Appendix A

Effect of Assembly Features on Structures: FE Modelling

JAM Jigless Aerospace Manufacturing

Cranfield UNIVERSITY

J.A.M. PROJECT

EFFECT OF ASSEMBLY FEATURES ON STRUCTURES:

FE MODELLING

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DOCUMENT HISTORY

This report documents the modelling work carried to analyse the effect of number of assembly features on the stress pattern of their parent structure.

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CONTENTS

INTRODUCTION

This report details the work that has been done to model a number of assembly features using the finite element analysis package EMRC NISA/DISPLAY. The main objective was to understand what effect the chosen features may have on the loading response of their parent structure. This work is a first step in the assessment of the impact of assembly features. It is hoped that this preliminary investigation will help with the definition of future work to be undertaken in this area.

1.- BACKGROUND

As part of the re-engineering activity of the JAM project, a number of concepts have been created. These concepts relied heavily on the use of a number of features selected to help with the assembly of the major componets without reliance on product-specific tooling (the so-called jigless assembly technique).

A key aspect of the methodology developed to enable jigless assembly of aerostructures is the use of features to perform as much as possible the main tasks of jigs, fixtures and tooling. This approach led to the inclusion of various assembly features in the design tool set created to help aircraft designers.

While all the efforts have been concetrated on understanding the role of tools and the way ifeatures could be selected to replace them, it has become apparent that it would be necessary to understand as well the interaction between the features and the structures where they are located. It is particularly important to understand how the features affect their parent structures static and fatigue strength.

Due to the time constraint, it is not possible to investigate in great depth every aspect of the problem. However, this study was devised to give a flavour of the potential difficulties the use of such features would pose.

2.- AIMS AND OBJECTIVES

The main aim of the study is to gain an understanding of the effects of assembly features on their parent structures. This would be achieved by modelling and analysing a number of structures with assembly features using the finite element method. A stress intensity factor will be calculated to quantify the effect of the feature on the load bearing capacity of the parent structure.

3.- MODELLING APPROACH

To carry out the study, a decision was made to select a section of the front spar used in the demonstrator as the parent structure. The spar is a primary structure on the aircraft, part of the wing box. As such the spar is an important structure. Any detrimetal effect from assembly features is likely to cause most problems on this sensitive component.

The study was carried out in two parts: the first part looked at the effect of a single feature on a section of spar and the second looked at the effect of a group of features on a section of spar similar in length to the demonstrator section.

3.1 - EFFECT OF A SINGLE FEATURE

The main hypothesis is that adding a feature to a load bearing structure will have a detrimental effect on the load-carrying capacity of that structure. It becomes important to be able to quantify the impact of the feature on the structure in order to use that feature effectively. Traditionally assembly features such as holes have acted as stress raisers. Stress intensity factors have been used to quantify the effect of such stress raisers. In this study it is proposed to define a measure similar to a stress intensity factor based on the Von Mises stress, σ_{vm}.

According to Young[1], a ductile metal is considered to have failed when it has suffered elastic failure. Several theories are available to determine the onset of elastic failure by comparing various stress components to the yield strength (σ_y) of the material under study:

- Maximum stress theory defines failure to have occurred when the maximum tensile stress equals the material yield strength
- Maximum Strain theory compares the maximum tensile strain to the strain that would be created by a stress equal to the yield strength
- Maximum Shear Stress theory uses the maximum shear stress and compares it to ½ the yield strength
- Constant Energy Distorsion Theory (or Von Mises Theory) defines failure when the following expression holds true:

  $$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_y^2$$

  where σ_1, σ_2 and σ_3 are principal stresses.

In general, the Von Mises theory agrees better with experimental results. The Von Mises stress can be defined by:

$$\sigma_{vm} = (1/\sqrt{2})*\sqrt{[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]}$$

A basic model of a spar section was modelled without any assembly features, subjected to a tensile load. The maximum Von Mises stress was obtained and used as a basis for comparison. Different features were then added to the basic model. The

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[1] Young, W C; "Roark's formulas for stress and strain", McGraw-Hill,

maximum Von Mises stress was also calculated for those models. A simple stress intensity factor was calculated a ratio of the maximum Von Mises stress of the model with assembly feature and that of the basic model.

The spar section was modelled using second order quadrilateral shell elements. These elements were selected because they offered a good compromise between ease of modelling and results accuracy. The choice of these elements meant that features were represented as cutouts within the spar section. Aluminium alloy 7075 was used as spar material the following properties:

Table 1 Aluminium Alloy 7075-T6 material properties([2])

Property	Value	Unit
Young's Modulus, E	72,000	MPa
Poisson's Ratio	0.33	MPa
Yield Strength	500	MPa
Ultimate Tensile Strength	570	MPa

3.2 - EFFECT OF A GROUP OF FEATURES

The second part of the study looked at the effect opf a number of features on their parent structure. A basic model was created that had no assembly features. Different features were then added to this basic model. The change in stress pattern (Von Mises) was recorded and use a mean to assess the features impact. Due to lack of time, it has not been possible to investigate aspects such as the effect of the numbero of features, the feautres positions etc…

4. - RESULTS AND DISCUSSION

The main results are presented and discussed in the following sections.

[2] Martin, J; "Materials for Engineering", Institute of Materials, 1996, p.87

4.1 - EFFECT OF A SINGLE FEATURE

4.1.1 – BASE MODEL

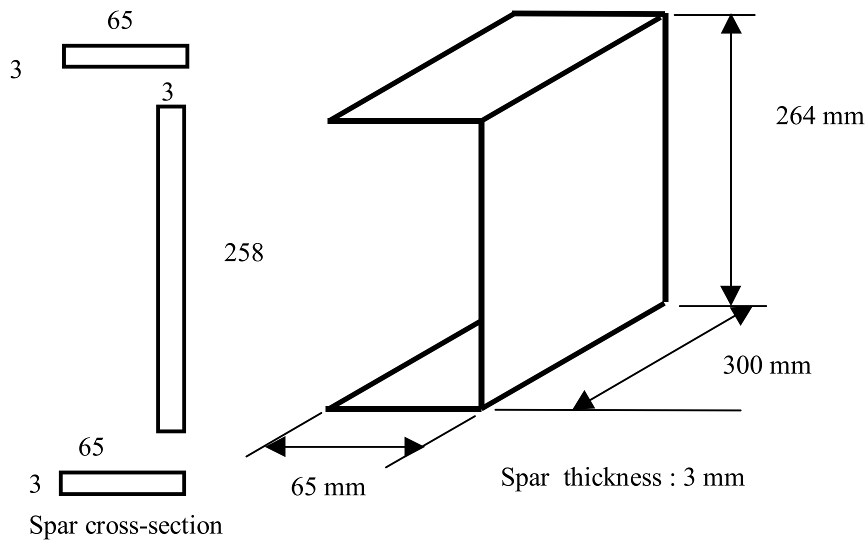


Figure 1 Base model

The dimensions of the base model are given in Figure 1. The spar thickness was chosen as 3 mm so that the spar could be modelled using quadrilateral shell elements. Using those elements rather than 3D solid elements offers the advantage of building relatively simple models. It was also envisaged to model the assembly features as cutouts added to the base model. Again, this was done for convenience, given the limited time available to carry out the study. It would have been useful to build full solid models to compare the results. For the time being the modelling approach chosen should be sufficient to given the first insight required.

The spar is loaded in tension (P=10 kN). A single node in the middle of the spar is restrained in all directions. These boundary conditions simulate a tensile test on the sapr section. The finite element mesh was created the Automeshing Generator set to Accuracy. This generated sufficient number of elements to ensure that the model would give results that were reasonably accurate. In anay case, one has to remember that the finite element method is an approximate solution whose accuracy depends on several factors.

For the cross-section shown in Figure 1, the total area is given by:

$$A = 2*(3*65) + (3*258) = \underline{1164\ mm^2}$$

The applied stress,σ, is given by:

$$\sigma = P/A = 10000/1164 = \underline{8.59\ Mpa}$$

The strain is :

$$\varepsilon = \sigma/E = 8.59/72000 = \underline{119.3\ \mu\varepsilon}$$

The total axial displacement,δL, is given by:

$$\Delta L = \varepsilon L = \underline{0.0358\ mm}$$

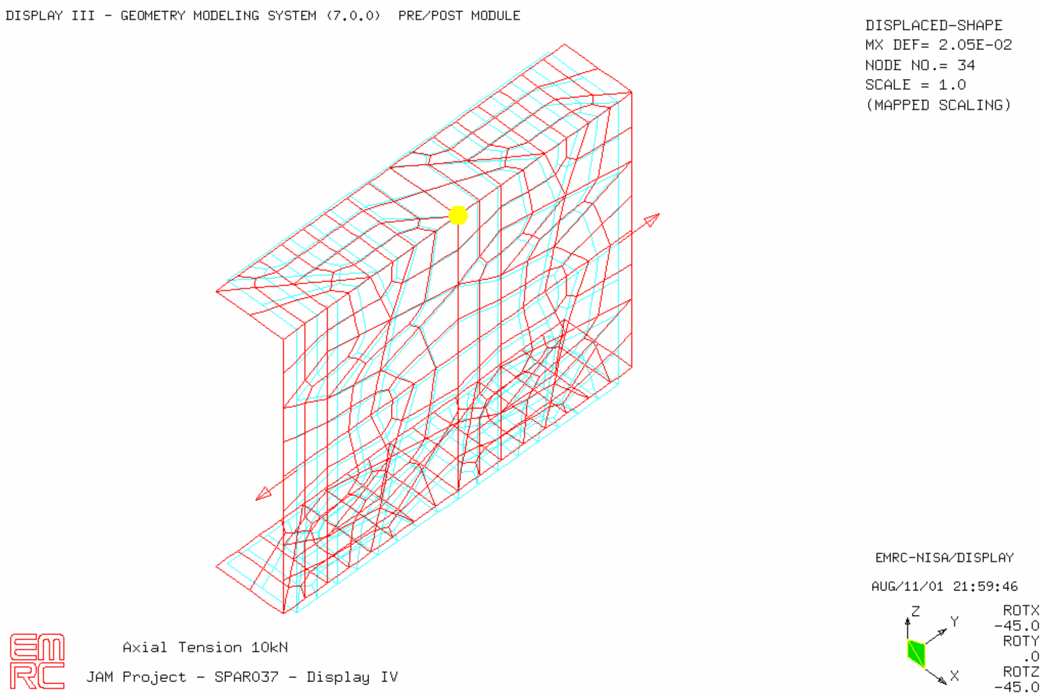


Figure 2 Deformation of base model under axial tension

Figure 2 shows that the spar extends axially under the tensile applied load.

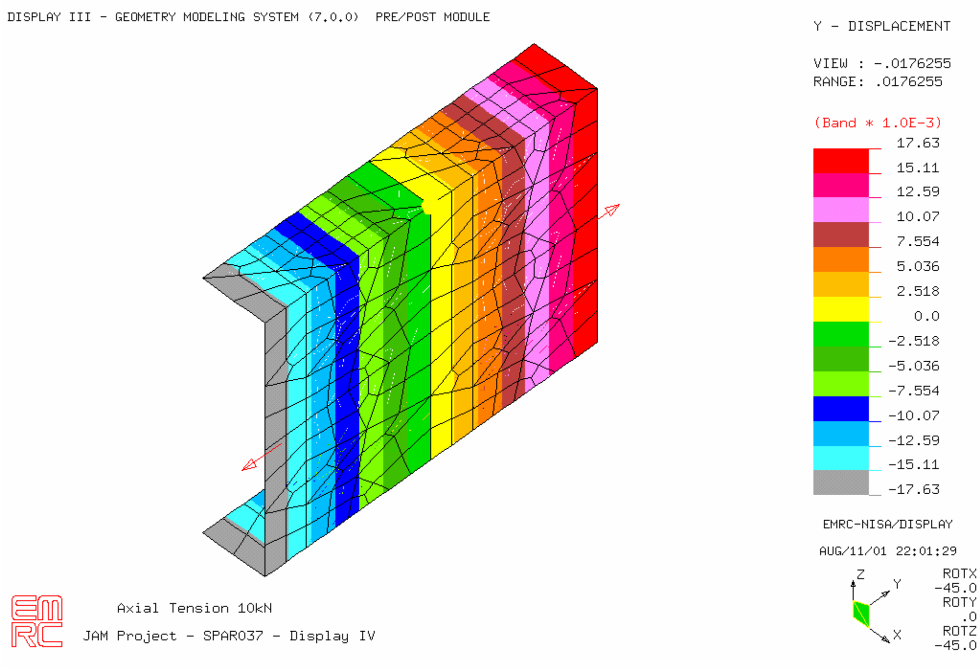


Figure 3 Axial displacement for base model

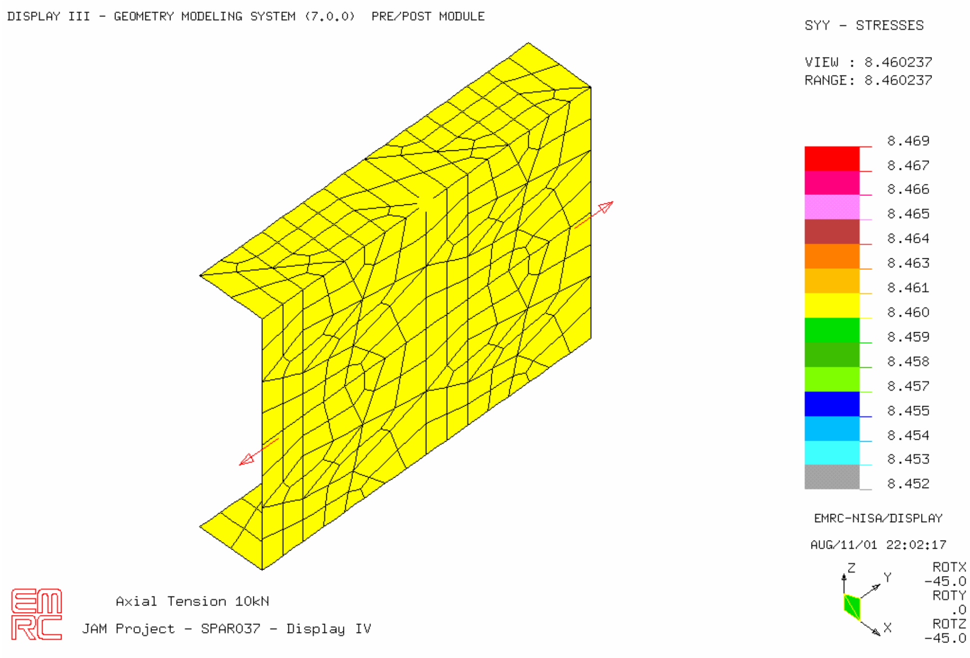


Figure 4 Axial stress contours for base model

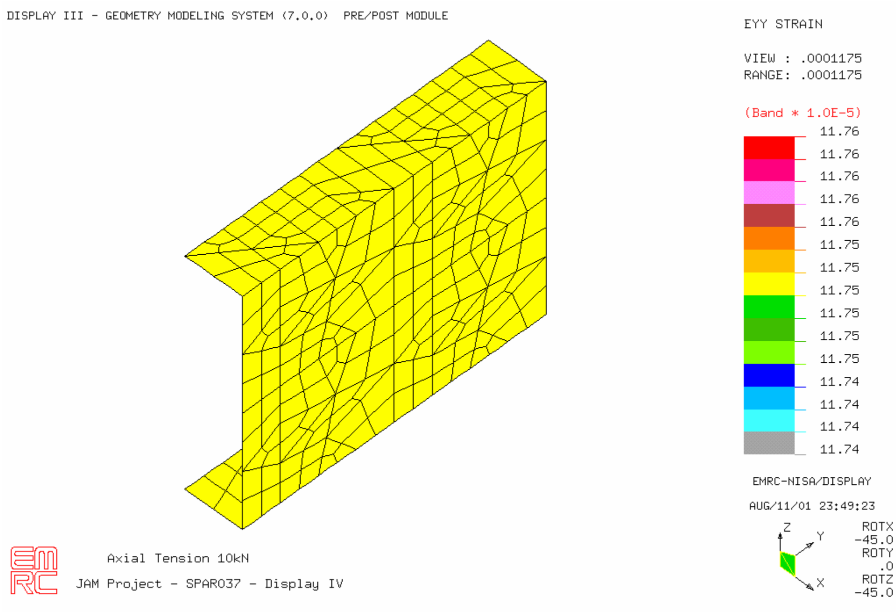


Figure 5 Axial strain for base model

Figure 4 shows that the spar is uniformly stressed to 8.46 MPa. From Figure 3, the total axial displacement is equal to (2*0.0176=) 0.0352 mm. The total axial strain predicted by the FE model is 117.5 με (Figure 5). The maximum Von Mises stress is 8.46 MPa. All the results are summarised in the following table, comparing the FE predictions with those using the Strength of Materials method.

Table 2 Base model results summary

	Strength of Materials	Finite Element Method	Percentage Difference
Axial Displacement (mm)	0.0358	0.0352	1.70%
Axial Stress (N/mm^2)	8.59	8.46	1.54%
Axial Strain (με)	119.3	117.5	1.53%

The summary in Table 2 shows that there is a very good agreement between the two methods. This gives a high degree of confidence in the base model.

4.1.2 – "T" SLOT MODEL

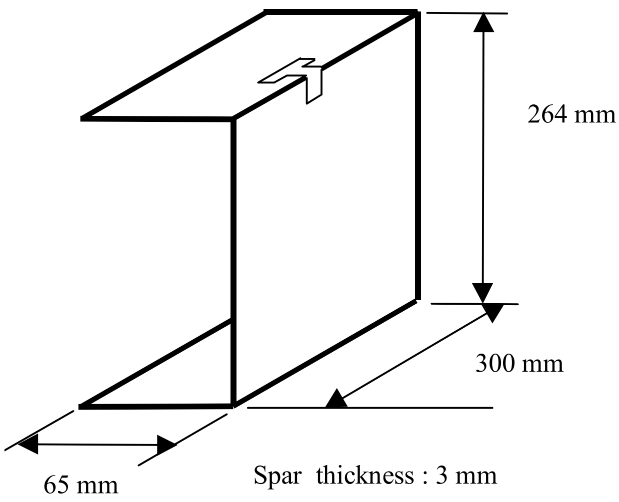


Figure 6 "T" slot model

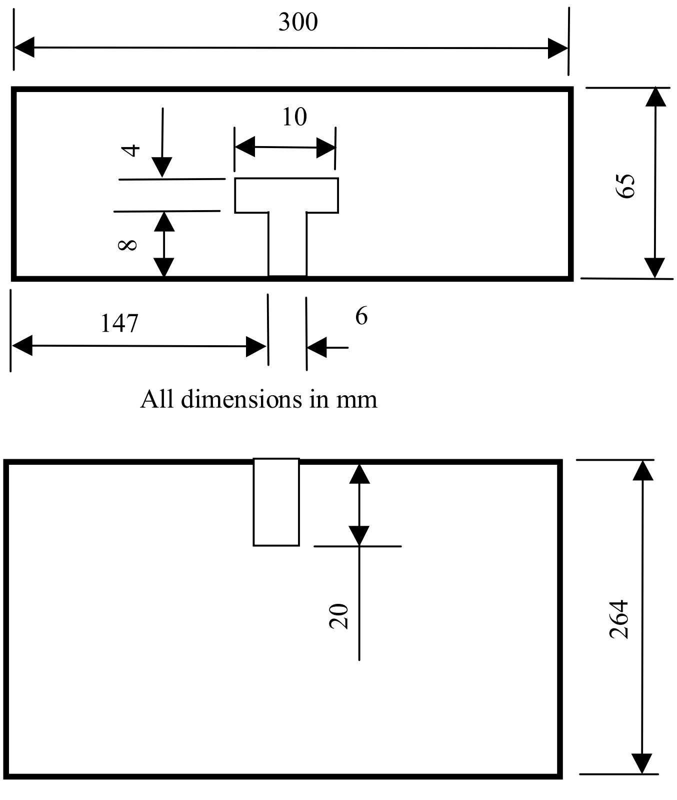


Figure 7 "T" slot dimensions

The " T"-slot model is based on the base model. A "T" shaped cutout was modelled into the top surface of the spar. The feature ended in the upper part of the front face of the spar.

