TU Delft

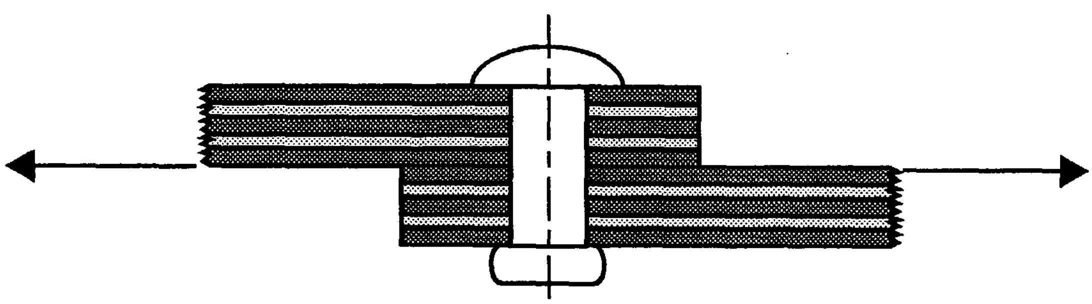
Faculty of Aerospace Engineering

Delft University of Technology

Memorandum M-676

User's Guide for the Computer Program JOINT

W.J. Slagter



Delft University of Technology
Faculty of Aerospace Engineering
February 1994

Computer Program JOINT

The program offers the designer a convenient tool to perform a strength and flexibility analysis of a rivet in a single-lap joint in any layup of Fibre Metal Laminates or in solid sheet material. This user's guide gives instructions for use of the program, describes various options available to the user, and provides an example of the required input data and resulting output.

1. Introduction

The computer program JOINT calculates the yield and ultimate strength and the flexibility of a rivet in a single-lap joint in any layup of Fibre Metal Laminates (FML) or in solid sheet material. The calculation is based entirely on the theoretical analysis developed in [1,2]. Section 2 provides a general description of the program. Section 3 contains detailed user's instructions and refers to the various options available to the user. An example of data input and execution of the program is given in Section 4. Certain additional facilities of the program are referred to in Section 5.

2. Program Description

The need for a computer program to predict the strength of riveted joints in FML is clear, because the many possible varieties of FML make comprehensive testing virtually impossible. A program which is simple to use and needs only a few basic parameters has obvious attraction provided it is sufficiently versatile, in particular if the input parameters do not change with layup for a given grade of FML. The program is, however, equally applicable to conventional sheet materials. The required input parameters and resulting output of the program are shown in Figure 1, together with an indication of the analysis procedures developed in Chapters 2 to 5 of [1].

The primary purpose of the program is to calculate the static strength of a rivet in a single-lap joint. In addition, rivet flexibility is calculated (necessary for the distribution of load between rivets in an actual joint). The static strength and flexibility of the joint are predicted using a semi-analytic approach based on the idealization of the rivet in the hole as a pin on a two-parameter, elastic-plastic foundation, and taking into account the tilting of the rivet in a single-lap joint. The model accounts for variation of in-plane stiffness and transverse shear stiffness through the thickness, which is of course essential for joints in FML. The rivet is capable of deforming in both shear and bending. The bearing behaviour of the sheet is assumed to be elastic, linear strain-hardening plastic. The computer program is capable of handling stresses well beyond the proportional limit of the material by use of an incremental plasticity theory.

The rivet flexibility calculated by the program includes both deformation of the rivet and local deformation of the sheet around the hole. It does not include the extension of the sheet itself, i.e. it refers to the additional displacement due to the rivet as if the sheet were uniform up to the centre of the rivet. The edge distance (distance from the rivet to the edge of the sheet) and the width of sheet are taken into account in the calculation of rivet flexibility through a reduced foundation stiffness. For the joint yield and ultimate strengths the user should specify bearing yield and bearing ultimate strengths for the metal sheet / layer which correspond to the edge distance and width of sheet chosen. Interference between the rivet and the sheet, i.e. residual stress in the sheet after setting the rivet, has a significant effect on rivet strength; this is taken into account in the program. It is assumed in the program that the formed head of the rivet (i.e. formed by setting the rivet) has a diameter of 1.5 times the rivet shank diameter. However, the user may also perform the calculation without interference (see Section 5). The program is applicable to both protruding head and flush head rivets. For flush head rivets the program calculates an increased flexibility, furthermore no interference is assumed at the countersunk side of a flush head rivet.

