "hole-filling" ice box rivets (2024 aluminum alloy), the "shank expansion" of this rivet in the hole produced significant increase in the joint fatigue lives. The data generated in the United Kingdom showed that as long as there was clearance fit, the effect of fastener geometry was not apparent. Only with interference fit was there a significant increase in fatigue lives. The Italian data showed the same trend; interference fit had significant influence on fatigue lives of the joint specimens regardless of hole quality. All test results are shown diagrammatically in Figure 12.

The load level verification activity of the programme substantially added to the confidence generated in each participant to mutually accept the others' data. The load level verification programme established the fact that there were no differences, within the range of test frequencies used in this pilot programme, in accuracy of loadings or comparability of data. It is not suggested that every programme generating fatigue data should have a universal load accuracy/verification activity, but each participant must develop his own resources to provide his own dynamic calibration and establish accuracy of loading.

5. WORK PROPOSALS

There was universal agreement among all participants that a follow-on activity should take place. The pilot programme reported herein could be the basis for the ability to generate and use the data across the participating countries with a high degree of confidence. A cooperative programme (i.e. one in which all interested AGARD members participate) could, for example, determine the fatigue lives obtained by a range of fatigue rated fastener systems in combination with a number of preparation processes. Fatigue lives would be evaluated in terms of installation costs of fastener system and hole preparation technique used. Low, medium, and high load transfer would be investigated using several aluminum alloys, together with different faying surface treatment and assembly processes. Fatigue testing would be carried out at several load levels using mainly the FALSTAFF loading; some tests would be performed under TWIST loading. Because of the lack of a standard specimen for evaluating fastener systems used in high load transfer single shear joints, a range of designs would be evaluated and compared. The collective programme content would be limited to ensure that the work could be completed within 2 years.

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TABLE I

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TABLE II

MECHANICAL PROPERTIES (as manufacturer's certification) 7050-T76 ALUMINUM ALLOY (5 mm sheet material)

		PHASE 1, 1A, 2 LOT 302-791		PHASE 3 LOT 219-521	
		1st SHIPMENT		2nd SHIPMENT	
		Max	Min	Max	Min
Tensile Strength	MPa	592.2	588.8	577.1	577.1
Yield Strength	MPa	553.0	546.8	522.0	522.0
Elongation	%	12.0	12.0	12.5	12.0
Conductivity	% IACS	-	35.4	-	37.5

CHEMICAL COMPOSITION

	Max	Min
Silicon	0.12	-
Iron	0.15	-
Copper	2.6	2.0
Manganese	0.10	-
Magnesium	2.6	1.9
Chromium	0.04	-
Zinc	6.7	5.7
Titanium	0.06	-
Zirconium	0.15	0.08
Others Each	0.05	-
Others Total	0.15	-

TABLE III

MACHINING CONDITIONS USED FOR MILLING THE SPECIMEN BLANKS

Cutter Diameter in	6
Tool Material	K68 Carbide
Feed in/tooth	.004
Cutting Speed ft/min	1200
Tool Wear (max) in	.006
Number of Teeth	8
Fluid	20:1 Soluble Oil

TABLE IV

MACHINING CONDITIONS USED FOR MILLING THE SPECIMEN CONTOUR

Cutter Diameter in	1
Tool Material	M2 HSS
Feed in/tooth	.0014
Cutting Speed rpm	950
Tool Wear (max) in	.006
Number of Teeth	6
Fluid	Dry

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TABLE V

SPECIMEN NUMBER IDENTIFICATION

	Belgium	France	Germany	Italy	Nether-lands	Sweden	Turkey	United Kingdom	United States
Tensile	1T4 1T10 1T17	1T6 1T11 1T14	1T1 1T8 1T22	1T21 1T23 1T26	1T2 1T13 1T15	1T9 1T12 1T16	1T27 1T29 1T33	1T3 1T5 1T18	1T19 1T24 1T30
Fatigue (with hole)	1F17 1F32 1F38 1F45 1F81 1F99 1F112 1F123	1F48 1F50 1F74 1F101 1F109 1F118 1F119 1F120	1F6 1F16 1F54 1F100 1F103 1F105 1F106 1F124	1F35 1F43 1F57 1F61 1F65 1F82 1F84	1F31 1F33 1F34 1F47 1F67 1F92 1F108 1F117	1F9 1F29 1F73 1F96 1F97 1F107 1F114 1F116	1F4 1F62 1F63 1F72 1F75 1F78	1F20 1F22 1F28 1F83 1F113 1F115 1F121 1F122	1F23 1F40 1F64 1F77 1F85 1F95 1F104
Fatigue (without hole)	1F94	1F42	1F12	1F98	1F66	1F52		1F93	1F36
Extra									1F37 1F10 1F24

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TABLE VI

MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY HOLES SELECTED BY FRANCE

HIGH QUALITY

Drill:
- Tool Material - HSS
- Diameter - 5.8 mm
- Geometry:
  - Point Angle - 120°
  - Helix Angle - 20°
- Spindle Speed - 3000 rpm
- Feed Rate - Manual (about 0.04 m/min)
- Cutting Fluid - Soluble Oil
- Tool Type - Sensitive Drill Machine

Broach I:
- Diameter - 6.1 mm
- Feed Rate - Manual
- Cutting Fluid - Soluble Oil

Broach II:
- Diameter - 6.255 mm
- Feed Rate - Manual
- Cutting Fluid - Soluble Oil

LOW QUALITY

Drill:
- Tool Material - HSS
- Diameter - 5.8 mm
- Geometry:
  - Point Angle - 120°
  - Helix Angle - 20°
- Spindle Speed - 3000 rpm
- Feed Rate - Manual (about 0.04 m/min)
- Cutting Fluid - Soluble Oil
- Tool Type - Sensitive Drill Machine

Ream and Countersink:
- Tool - Monobloc - Reamer Drill
- Diameter - 6.255 mm
- Number of Flutes - 3
- Geometry:
  - Helix Angle - 20°
  - Chamfer Angle - 135°
- Spindle Speed - 3000 rpm
- Feed Rate - Manual (about 0.04 m/min)
- Cutting Fluid - Soluble Oil
- Tool Type - Manual Drilling Machine

TABLE VII

MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY HOLES SELECTED BY SWEDEN

HIGH QUALITY

Pre-drill:

Tool	- Standard twist drill
Diameter	- 4.1 mm
Spindle Speed	- 1800 rpm
Feed Rate	- Hand feed

Drill:

Tool Material	- HSS
Diameter (Phase 2)	- 6.2 mm
Diameter (Phase 3)	- 5.7 mm
Geometry:	
Point Angle	- 118°
Point Type	- Crankshaft (split)
Helix Angle	- 28°
Relief Angle	- 10°
Spindle Speed	- 1800 rpm
Feed Rate	- Hand feed
Cutting Fluid	- 2% Cimcool S4
Tool Type	- Twist drill with a pilot. Bench drilling machine for Phase 2. Horizontally hand held machine for Phase 3.

Ream:

Tool	- Standard reamer
Tool Material	- HSS
Diameter (Phase 2)	- 6.355 mm
Diameter (Phase 3)	- 5.950 mm
Geometry:	
Taper Lead	- 21 mm long
No of flutes	- 6
Helix Angle	- 8° left hand
Chamfer Angle	- 45°/1.5°
Chamfer Relief	- ?/4°
Spindle Speed	- 300 rpm
Feed Rate	- Hand feed
Cutting Fluid	- Mineral oil + 30% lard oil
Tool Type	- Standard reamer. Bench drilling machine for Phase 2. Horizontally hand held machine for Phase 3.

De-burr:

Chamfer	- 45° 0.1 mm - 0.3 mm deep
Tool	- Hand tool with one flute (lip)
Geometry:	
Cone Angle	- 90°
Rake Angle	- 10°
Relief Angle	- 10°

LOW QUALITY

Pre-drill:	- Exactly as for HIGH QUALITY
Drill:	- Exactly as for HIGH QUALITY, except drill diameter 6.35 mm for Phase 2. 5.95 mm for Phase 3.
De-burr:	- Exactly as for HIGH QUALITY

****

TABLE VIII

MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY HOLES SELECTED BY THE NETHERLANDS

HIGH QUALITY		LOW QUALITY	
Drill:		Drill:	
Tool	- Double margin	Tool	- Standard twist
Tool Material	- HSS	Tool Material	- HSS
Diameter	- .2465 inch	Diameter	- 6.4 mm
Geometry:		Geometry:	
Point Angle (Split)	- $118^{\circ} \pm 2^{\circ}$	Point Angle (Split)	- $118^{\circ} \pm 2^{\circ}$
Helix Angle	- 28°	Helix Angle	- 28°
Spindle Speed (Phase 2)	- 1740 rpm	Spindle Speed (Phase 2)	- 1740 rpm
Spindle Speed (Phase 3)	- 1800 rpm	Spindle Speed (Phase 3)	- 1800 rpm
Feed Rate	- Manual	Feed Rate	- Manual
Tool Type	- Cincinnati vertical Type PM	Tool Type	- Cincinnati vertical Yype PM
De-burr:	- Manual using countersink tool	De-burr:	- Manual using emery paper

HOLE QUALITY USED IN NON-FATIGUE RATED JOINT

Drill:	
Tool	- Double margin drill
Tool Material	- HSS
Diameter	- 0.262 inch
Geometry:	
Point Angle (Split)	- $118^{\circ} \pm 2^{\circ}$
Helix Angle	- ?
Spindle Speed	- 1800 rpm
Tool Type	- Vertical drilling machine
De-burr:	- Manual using countersink tool

****

TABLE IX

MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY HOLES SELECTED BY THE UNITED STATES

HIGH QUALITY		LOW QUALITY	
Drill:		Drill:	
Tool Material	- HSS	Tool Material	- HSS
Diameter	- 6.35 mm	Diameter-for fasteners	- 6.7 mm
		Diameter for open hole	- 6.35 mm
Geometry:		Geometry:	
Point Angle	- 140°	Point Angle	- 118°
Point Type	- Crankshaft-split	Point Type	- Crankshaft-split
Helix Angle	- 30°	Helix Angle	- 30°
Spindle Speed	- 3000 rpm	Spindle Speed	- 800 rpm
Feed Rate	- .076 m/min	Feed Rate	- Heavy manual
Cutting Fluid	- LPS No 1 (mist)	Cutting Fluid	- Dry
Tool Type	- Heavy duty stationary equipment	Tool Type	- Light duty drill press

****

TABLE X

MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY HOLES SELECTED BY GERMANY

HIGH QUALITY		LOW QUALITY	
Pilot Hole:	- 1/8 inch (3 mm)	Pilot Hole:	- 1/8 inch (3 mm)
Drill:		Drill:	
Tool	- Standard drill		
Tool Material	- HSS		
Diameter	- 6.2 mm		SEE OVERLEAF
Spindle Speed	- 1450 rpm		
Feed Rate	- Manual		

TABLE X (CONT)

HIGH QUALITY

Ream:	
Tool	- Standard reamer
Tool Material	- HSS
Diameter	- 6.29H7 mm
Geometry:	
No of flutes	- 6
Helix Angle	- 8°
Chamfer Angle	- 45°
Chamfer Relief	- 23°30'
Spindle Speed	- 270 rpm
Feed Rate	- Manual
Cutting Fluid	- Dry
Tool Type	- Cordia S-18

LOW QUALITY

Drill:	
Tool	- Double margin
Tool Material	- HSS/Cobalt
Diameter	- 4.00/6.26 mm
Geometry:	
Point Angle	- 116°
Point Type	- Split
Helix Angle	- 24°
Relief Angle	- 10°15'
Spindle Speed	- 1450 rpm
Feed Rate	- Manual
Cutting Fluid	- Dry
Tool Type	- Cordia S-18

****

TABLE XI

MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY HOLES SELECTED BY THE UNITED KINGDOM

HIGH QUALITY

Pilot Hole:	- 1/8 inch
Drill:	
Tool Material	- HSS
Diameter	- 6.0 mm
Geometry:	
Point Angle	- 134°
Point Type	- Split
Helix Angle	- 26°
Relief Angle	- 2°
Spindle Speed	- 2000 rpm
Feed Rate	- .003 inch/rev
Ream:	
Tool Material	- HSS
Diamter	- .2502 inch
Geometry:	
No of flutes	- 6
Helix Angle	- 7.5°
Chamfer Angle	- 50°
Chamfer Relief	- 19°
Spindle Speed	- 1100 rpm
Cutting Fluid	- Boelube
Tool Type	- Femlman P18

LOW QUALITY

Pilot Hole:	- 1/8 inch
Drill:	
Tool Material	- HSS
Diameter	- 6.5 mm
Geometry:	
Point Angle	- 134°
Point Type	- Split
Helix Angle	- 30°
Relief Angle	- 10°
Spindle Speed	- 2000 rpm representing hand-held air drill under load
Feed Rate	- .003 inch/rev
Cutting Fluid	- Dry
Tool Type	- Femlman P18

****

TABLE XII

MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY HOLES SELECTED BY ITALY

HIGH QUALITY

Drill:	-
Tool Material	- HSS
Diameter	- 5.9 mm
Geometry:	
Point Angle	- 130°
Point Type	- Cylindrical
Helix Angle	- 30°
Relief Angle	- 12°
Spindle Speed	- 1500 rpm
Feed Rate	- Manual
Cutting Fluid	- Water-soluble Naphtenic oil
Tool Type	- Kramic-HV
Broach:	
Tool Material	- HSS
Diameter	- 6.4 mm
No of cutters	- 4
Tool Type	- B.03.101