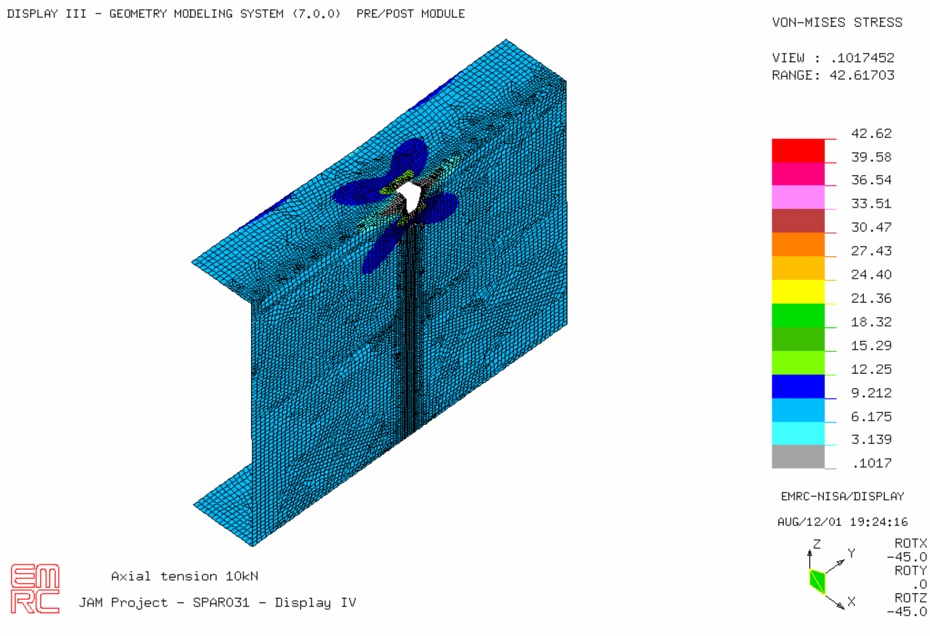


Figure 8 Von Mises stress contours for "T" slot model

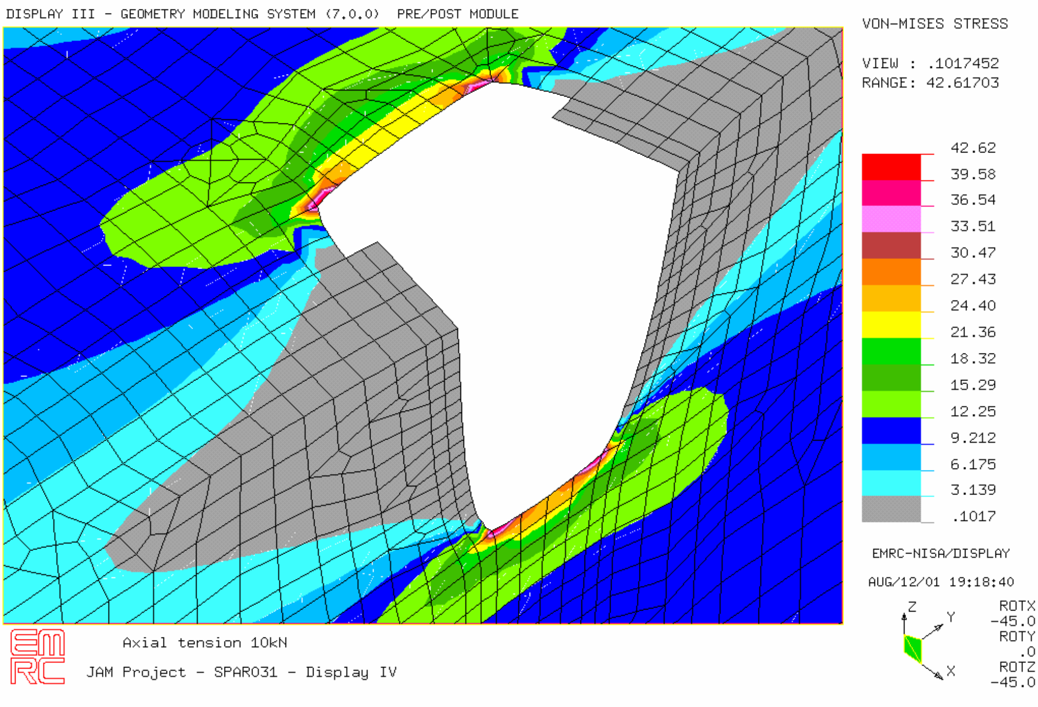


Figure 9 Von Mises stress distribution around "T" slot

The Von Mises stress contours for the "T" slot model is shown in Figure 8. The maximum value is 42.62 MPa. There is a stress "hot spot" around the feature itself, as could have been expected. Figure 9 shows the stress distribution around the feature in more detail. Most of the spar has a stress value around 8.46 MPa (which is the value for the base model). One can also notice that the main corners of the "T" slot have high stress values. The stress intensity factor is 5.04.

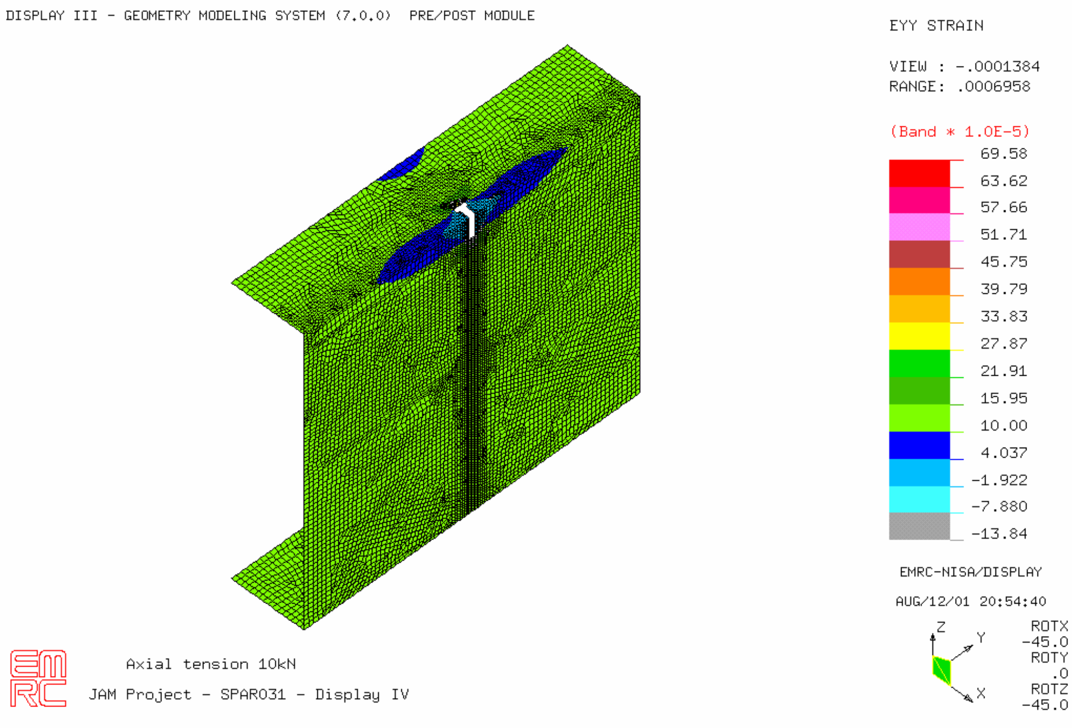


Figure 10 Strain contours for "T" slot model

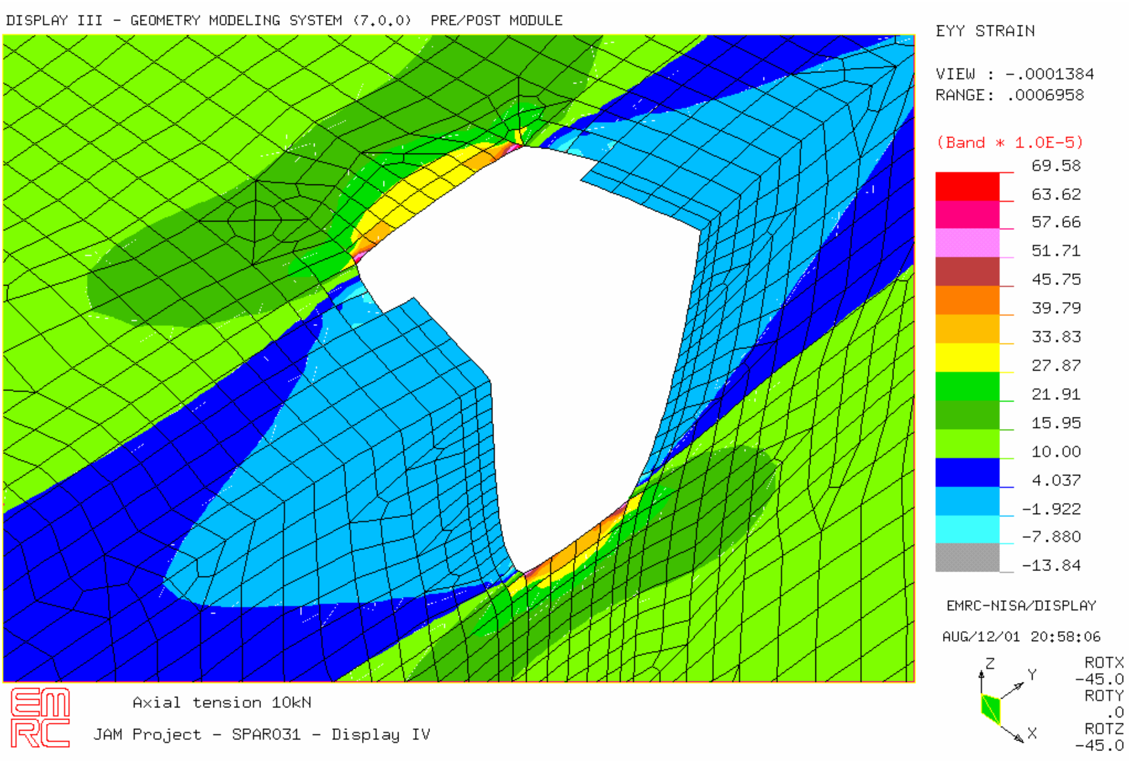


Figure 11 Axial strain around "T" slot

The axial strain contours (Figure 10 and Figure 11) also show that away from the feature, the value of axial strain is around 117.5με , like the base model. The maximum strain is 685.8 με.

4.1.3 - SQUARE TIP SLOT

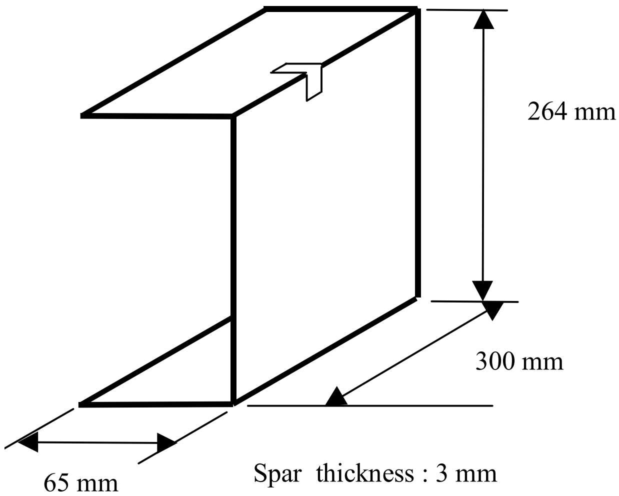


Figure 12 Square tipslot model

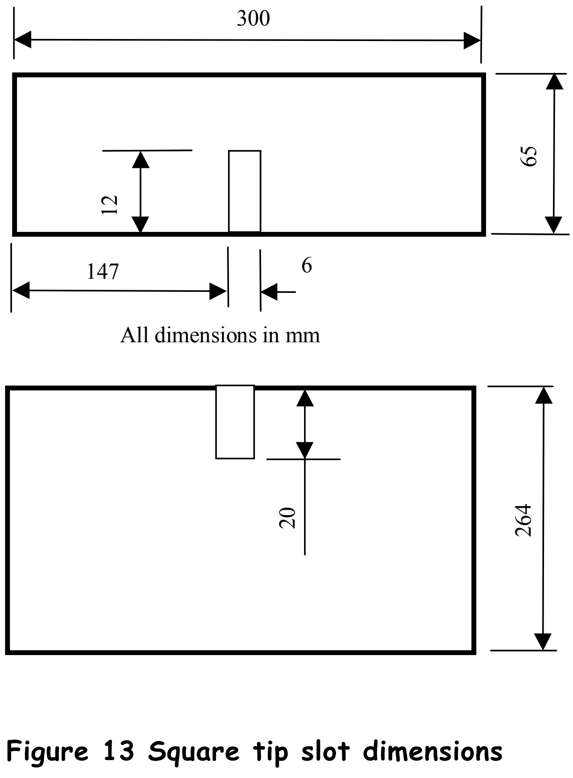


Figure 13 Square tip slot dimensions

The square tip slot model model is based on the "T" slot model dimensions. All the relevant dimensions are shown in Figure 12 and Figure 13.

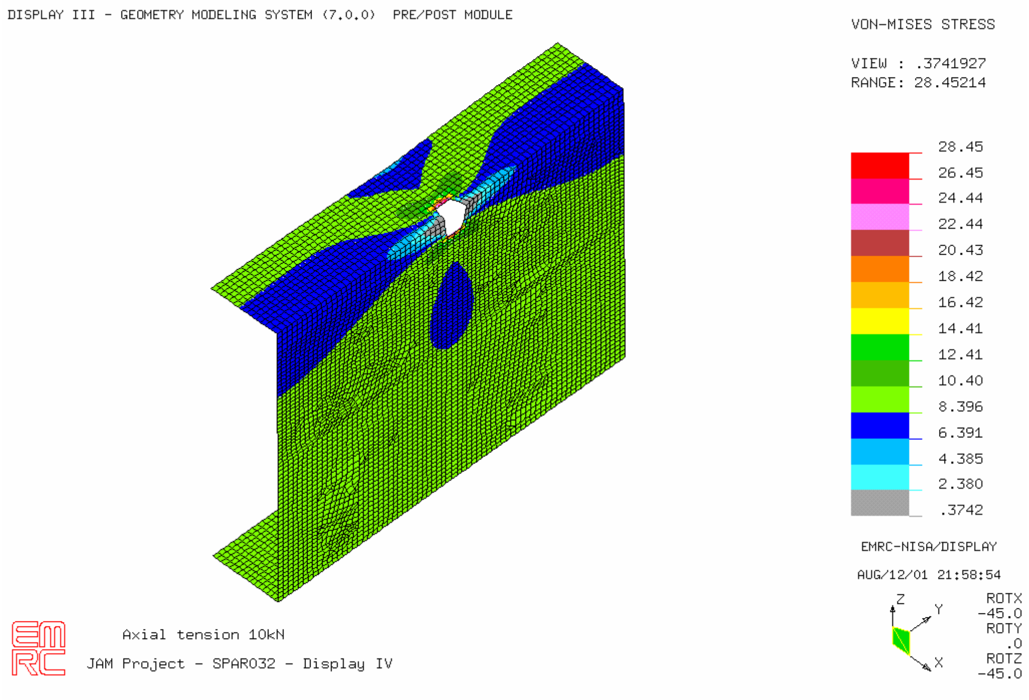


Figure 14 Von Mises Stress contours for Square tip slot model

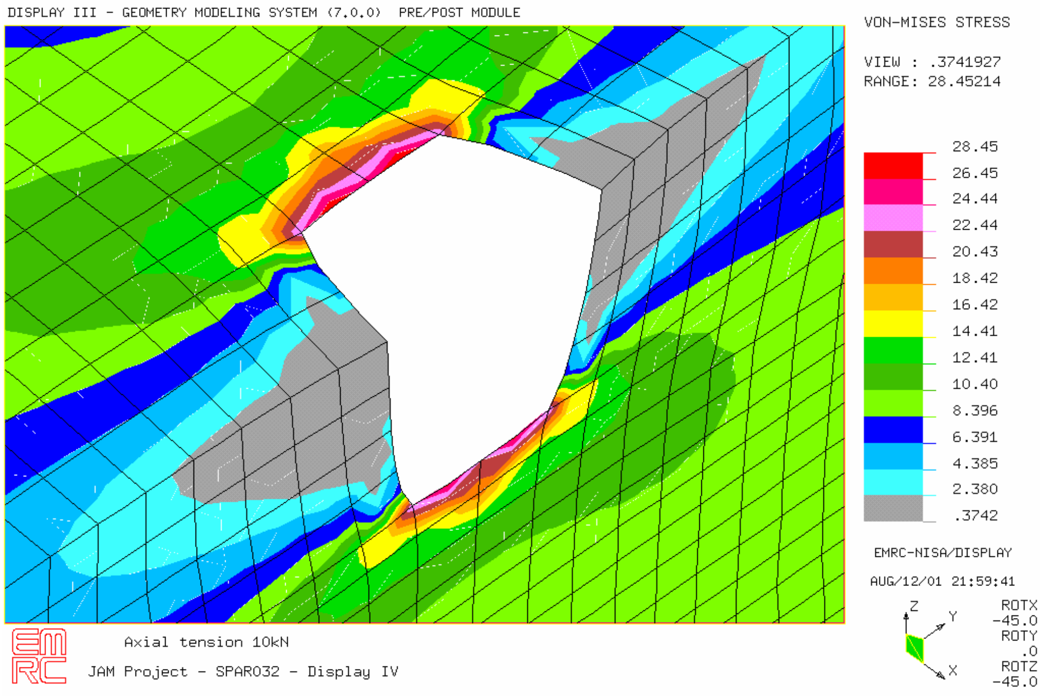


Figure 15 Von Mises stress distribution around square tip slot

Compared to the "T" slot model, the Von Mises stress contours for Square tip slot model indicate that the changes in stress due to the feature is felt further afield. However, the maximum value is only 28.45 MPa compared to 42.62 for the "T" slot feature.