Joint yield strength is defined as the load which produces a permanent deformation of the joint equal to 4 % of the rivet diameter. For joint ultimate strength the program uses an appropriate failure hypothesis to determine the maximum load in one of the following failure modes:

- bearing failure of the sheet;
- rivet pull-through (associated with a large degree of tilting of the rivet);
- rivet shear failure.

The experimental validation described in [1] encourages the belief that the program predicts with good accuracy the static strength of rivets in both aluminium alloy sheet and FML materials. In addition, the program is effective for parametric studies because problems can be run very quickly, allowing many design iterations to be performed in a short period of time.

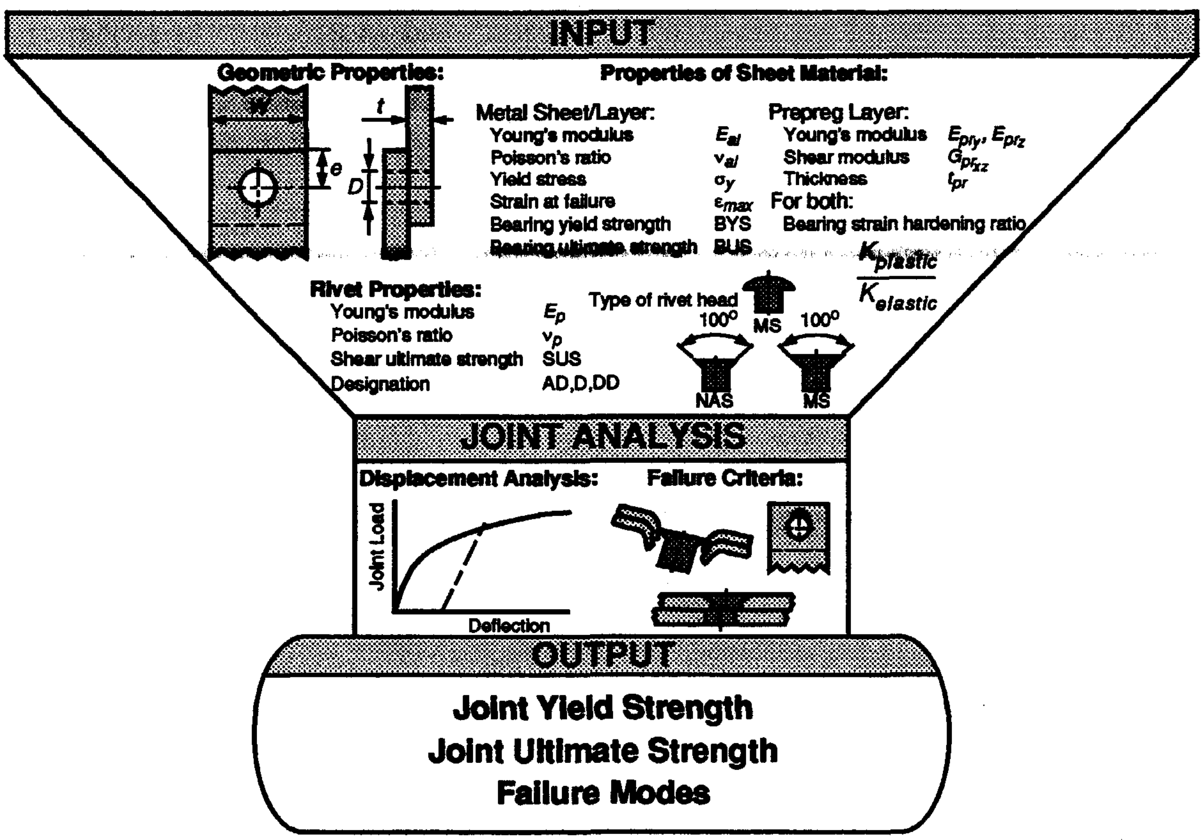


Figure 1. "Schematic flow chart" of the computer program JOINT.