LOW QUALITY

Drill:	-
Tool Material	- HSS
Diameter	- 6.35 mm
Geometry:	
Point Angle	- 130°
Point Type	- Cylindrical
Helix Angle	- 30°
Relief Angle	- 12°
Spindle Speed	- 1500 rpm
Feed Rate	- Manual
Cutting Fluid	- Water-soluble Naphtenic oil
Tool Type	- Kramic-HV

TABLE XIII

PHASE 3 - FATIGUE ENHANCEMENT FASTENER SYSTEMS

Country	Part Number Fastener Material	Description	Nut/Collar Element	Installation Torque N.m	High Quality Fastener Fit + Clearance - Interference* mm	Low Quality Fastener Fit + Clearance - Interference* mm
France	NSA5351-4-7 Alloy Steel	Hi Lok Bull Nose (Hi Shear)	NSA5050-4-7		-0.060 to -0.070	-0.060 to -0.065
Germany	HL10-VF-8-7	Hi Lok	HL 70-06 Aluminium Torque-Off Collar		ave -0.020	ave -0.035
Italy	HLM310-6-11 Ti-6A1-4V	Hi Lok (Hi Shear)	HLM 70-06 Aluminium Torque-Off Collar		-0.020 -0.054	+0.012 -0.090
Nether-lands	HL10VF-8-7	Hi Lok (Hi Shear)	Torque-Off Collar		+0.025 -0.076	+0.063 +0.255
Sweden	AS212150/2 Ti-6A1-4V	Hex Head Bolt M6x20	Simloc Nut AS215445-M6	5.4-6.4	+0.02 -0.01	+0.11 +0.14
UK	HL512PN-8-7 Ti-6A1-4V	Hi Lok Hi Tigue (Hi Shear)	BAS 7066-8 Aluminium Collar	7.0-7.9	-0.050 -0.102	+0.053 +0.122
USA	KLB60V4M7 Ti-6A1-4V	K-Lobe (Kaynar)	AFN542-4 Washernut	11.3	-0.119 -0.104	-0.119 -0.063

* Based on measured rather than specified diameters not including surface coatings.

****

TABLE XIIIa

PHASE 3 - STANDARD FASTENER (NON-FATIGUE RATED) SYSTEMS

Country	Part Number Fastener Material	Description	Nut/Collar Element	Installation Torque N.m	Fastener Fit + Clearance - Interference mm	Remarks
France	NSA5041-V.4.7 Titanium	Hi Lok Pin	NSA5050-4		+0.015 +0.030	
Germany	HL10-VF-8-7	Hi Lok Pin	Torque-Off Collar		ave +0.014	
Italy	NAS1104-6 Alloy Steel	Hex Head Bolt	H14 Steel Nut	7.91	+0.033 +0.098	Short Thread Bolt AN960 Steel Washer
Nether-erlands		Blind Huckbolt	N/A	N/A	+0.000 +0.143	Blind Rivet System
Sweden	AS211501 2024-T4	Rivet	N/A	N/A		
UK	BAS9083-4-7 Titanium	Bolt	BAS7094-4	7.345	+0.023 +0.071	
USA	PLT210-8-6 Alloy Steel	Visu-Lok (Jo-Bolt)	Blind Fastener System	N/A	+0.152 +0.102	Visu-Lok Nominal dia = 6.553

****

TABLE XIV

PHASE 1 TENSILE COUPON DATA

7050-T76 SHEET

Country	Spec No	Area in^2	Area mm^2	% Elong 2 in GL	Yield ksi	Yield MPa	UTS ksi	UTS MPa
France	1T6			11.7		563		592
	1T11			11.8		564		593
	1T14			12.4		562		593
Germany	1T1			11.5	81.20	559.9	85.83	591.8
	1T8			11.5	81.46	561.7	86.08	593.5
	1T22			11.3	81.90	564.7	86.28	594.9
Italy	1T22			10.7		557.4		585.3
	1T23			10.7		560.0		587.5
	1T26			10.7		557.1		586.1
Nether-lands	1T2	0.0904	58.35	11.0	80.78	557.0	84.55	583.0
	1T13	0.0903	58.25	11.0	80.20	553.0	84.41	582.0
	1T15	0.0904	58.35	11.0	80.49	555.0	84.41	582.0
Sweden	1T9			10.8	80.35	554.0	84.68	583.9
	1T12			11.0	80.57	555.5	84.57	583.1
	1T16			10.3	80.55	555.4	84.64	583.6
Turkey	1T27			11.1		560.4		587.5
	1T29			11.2		560.9		587.3
	1T33			10.6		563.2		589.4
UK	1T3			10.0	78.89	544.0	85.13	587.0
	1T5			10.0	76.43	527.0	83.53	576.0
	1T18			11.0	78.75	543.0	83.25	574.0
USA	1T24	0.0919		11.5	80.79	557.0	84.40	581.9
	1T30	0.0925		11.5	80.60	555.7	84.34	581.5
	1T19	0.0928		11.0	80.22	553.1	84.15	580.2

****

TABLE XV

PHASE 1 OPEN HOLE (K_t=3) COUPON FATIGUE DATA 7050-T76 5mm SHEET

FALSTAFF (34ksi) 234.4MPa GROSS STRESS

Country	Spec No		Log Life	Flights to Complete Failure
France	1F101		3.817	6573
	1F120		3.6602	4573
	1F109		3.6841	4832
	1F50		3.6466	4432
	1F119		3.6966	4973
	1F74		3.7057	5632
		$S = 0.0678$ $S^2 = 0.0046$	$\bar{x}$ = 3.7009	
Germany	1F6		3.868	7372
	1F16		3.856	7172
	1F100		3.828	6725
	1F103		3.864	7311
	1F105		3.894	7831
	1F124		3.912	8172
		$S = 0.0295$ $S^2 = 0.0009$	$\bar{x}$ = 3.870	
Italy	1F65		4.024	10574
	1F35		4.077	11944
	1F57		4.116	13064
	1F61		4.080	12025
	1F82		3.847	7025
	1F43		3.943	8774
		$S = 0.0974$ $S^2 = 0.0095$	$\bar{x}$ = 4.0145	
Nether-lands	1F108		3.743	5529
	1F34		3.853	7129
	1F33		3.902	7972
	1F117		3.719	5231
	1F92		3.702	5032
	1F31		3.804	6372
	1F67		3.847	7029
		$S = 0.0763$ $S^2 = 0.0058$	$\bar{x}$ = 3.796	
Sweden	1F97		3.790	6159
	1F73		3.776	5972
	1F116		3.790	6172
	1F9		3.679	4772
	1F96		3.801	6329
	1F114		3.746	5572
		$S = 0.0456$ $S^2 = 0.0021$	$\bar{x}$ = 3.764	
UK	1F20		3.831	6772
	1F22		3.804	6372
	1F28		3.818	6572
	1F83		3.808	6431
	1F113		3.719	5231
	1F115		3.888	7729
		$S = 0.0546$ $S^2 = 0.0030$	$\bar{x}$ = 3.811	
USA	1F40		3.988	9728
	1F23		3.972	9373
	1F64		3.946	8824
	1F77		3.981	9564
	1F85		4.039	10934
	1F10		3.922	8364
		$S = 0.040$ $S^2 = 0.0016$	$\bar{x}$ = 3.975	

ONE-WAY ANALYSIS OF VARIANCE (ANOVA)

One-way analysis of variance is a technique for testing the differences between the population means of k treatment groups, where each group $i(i=1, 2, \ldots k)$ consists of n_j observations x_{ij} $(j=1,2,\ldots n_j)$. The different groups need not have the same number of observations.

$$F = \frac{DF_2 \text{ (Error degrees of freedom) x TSS}}{DF_1 \text{ (Treatment degrees of freedom) x ESS}}$$

TSS = Treatment sum of squares

ESS = Error sum of squares

For Phase 1 Test Results:

$F = 20.314$

$DF_2 = 33 \; (\sum_{i=1}^{k} nj - k)$

$DF_1 = 6 \; (k - 1)$

TABLE XVI

REPEAT PHASE 1 TEST RESULTS (PHASE 1A)

Country	Spec No		Log Life	Flights to Complete Failure
France	AF125		3.7614	5773
	AF32		3.7291	5360
	BF175		3.8539	7144
	BF264		3.7321	5337
	AF152		3.7137	5173
	AF48		3.625	4222
		$S = 0.067$ $S^2 = 0.0045$ $\bar{x} =$	3.736	
Germany	BF298		3.905	8031
	BF296		3.794	6224
	BF208		3.847	7031
	AF158		3.901	7959
	AF42		3.780	6024
	AF38		3.758	5729
		$S = 0.063$ $S^2 = 0.00399$ $\bar{x} =$	3.831	
Italy	AF229		3.834	6832
	AF19		3.746	5573
		$\bar{x} =$	3.790	
Netherlands	BF282		3.742	5528
	AF117		3.857	7195
	BF206		3.660	4572
	AF33		3.779	6021
	BF291		3.808	6429
	BF176		3.640	4372
		$S = 0.07722$ $S^2 = 0.00596$ $\bar{x} =$	3.748	
Sweden	AF25		3.902	7972
	BF259		3.853	7129
	AF70		3.822	6631
	BF221		3.915	8231
	AF29		3.804	6372
	BF279		3.822	6631
		$S = 0.046$ $S^2 = 0.00176$ $\bar{x} =$	3.853	
UK	BF288		3.765	5831
	AF75		3.790	6172
	BF162		3.840	6929
	AF63		3.746	5572
	BF232		3.827	6729
		$S = 0.0359$ $S^2 = 0.001289$ $\bar{x} =$	3.794	
USA	AF26		3.912	8172
	BF242		3.824	6680
	BF235		3.803	6359
	BF224		3.888	7729
	AF45		3.834	6831
	AF47		3.834	6831
		$S = 0.038$ $S^2 = 0.00144$ $\bar{x} =$	3.849	

ONE-WAY ANALYSIS OF VARIANCE (ANOVA)

(See Footnote to Table XV)

For Repeat Phase 1 Test Results:

$F = 3.468$

$DF_2 = 30 \ (\sum_{i=1}^{k} nj - k)$

$DF_1 = 6 \ (k-1)$

TABLE XVII

COMPARISONS WITHIN COUNTRIES ON PHASE 1 vs PHASE 1 REPEAT TEST RESULTS

Country	Phase 1 Log Mean Life	Phase 1 Repeat Log Mean Life	T Statistic	DF
France	3.701 (5023)	3.736 (5445)	1.353	9
Germany	3.870 (7413)	3.831 (6776)	1.412	10
Italy	4.0145 (10339)	3.790 (6166)	2.828	6
Netherlands	3.796 (6252)	3.748 (5597)		
Sweden	3.764 (5810)	3.853 (7127)	3.365	10
United Kingdom	3.811 (6476)	3.794 (6223)	0.6024	9
United States	3.975 (9440)	3.849 (7063)	5.328	10

****

TABLE XVIII

PHASE 2 HOLE QUALITY TEST RESULTS

HIGH QUALITY / LOW QUALITY

FRANCE

High Quality Specimen Number	Log Life	Flights to Complete Failure	Statistic	Low Quality Specimen Number	Log Life	Flights to Complete Failure	Statistic
AF41	4.056	11382		BF186	4.069	11725	
AF93	3.774	5944	$\bar{x}$ = 3.921	BF172	4.067	11681	$\bar{x}$ = 4.042
AF60	3.938	8681	(8348)	AF17	4.134	13612	(11030)
AF143	3.946	8832	S^2 = 0.0104	AF80	4.063	11560	S^2 = 0.0049
AF31	3.894	7832	S = 0.101	BF272	3.893	7812	S = 0.070
				AF174	4.100	12597	
				BF144	3.990	9773	
				AF14	4.046	11130	
				BF194	3.979	9530	
				BF188	4.085	12173	

GERMANY

High Quality Specimen Number	Log Life	Flights to Complete Failure	Statistic	Low Quality Specimen Number	Log Life	Flights to Complete Failure	Statistic
AF129	3.765	5824		AF6	3.920	8324	
AF132	3.843	6972	$\bar{x}$ = 3.843	AF39	3.750	5624	$\bar{x}$ = 3.848
BF177	3.761	5772	(6966)	AF44	3.859	7231	(7046)
BF217	3.888	7729	S^2 = 0.0034	AF59	3.843	6972	S^2 = 0.0035
BF256	3.883	7631	S = 0.058		3.894	7772	S = 0.059
BF257	3.854	7143		AF126	3.821	6631	
BF294	3.932	8559					
BF300	3.821	6631					
BF314	3.893	7825					
BF319	3.790	6159					

ITALY

High Quality Specimen Number	Log Life	Flights to Complete Failure	Statistic	Low Quality Specimen Number	Log Life	Flights to Complete Failure	Statistic
BF173	3.334	2161		BF219	3.899	7925	
AF108	3.375	2373	$\bar{x}$ = 3.509	AF69	3.912	8173	$\bar{x}$ = 3.950
BF171	3.509	3232	(3233)	BF311	3.912	8173	(8929)
BF255	3.522	3330	S^2 = 0.0189	AF87	3.965	9232	S^2= 0.0025
AF90	3.640	4373	S = 0.137	BF304	4.007	10173	S = 0.050
BF216	3.678	4773		AF21	4.010	10232	