4.1.4 - ROUND TIP SLOT

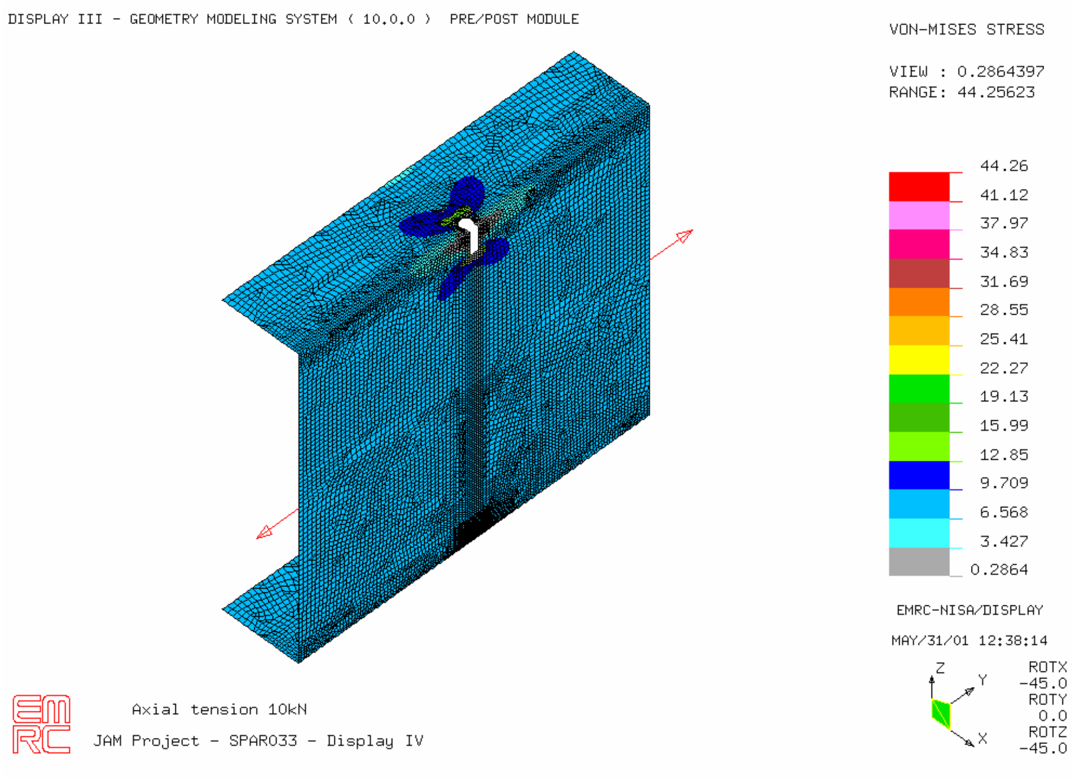


Figure 16 Von Mises stress distribution for Round Tip Slot model

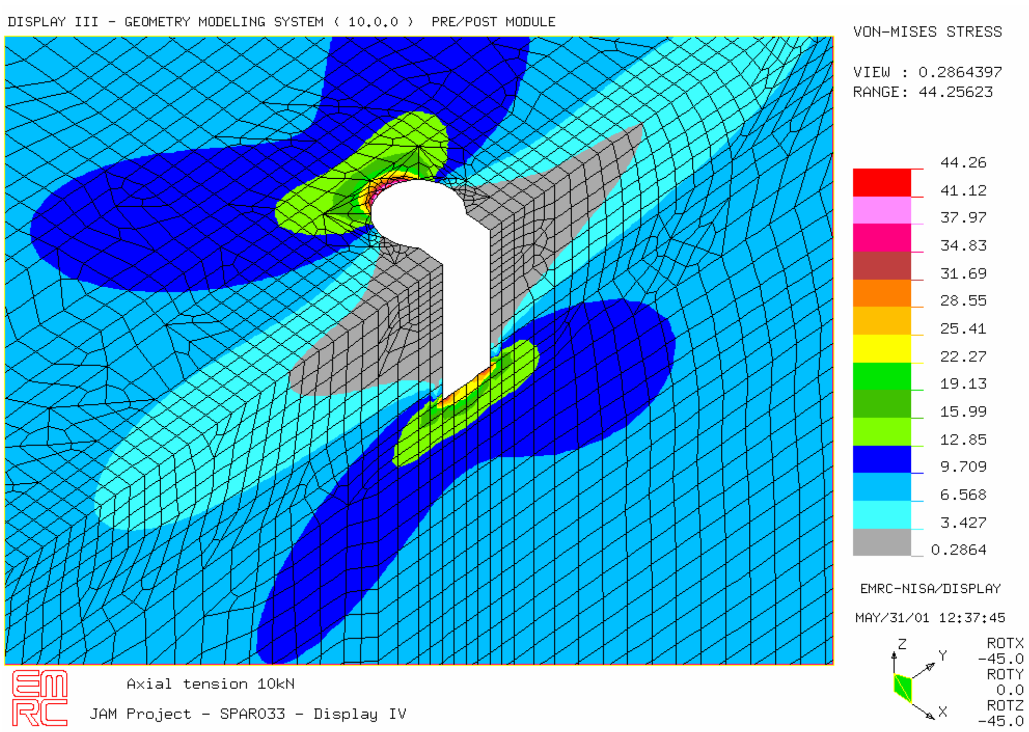


Figure 17 Von Mises stress distribution around round tip slot

Compared to the square tip slot, the effect of the round tip slot is more localised and close to the feature itself. The maximum Von Mises stres is 44.26 MPa. Thus the feature has a powerful localised effect upon the structure.

4.1.5 – SUMMARY

The main results of the first part of the study are summarised in the following table:

Table 3 Results summary

	Maximum Von Mises Stress (MPa)	**Stress intensity factor**
Base model	8.46	1.0
"T" slot model	42.62	5.04
Square tip slot model	28.45	3.36
Round tip slo model	44.25	5.23

All the features selected are variations of the slot. However, the stress intensity factors indicate that they have very different impact upon their parent structures. The most disupting appears to be the round tip slot, followed very closely by the "T" slot. Those two features had a very localised but highly disruptive effect on the Von Mises stress distribution. The square tip slot was less intense in its effect but it was felt further a field.

This part of the study has been very useful in giving an insight into the effect of assembly features on their parent structures.

4.2 - EFFECT OF A GROUP OF FEATURES

This part of the study investigated the effect of a group of feature on their parent structure. A base model of the spar has been constructed and loaded in bending. A stress intensity ratio similar to that calculated in the first study is used to quantify the effect of the group of features.

4.2.1 – BASE MODEL

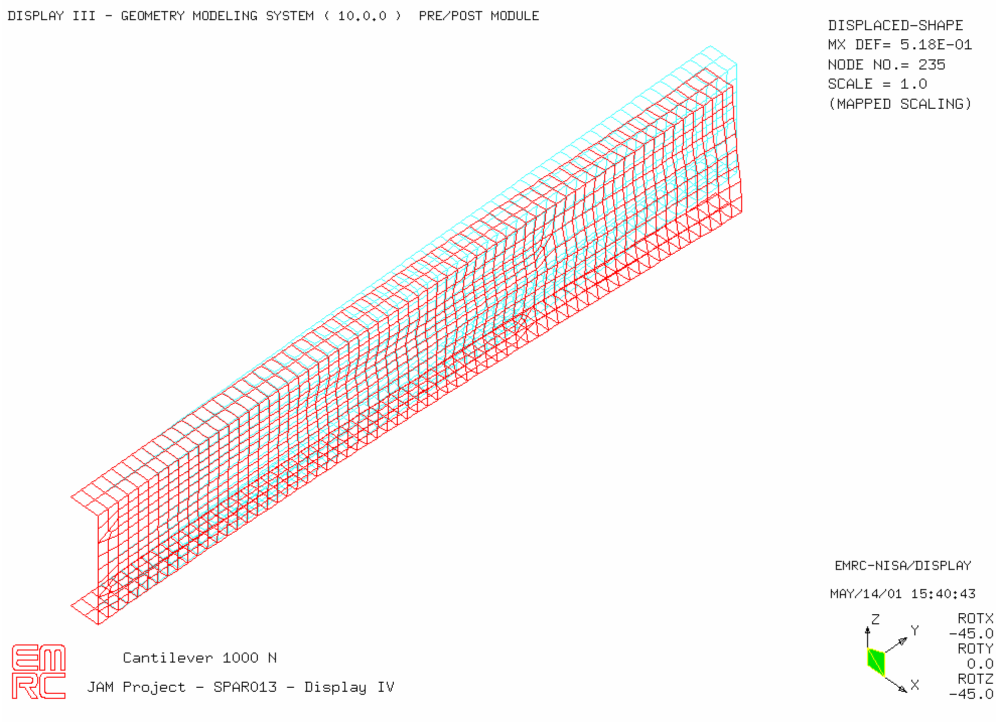


Figure 18 Deformation of the spar section under bending

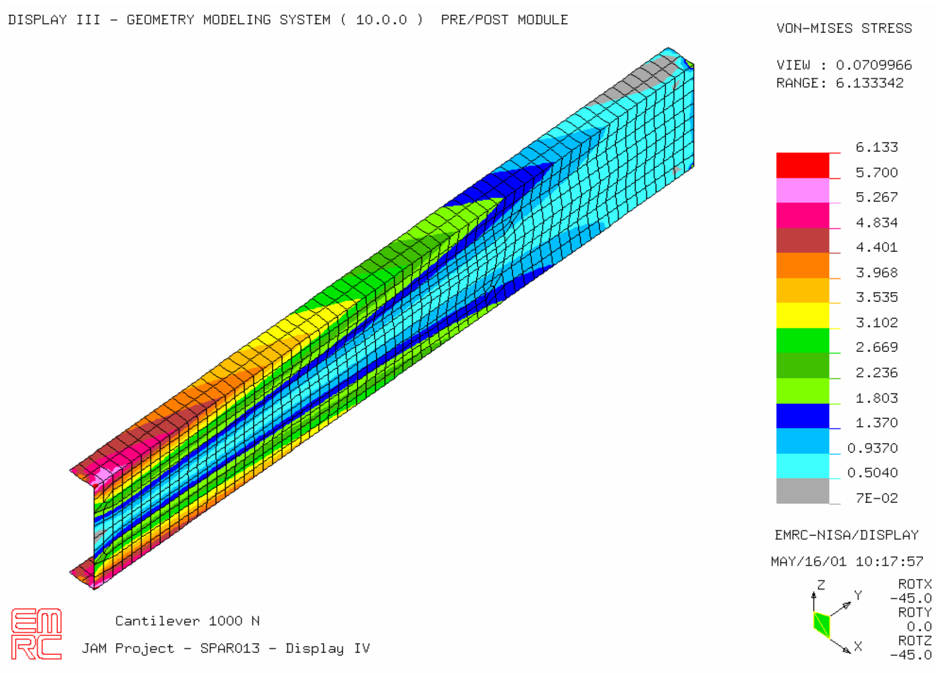


Figure 19 Von mises stress contours for base model

The basic model does not have any cutouts as in the real spar. The maximum Von Mises stress is 6.13 MPa. This occurs at the build-in end of the spar section, which acts as a cantilever beam.

4.2.2 – BASIC MODEL WITH CUTOUTS

In order to look at realistic scenarios, cutouts representing the track can apertures have been added to the basic model. Their would ascertain the changes these features bring to the maximum Von Mises stress.

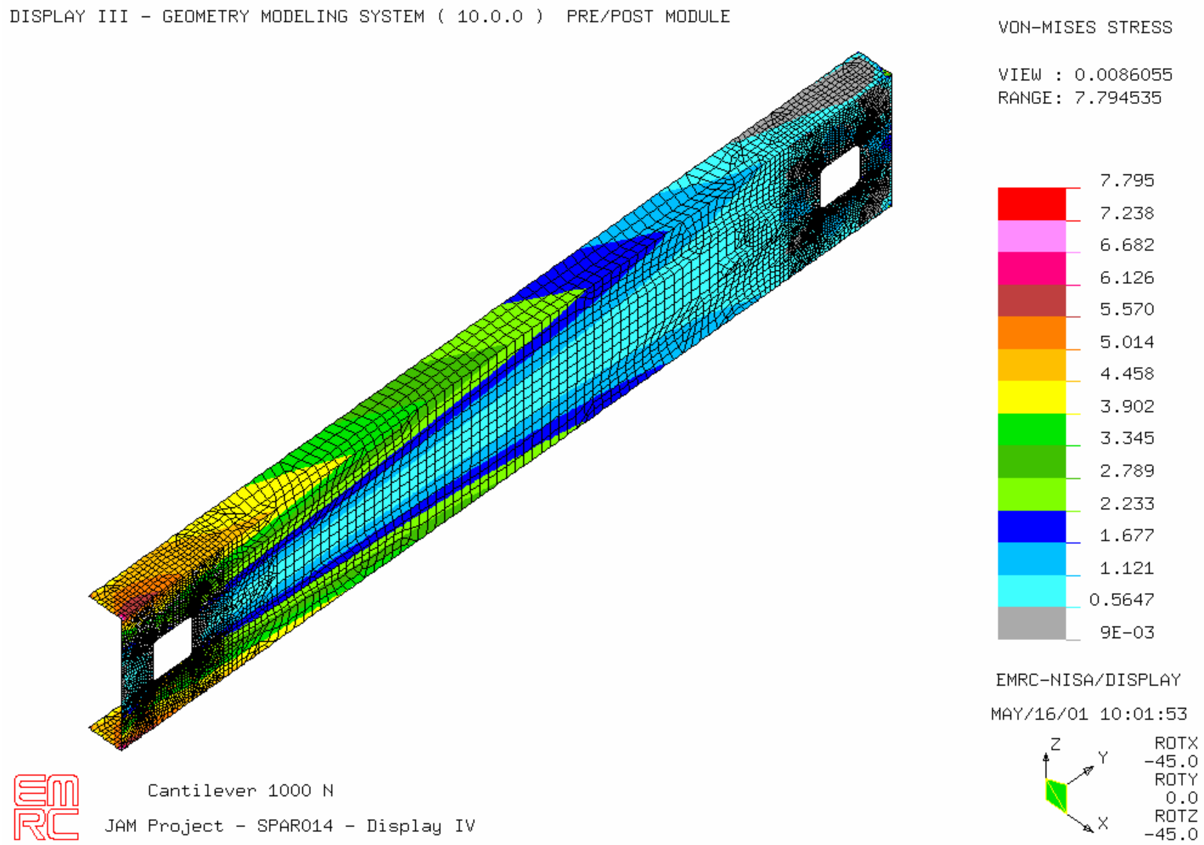


Figure 20 Von mises stress contours for base model with cutouts

Figure 20 shows that the addition of the cutouts creates a chage in the Von Mises stress contours. The maximum value goes from 6.13 to 7.95 MPa, again close to the built-in end. It is interesting to note that the build in end has a stronger effect on the structure than the cutout closest to it. The cutout further away from the built-in end does have the same high stress values.

4.2.3 – KING HOLES AND SECONDARY HOLES

This model includes a set of 4 holes around the cutouts to simulate the presence on a king hole and secondary holes in the spar section,as used in the demonstrator section. For ease of modelling both the king holes and secondary hole diameters have been set to 6.35 mm.

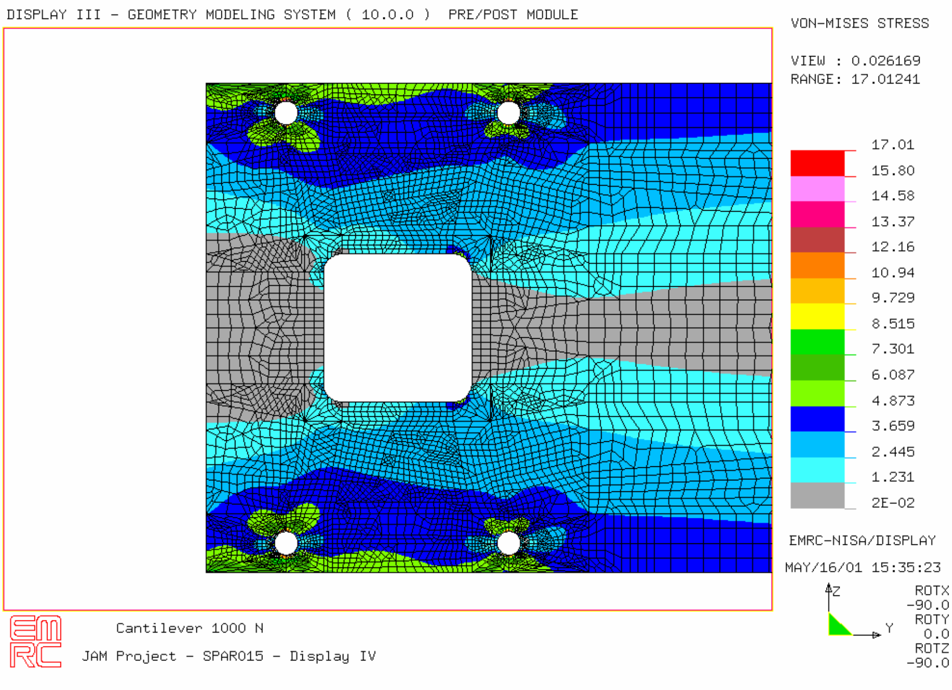


Figure 21 Von mises stess contours around king and secondary holes

Figure 21 shows that the holes acts as very strong stress raisers. On the top of the spar, the von mises stress remains around 6.09 MPa whereas in the viscinity of the holes it rises very rapidly to a maximum of 17.01 MPa. The stress pattern around the holes appears symmetrical about the spar center line.

4.2.4 – SPAR WITH GROOVE-HOLE AND SLOT

This model has been constructed from the basic spar model with cutouts. Around each cutout, two holes have been created on the top part of the spar and two slots have been added in the bottom section. The model represent one of the concept considered in the redesign of the fixed leading edge section. The groove has been simulated by reducing the thickness of the shell elements in around the cutouts.

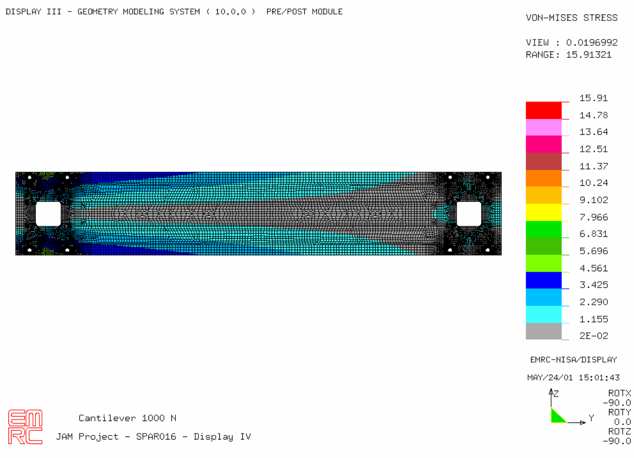


Figure 22 Von Mises stress contours for spar with groove, hole and slot

At first glance the presence of the various features does not appear to have changed the stress distribution along the spar (Figure 22).

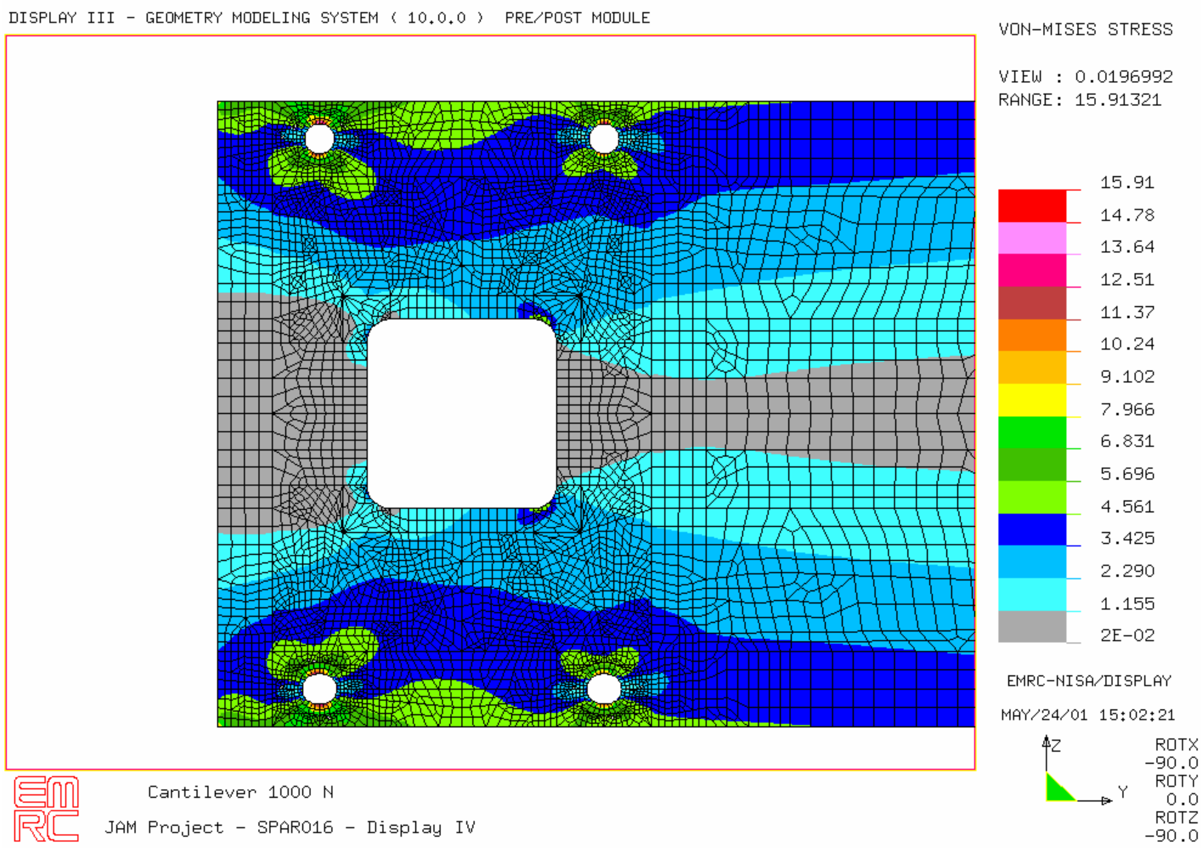


Figure 23 Von Mises Stress around groove, holes and slots

A closer look at the built-in end of the spar shows that the top part is still aroung 6 MPa (green colours). However the stresses peak around the holes and slots.