3. User's Instructions

The analysis is coded in Fortran 77 in the semi-interactive computer program JOINT. The development of this program is described in [1]. The basic input is a file indicating which options are required and giving the data associated with those options. These data are defined in four blocks describing the geometric properties of the joint, non-standard sheet material properties, rivet properties, and an additional option permitting certain extra output. Due to the fixed sequence of input data, data can be read in unformatted over the first 10 characters. The units shown in the input and output of the program are the customary SI units. However, formulae used in the program involve only dimensionless parameters and can, therefore, be evaluated in any consistent system of units.

Some supplementary input of data is also required while running the program. Interactive procedures are used to specify this supplementary data for operation of the program, again as unformatted input data. If the entered input data is detected as invalid, a message will be displayed and a bell activated. The user must correct and repeat the input data before further execution of commands. When the user is prompted for data, the request must be completely fulfilled before the program can continue. All data is transmitted by striking the terminal *Return* key. Correction of data may be accomplished by backspacing and re-entering at any time before the *Return* key has been struck. If the *Return* key has already been struck, the analysis has to be stopped and repeated with the correct data. A flow chart of on-line "conversational" language instructions used to request input data for entry via the keyboard is shown in Figure 2. This gives an overview of the user-friendly menu structure and shows the main program options available to the user.

The program may be started by typing the program name *joint*. A demo-input file is provided to help the user run the program for the first time. In addition, this demo-input file can be used as a model for input data to the program, i.e. it can be modified for a specific problem. The user may select output to be displayed on screen or written to a data file. A data file enables the user to obtain a hard copy print-out of the problem analyzed. In this case, the user must label each analysis by supplying a file name. The program does not check a file name for duplication. The analysis performed by the program is such that the designer will be mainly interested in numerical results. There is no graphics output from this program. However, the output of load versus displacement (LVD-) data can optionally be stored to an output file. If desired this output file can, of course, be visualized by means of an external plot program.

The user is given the option of calculation of rivet flexibility only, or both rivet flexibility and joint strength. When the first option is selected, execution of the program is restricted to an elastic analysis. More comprehensive output data is provided for the user who is familiar with the theory on which the computer program is based; an example of this additional output is given in the final section of this user's guide.