TABLE XVIII (CONT)

HIGH QUALITY Specimen Number	Log Life	Flights to Complete Failure	Statistic	LOW QUALITY Specimen Number	Log Life	Flights to Complete Failure	Statistic
NETHERLANDS							
AF62	3.750	5630		AF91	3.695	4959	
AF101	3.620	4169	$\bar{x}$ = 3.691	AF326	3.750	5825	$\bar{x}$ = 3.702
BF246	3.742	5529	(4909)	AF127	3.713	5168	(5042)
BF284	3.734	5431	S^2 = 0.0037	AF107	3.559	3629	S^2 = 0.0038
BF270	3.677	4758	S = 0.060	AF12	3.713	5171	S = 0.061
AF106	3.620	4172		BF189	3.727	5338	
				BF163	3.692	4929	
				AF141	3.815	6529	
				BF184	3.629	4231	
				BF267	3.701	5031	
				BF268	3.759	5743	
				AF24	3.695	4958	
				AF140	3.684	4831	
SWEDEN							
BF193	3.974	9425		AF146	3.825	6691	
AF8	4.159	14424	$\bar{x}$ = 4.093	BF239	3.761	5772	$\bar{x}$ = 3.793
AF145	4.032	10772	(12398)	AF89	3.761	5772	(6210)
BF165	4.209	16172	S^2 = 0.0074	BF167	3.808	6424	S^2 = 0.0014
AF9	4.069	11729	S = 0.086	BF210	3.766	5831	S = 0.037
AF49	4.117	13080		BF185	3.815	6529	
				AF96	3.746	5572	
				AF97	3.765	5824	
				BF299	3.843	6972	
				AF18	3.843	6972	
UNITED KINGDOM							
BF248	3.926	8431		AF156	3.888	7729	$\bar{x}$ = 3.812
AF55	3.776	5972	$\bar{x}$ = 3.827	AF119	3.821	6624	(6497)
BF215	3.912	8172	(6719)	AF58	3.843	6972	
BF211	3.651	4480	S^2 = 0.0131	AF22	3.888	7729	S^2 = 0.0038
BF241	3.871	7431	S = 0.114	AF16	3.750	5631	S = 0.062
				BF166	3.794	6231	
				AF133	3.780	6031	
				BF207	3.887	7724	
				BF220	3.730	5372	
				BF303	3.746	5572	
UNITED STATES							
BF227	3.910	8129		BF305	3.920	8329	
AF122	3.923	8392	$\bar{x}$ = 3.909	BF323	3.730	5372	$\bar{x}$ = 3.796
BF281	3.981	9572	(8109)	BF228	3.821	6631	(6251)
AF136	4.013	10324	S^2 = 0.0132	AF123	3.794	6224	S^2 = 0.0053
AF78	3.718	5231	S = 0.114	AF88	3.730	5372	S = 0.072
				AF43	3.871	7431	
				AF138	3.834	6831	
				AF114	3.696	4972	
				BF223	3.837	6877	
				AF112	3.734	5431	

For all Test Results Obtained on High Quality Holes

F = 22.462

DF_1 = 6

DF_2 = 36

For all Test Results Obtained on Low Quality Holes

F = 34.763

DF_1 = 6 (k-1)

$DF_2 = 57 \ (\sum_{i=1}^{k} nj - k)$

TABLE XIX

SUMMARY OF MANUFACTURING DETAILS FOR HIGH AND LOW QUALITY (COST) HOLES SELECTED BY ALL PARTICIPANTS

Ref Table	Country	PRE-DRILL mm	PRE-DRILL rpm	PRE-DRILL m/min	DRILL mm	DRILL rpm	DRILL m/min	BROACH 1 mm	BROACH 1 m/min	BROACH 2 mm	BROACH 2 m/min	REAM mm	REAM rpm	Remarks
							HIGH QUALITY							
VI	France	5.8	3000	Man. 0.04				6.1	Man.	6.255	Man.			Standard Drill Soluble Oil
X	Germany				6.2	1450	Man.					6.29	270 Man.	Standard Drill, Dry
XII	Italy				5.9	1500	Man.	6.4						Water Soluble Naphtenic Oil
VIII	Nether-lands				6.26	1740 1800	Man.Phase 2 Man.Phase 3							Double Margin Split Point
VII	Sweden	4.1	1800	Man.	6.2	1800	Man.					6.355	300 Man.	Standard Drill with Pilot
XI	United Kingdom				6.0	2000	0.152					6.35	1100	Drill-Dry Ream-Boelube
IX	United States				6.35	3000	0.076							Heavy Duty Stationary Equip. LPS No.1 Mist
							LOW QUALITY							
VI	France	5.8	3000	Man. 0.04								6.255	3000 Man.	Standard Drill Soluble Oil
X	Germany				6.26	1450	Man.							Double Margin Split Point
XII	Italy				6.35	1500	Man.							Standard Drill Water Soluble Naphtenic Oil
VIII	Nether-lands				6.4	1740 1800	Man.Phase 2 Man.Phase 3							Standard Drill Split Point
VII	Sweden	4.1	1800	Man.	6.35	1800	Man.							Standard Drill with Pilot
XI	United Kingdom				6.5	2000	0.152							Split Point, Dry
IX	United States				6.35	800	Heavy Manual							Standard Split Point No Coolant

****

TABLE XX

COMPARISONS OF HIGH AND LOW QUALITY HOLES WITHIN PARTICIPANTS

Country	High Quality Mean Log Life	Low Quality Mean Log Life	Student "T" Statistic	Degrees of Freedom	Null Hypothesis $\bar{x}$ Hi Qual = $\bar{x}$ Lo Qual
France	3.921 (8348)	4.042 (11030)	2.718	13	No (Significant Difference)
Germany	3.843 (6966)	3.848 (7046)	0.126	14	Yes (Accept)
Italy	3.509 (3233)	3.950 (8929)	7.386	10	No (Significant Difference)
Netherlands	3.691 (4909)	3.702 (5042)	0.400	17	Yes (Accept)
Sweden	4.093 (12398)	3.793 (6215)	9.773	14	No (Significant Difference)
U K	3.827 (6719)	3.812 (6497)	0.323	13	Yes (Accept)
U S A	3.909 (8109)	3.796 (6251)	2.337	13	No (Significant Difference)

NOTE: Please refer to text, Section 3.2, for a cursory discussion of the "open" hole, high and low quality, test results summarized in this Table.

TABLE XXI

FALSTAFF DISTRIBUTIONS FOR 200 FLIGHTS BY VARIOUS COUNTING METHODS SUPPLIED BY NLR (NETHERLANDS)

		PEAK COUNT RESULT			LEVEL CROSS COUNT		RANGE COUNT		
Falstaff level	Peaks at level	Troughs at level	Peaks at or above 1	Troughs at or below 1	Level	Positive crossings	Range Size	Counts Upward	Counts Downward
32	2	0	2	17983	31.5	2	1	0	0
31	0	0	2	17983	30.5	2	2	599	445
30	7	0	9	17983	29.5	9	3	7163	7004
29	10	0	19	17983	28.5	19	4	3834	3814
28	24	0	43	17983	27.5	43	5	1622	1873
27	45	0	88	17983	26.5	88	6	1127	1094
26	76	0	164	17983	25.5	164	7	886	1004
25	104	1	268	17983	24.5	267	8	715	832
24	193	2	461	17982	23.5	458	9	554	539
23	233	3	694	17980	22.5	688	10	417	477
22	404	4	1098	17977	21.5	1088	11	333	317
21	533	12	1631	17973	20.5	1609	12	198	201
20	640	23	2271	17961	19.5	2226	13	155	130
19	954	37	3225	17938	18.5	3143	14	140	86
18	987	69	4212	17901	17.5	4061	15	81	78
17	1151	135	5363	17832	16.5	5077	16	76	36
16	1282	234	6645	17697	15.5	6125	17	44	16
15	1999	327	8644	17463	14.5	7797	18	17	24
14	4145	511	12789	17136	13.5	11431	19	14	6
13	4058	716	16847	16625	12.5	14773	20	3	5
12	493	1445	17340	15909	11.5	13821	21	2	1
11	43	4387	17383	14464	10.5	9477	22	0	1
10	0	6711	17383	10077	9.5	2766	23	0	0
9	0	1941	17383	3366	8.5	825	24	1	0
8	445	543	17828	1425	7.5	727	25	0	0
7	155	36	17983	882	6.5	846	26	1	0
6	0	508	17983	846	5.5	338	27	0	0
5	0	327	17983	338	4.5	11	28	0	0
4	0	6	17983	11	3.5	5	29	0	0
3	0	1	17983	5	2.5	4	30	0	0
2	0	2	17983	4	1.5	2	31	0	0
1	0	2	17983	2	0.5	0			

****

TABLE XXII

PHASE 3 - JOINT FATIGUE TEST RESULTS

Fastener Hole Quality Fastener System	Specimen Number	Log Life	Flights to Complete Failure	Statistic
F R A N C E				
High Hole Quality Fatigue Rated Fastener System	FJH1	3.835	6832	
	FJH2	3.868	7373	$\bar{x}$ = 3.831
	FJH3	3.856	7173	(6783)
	FJH4	3.730	5373	S^2 = 0.003
	FJH5	3.818	6573	S = 0.055
	FJH6	3.883	7632	
Standard Hole Quality Standard "Non-Fatigue Rated" Fastener System	FJL7	3.349	2232	
	FJL8	3.358	2282	$\bar{x}$ = 3.370
	FJL9	3.375	2373	(2345)
	FJL10	3.367	2329	S^2 = 0.000
	FJL11	3.386	2432	S = 0.015
	FJL12	3.386	2432	
Standard Hole Quality Fatigue Rated Fastener System	FJL1	3.841	6930	
	FJL2	3.843	6973	$\bar{x}$ = 3.823
	FJL3	3.831	6773	(6646)
	FJL4	3.808	6432	S^2 = 0.000
	FJL5	3.822	6632	S = 0.020
	FJL6	3.790	6173	

TABLE XXI (CONT)

Fastener Hole Quality Fastener System	Specimen Number	Log Life	Flights to Complete Failure	Statistic
GERMANY				
	gjh1	3.894	7831	
High Hole Quality	gjh2	3.902	7972	$\bar{x}$ = 3.854
Fatigue Rated Fastener System	gjh3	3.808	6431	(7145)
	gjh5	3.847	7031	S^2 = 0.002
	gjh6	3.817	6559	S = 0.043
	gjc1	3.679	4772	
Low Hole Quality	gjc3	3.843	6972	$\bar{x}$ = 3.764
"Non-Fatigue Rated" Fastener System	gjc4	3.746	5572	(5808)
Fastener System	gjc5	3.905	8031	S^2 = 0.012
	gjc6	3.647	4431	S = 0.109
	gjl1	3.923	8372	
Low Hole Quality	gjl2	3.905	8031	$\bar{x}$ = 3.923
Fatigue Rated Fastener System	gjl3	3.856	7172	(8375)
	gjl4	4.001	10031	S^2 = 0.003
	gjl5	3.932	8543	S = 0.052
ITALY				
	IJH1	3.916	8232	
	IJH2	3.972	9381	
High Quality Hole	IJH3	3.943	8773	$\bar{x}$ = 3.906
Fatigue Rated Fastener System	IJH4	3.822	6632	(8047)
	IJH5	3.855	7160	S^2 = 0.003
	IJH6	3.926	8432	S = 0.056
	IJL6	3.386	2432	
Standard Hole Quality	IJL5	3.349	2232	$\bar{x}$ = 3.327
"Non-Fatigue Rated" Fastener System	IJL1	3.337	2173	(2122)
Fastener System	IJL2	3.308	2032	S^2 = 0.001
	IJL3	3.286	1930	S = 0.038
	IJL4	3.295	1973	
	IJL7	3.466	2925	
	IJL8	3.509	3232	$\bar{x}$ = 3.492
Standard Hole Quality	IJL9	3.528	3373	(3105)
Fatigue Rated Fastener System	IJL10	3.482	3032	S^2 = 0.001
	IJL11	3.471	2960	S = 0.024
	IJL12	3.496	3130	
NETHERLANDS				
	NJH111	3.718	5225	
	NJH112	3.443	2772	
High Hole Quality	NJH113	3.678	4772	$\bar{x}$ = 3.685
Fatigue Rated Fastener System	NJH114	3.965	9231	(4842)
	NJH115	3.665	4625	S^2 = 0.026
	NJH116	3.761	5772	S = 0.163
	NJH118	3.564	3666	
	NJL211	3.209	1621	
Standard Hole Quality (High)	NJL212	3.155	1431	$\bar{x}$ = 3.175
Standard "Non-Fatigue Rated"	NJL213	3.212	1631	(1498)
Fastener System	NJL216	3.090	1231	S^2 = 0.003
	NJL217	3.137	1372	S = 0.058
	NJL218	3.248	1772	
	NJL112	3.435	2724	
	NJL113	3.473	2972	$\bar{x}$ = 3.449
Standard Hole Quality (Low)	NJL114	3.294	1971	(2812)
Fatigue Rated Fastener System	NJL115	3.442	2772	S^2 = 0.007
	NJL116	3.522	3329	S = 0.085
	NJL117	3.526	3359	

TABLE XXI (CONT)