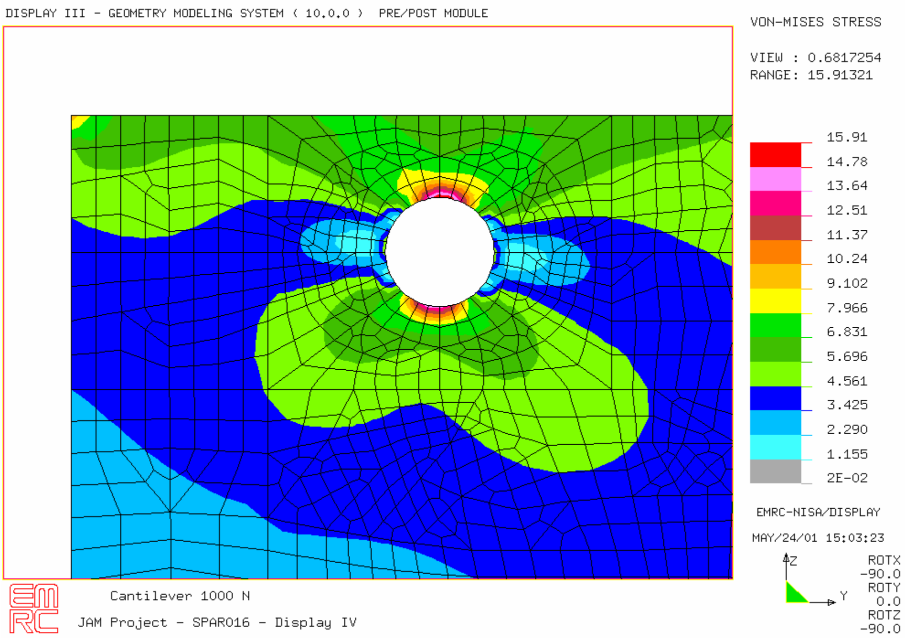


Figure 24 Von Mises stress contours around hole

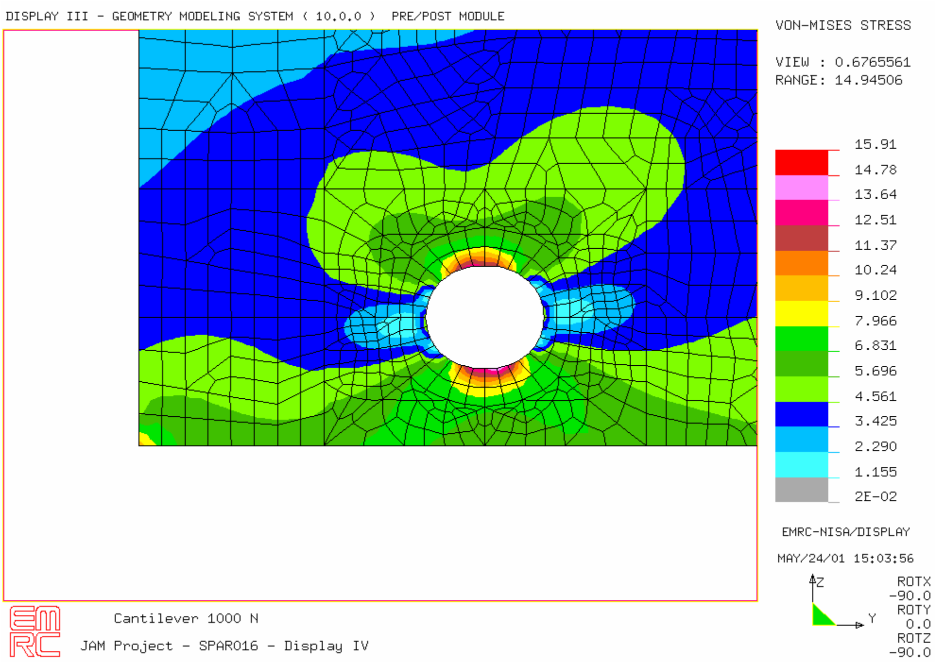


Figure 25 Von Mises stress contours around slot

The maximum stress value arounf the hole is 15.91 MPa (Figure 24) whereas the same value around the slot is 14.95 MPa (Figure 25). The slot has been constructed from 2 holes, 6.35 mm diameter, whose centres are 1 mm apart. The slot appears to be a lower stress raiser than the holes. However the combination of groove-hole and slot raises the maximum Von Mises stress to only 15.91 MPa compared to the King Hole-Secondary Holes combinations. The groove does not appear to have affected the stress distribution very much.

As the groove was only 1 mm deep, two models were made to check further its effect on the maximum von mises stress. Using the same geometry as for the first model, the automesher was set to speed rather than accuracy. This provided a coarser mesh that could be analysed very quickly compared to the accurate model.

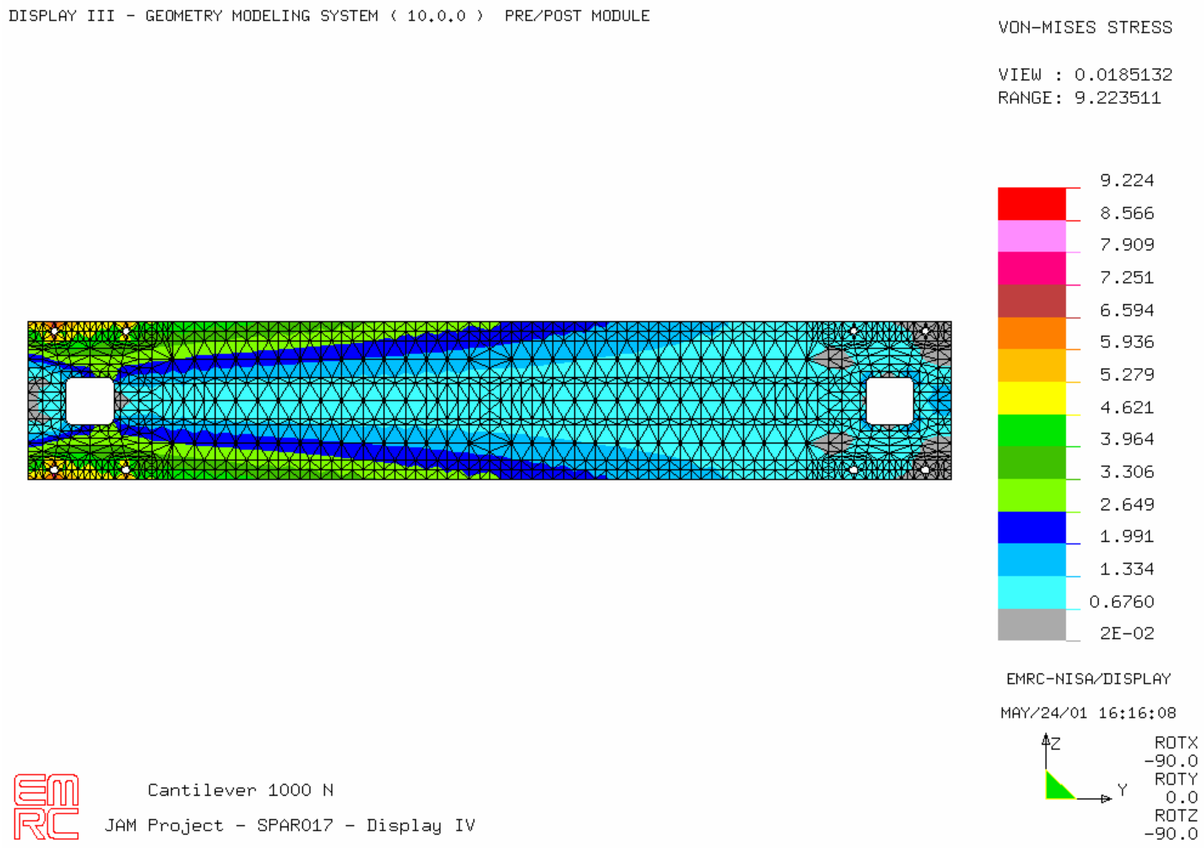


Figure 26 Von mises stress contours for speed model

The results for a 1mm groove is shown in Figure 26 and can be compared to the accurate model values. The maximum Von Mises stress is now 9.22 MPa (compared to 15.91 MPa). However the stress distribution is very similar to the more accurate model. When the groove for the speed model is set to 5 mm, the maximum Von Mises stress goes up to 13.01 MPa as shown in the following picture. This shows very briefly that the groove depth does affect the maximum Von Mises stress: the deeper the grouve, the higher the effect. However the basic stress distribution stays the same.

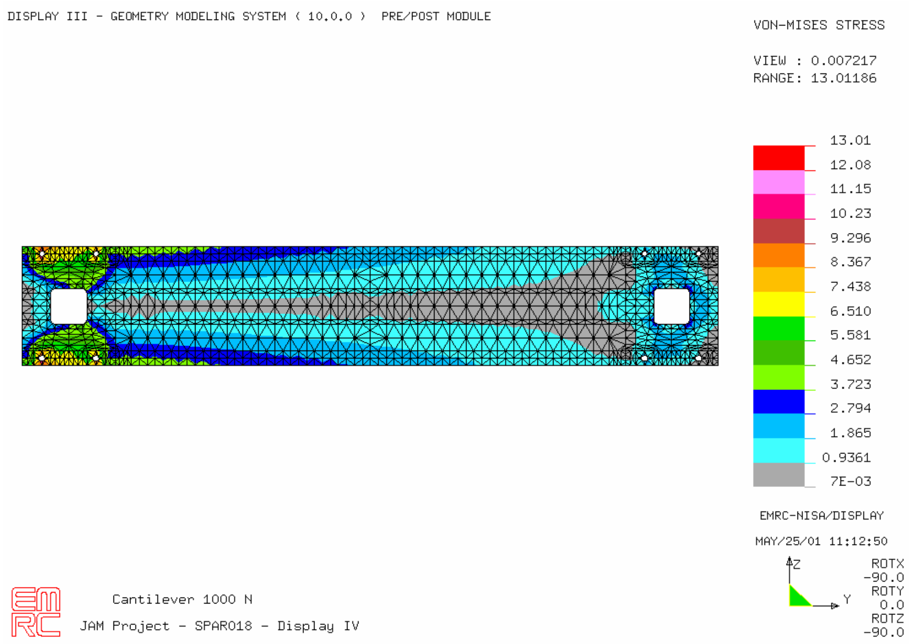


Figure 27 Von Mises stress contours for speed model with deeper groove

4.2.5 - SPAR WITH BOSS, HOLE AND SLOT

This model is similar to the spar with groove, hole and slots. In this case , the elements that were part of the groove are now set to bigger thickness values to simulate the presence of a boss, rather than a groove.

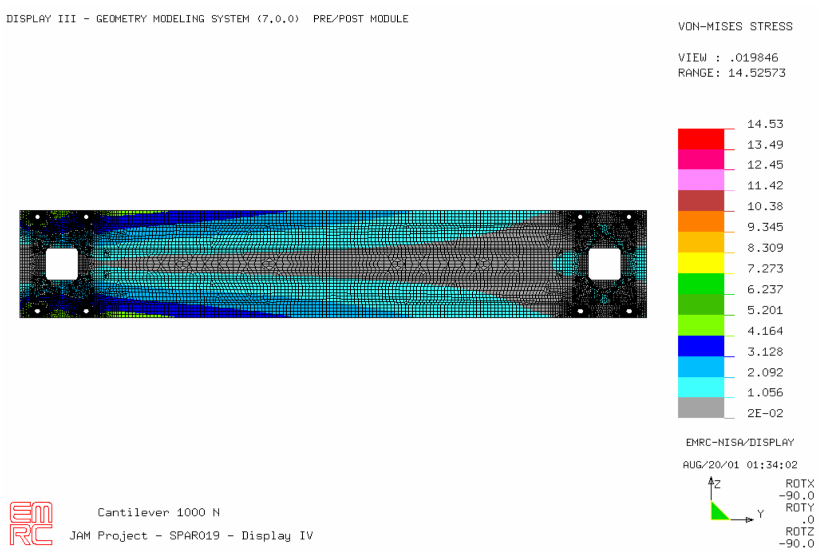


Figure 28 Von mises stres contours for spar with boss, hole and slots

The maximum von mises stress is now <u>14.53 MPa</u>.

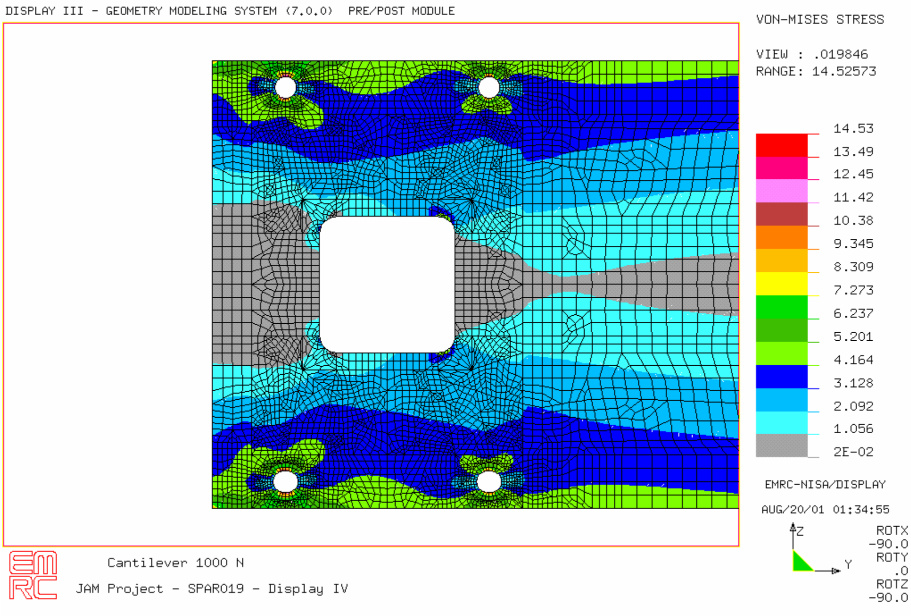


Figure 29 Von mises stress contours at built-in end

4.2.6 – SPAR WITH PAD, HOLE AND SLOT

The pad on this model is simulated by increasing the thickness of elements above the cutouts. It is like a spar with boss, hole and slot model with only half the boss size.

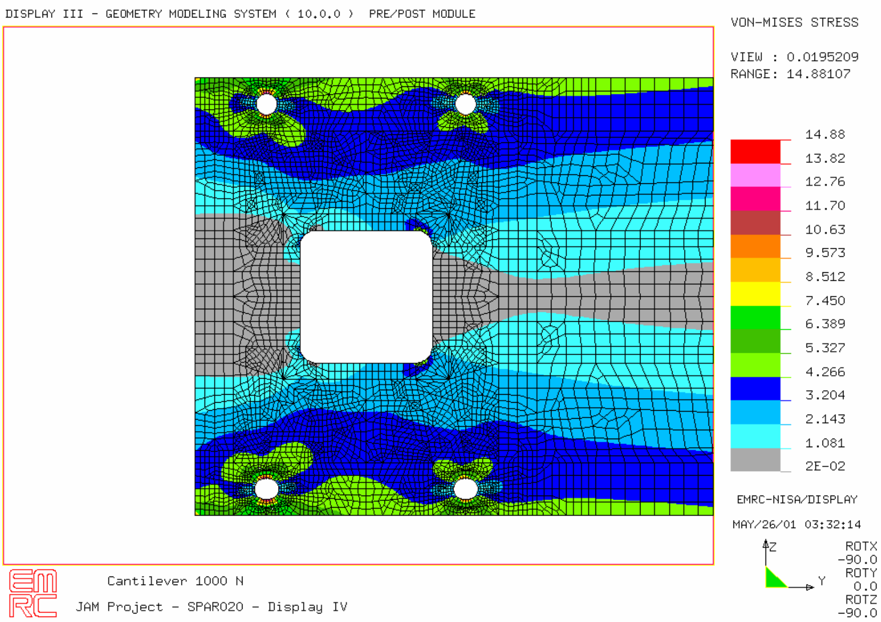


Figure 30 Von mises stress contours for spar with pad, hole and slot

The maximum von Mises stress is now 14.88 MPa.

4.2.7 – SPAR WITH EXTERNAL CONE AND SLOT

For this model, a mixture of shell elements and 3D solid elements were used. The external cones were modelled using the solid elements and the joined at their base to the basic spar model with slot. The attachement was effected by simply merging the nodes at the base of the cones. This may not be an ideal situation because the load transfer from the spar to the cones may not be as required because of the mixture of elements. A full 3D model may have provided an answer regarding the adequacy of this approach.