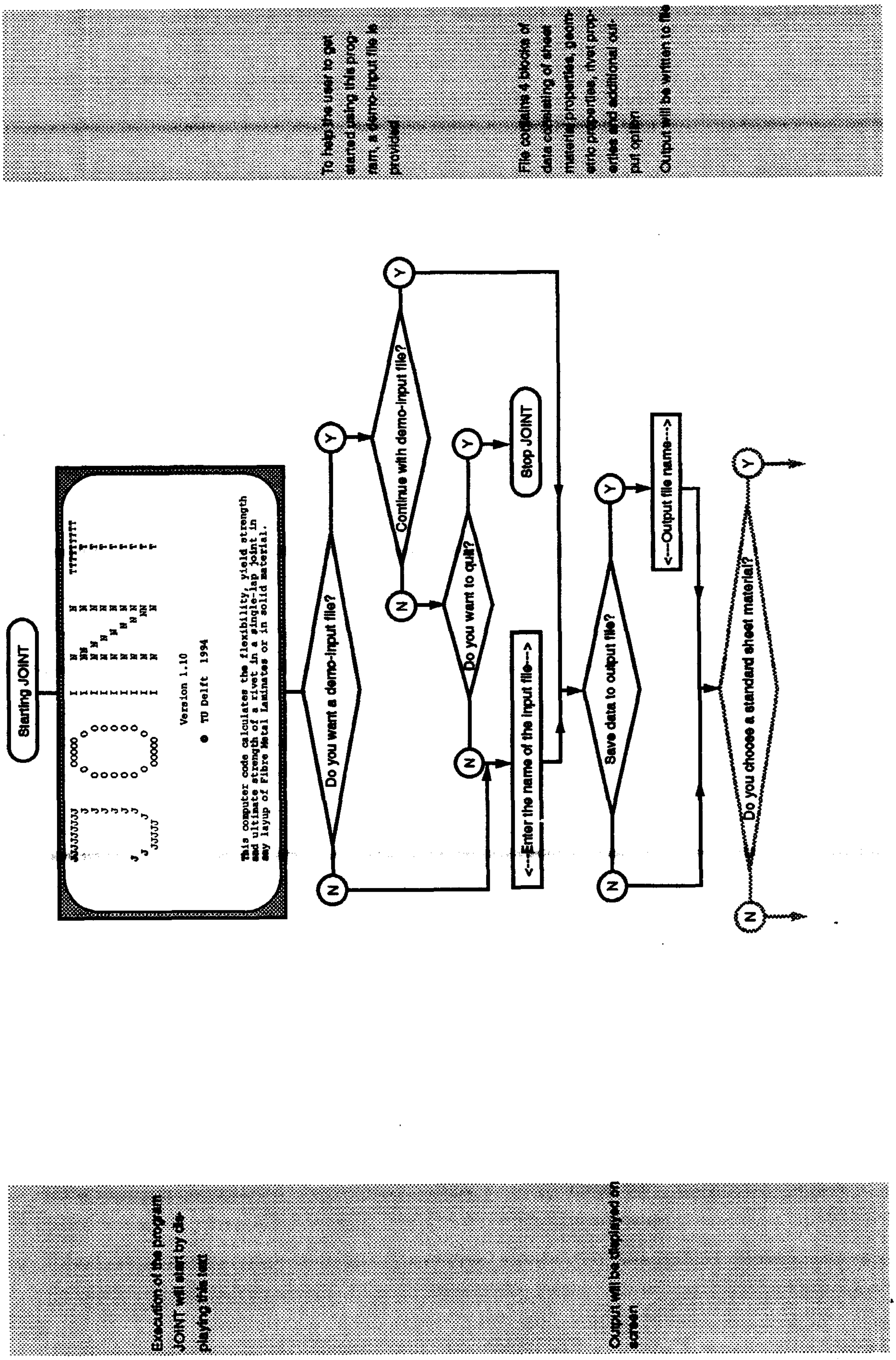