Fastener Hole Quality Fastener System	Specimen Number	Log Life	Flights to Complete Failure	Statistic
SWEDEN				
	BR10	3.583	3831	
	BR26	3.660	4572	$\bar{x}$ = 3.683
High Hole Quality Fatigue Rated Fastener System	BR42	3.553	3570	(4816)
	BR2	3.693	4929	S^2= 0.015
	BR18	3.714	5172	S = 0.121
	BR34	3.894	7831	
	RD30	3.683	4824	
Standard Hole Quality "Non-Fatigue Rated" Fastener System	RD6	3.795	6231	$\bar{x}$ = 3.736
	RD14	3.751	5631	(5441)
	RD22	3.923	8372	S^2= 0.017
	RD46	3.735	5431	S = 0.130
	RD38	3.528	3372	
	BD36	3.295	1972	
	BD4	3.386	2431	$\bar{x}$ = 3.380
Standard Hole Quality Fatigue Rated Fastener System	BD28	3.443	2772	(2400)
	BD44	3.420	2631	S^2= 0.003
	BD20	3.410	2572	S = 0.057
	BD12	3.328	2129	
UNITED KINGDOM				
High Hole Quality Fatigue Rated Fastener System	FPG2	4.112	12962	$\bar{x}$ = 4.172
	FPG3	4.225	16780	(14955)
	FPG4	4.087	12233	S^2= 0.012
	FPG5	4.108	12831	S = 0.108
	FPG6	4.342	21972	
	FPG16	3.641	4372	
Standard (Low) Hole Quality Standard "Non-Fatigue Rated" Fastener System	FPG17	3.481	3031	$\bar{x}$ = 3.541
	FPG15	3.385	2431	(3472)
	FPG13	3.604	4024	S^2= 0.009
	FPG14	3.534	3424	S = 0.095
	FPG18	3.599	3972	
	FPG12	3.367	2329	
Standard (Low) Hole Quality Fatigue Rated Fastener System	FPG10	3.501	3172	$\bar{x}$ = 3.440
	FPG9	3.443	2772	(2754)
	FPG8	3.481	3031	S^2= 0.003
	FPG7	3.408	2559	S = 0.054
UNITED STATES				
	J25/35	3.850	7080	
	J2/17	4.105	12734	$\bar{x}$ = 4.018
High Hole Quality Fatigue Rated Fastener System	J45/50	3.881	7597	(10416)
	J41/48	4.181	15160	S^2= 0.017
	J20/42	4.091	12344	S = 0.132
	J8/43	3.998	9964	
	J32/51	3.135	1364	
Standard Hole Quality "Non-Fatigue Rated" Fastener System	J6/40	3.293	1964	$\bar{x}$ = 3.201
	J5/55	3.186	1534	(1589)
	J7/36	3.189	1544	S^2= 0.003
	J24/30	3.203	1597	S = 0.058
	J47/10	4.236	17228	
	J4/33	3.962	9164	$\bar{x}$ = 4.022
Standard (Low) Hole Quality Fatigue Rated Fastener System	J18/12	3.997	9924	(10513)
	J22/26	3.790	6164	S^2= 0.024
	J13/53	4.007	10164	S = 0.153
	J2/16	4.138	13755	

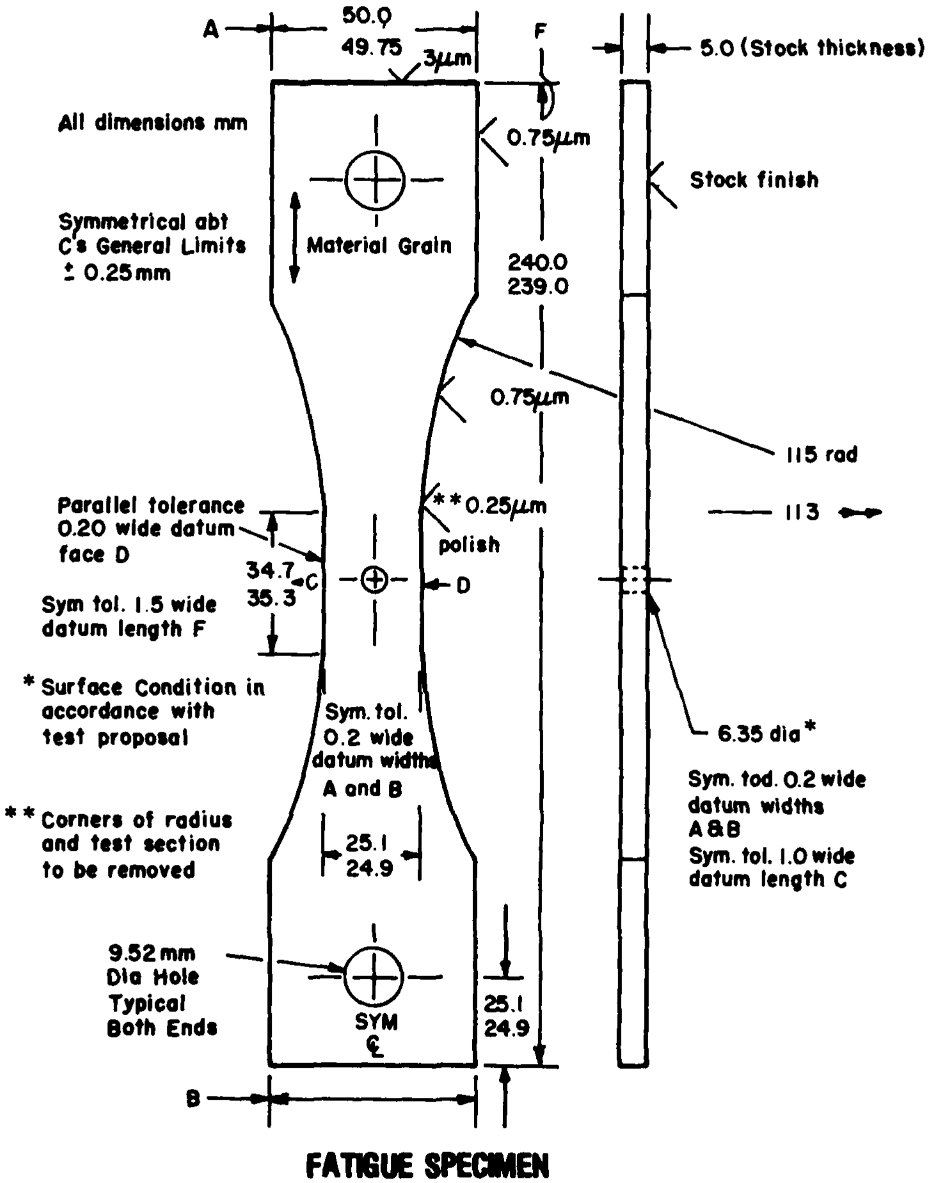


FIGURE 1 PHASE 1 TEST SPECIMEN

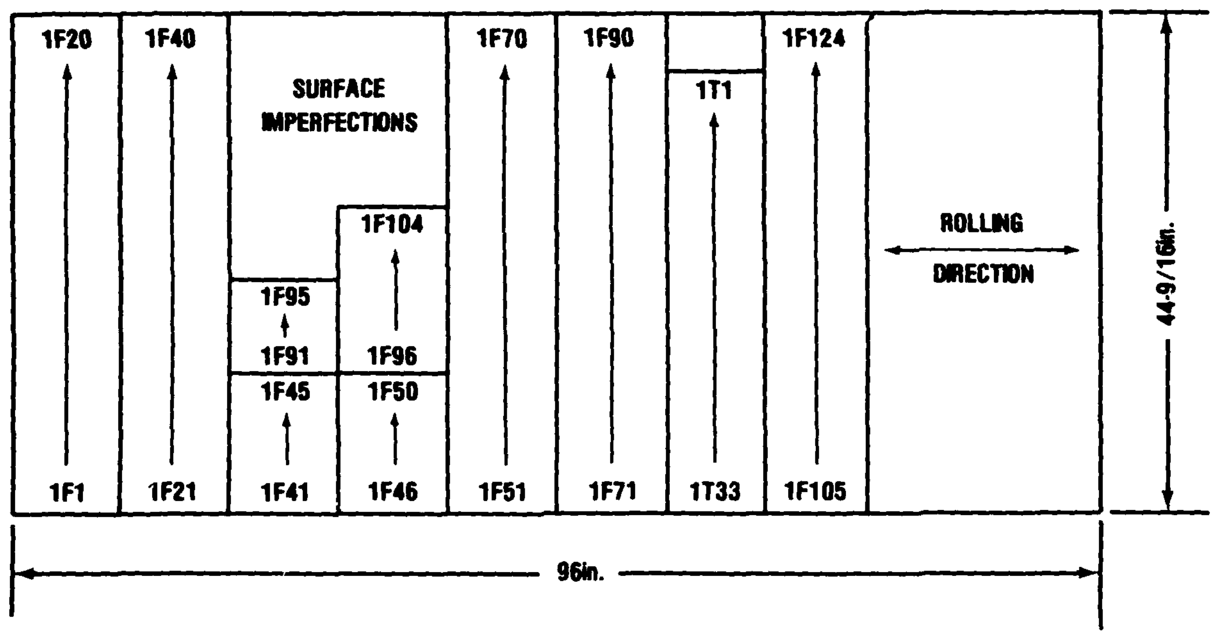


FIGURE 2 AGARD SMP CRITICALLY LOADED HOLE TECHNOLOGY SPECIMEN LOCATION

PHASE 1 - AGARD/SMP - CRITICALLY LOADED HOLE TECHNOLOGY

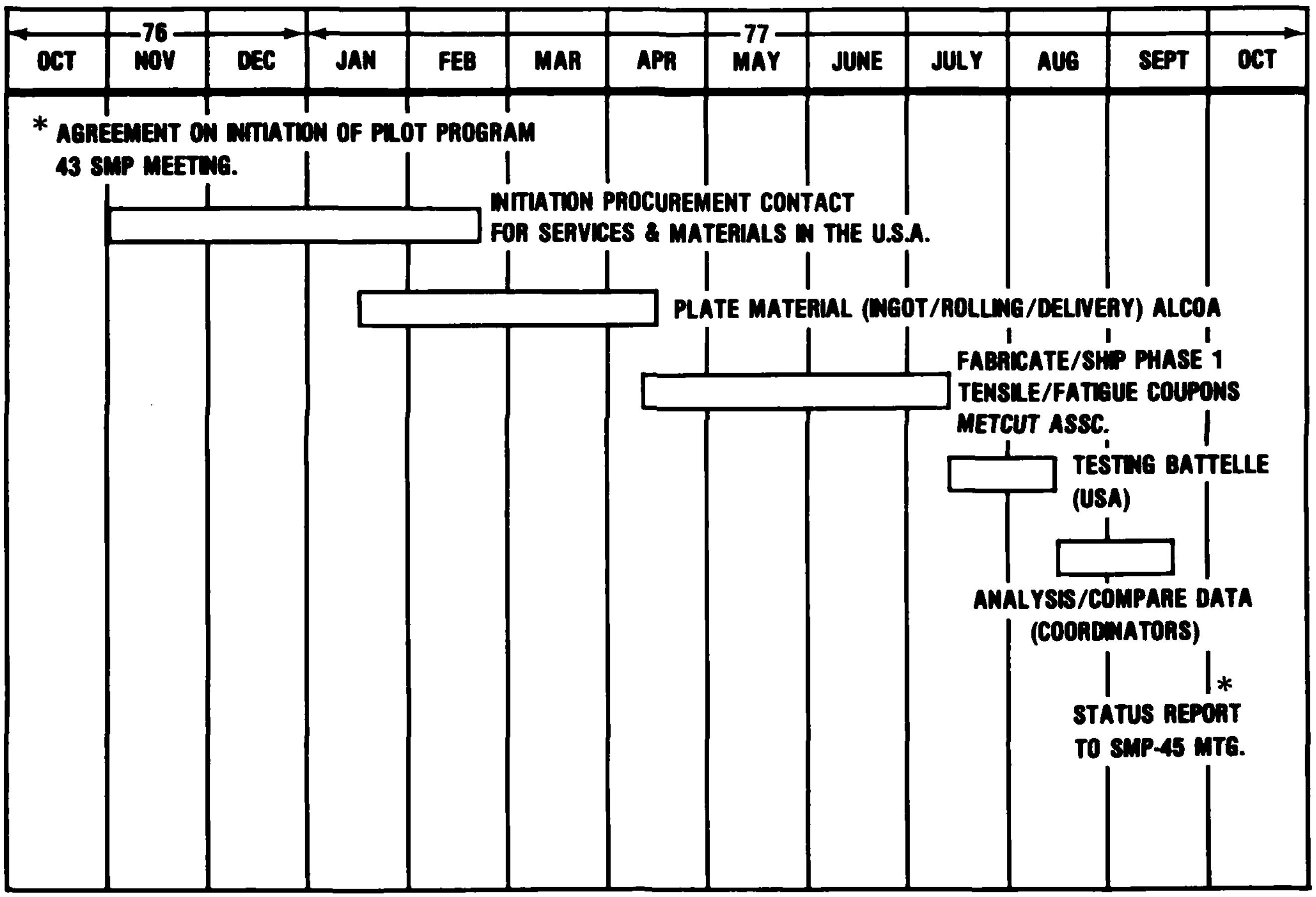


FIGURE 3 SCHEDULE AND MILESTONES FOR PHASE 1

MANUFACTURING REPORT

DRILL: ______

TOOL MATERIAL: ______
DIAMETER: ______
GEOMETRY: ______
POINT ANGLE: ______
TYPE POINT: ______
HELIX ANGLE: ______
RELIEF ANGLE: ______
SPINDLE SPEED, rpm: ______
FEED RATE, ipr.: ______
CUTTING FLUID: ______
TYPE TOOL: ______
WEARLAND: ______