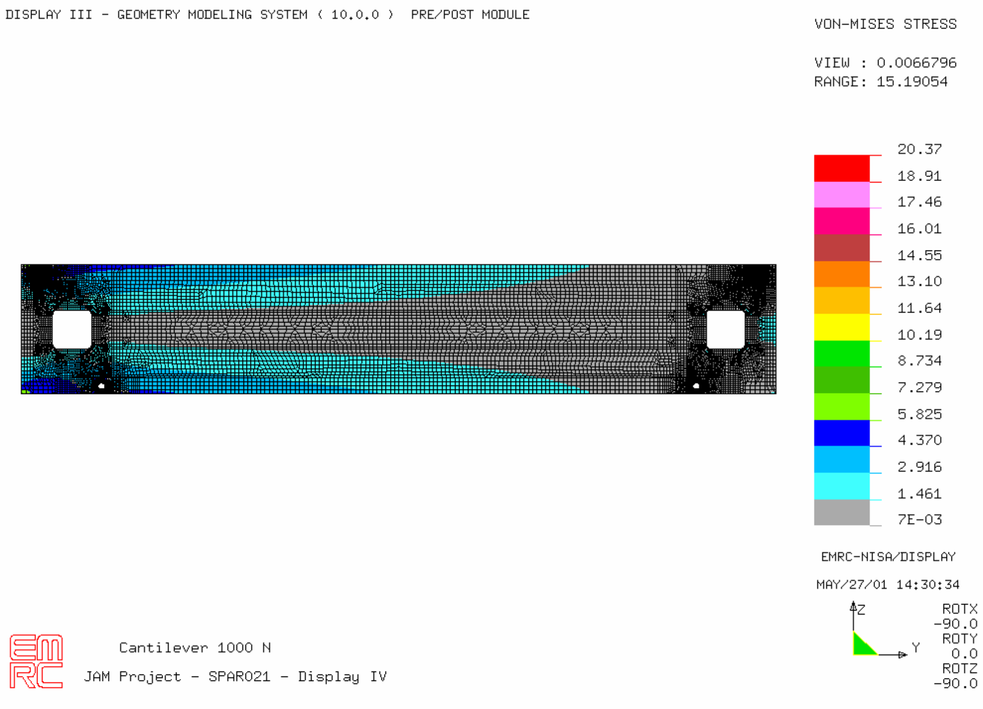


Figure 31 Von mises stress contours for spar with external cones

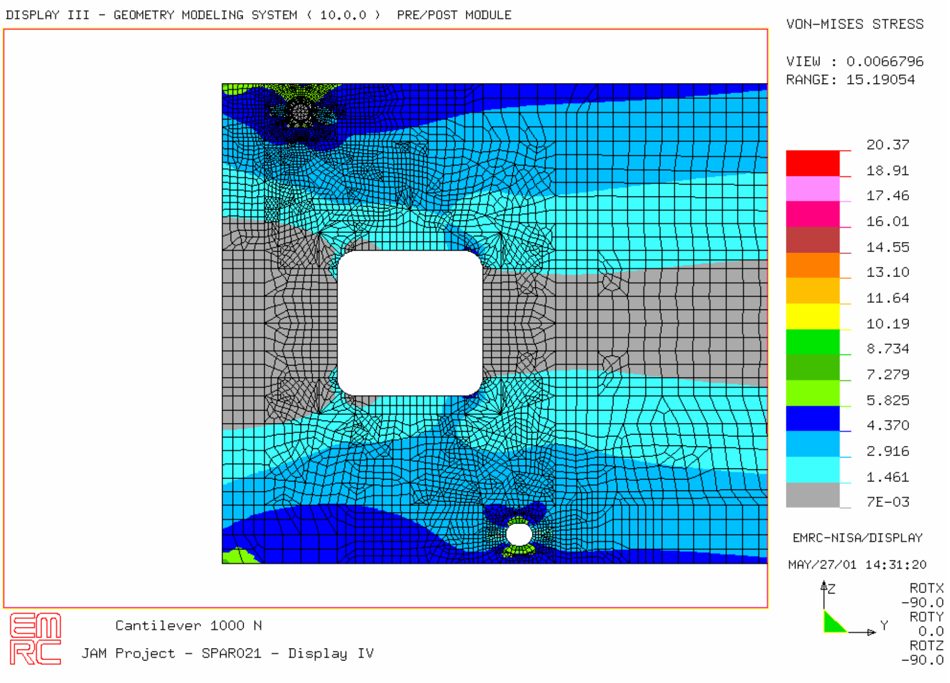


Figure 32 Von Mises stress distribution around the cone and slot

The maximum von mises stress is raised to 20.37 MPa. However the change in distribution is not greatly changed form the previous models. The high stress value occurs very locally to the cone. This is illustrated in the following pictures.

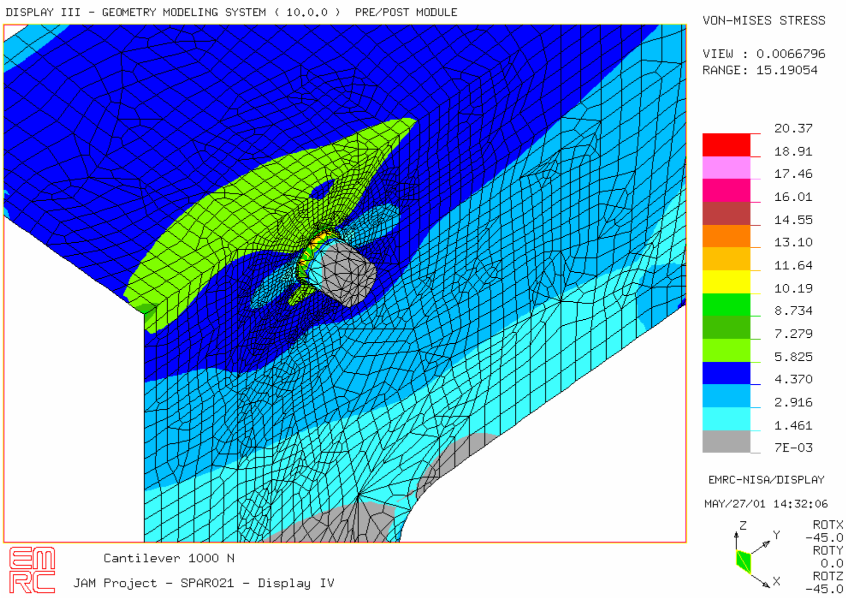


Figure 33 Von Mises stress around cone

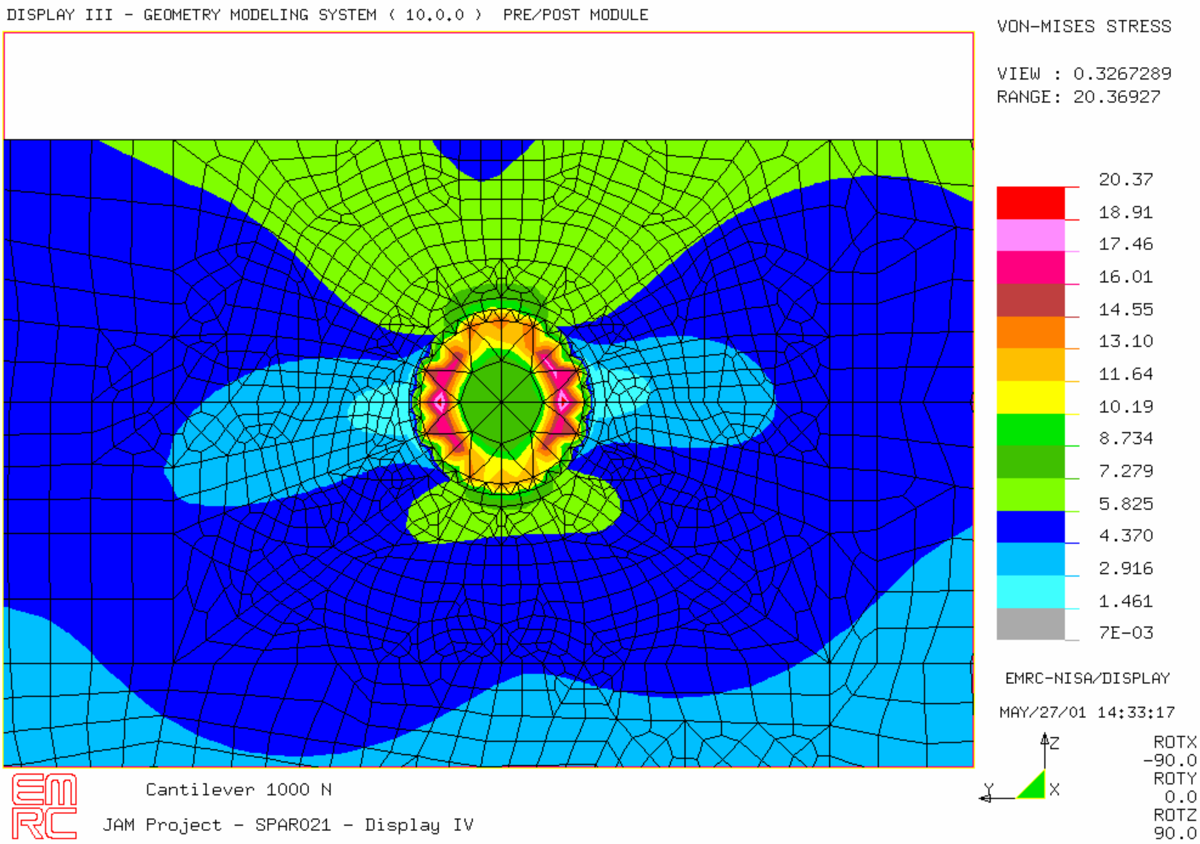


Figure 34 Von Mises stress at the back of the spar

Figure 33 and Figure 34 show the local stress concentration on the cone.

4.2.8 – SUMMARY

The main results of the second part of the study are summarised in the following table:

Table 4 Results summary

	Maximum Von Mises Stress (MPa)	**Stress intensity factor**
Base model	6.13	1.0
Spar with cutouts	7.79	1.27
Spar with King Hole and Secondary Holes	17.01	2.77
Spar with Groove, Hole and Slot	15.91	2.60
Spar with Boss, Hole and Slot	14.53	2.37
Spar with Pad, Hole and Slot	14.88	2.43
Spar with External Cone and Slot	20.37	3.32

The results summarised in the table above indicate clearly that group of features act as stress raisers in the same way that single features do on their parent structures. The worst effect is the combination of external cone and slot. The boss, hole and slot combination has the lowest effect on the spar. It can be noted that slots have a less pronounced effect than holes.

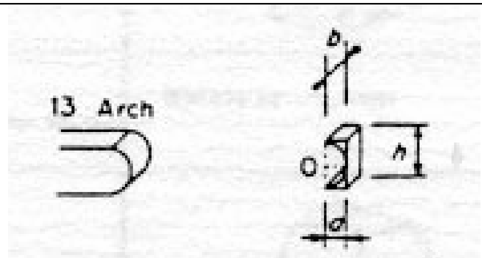
CONCLUSIONS

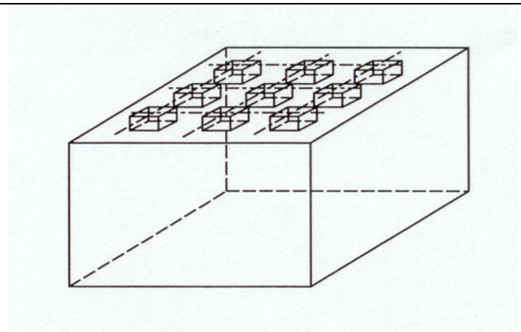
It would be unsafe to draw any general conclusions but this work points to the fact any features added to the spar will end up acting as a significant stress raiser. It is imperative that this fact in taken into account when advising designers on the use of features to facilitate jigless assembly.

Appendix B

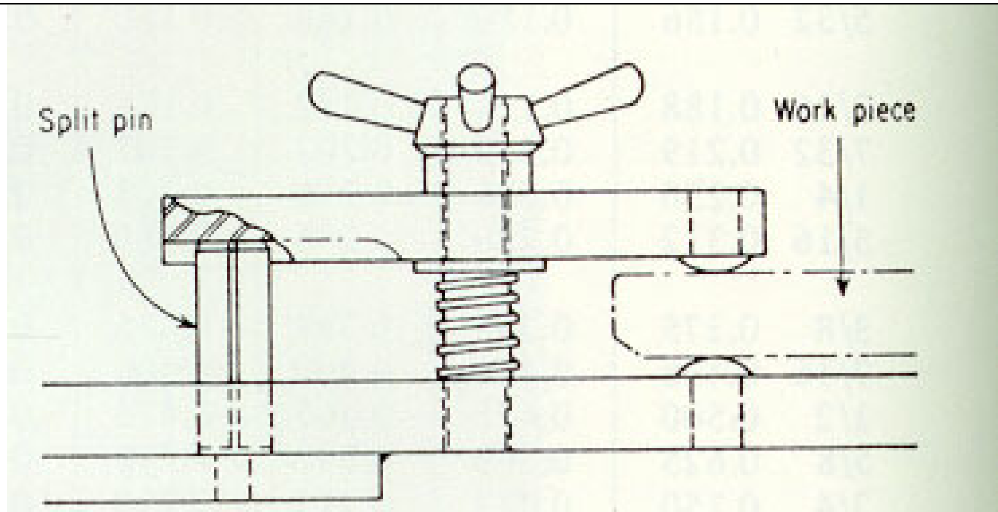
Assembly Feature Library

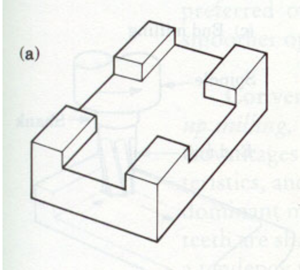
B.1 Location Features

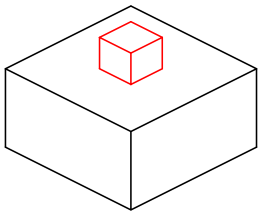
Feature:	Arch
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

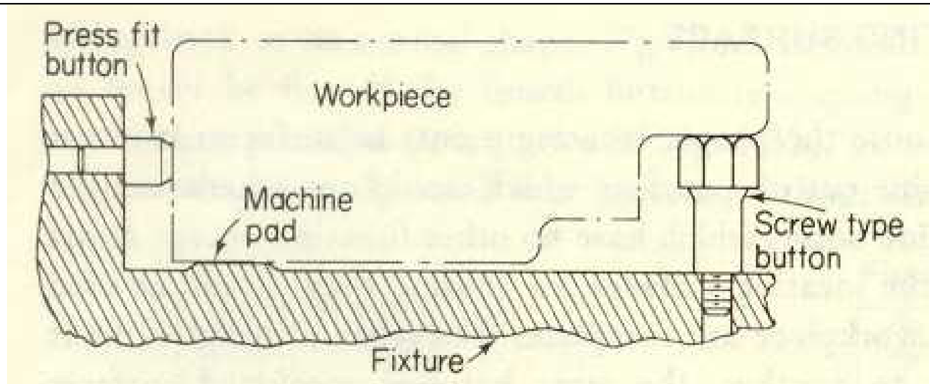
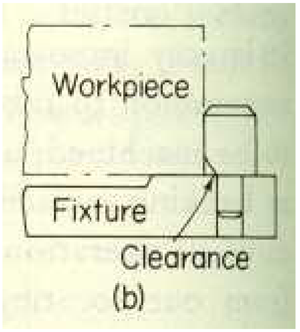
Feature:	Array Pattern
Example(s):	

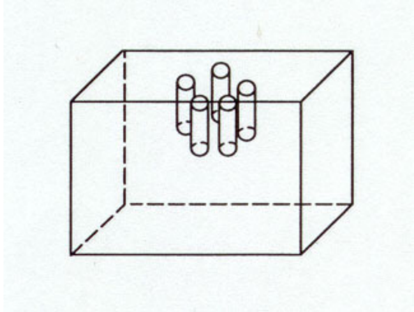
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Configuration, Dimensions
Reference:	Kyriacou, 1998

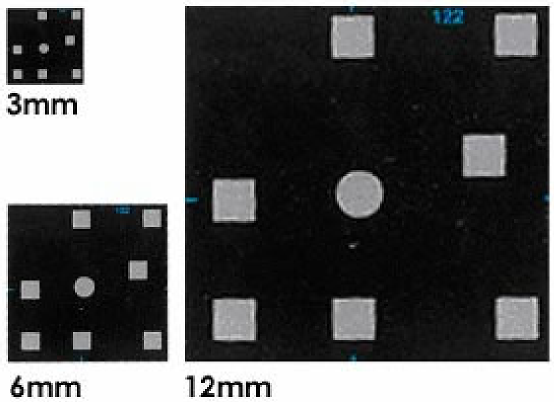
Feature:	Bead
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Parmley, 1989

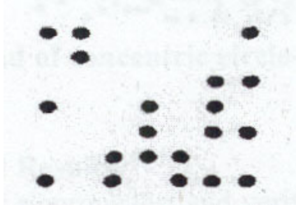
Feature:	Block
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Kalpakjian, 1995

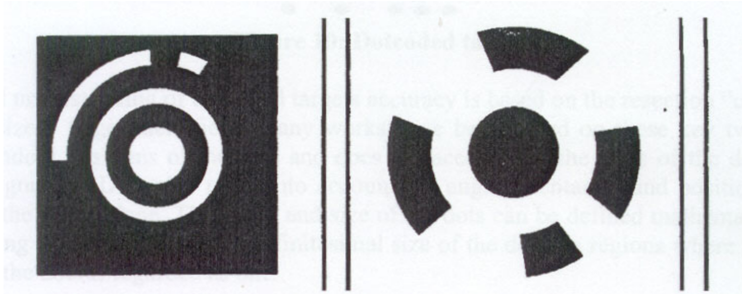
Feature:	Boss
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

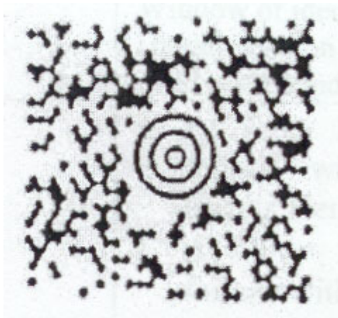
Feature:	Button
Example(s):	 
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Press Fit, Screw Type), Dimensions
Reference:	Pollack, 1976

Feature:	Circular Pattern
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Configuration, Dimensions
Reference:	Kyriacou, 1998

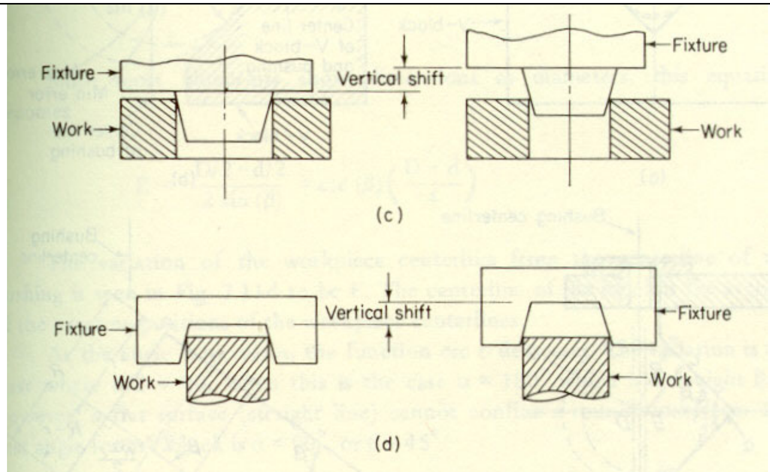
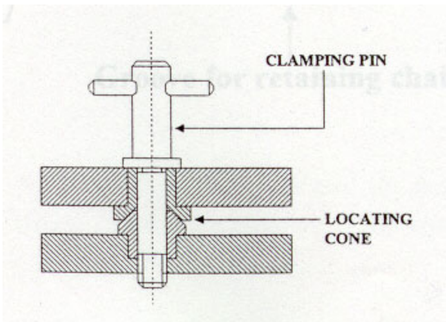
Feature:	Coded Target (Theodolite / Laser Tracker / Photogrammetry)
Example(s):	







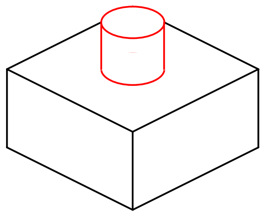
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Type, Configuration, Dimensions
Reference:	Geodetic Services – Website and Clarke et al, 2000

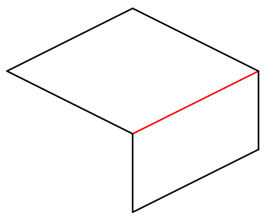
Feature:	Cone
Example(s):	 

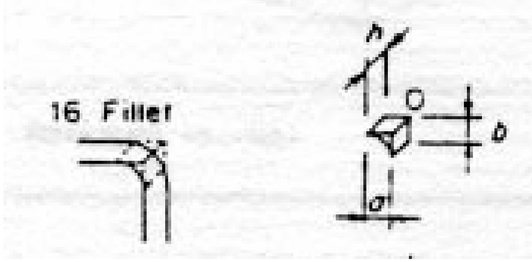
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Pollack, 1976 and Dixon, 1998

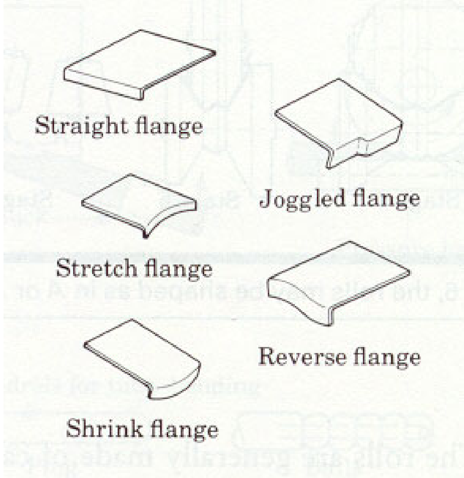
Feature:	Corner Cube Reflector (Theodolite / Laser Tracker / Photogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Configuration (Mirror Numbers: Two, Three, Four), Dimensions
Reference:	Leica Geosystems – Website