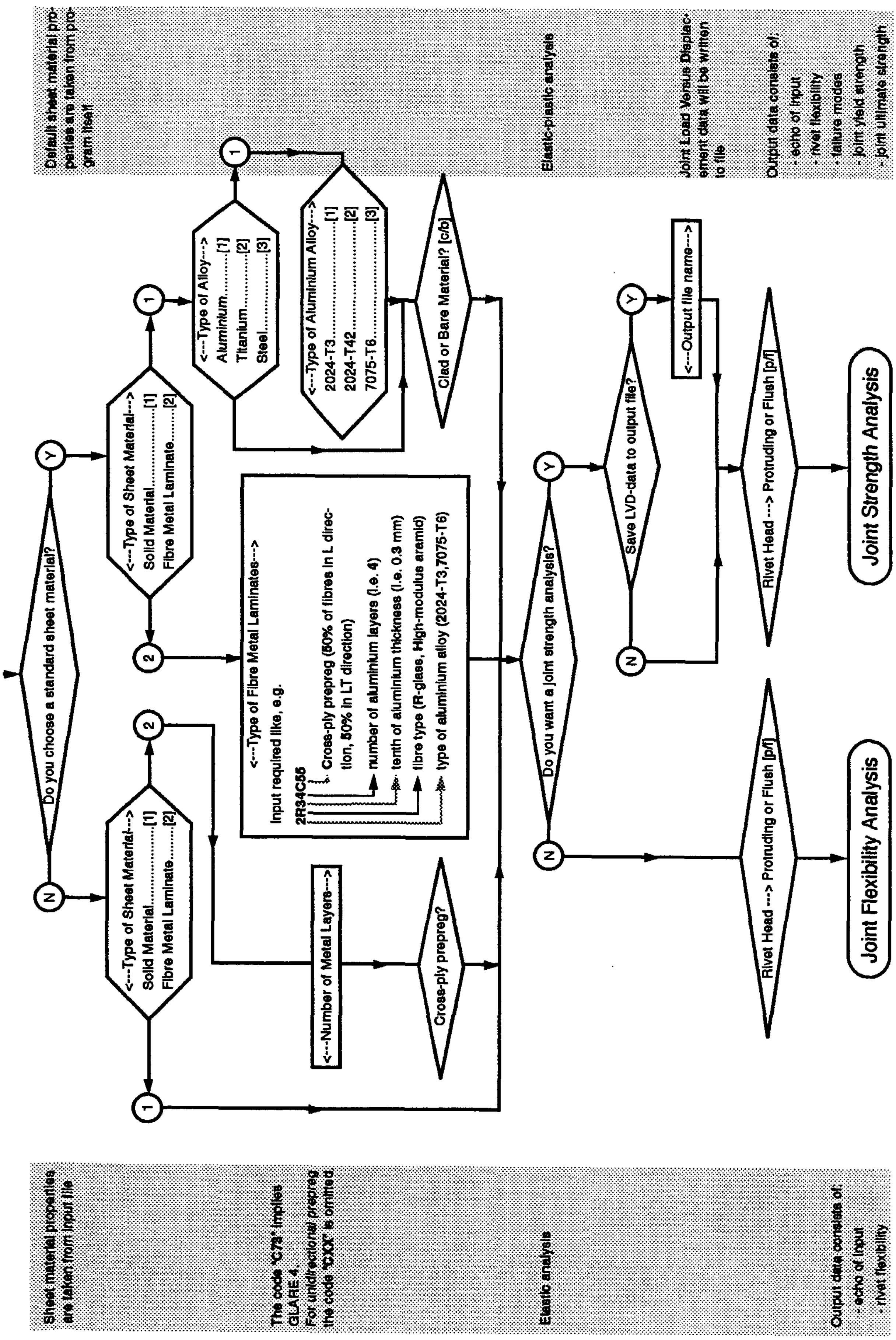