REAMER: ______

TOOL MATERIAL: ______
DIAMETER: ______
GEOMETRY: ______
No. OF FLUTES: ______
HELIX ANGLE: ______
CHAMFER ANGLE: ______
CHAMFER RELIEF: ______
SPINDLE SPEED, rpm.: ______
FEED RATE, ipr.: ______
CUTTING FLUID: ______
TYPE TOOLING: ______
WEARLAND: ______

INSPECTION REPORT

DIAMETER OF HOLE: ______
SURFACE ROUGHNESS: ______
VISUAL OBSERVATION (INCLUDE COMMENTS ON RIFLING, CHATTER, OR OTHER VARIATIONS):

______
______
______
______

DIMENSIONAL DEVIATION (INCLUDE COMMENTS ON STRAIGHTNESS, BELLMOUTH, BARREL OR TAPERED HOLE)

______
______
______
______

FIGURE 4 DATA SHEET FOR MANUFACTURING VARIABLES ON HI AND LOW QUALITY HOLES

PHASE 2 - AGARD/SMP-CRITICALLY LOADED HOLE TECHNOLOGY

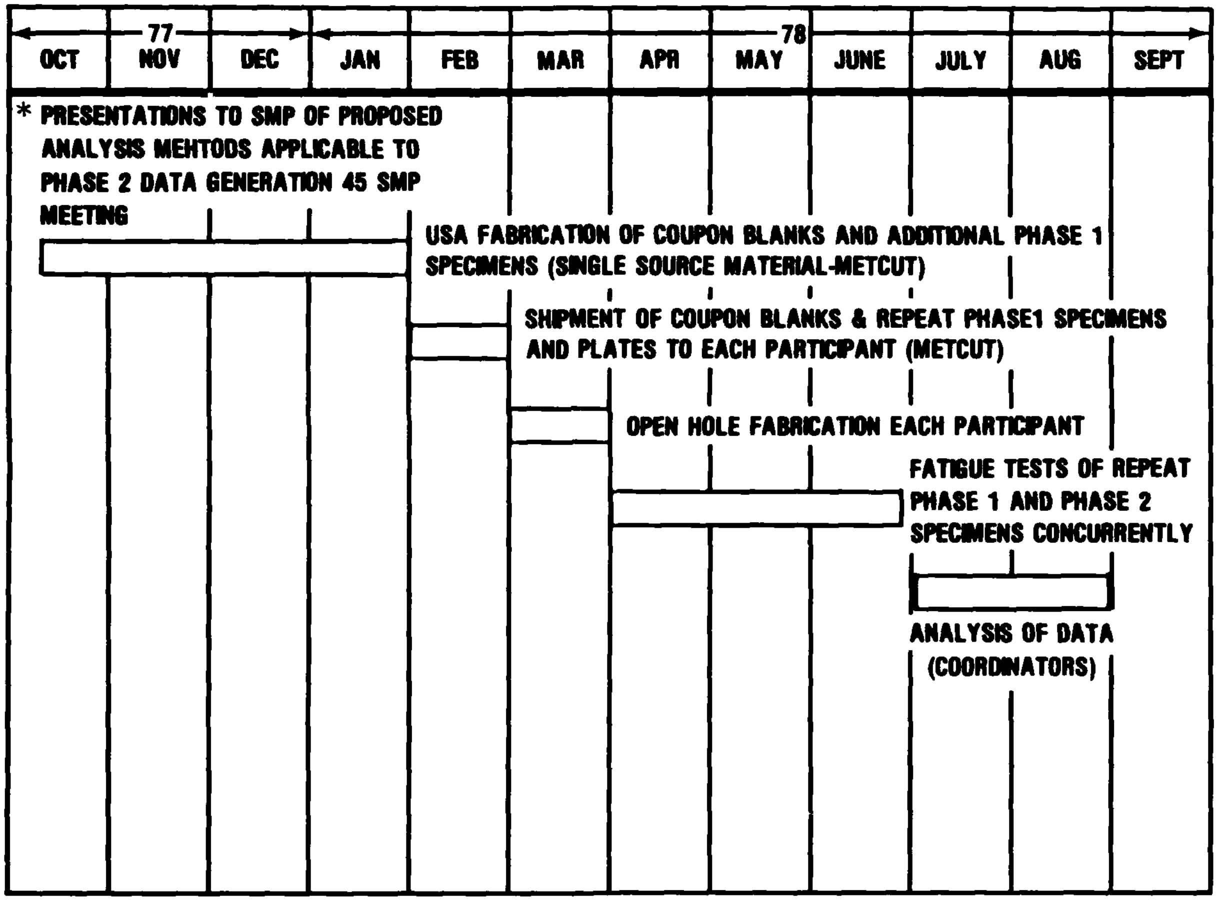
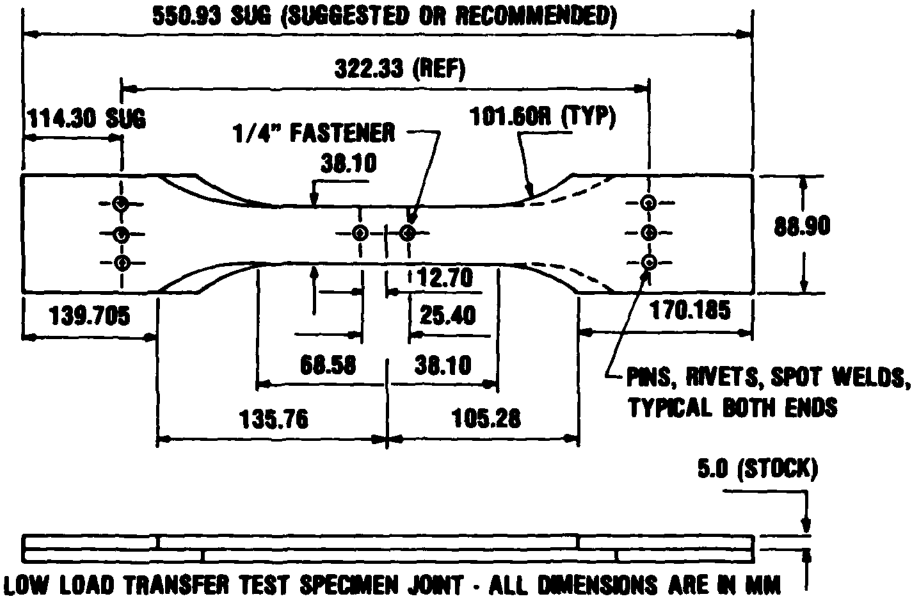


FIGURE 5 SCHEDULES/MILESTONES FOR PHASE 2



FAYING SURFACE TREATMENT

1. CLEAN (DEGREASE WITH SUITABLE SOLVENT)
2. SPRAY PAINT WITH EPOXY PRIMER DRY FILM THICKNESS .050 to .13
3. FAYING SURFACE SEALANT (PR-1431)
4. ALL FASTENERS INSTALLED WET WITH SEALANT (PR-1431)