Feature:	CMM Probe Tip (Videogrammetry Hand-Held Probes)
Example(s):	   
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Type (Ball, Point), Dimensions
Reference:	Geodetic Services – Website

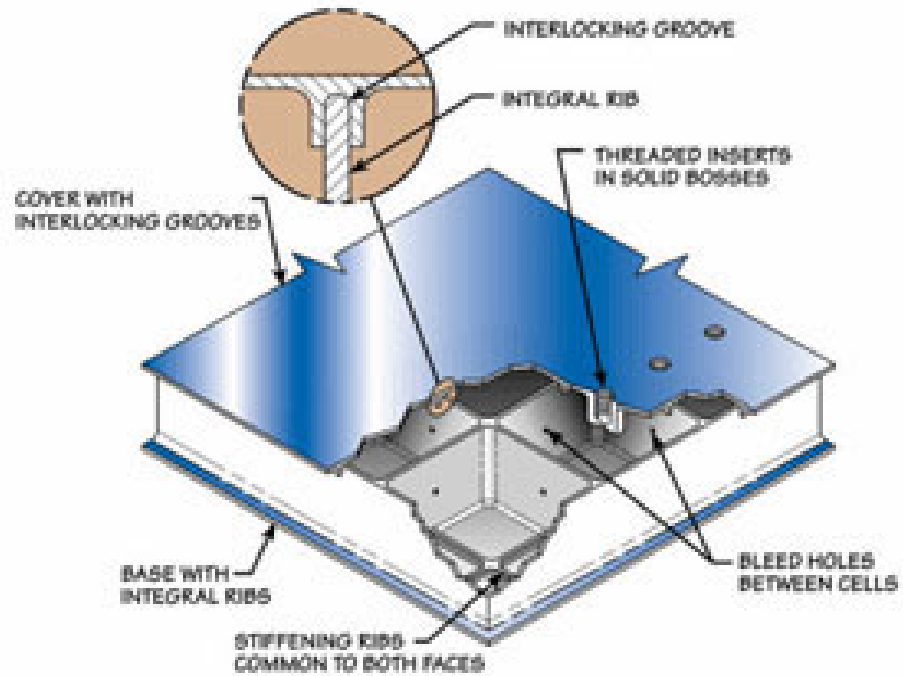
Feature:	Cylinder
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

Feature:	Edge (Theodolite / Laser Radar / Photogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

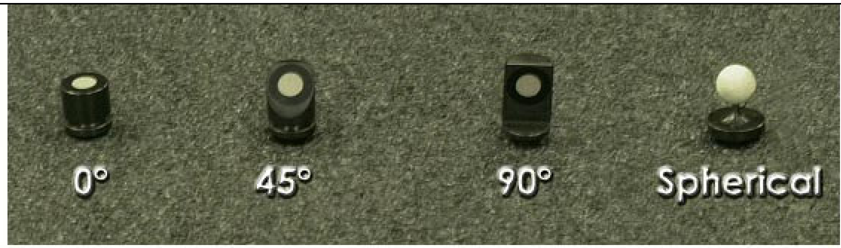
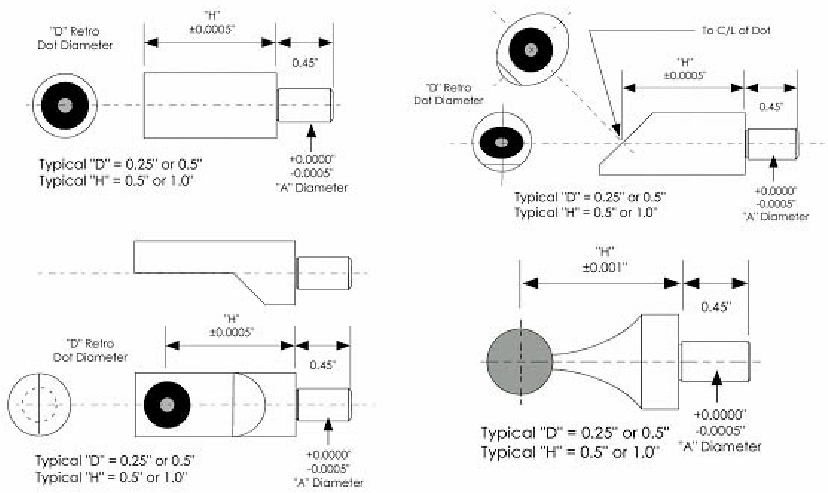
Feature:	Fillet
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

Feature:	Flange
Example(s):	

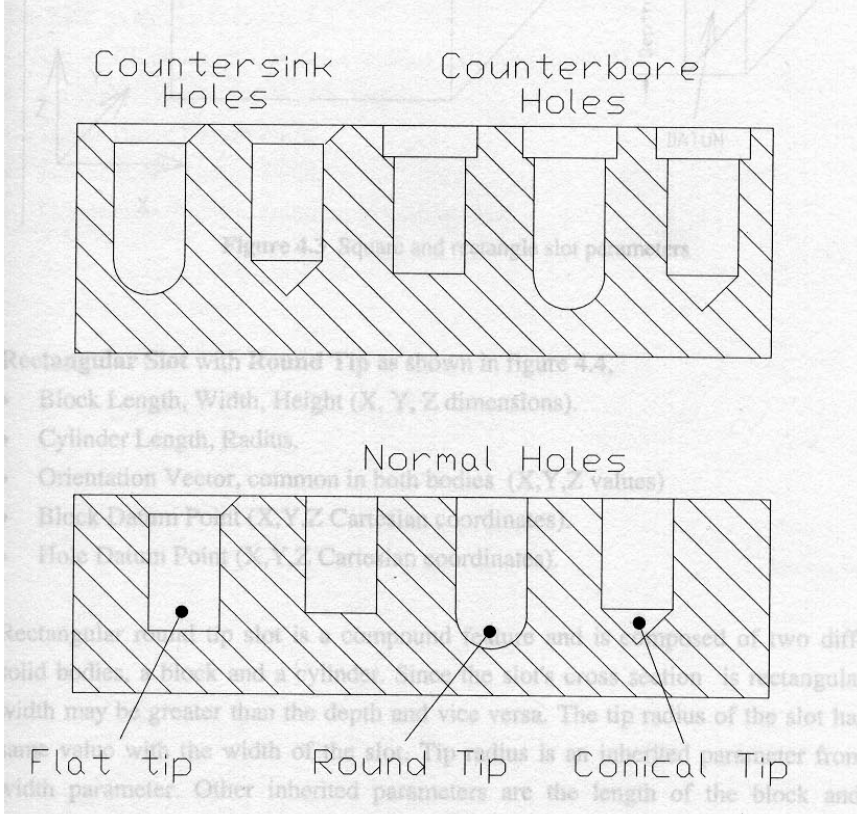
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Kalpakjian, 1995

Feature:	Groove
Example(s):	

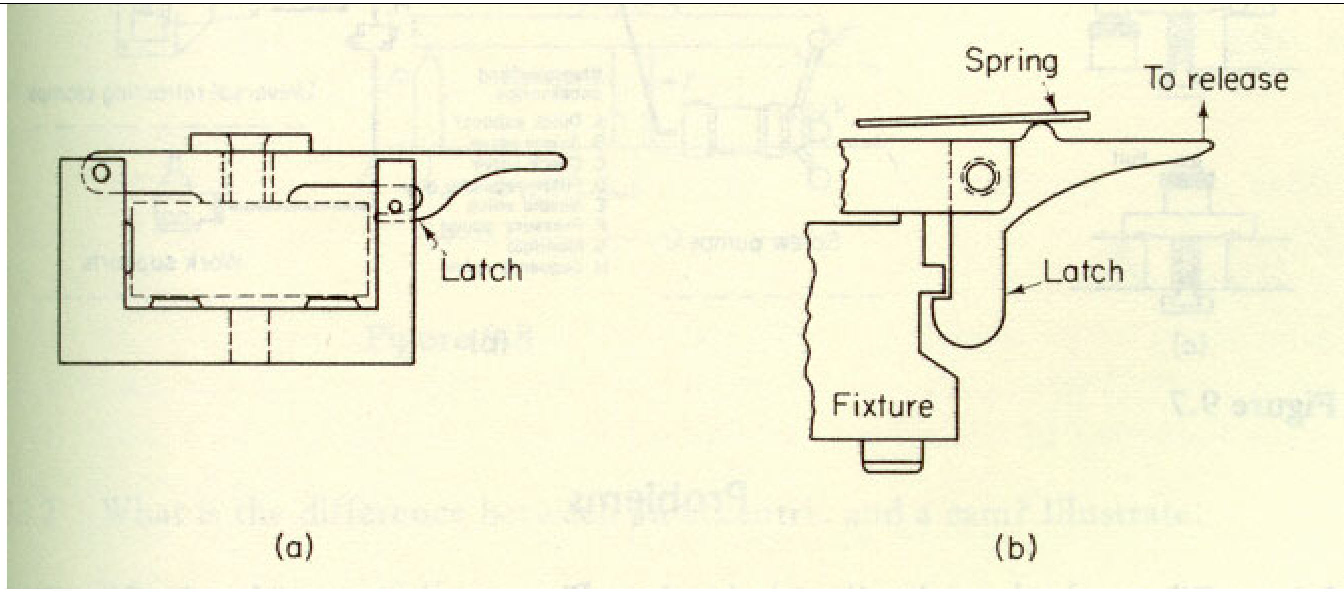
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Goodrich Aerostructures Group, 2001

Feature:	Hard-Body Tooling Target
Example(s):	 

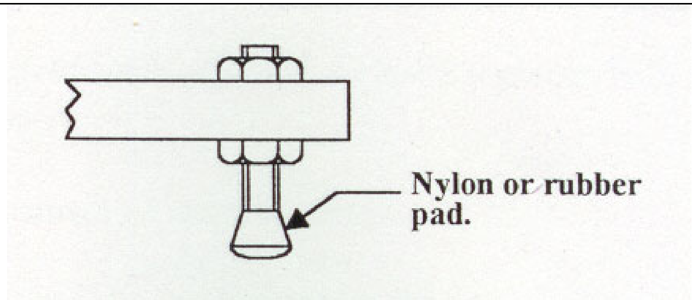
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Type (0 deg, 45 deg, 90 deg, Spherical), Dimensions
Reference:	Geodetic Services – Website

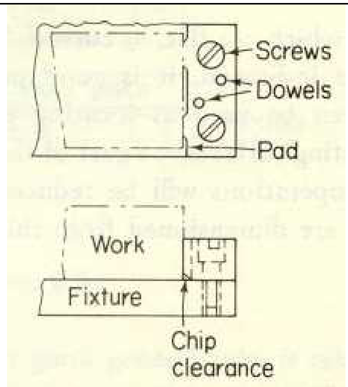
Feature:	Hole (Laser Radar / Photogrammetry)
Example(s):	

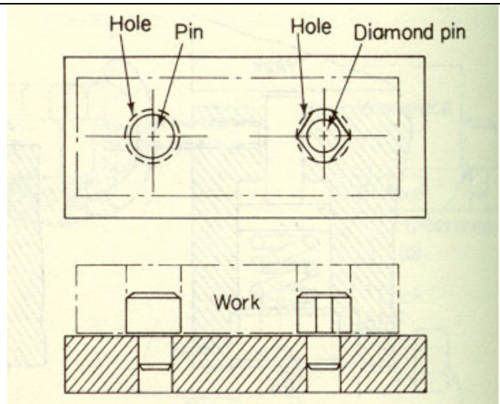
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Countersink, Counterbore, Flat Tip, Round Tip, Conical Tip), Dimensions
Reference:	Burley at al, 1999b and Leica Geosystems – Website

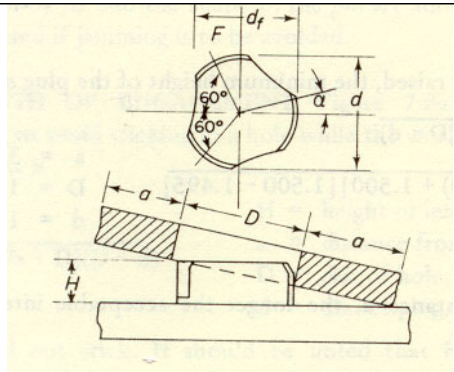
Feature:	Latch
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Cam-action Hook, Self-Locking Hook), Dimensions
Reference:	Pollack, 1976

Feature:	Light Emitting Diode (Metronor)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Orientation, Intensity, Dimensions
Reference:	Metronor – Website

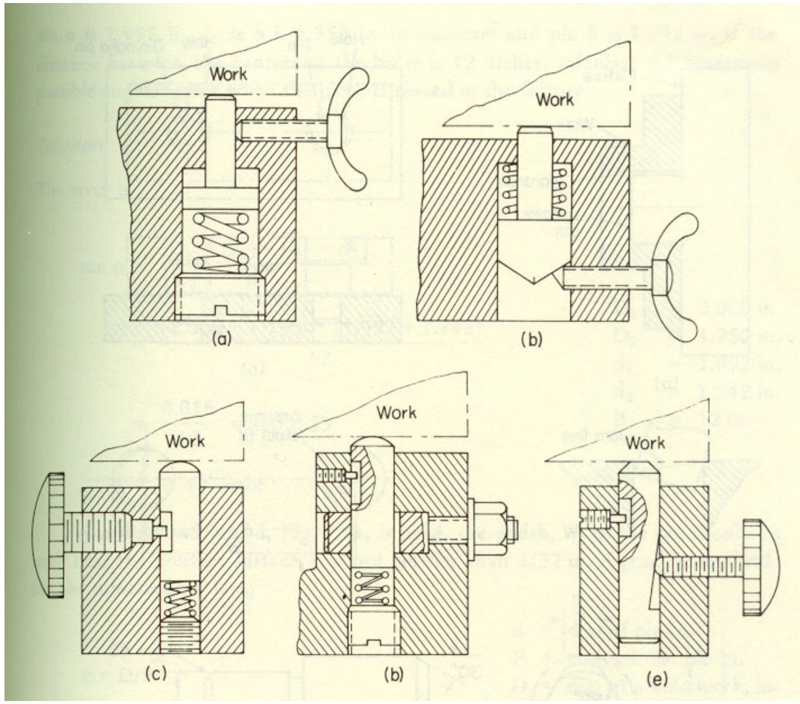
Feature:	Pad
Example(s):	

	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Dixon, 1998 and Pollack, 1976

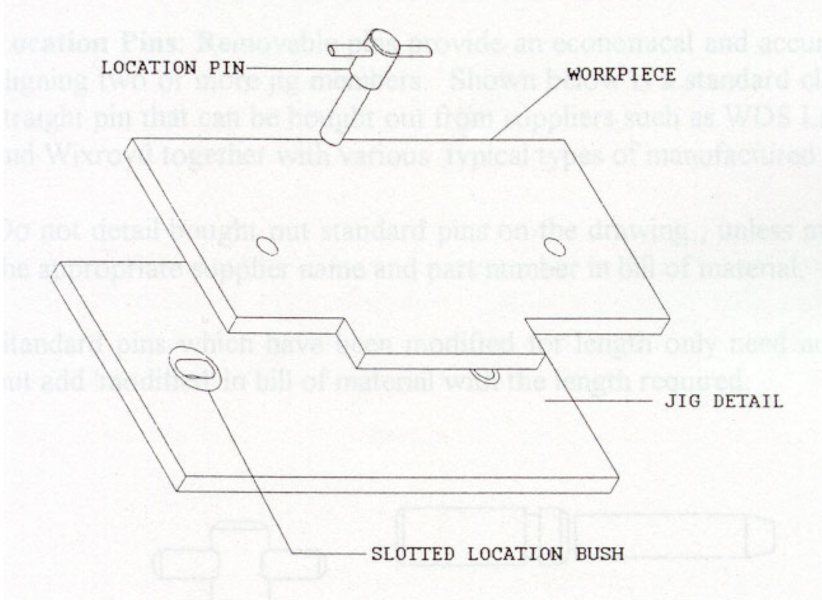
Feature:	Pin
Example(s):	

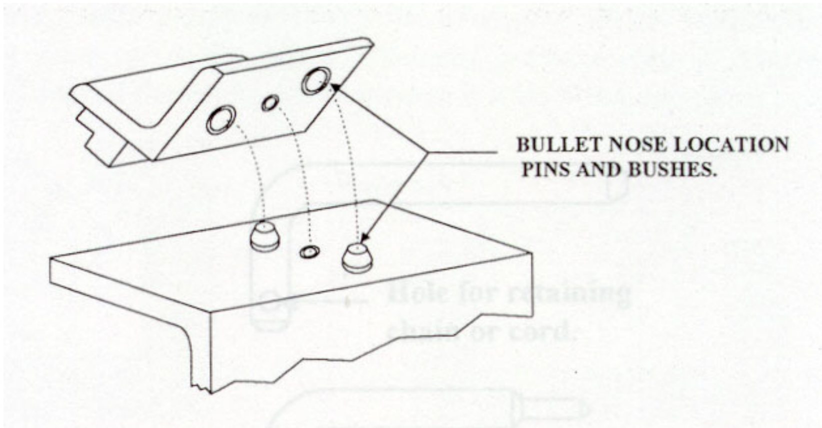


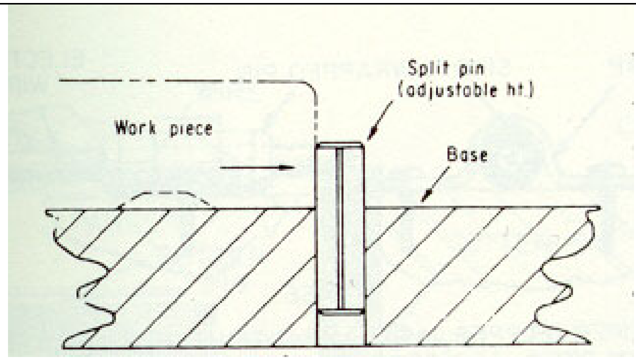
d_f
F
60°
60°
α
d
a
D
a
H

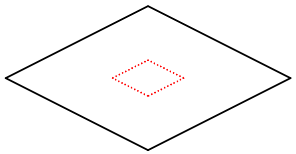


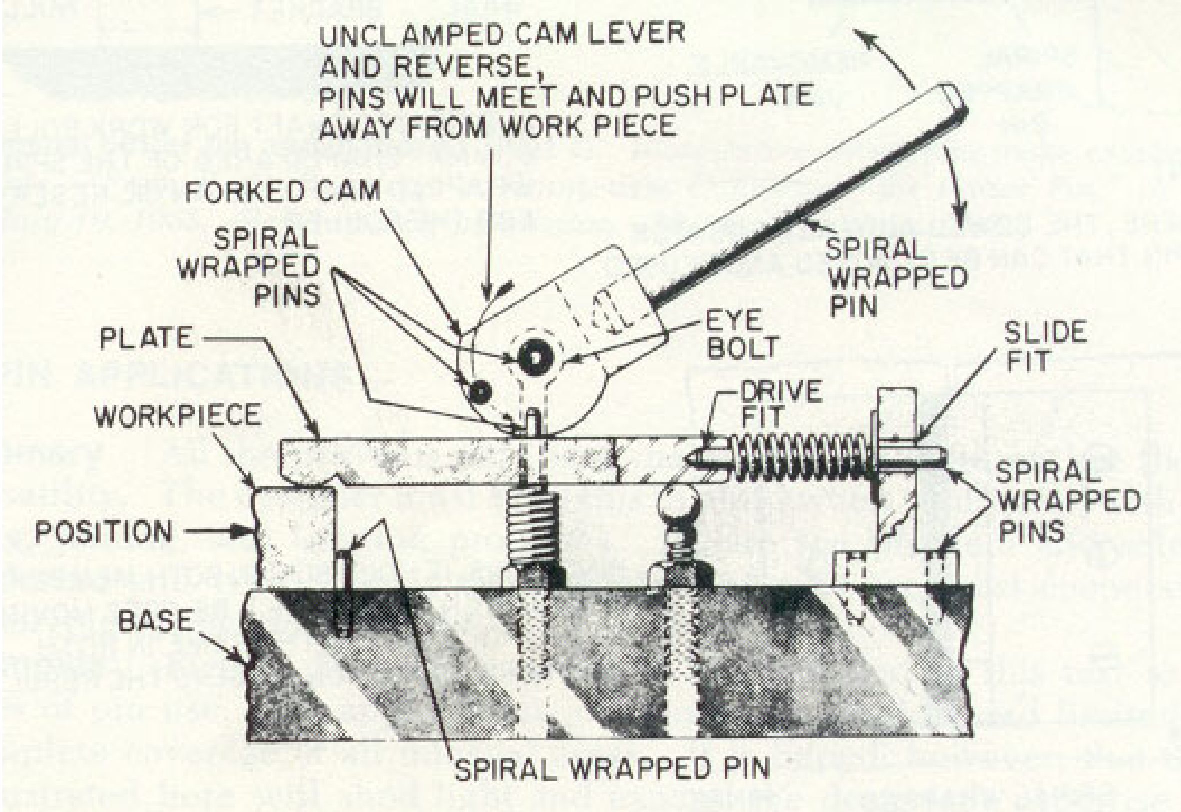
Work
(a)
Work
(b)
Work
(c)
Work
(b)
Work
(e)