Figure 2. Flow chart of "conversational" language used to request input data.



Continuation of Figure 2.

4. Example of Joint Strength Calculation

This section gives an example of data input and execution of the program JOINT, and illustrates the static strength analysis of a riveted, single-lap joint. Figure 3 shows a single-lap joint in which a protruding head rivet of 4.0 mm diameter is used to connect two sheets of GLARE 3 consisting of three aluminium layers of 0.2 mm thickness and two cross-ply prepreg layers of 0.25 mm thickness (i.e. 2R23C55, see Fig. 2). The diameter of the rivet hole is 4.1 mm.

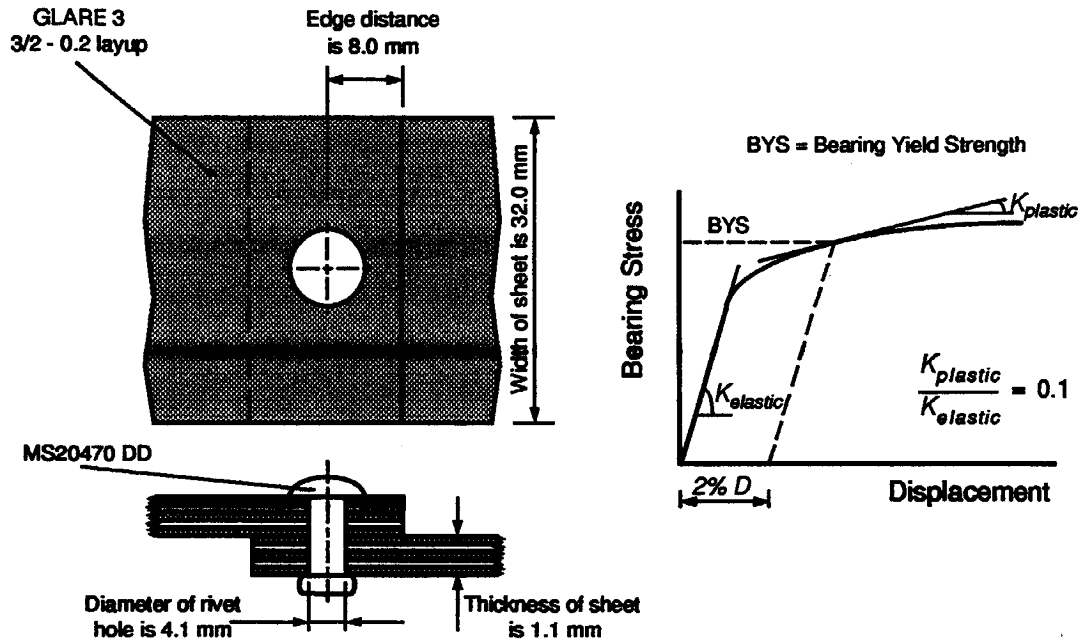


Figure 3. Example of single-lap joint (including definition of bearing strain hardening ratio $K_{plastic}/K_{elastic}$).

In this example the demo-input file (Fig. 4) is chosen, producing the input display shown in Figure 5. Since a standard material is chosen, the non-standard sheet material properties shown in Figure 4 are retained but not read. Figure 6 shows how the result of the input in Figures 4 and 5 is displayed. This includes both input and output data values. As seen from the echo of input (Fig. 6), the prepreg properties in this example do not correspond to those of the non-standard material data given by the demo-input file (Fig. 4) because for standard materials default material properties are taken from the program itself. The output contains the rivet flexibility, the ultimate strength for each of the failure modes, the joint yield strength and joint ultimate strength (smallest value of the individual failure modes).

```
G E O M E T R I C   P R O P E R T I E S   O F   T H E   J O I N T
     8.0   <--- Edge Distance ---------------------------->  [mm]
     4.1   <--- Diameter of the Rivet Hole --------------->  [mm]
    32.0   <--- Width of the Sheet ----------------------->  [mm]
     1.1   <--- Thickness of Sheet ----------------------->  [mm]
$          $         $         $         $         $         $
      N O N  -  S T A N D A R D   S H E E T   M A T E R I A L
......................Metal Sheet/Layer........................
Aluminium <--- Type of Material (xxxxxxxxxx)-------------->
 72000.    <--- Young's Modulus --------------------------> [MPa]
     0.3   <--- Poisson's Ratio -------------------------->
   324.    <--- 0.2 % Yield Stress ----------------------> [MPa]
    12.    <--- Strain at Failure -----------------------> [ % ]
     0.20 <--- Thickness of Metal Layer ------------------>  [mm]
   629.    <--- Bearing Yield Strength -------------------> [MPa]
   959.    <--- Bearing Ultimate Strength ----------------> [MPa]
     0.1   <--- Kplastic/Kelastic ------------------------>
......................Prepreg Layer of FML.....................
 53980.    <--- Young's Modulus (Ey) ---------------------> [MPa]
  9412.    <--- Through-the-thickness Young's Modulus (Ez)-> [MPa]
  5548.    <--- Through-the-thickness Shear Modulus (Gyz)--> [MPa]
     0.25 <--- Thickness of Prepreg Layer ---------------->  [mm]
     0.0   <--- Kplastic/Kelastic ------------------------>
$          $         $         $         $         $         $
               R I V E T   P R O P E R T I E S
 MS20470   <--- Type of Material (MSxxxxx/NASxxxx) -------->
   DD      <--- Rivet Designation (AD/D/DD/E) ------------>
 72000.    <--- Young's Modulus --------------------------> [MPa]
     0.3   <--- Poisson's Ratio -------------------------->
   282.    <--- Shear Strength ---------------------------> [MPa]
$          $         $         $         $         $         $
          A D D I T I O N A L   O U T P U T   O P T I O N
   n       <--- Do you want additional output ? ----------> [y/n]
```