FIGURE 6 LOW LOAD TRANSFER SPECIMEN

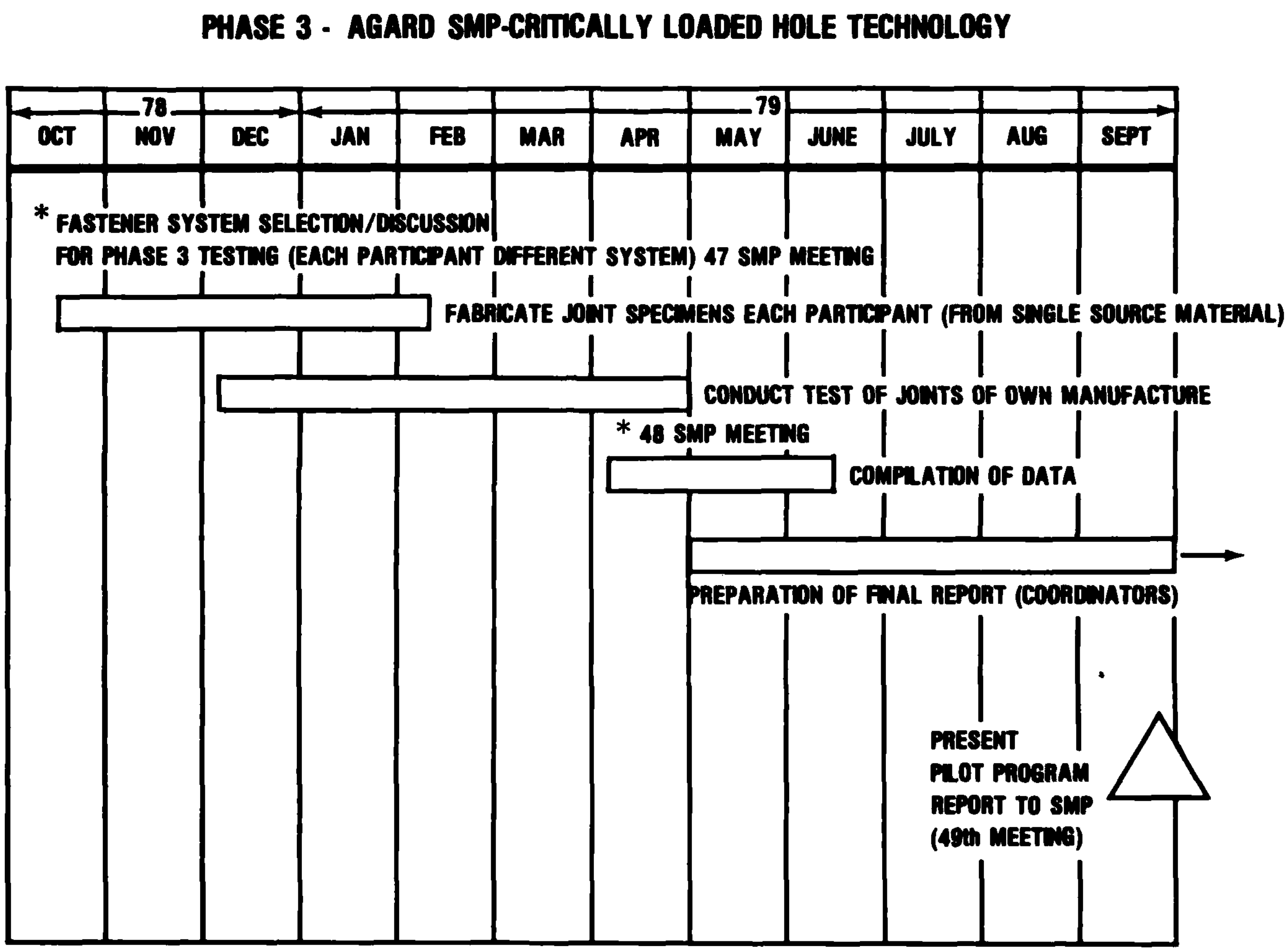


FIGURE 7 SCHEDULE AND MILESTONES FOR PHASE 3

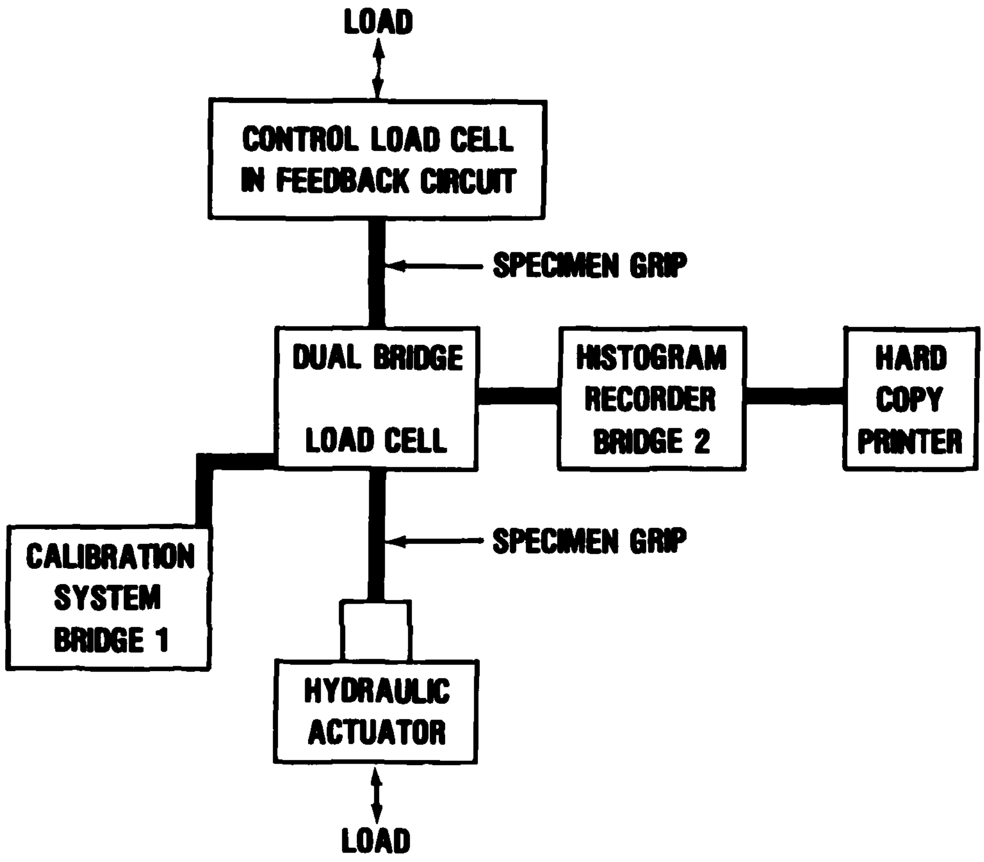


FIGURE 8 LOAD MEASUREMENT AND RECORDING METHOD

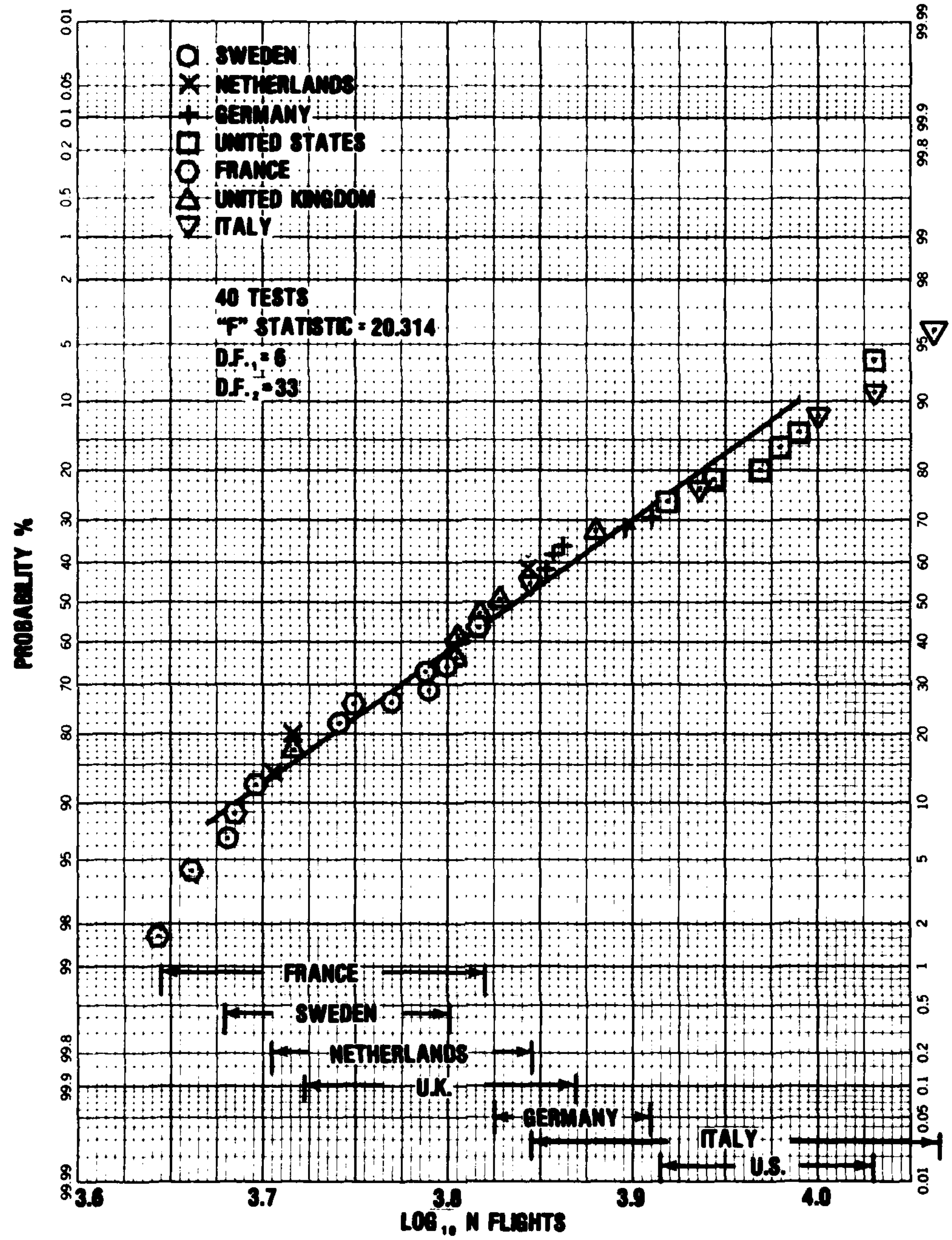


FIGURE 9 CRITICALLY LOADED HOLE TECHNOLOGY PHASE 1 TEST RESULTS

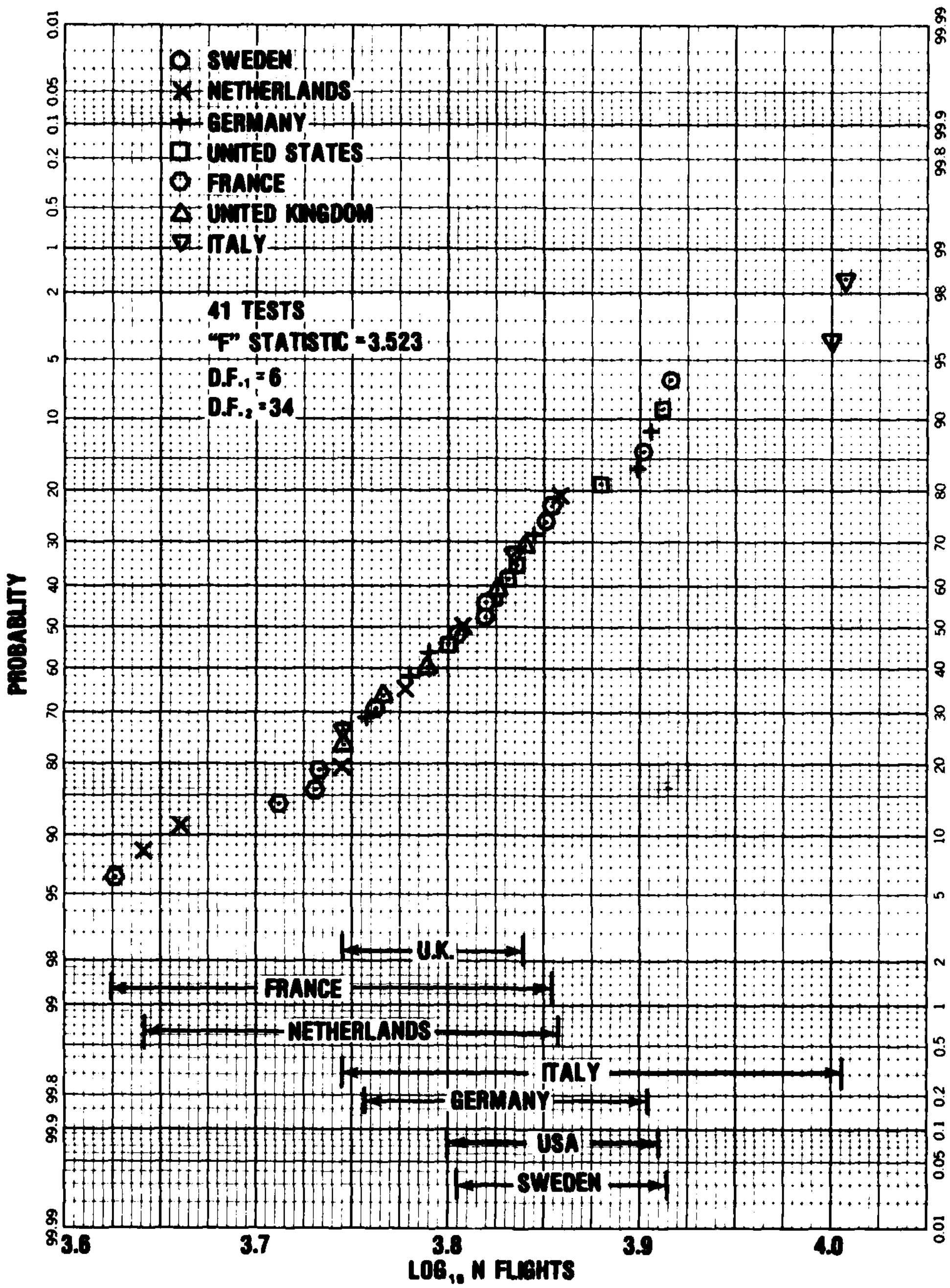


FIGURE 10

FATIGUE TEST RESULTS - PHASE 1A (REPEAT OF PHASE 1 TESTING - IDENTICAL SPECIMENS)

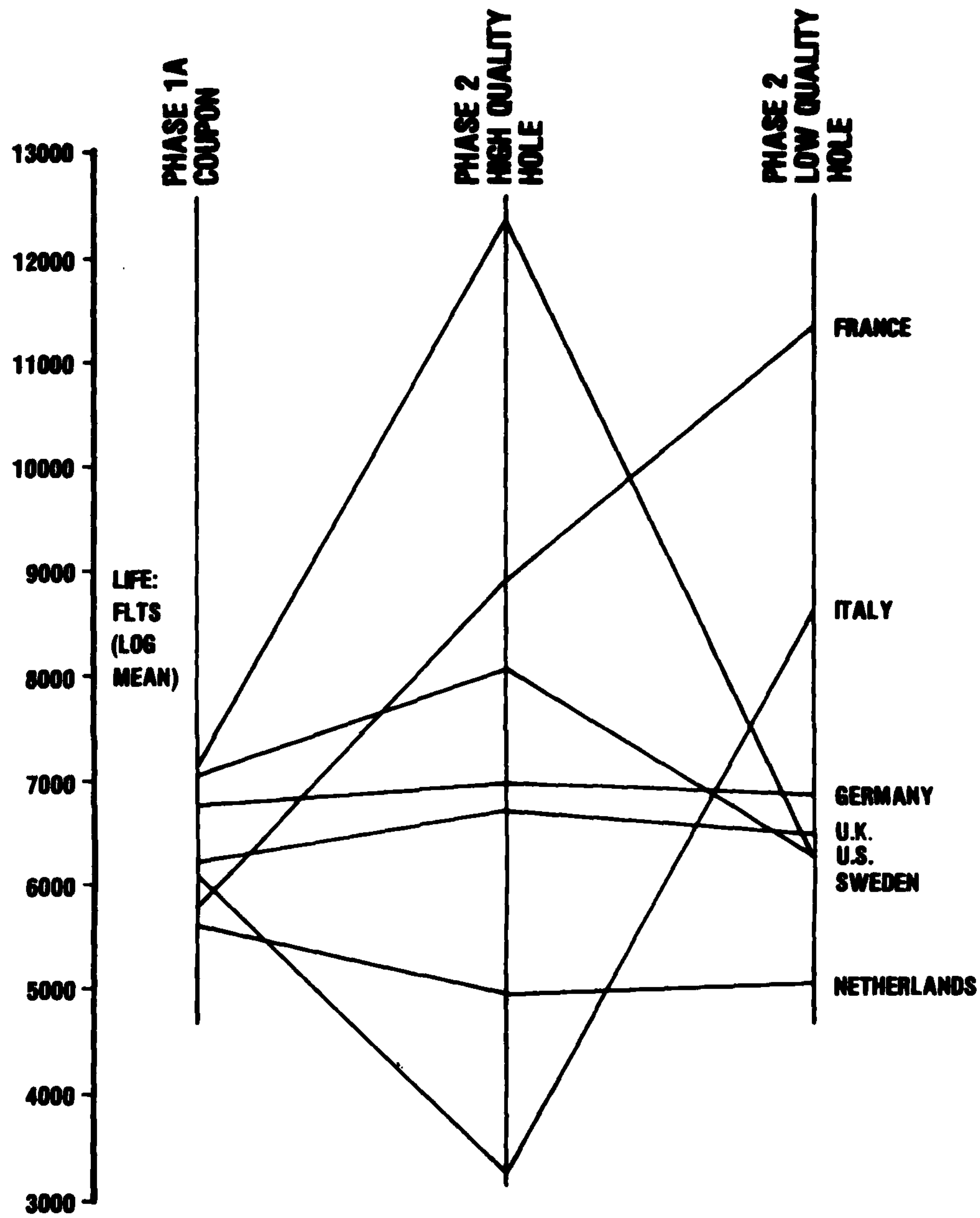


FIGURE 11

COMPARISON OF PHASE 1 REPEAT, LOW QUALITY AND HIGH QUALITY HOLE - LOG MEAN LIFE FOR ALL PARTICIPANTS. ALL SPECIMENS "OPEN HOLE" PER FIGURE 1