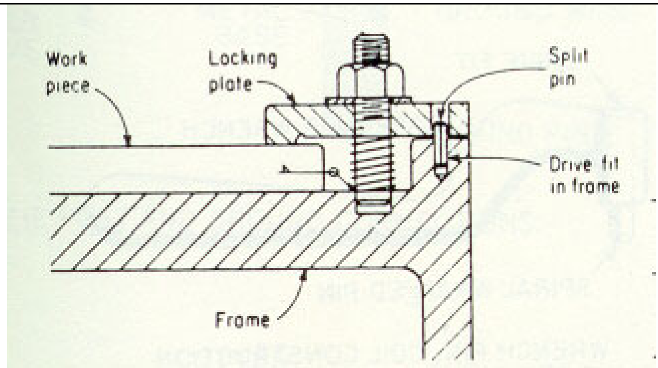

LOCATION PIN
WORKPIECE
JIG DETAIL
SLOTTED LOCATION BUSH

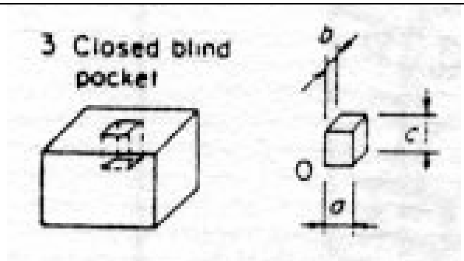

BULLET NOSE LOCATION
PINS AND BUSHES.

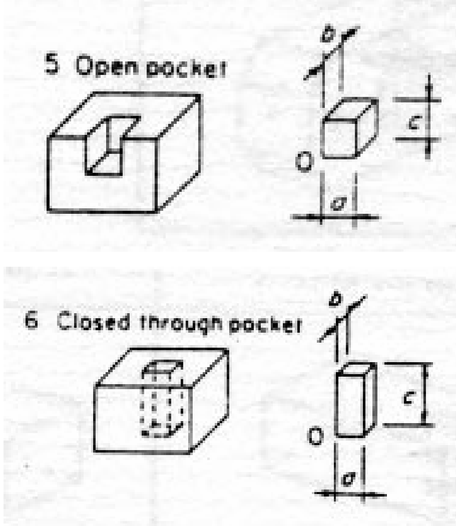
	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard / Soft
Feature Attributes:	Shape (Circular, Diamond, Equilateral, Bullet Nose), Dimensions
Reference:	Pollack, 1976; Dixon, 1998 and Parmley, 1989

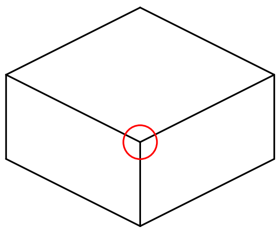
Feature:	Plane
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

Feature:	Plate
Example(s):	

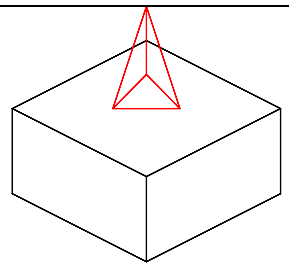
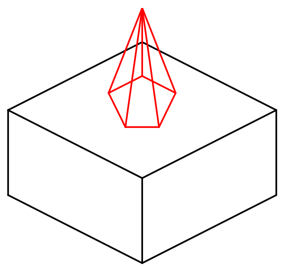
	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Parmley, 1989 and Pollack, 1976

Feature:	Pocket
Example(s):	

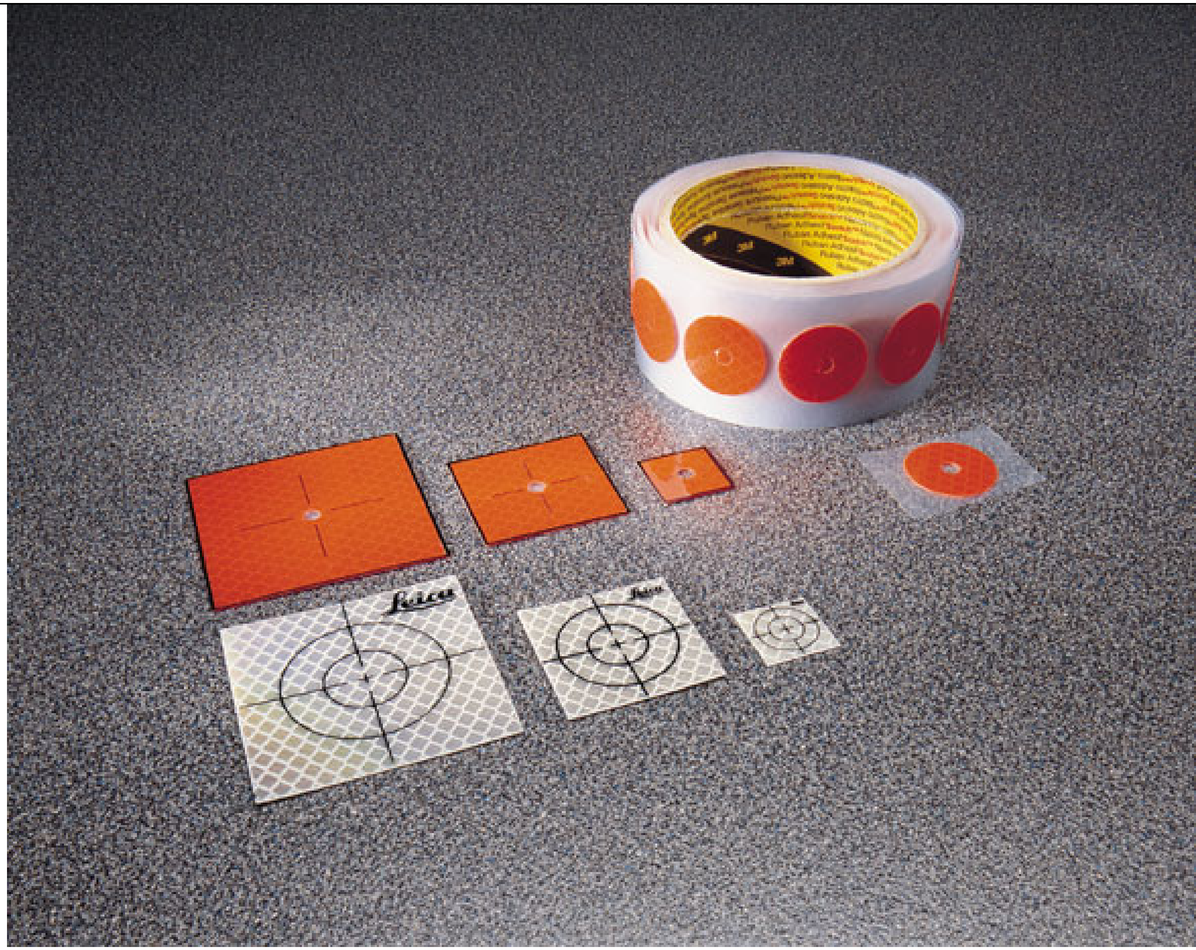
	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Closed, Open, Closed Through),Dimensions
Reference:	Burley et al, 1999b

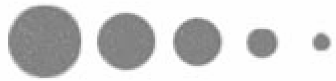
Feature:	Point (Theodolite / Laser Tracker / Photogrammetry)
Example(s):	

Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Leica Geosystems – Website

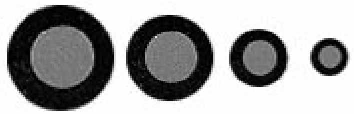
Feature:	Prism
Example(s):	 
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Shape (N-gonal), Dimensions
Reference:	Burley et al, 1999b

Feature:	Projected Spots of Light (Videogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Point Densities, Point Patterns
Reference:	Geodetic Services – Website

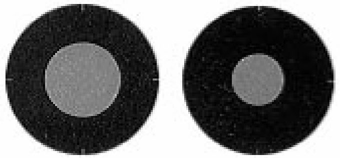
Feature:	Retro-Reflective Tape (Theodolite / Photogrammetry)
Example(s):	



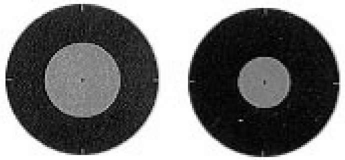
Single retro dot, no mask, various sizes



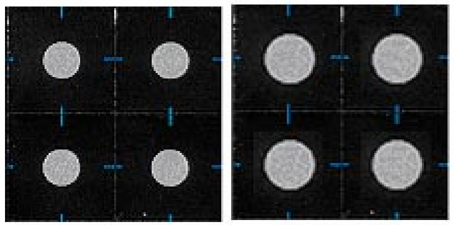
Single retro dot, masked, various sizes



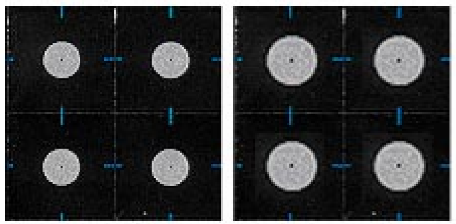
Single retro dot, masked, alignment marks, various sizes



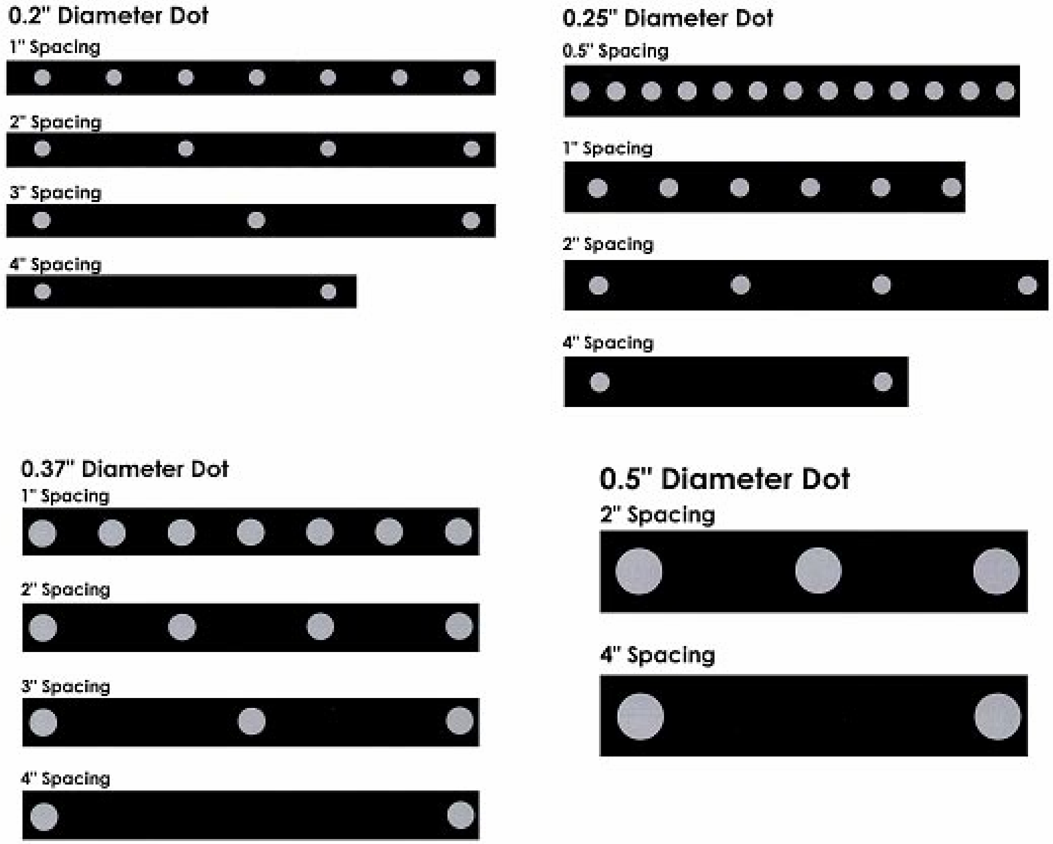
Single retro dot, masked, alignment marks, theodolite dot, various sizes



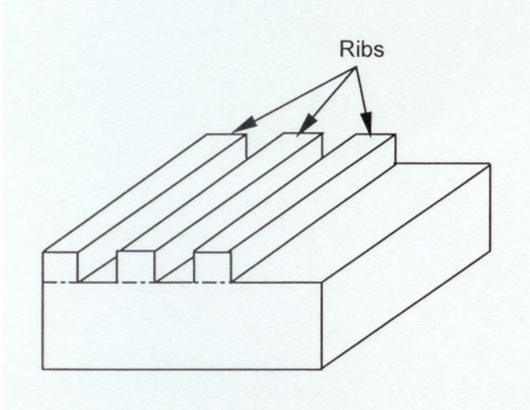
Sheet of single retro dots, masked, alignment marks, various sizes

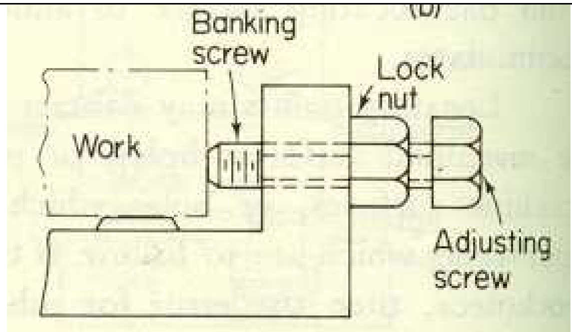


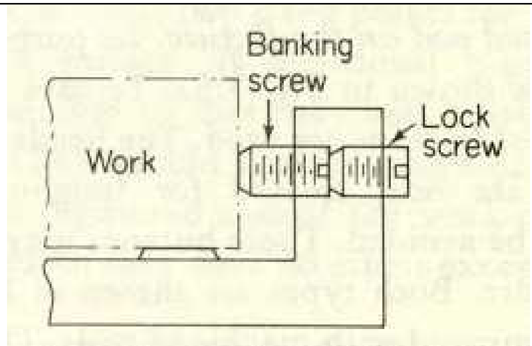
Sheet of single retro dots, masked, alignment marks, theodolite dot, various sizes

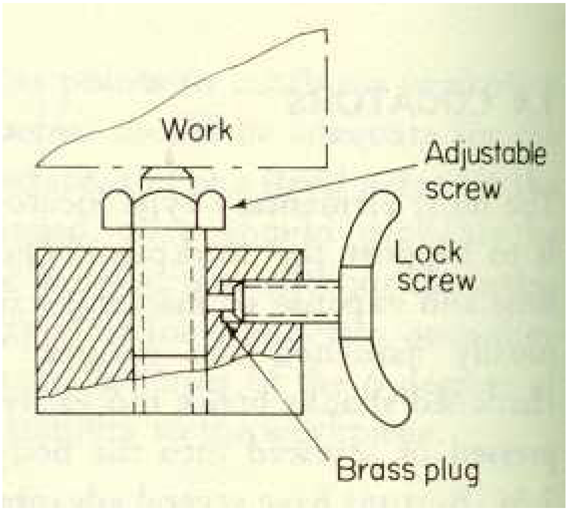


Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Shape, Configuration, Dimensions
Reference:	Leica Geosystems – Website / Geodetic Services – Website

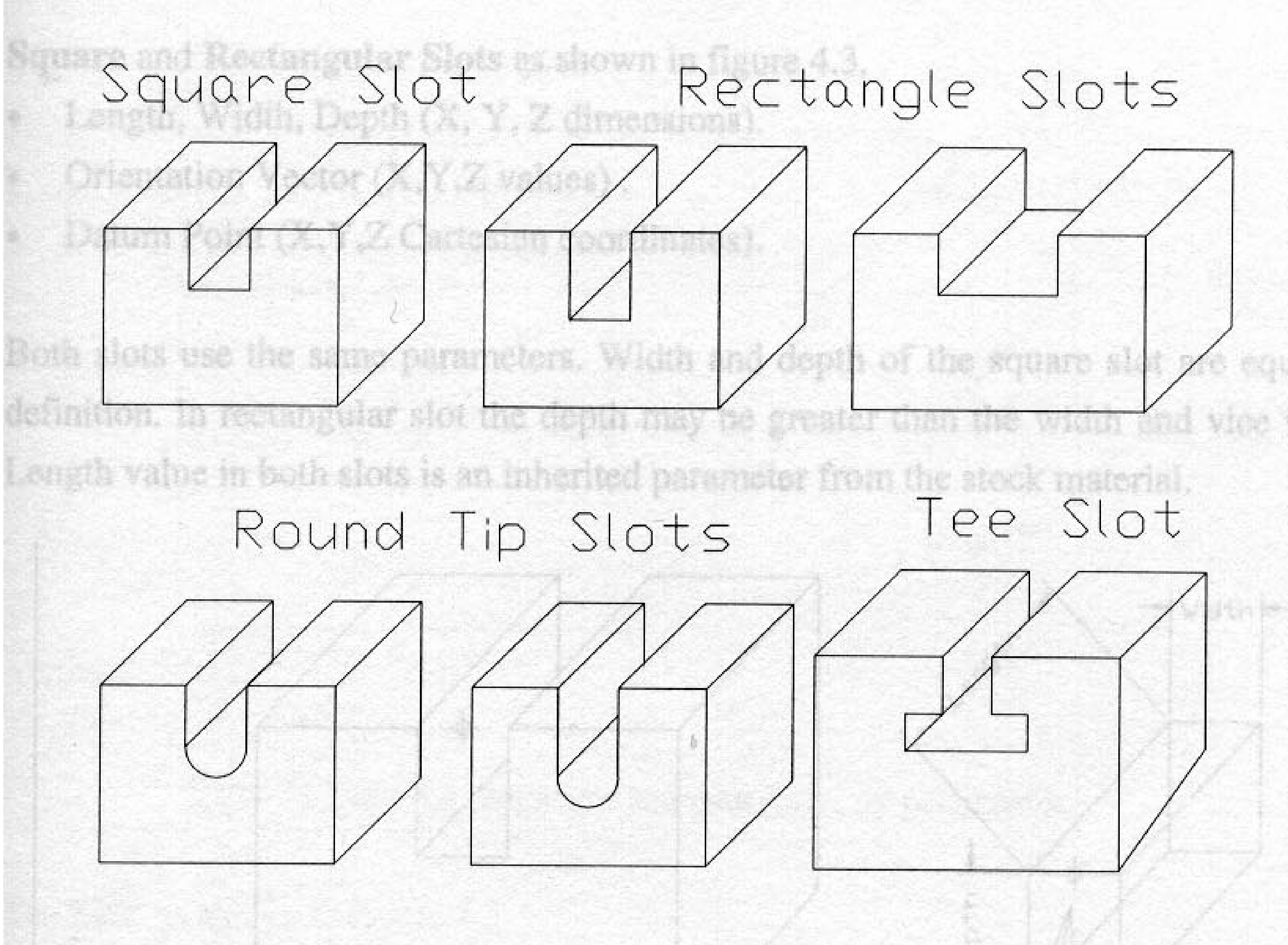
Feature:	Rib
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Kyriacou, 1998