Figure 4. Demo-input file used in the example of joint strength calculation ("xx..." are for identification only, and are not used by the program).

```
JJJJJJJJJ       OOOOO       I     N       N     TTTTTTTTT
        J      O     O      I     NN      N         T
        J     O       O     I     N N     N         T
        J     O       O     I     N  N    N         T
        J     O       O     I     N   N   N         T
        J     O       O     I     N    N  N         T
J       J     O       O     I     N     N N         T
 J     J       O     O      I     N      NN         T
  JJJJJ         OOOOO       I     N       N         T

                        Version 1.10

                     © TU Delft  1994


     This computer code calculates the flexibility, yield strength
     and ultimate strength of a rivet in a single-lap joint in
     any layup of Fibre Metal Laminates or in solid material.


     To help you get started using this program, a demo-input
     file can be created.

Do you want a demo-input file? [y/n]
y
The demo-input file called "demo.inp" has been created !

Do you want to continue the calculation with "demo.inp" file? [y/n]
y
Save data to output file ? [y/n]
y
<---Output file name--->
output.dat
Do you choose a standard sheet material ? [y/n]
y
<---Type of Sheet Material--->
Solid Material ............[1]
Fibre Metal Laminate.......[2]
2
<---Type of Fibre Metal Laminates--->
**** Use format of type: 2R34C55 ****
2R23C55
Do you want a joint strength analysis ? [y/n]
y
Save LVD-data to output file ? [y/n]
n
Rivet Head ---> Protruding or Flush ? [p/f]
P

     ---> Awaiting Execution <---

Do you want another calculation ? [y/n]
n
```

Figure 5. Interactive input display in the example.

```
************************ <      ECHO OF INPUT     >  *******************

          Geometric Properties of the Joint :

             Thickness of Sheet                =     1.100  mm
             Edge Distance                     =     8.000  mm
             Width of Sheet                    =    32.000  mm
             Diameter of Rivet Hole            =     4.100  mm
          _____________________________________________________

          Type of Protruding Head Rivet        : MS20470 (DD)

             Shear Strength                    =     282.0  MPa
             Young's Modulus                   =   72000.0  MPa
             Poisson's Ratio                   =     0.300
          _____________________________________________________

                    FIBRE METAL LAMINATES DATA

          Type of FML                          :     2R23C55

          Aluminium Layer Properties:
             Young's Modulus                   =   72000.0  MPa
             Poisson's Ratio                   =     0.300
             0.2 % Yield Stress                =     324.0  MPa
             Strain at Failure                 =      12.0  %
             Bearing Yield Strength            =     629.0  MPa
             Bearing Ultimate Strength         =     959.0  MPa
             Bearing Strain Hardening Ratio    =     0.100

          Prepreg Properties :
             Young's Modulus  (Ey)             =   32000.0  MPa
             Shear Modulus    (Gyz)            =    5548.0  MPa
             Thickness                         =     0.250  mm
             Bearing Strain Hardening Ratio    =     0.100
_______________________________________________________________________

*********** <    SINGLE-RIVET JOINT STRENGTH ANALYSIS     > *********

          Flexibility of Rivet            =     60.38 *10-6 mm/N

          Ultimate Strength for :
             Bearing Failure              =      3686 N
             Rivet Shear Failure          =      3723 N
             Rivet Pull-through Failure   =      3060 N

          Joint Yield Strength            =      2727 N
          Joint Ultimate Strength         =      3060 N
             (based on Rivet Pull-through Failure)
```

Figure 6. Output obtained in the example.