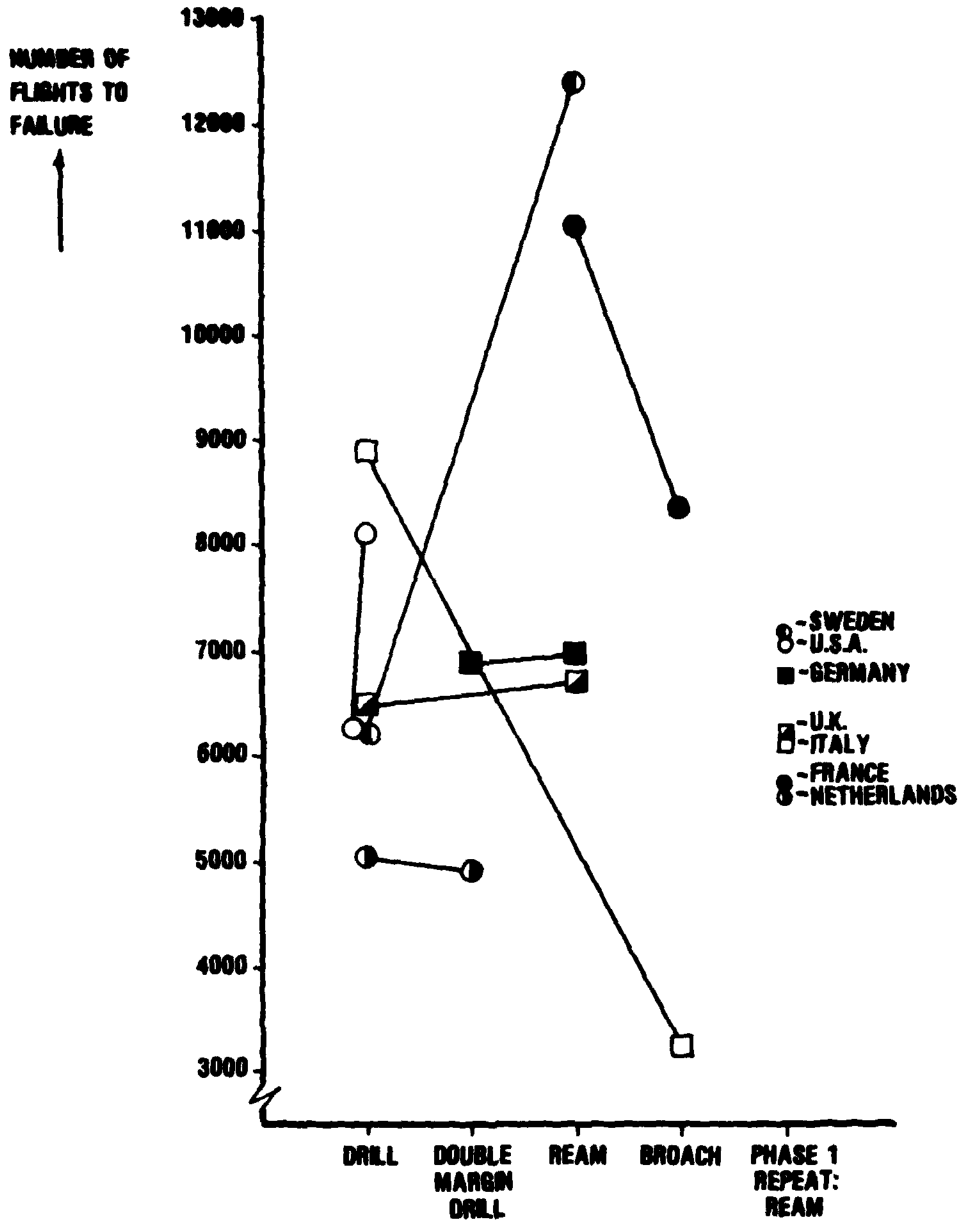


FIGURE 11a COMPARISON OF DIFFERENT HOLE PREPARATION TECHNIQUES
AS USED IN PHASE 1 REPEAT AND PHASE 2 OPEN HOLE SPECIMENS

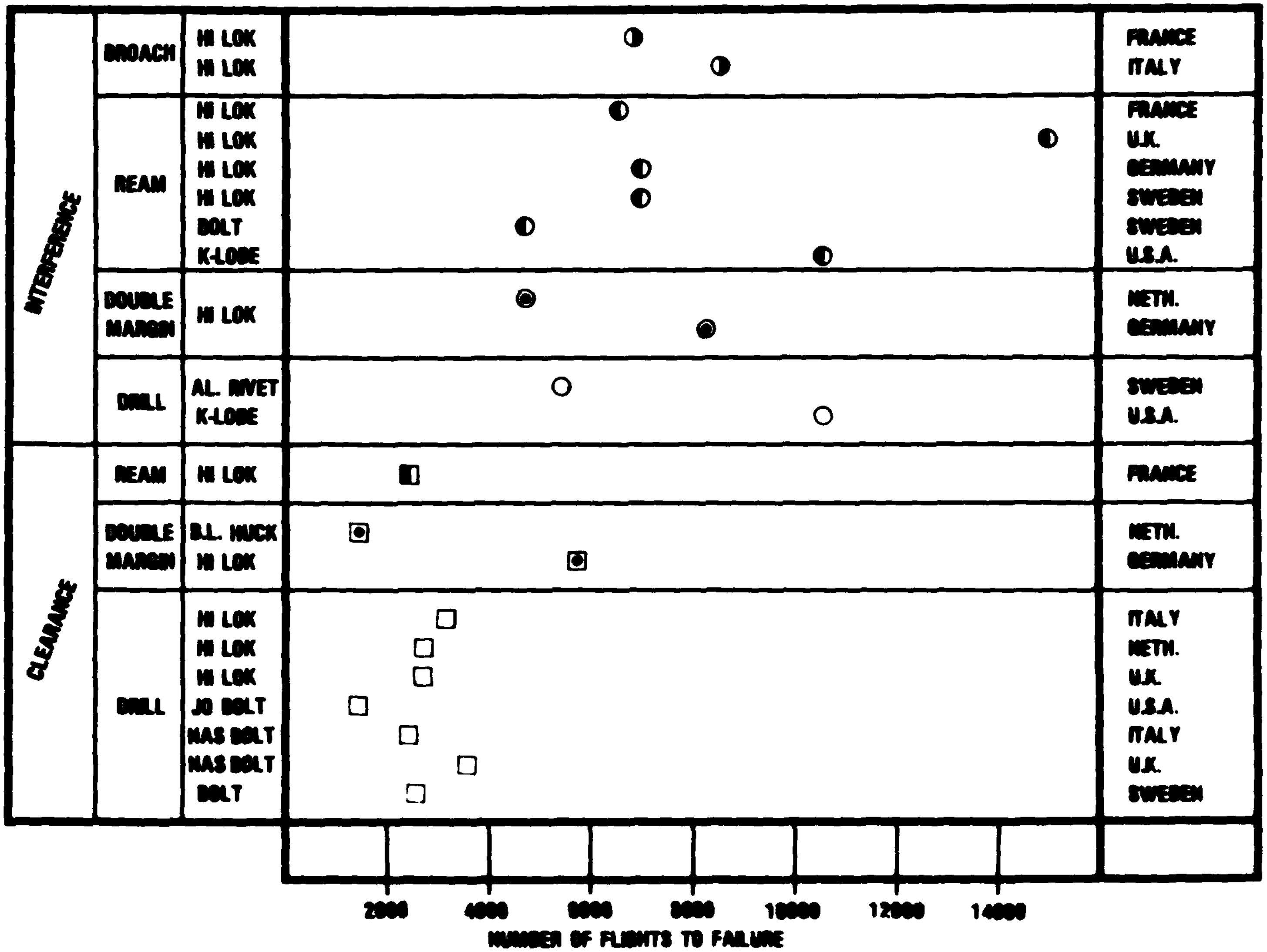


FIGURE 12 PHASE 3 FATIGUE TEST RESULTS

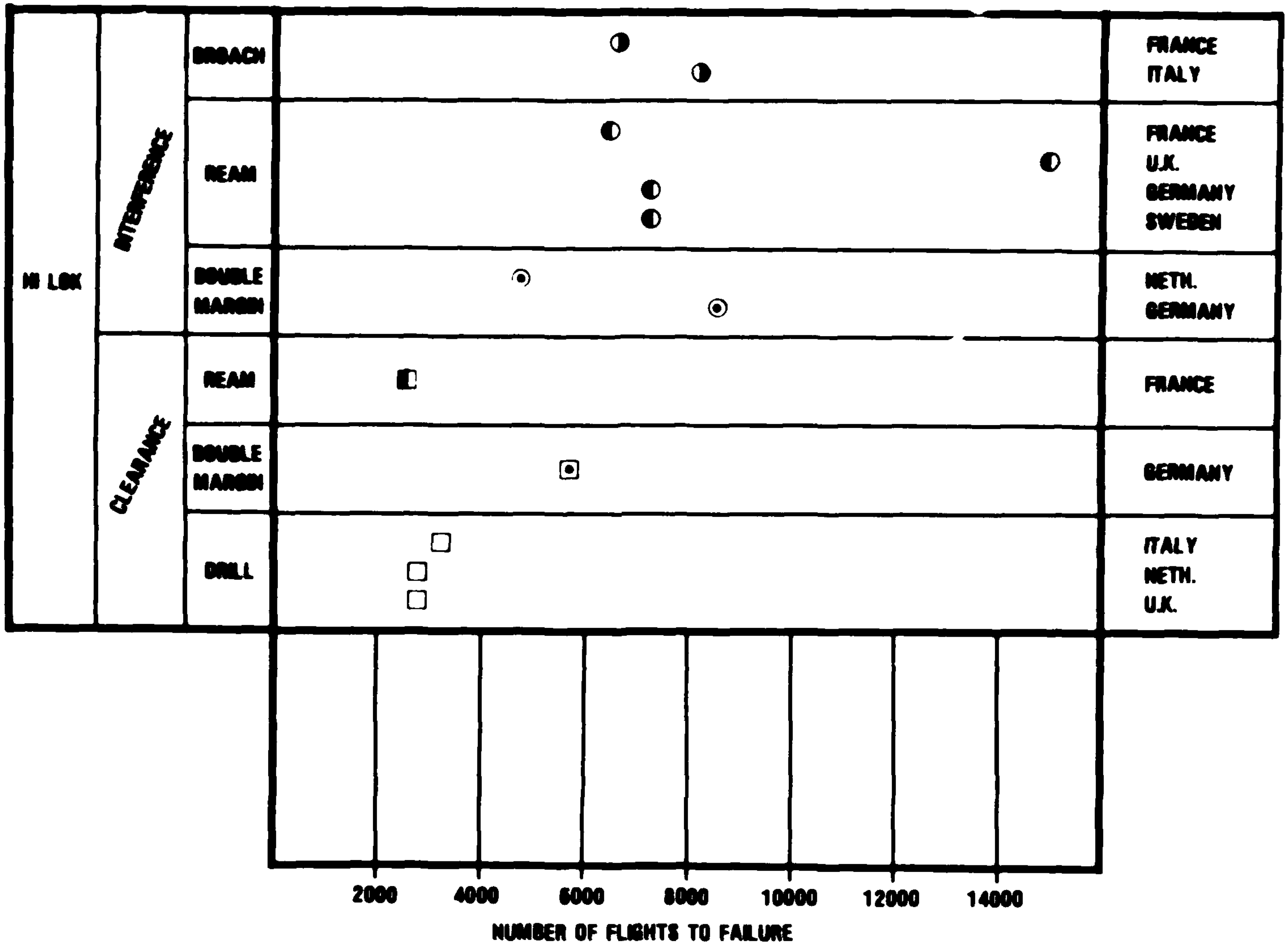


FIGURE 13 PHASE 3 FATIGUE TEST RESULTS COMPARISION OF JOINTS UTILIZING HI LOK FASTENERS

APPENDIX

VERIFICATION OF LOADING ACCURACY FOR FALSTAFF LOAD SEQUENCE

As a part of the critically loaded hole programme, the University of Dayton, USA, conducted a programme to determine whether or not all participating countries were applying identical spectrum load levels at the agreed reference stress level.

A.1 METHOD OF VERIFICATION

The evaluation was conducted using a master load cell specimen which replaced the standard test specimen (Phase 3) in the fatigue machine. Each participating laboratory applied one complete spectrum (200 flights) of FALSTAFF to the master load cell specimen using the same servo control and programme as were used for the Phase 3 low load transfer specimen.

A histogram recorder (data acquisition system) was used to record the number of load reversals that occurred within a narrow range of the load. The band width for each range was one-fourth of a FALSTAFF load level. The recorder had 128 storage locations for the reversals that were peaks and 128 storage locations for the reversals that were valleys. A schematic diagram of the recording system is shown in Figure A.1.

A.2 DESCRIPTION AND FUNCTION OF EQUIPMENT

A.2.1 Master Load Cell Specimen

The master load cell specimen was designed to fit in the testing machines without any modification to the grip arrangement. The specimen was designed so that it had the same stiffness as the reverse double dog-bone low load transfer test specimen.

The master load cell specimen had two strain gauge bridges; one of the bridges was calibrated by the USA Bureau of Standards and was used to calibrate the second bridge and the histogram recorder.

A.2.2 Histogram Recorder

The histogram recorder was a Sun Systems, Inc ADASTOR II Solid State Recorder with duplicate sections for the peak and valley histograms. The recorder had two analogue-to-digital converters and two microprocessors, one each for the peak recorder and the valley recorder. The fact that there were two analogue-to-digital converters and two processors caused some confusion because the number of peaks recorded did not always equal the number of valleys recorded. It was expected that the number of peaks would have to equal the number of valleys since the programme for the peaks was the same as for the valleys. The only reason for any difference would have to be due to a different requirement for the change in load to define a peak than to define a valley. Both recorders were programmed to require a change in load of 1.5 FALSTAFF steps to define a peak or valley.

During the recording phase of the programme, there were several times when many more valleys than peaks were recorded. This difficulty was at first thought to be caused by low battery voltage. However, after the recording programme was completed, the ADASTOR II was returned to Sun Systems for analysis. Sun Systems reported that the analogue-to-digital converter on the valley recorder was adding electronic noise to the signal which was then processed by the microprocessor. Sun Systems replaced the A-D converter in the valley recorder and since that time there have been no extra readings in the valley recorder.

The introduction of the noise on the valley recorder signal may have caused some valleys to be recorded at a lower value than was actually applied to the specimen, and it is known that it caused additional valleys to be recorded. For these reasons not all of the valley data for one country has been reported.

A.3 RESULTS

The results of the study are presented in Table A.1. The first column in the table (labelled FALSTAFF) lists the expected number of peaks or valleys at the particular FALSTAFF load level. Note that all of these levels are integer levels. The other seven columns are the recordings from the seven countries that participated in the programme.

In the following presentation of the results, no comments will be made, with reference to any one laboratory, about load levels 7 and 8 for the peaks and load levels 5 and 6 for the valleys. The zero load level for the FALSTAFF sequence is 7.527; the first load in the sequence is level 8 and the last load level in flight 200 is load level 6. Because the various laboratories used different initial values before the sequence was started and also different techniques to stop after 200 flights, there was the problem of perhaps not having the first or last load reversal. In some laboratories, it was also possible that one or two of the taxi cycles were too small for the histogram recorder to recognise a peak or valley. (The taxi cycles were equal to two FALSTAFF levels and the histogram recorder required 1½ levels to identify a peak or valley). Actually most countries had the exact number of peaks or valleys for levels 5, 6, 7 and 8 and those that did not were only in error by one or two counts.

The data are banded by FALSTAFF load levels.

A.3.1 Countries 1, 2, 3 and 6

As can be seen from an examination of the data in Table A.1, there does not appear to be any question about which programmed load levels correlate with the histogram recordings for the Countries 1, 2, 3 and 6.

A.3.2 Country 4

For Country No. 4, there is a question about the peaks at load levels 16 and 17 since load level 16 has five extra peaks and load level 17 has five too few peaks; also load level 12 has two extra peaks whereas load level 13 is two short. There is no way from the histogram data to conclude if these loads are programmed incorrectly, or if the incorrect load was applied by the hydraulics, or if the histogram recorder assigned these few peaks to the wrong memory cell. The valley data for column four also shows an extra valley in load level 12 and one too few at load level 13. Because there is no separation between the valley recording at load levels 12 and 13 it is impossible to say whether one of the recordings (counts) at load level 12.25 was programmed for load level 13 or load level 12. The number 28 recorded for load level 12.25 could be interpreted as one valley intended for level 13 and 27 intended for load level 12.

A.3.3 Country 5

The histogram recordings reported in column five required more deduction to assign the numbers to the bands. The higher levels of peaks have a one-to-one correspondence between the expected and recorded numbers. The recordings at load levels 15.5, 16.5, 17.5, 18.5 and 19.5 had to be divided between the next higher and lower integer levels to make the histograms correlate. The difficulty here is in deciding whether some of the peaks recorded at 15.25, 16.25, 17.25, 18.25 and 19.25 were programmed to be at the next higher integer level. However, since at the other load levels there was not this great a variation, it was assumed that the overlap was only in the one level, i.e. half way between the integer levels. This assumption made all of the recordings correlate with the expected values except that load level 15 was one short and load level 13 was two short. The same procedure was used for the valleys. All of the recordings could be assigned to one of the load levels except that level 12 was short by four valleys.

A.3.4 Country 7

The data from Country No. 7 is the only set which contains an excess of counts in the peaks recorder. Some load levels contained the correct number of peaks (levels 32, 30, 29, 25, 22, 8 and 7) and some other levels were only short of a few counts (levels 26, 21, 18, 14, 13). Based on the number of load levels that had the correct or nearly correct number of peaks, it can be assumed that the spectrum generation was correct and that the hydraulic-servo system was capable of applying the correct load levels. There is, however, the question as to what caused the extra counts in the peak recorder, since no other time, before or after this recording, did extra counts occur in the peak recorder. It is possible that the recorder malfunctioned or that the hydraulic-servo system was introducing a vibration in the system. Since only certain load levels were involved, it could be that the vibration was frequency dependent since the frequency used was a function of the range of the load change.

The histogram of the valleys was more erratic than the one for the peaks and had many more recordings than the peaks. Some of the load levels were correct (levels 24, 23, 20, 19, 17, 16, 3, 2, and 1) but the other load levels except for level 18 had too many valleys. Some of these extra recordings could be due to the noise on the analogue-to-digital converter and some of them could be due to a vibration in the test machine.

The data from Country No. 7 are not as meaningful as the others since the servo-valve system used with the test machine and the spectrum frequency were not the same as were used for the Phase 3 test programme.

A.4 DISCUSSION

The general conclusion from the verification programme is that the various participating laboratories did a satisfactory job in applying spectrum loads.

Country No. 1 was excellent.

Country No. 2 was also excellent but with the peaks biased toward the high side and the valleys toward the low side. (Too much span).

Country No. 3 was also excellent but with the peaks biased toward the low side and the valleys also biased toward the low side (A DC offset).

Country No. 4 was very good with the peaks biased toward the high side and the valleys centred about the correct value.

Country No. 5 was also very good but with a little more variability (scatter) in the magnitude of the loads. The peaks and valleys were both distributed high and low about the correct values.

Country No. 6 was also excellent but with the peaks biased toward the high side. The valleys were generally correct.

Country No. 7 was difficult to evaluate since the system which had been used for the Phase 3 testing could no longer be operated. However, the data indicate a very good capability to do spectrum loading.

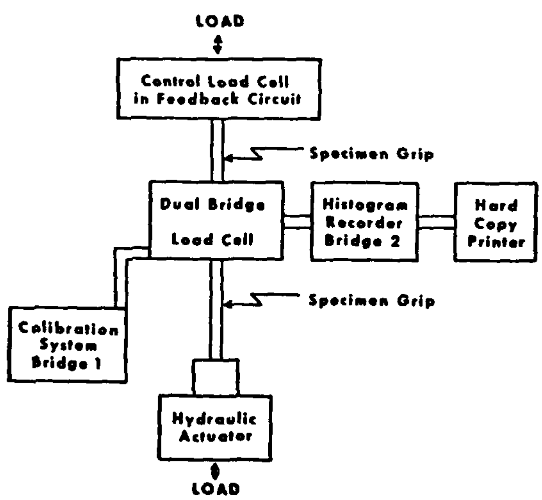


Figure A.1

TABLE A.1

FALSTAFF HISTOGRAMS - PEAKS

	Falstaff	1	2	3	4	5	6	7
33								
32.5								
					1		2	
32	2	2			1	2		
			2	2				
31.5								1
								1
31								
30.5							1	
					7	6	6	
30	7	7	7	1		1		
				6				
29.5					3		1	5
					7		8	2
29	10	10	10			10	1	
				10				
28.5					21			5
			15		3	13	10	5
28	24	24	9	2		9	14	
				22		2		6
27.5					35		1	20
					10	2	40	5
27	45	45	45	1		42	4	
				44		1		6
26.5					59		1	39
			8		16	40	71	8
26	76	76	68	6	1	31	4	
				70		4		
25.5					80	1	1	67
			97		24	81	83	9
25	104	104	7	8		13	20	1
				96		10		
24.5					119			101
		2	193		72	118	155	3
24	193	191		11	2	61	38	3
				182		12		64
23.5					96	2		188
			22		128	157	206	6
23	233	233	211	17	9	52	27	27
				216		21		61
22.5					81	3		232
			325		298	253	322	2
22	404	404	79	26	25	115	82	
				378		31		7
21.5					267	5		393
			532		241	272	404	4
21	533	533	1	35	25	191	129	
				498		57		30
20.5					67	13		495
			640		510	267	511	9
20	640	640		65	63	256	129	199
				575		109		216
19.5					24	8 4		580
			954		787	364	737	4
19	954	954		72	142	452	216	303
				882	1	116	1	441
18.5					33	18 12		686
			349		801	428	743	3
18	987	987	638	53	153	416	241	
				934		122	3	402
17.5						9 10		586
			978		809	370	938	1
17	1151	1151	173	47	328	599	213	1
				1104	9	156		645
16.5						16 5		508
			1244		764	313	930	6
16	1282	1282	38	38	514	731	350	672
				1244	9	205	2	1119
15.5						28		279
								2

TABLE A.1 (CONT)

	Falstaff	1	2	3	4	5	6	7
15.5								
15	1999	1999	1997 2	12 1987	1153 837 9	9 188 1423 370 8	1523 476	775 1758 358
14.5								
14	4145	3896 249	5 4140	64 4081	2898 1245 2	144 3199 780	3903 241 1	2 3819 325
13.5								
13	4058	3732 326	6 4052	70 3988	1670 2381 5	22 72 3146 835 3	3949 109	127 3867 61
12.5								
12	493	446 47	5 488	3 490	128 364 3	12 385 96	486 7	1290 511
11.5								
11	43	39 4	3 40	43	9 34	2 24 17	43	346 292 24
10.5								
10								
9.5								
9								
8.5								
8	445	182 263	444 1	303 440 4	142	142 274 27	441 4	368 76 1
7.5								
7	155	155	155	153 1	155	155	1 153 1	150 5
6.5								

TABLE A.2

FALSTAFF HISTOGRAMS - VALLEYS

	Falstaff	1	2	3	4	5	6	7
26								
25.5								
25	1	1	1	1	1	1	1	
24.5								
24	2	2	2	2	1 1	1 1	1 1	2
23.5								
23	3	3	1 2	3	3	1 2	1 1 1	3
22.5								
22	4	3 1	1 3	4	1 2	3 1	3 1	16 4
21.5								
21	12	10 2	10 2	12	1 5 7	10 2	4 2 6	5 25 2 1
20.5								
20	23	12 11	22 1	23	8 12 3	7 9 5 2	9 3 11	8 15
19.5								
19	37	23 14	36 1	37	6 26 4 1	11 16 6 2 2	7 4 26	18 19
18.5								
18								

TABLE A-2 (CONT)

	Falstaff	1	2	3	4	5	6	7
18.5							3	
		41	1		15	13	5	
18	69	28	68		41	31	61	49
				69	12	17		18
17.5					1	5	1	
		15	6		14	3 37	10	
17	135	120	129		99	71	124	109
				132	18	16		20
16.5				3	4	9		4
		10	23		9	2 36	20	2
16	234	224	211		170	108	214	225
				232	46	69		9
15.5				2	9	19		
		7	104		6	2 62	28	4
15	327	320	223		239	144	299	305
				322	59	88		8
14.5				5	23	33		
					44	74	42	17
14	511	511	425		326	226	469	471
			86	506	132	169		80
13.5				5	9	42		
					18	82	65	
13	716	716	619		472	328	651	
			97	697	206	232		
12.5				19	19	73		
					28	1 193	75	
12	1445	1445	1290		992	766	1364	
			155	1404	385	381	6	
11.5				41	41	101 6		
					49	1154	104	
11	4387	4387	3884		3353	2206	2528	
			503	4228	906	829	1755	
10.5				159	79	192 24		
					12	2143	48	
10	6711	6709	6180		5678	3789	3139	
		2	531	6425	926	634	3524	
9.5				286	95	121 2		
					3	324	23	
9	1941	1941	29		1382	1194	1078	
			1911	1860	525	375	840	
8.5			1	81	31	46 1		
						33	12	
8	543	543	28		190	306	288	
			515	530	343	200	243	
7.5				13	10	3		
		1			31	1	2	
7	36	35	7		5	18	21	
			29	36		17	13	
6.5						26		
		266			441	269	2	
6	508	243	508	41	67	158	368	
				435		54	137	
5.5				31				
		182			269	309		
5	327	145			58	11	144	
			161	321		7	183	
4.5			166	4				
		5			3			
4	6	1			3	2		
			5	6		4	6	
3.5			1					
					1			
3	1	1				1	1	
			1	1				
2.5								2
					2			
2	2	2				2		
			1	2			2	
1.5			1					2
					2			
1	2	2				2	1	
			2	2			1	
0.5								
0								

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14. Abstract

This report contains the results of a pilot cooperative experimental programme which investigated the interaction of fastener hole quality and resulting fatigue lives of low load transfer structural joints when subsequently utilizing fatigue rated and non-fatigue rated fastener systems. These fastener systems were primarily loaded in shear.

A load level verification was made and it was established that there were few differences, within the range of testing frequencies used in this pilot programme, in the accuracy of loading or comparability of data between participants.

Highlights of the data indicated that interference fit fasteners may be relatively insensitive to effects of surface finish and hole quality with the exception of dimensional tolerance which is important because it affects interference fit. Interference fit fasteners gave better results than clearance fit.

This Programme was sponsored by the Structures and Materials Panel of AGARD.

AGARD Report No.678	AGARD-R-678
Advisory Group for Aerospace Research and Development, NATO CRITICALLY LOADED HOLE TECHNOLOGY – PILOT COLLABORATIVE TEST PROGRAMME Final Technical Report by Dr T.Coombe and R.B.Urzi Published November 1980 60 pages This report contains the results of a pilot cooperative experimental programme which investigated the interaction of fastener hole quality and resulting fatigue lives of low load transfer structural joints when subsequently utilizing fatigue rated and non-fatigue rated fastener systems. These fastener systems were primarily loaded in shear. P.T.O.	Fasteners Joints (junctions) Drill holes Loads (forces) Fatigue (materials)

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