5. Additional Output

As stated previously, there is an option to obtain additional output data related to the strength of a riveted, single-lap joint but not included in the standard output. For this purpose, the question on the last line of the input file (Fig. 4) should be answered appropriately, i.e. by replacing "n" by "y". Figure 7 shows the additional output for the example already discussed in Section 4. Via the screen menu an extra question is asked: whether or not there exists an interference fit situation of the rivet in the hole. In the example in this section interference is not taken into account, to demonstrate the significant effect of interference (compare the joint yield and ultimate strengths in Figure 6 with those in Figure 7). Equation numbers referred to in Figure 7 are those used in [1] with regard to the additional output data.

```
*********************** <     ECHO OF INPUT     > *******************

          Geometric Properties of the Joint :

             Thickness of Sheet                 =     1.100  mm
             Edge Distance                      =     8.000  mm
             Width of Sheet                     =    32.000  mm
             Diameter of Rivet Hole             =     4.100  mm
          ____________________________________________________

          Type of Protruding Head Rivet         : MS20470 (non-interf.)

             Shear Strength                     =     282.0  MPa
             Young's Modulus                    =   72000.0  MPa
             Poisson's Ratio                    =     0.300
          ____________________________________________________

                     FIBRE METAL LAMINATES DATA

          Type of FML                           :      2R23C55

          Aluminium Layer Properties:
             Young's Modulus                    =   72000.0  MPa
             Poisson's Ratio                    =     0.300
             0.2 % Yield Stress                 =     324.0  MPa
             Strain at Failure                  =      12.0  %
             Bearing Yield Strength             =     629.0  MPa
             Bearing Ultimate Strength          =     959.0  MPa
             Bearing Strain Hardening Ratio     =     0.100

          Prepreg Properties  :
             Young's Modulus  (Ey)              =   32000.0  MPa
             Young's Modulus  (Ez)              =    9412.0  MPa
             Shear Modulus    (Gyz)             =    5548.0  MPa
             Thickness                          =     0.250  mm
             Bearing Strain Hardening Ratio     =     0.100
____________________________________________________________________

********************* <    ADDITIONAL OUTPUT    > ********************

      Bearing Strength Properties of FML:
          Bearing Yield Strength                =       470  MPa      eqn (3.5)
          Bearing Ultimate Strength             =       717  MPa      eqn (4.15)

      Delamination Buckling:
          Bearing Ultimate Strength             =       236  MPa      eqn (4.14)

      Tension Load on Rivet Perpendicular to Sheet:
          Rivet Tensile Strength                =      1387  N        eqn (4.32)
             (based on Rivet Pull-through Failure)

      Single-lap joint:
          Bearing Load Concentration Factor     =      1.79           eqn (3.4)
____________________________________________________________________

*********** <    SINGLE-RIVET JOINT STRENGTH ANALYSIS     > *********

          Flexibility of Rivet            =     60.38 *10-6 mm/N

          Ultimate Strength for :
             Bearing Failure              =      3602 N
             Rivet Shear Failure          =      3723 N
             Rivet Pull-through Failure   =      2506 N

          Joint Yield Strength            =      2087 N
          Joint Ultimate Strength         =      2506 N
             (based on Rivet Pull-through Failure)
```

Figure 7. Example of additional output.

References

1. W.J. Slagter, "Static Strength of Riveted Joints in Fibre Metal Laminates". *PhD thesis*, Delft University of Technology, Faculty of Aerospace Engineering (to be published in 1994).

2. W.J. Slagter and A. Rothwell, "Static Strength of Riveted Joints in Fibre Metal Laminates" (submitted for publication).

Memorandum 676

891156