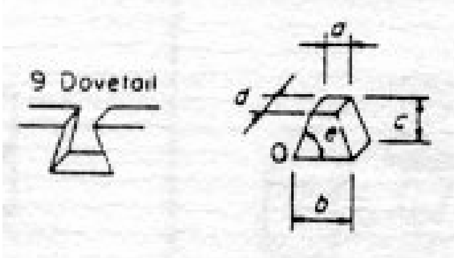
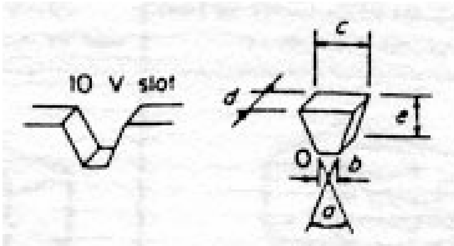
Feature:	Screw
Example(s):	

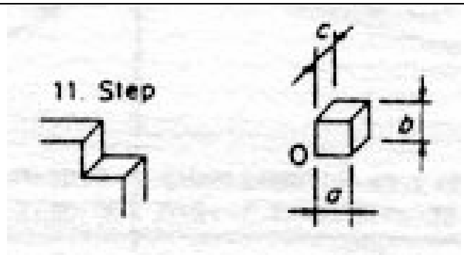




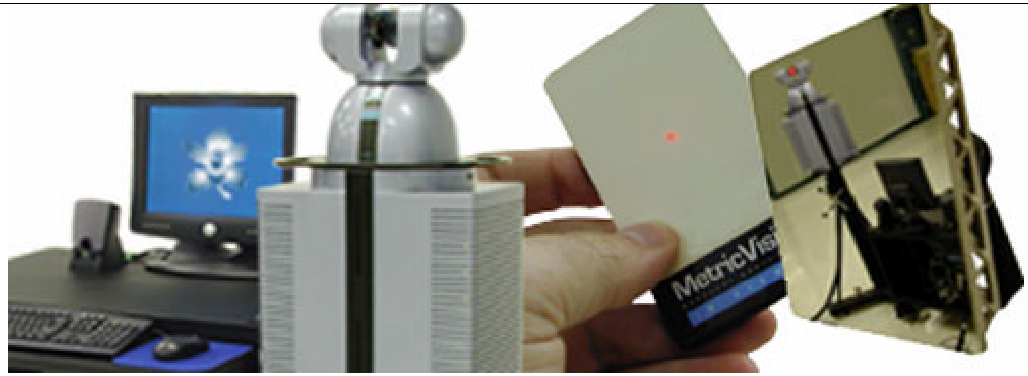
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Type (Banking, Adjustable), Dimensions
Reference:	Pollack, 1976

Feature:	Slot
Example(s):	

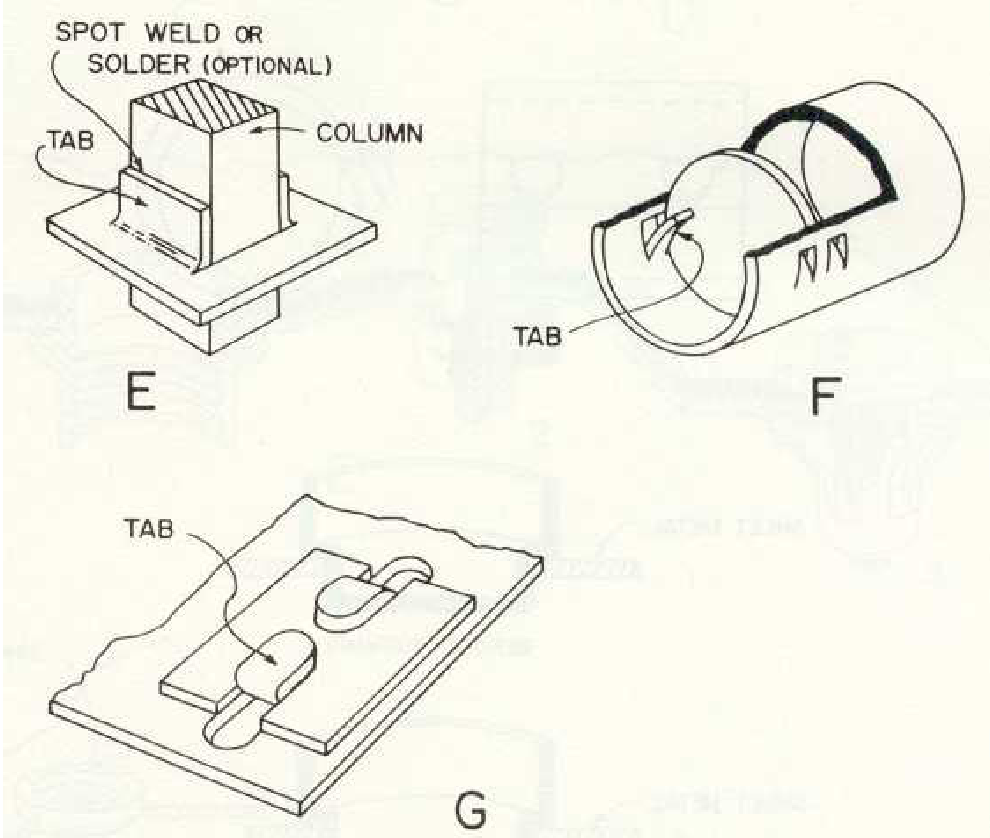
	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Shape (T, V, Square, Round Tip, Rectangle, Dovetail, Cylinder), Dimensions
Reference:	Burley et al, 1999b

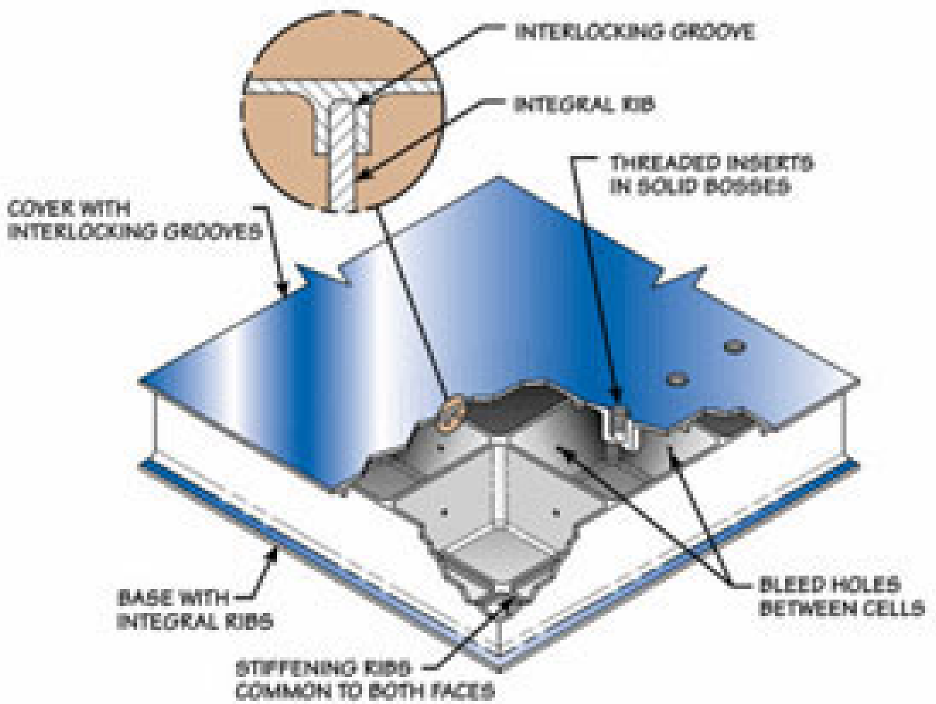
Feature:	Step
Example(s):	

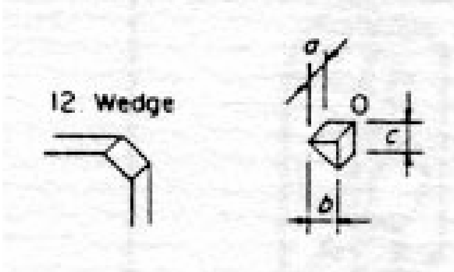
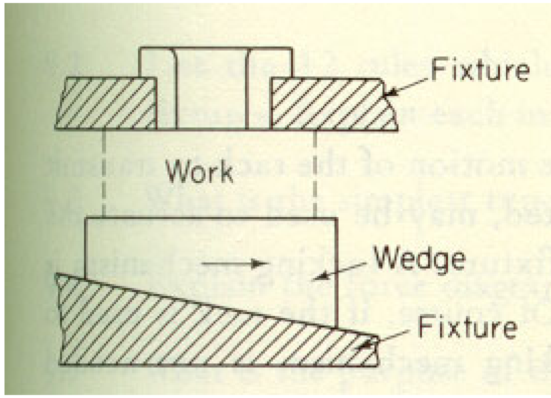
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

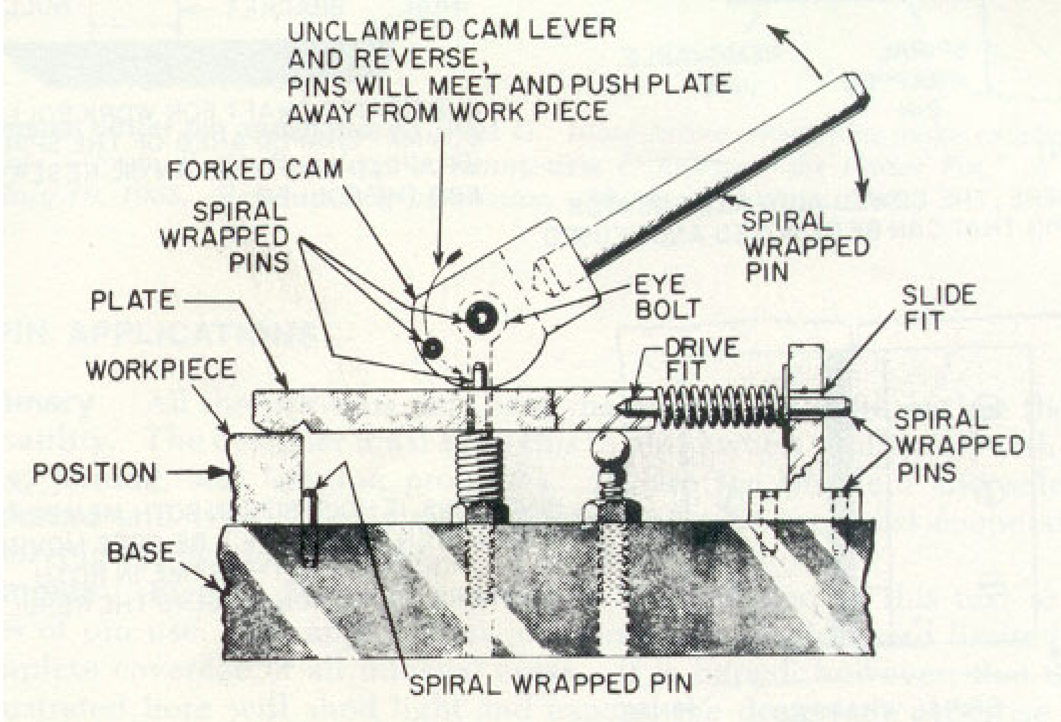
Feature:	Surface (Laser Radar / Photogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	MetricVision – Website

Feature:	Surface Reflector (Theodolite / Laser Tracker / Photogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Configuration, Dimensions
Reference:	Leica Geosystems – Website

Feature:	Tabs
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Lanced, Alignment), Dimensions
Reference:	Parmley, 1989

Feature:	Tongue
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Goodrich Aerostructures Group, 2001

Feature:	Wedge
Example(s):	 

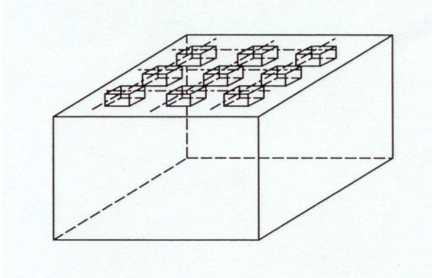


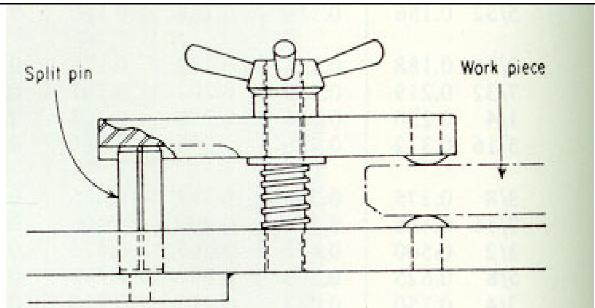
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b; Pollack, 1976 and Parmley, 1989

Feature:	XXX-LF*1*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Hard
Feature Attributes:	L1, L2, L3
Reference:	

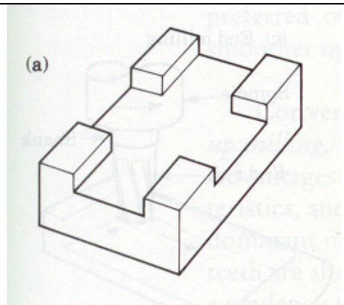
Feature:	XXX-LF*2*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Soft
Feature Attributes:	L4, L5, L6
Reference:	

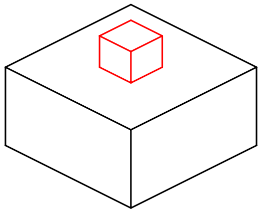
B.2 Support Features

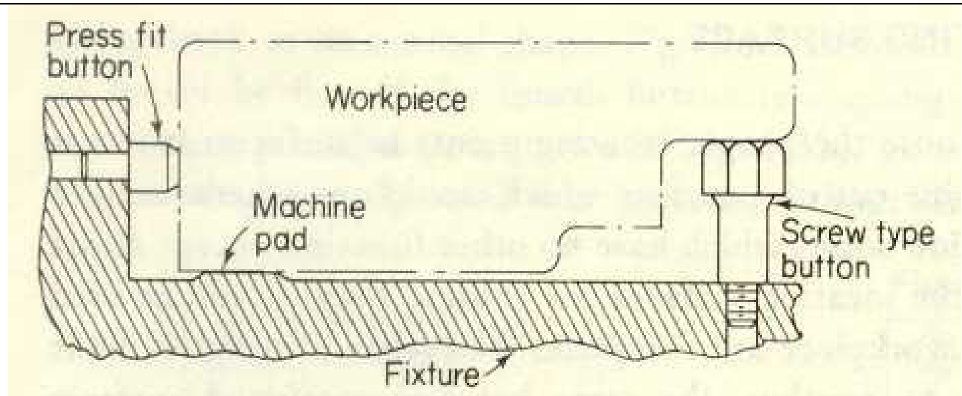
Feature:	Array Pattern
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Configuration, Dimensions
Reference:	Kyriacou, 1998

Feature:	Bead
Example(s):	

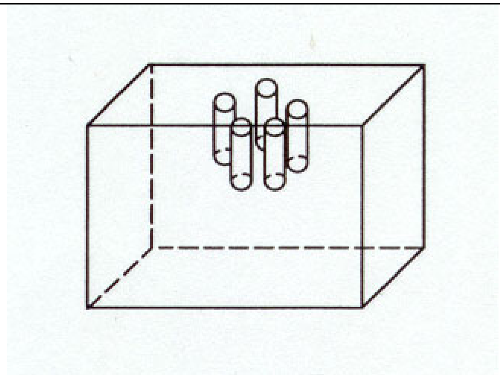
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Parmley, 1989

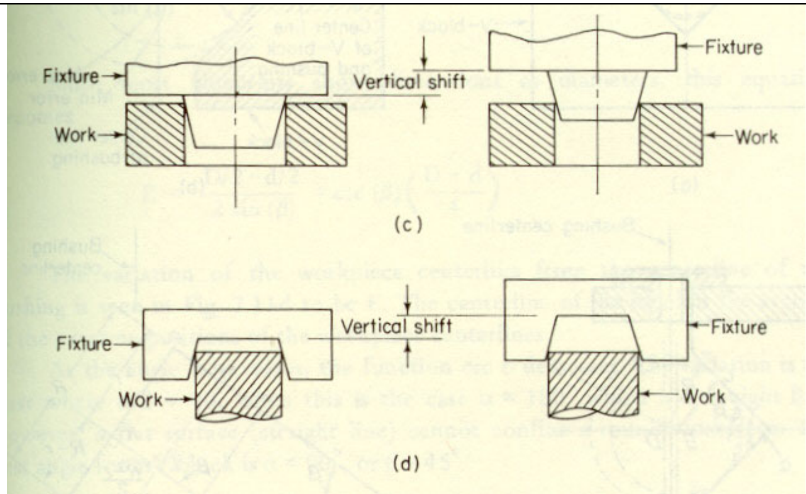
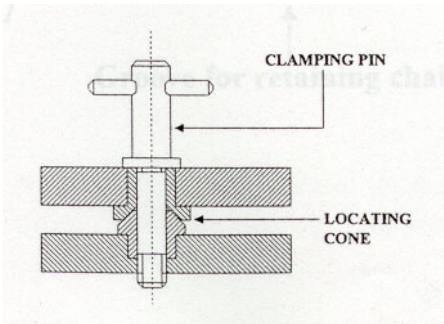
Feature:	Block
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Kalpakjian, 1995

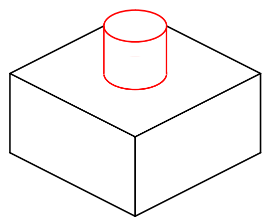
Feature:	Boss
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

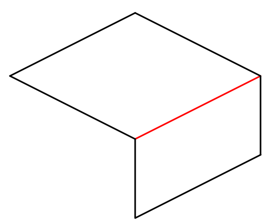
Feature:	Button
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard

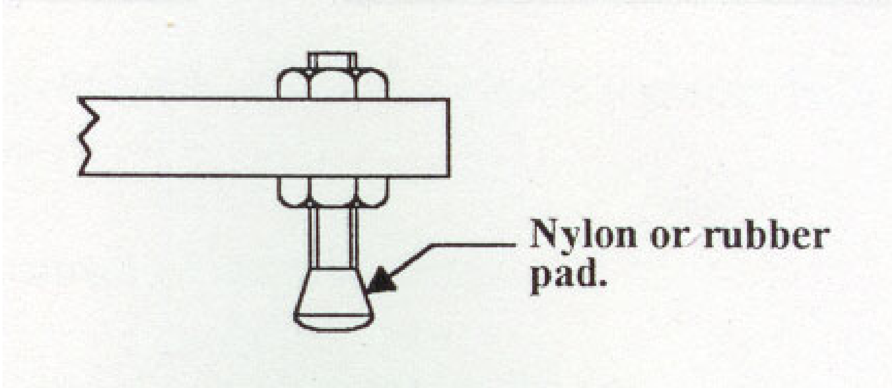
Feature Attributes:	Type (Press Fit, Screw Type), Dimensions
Reference:	Pollack, 1976

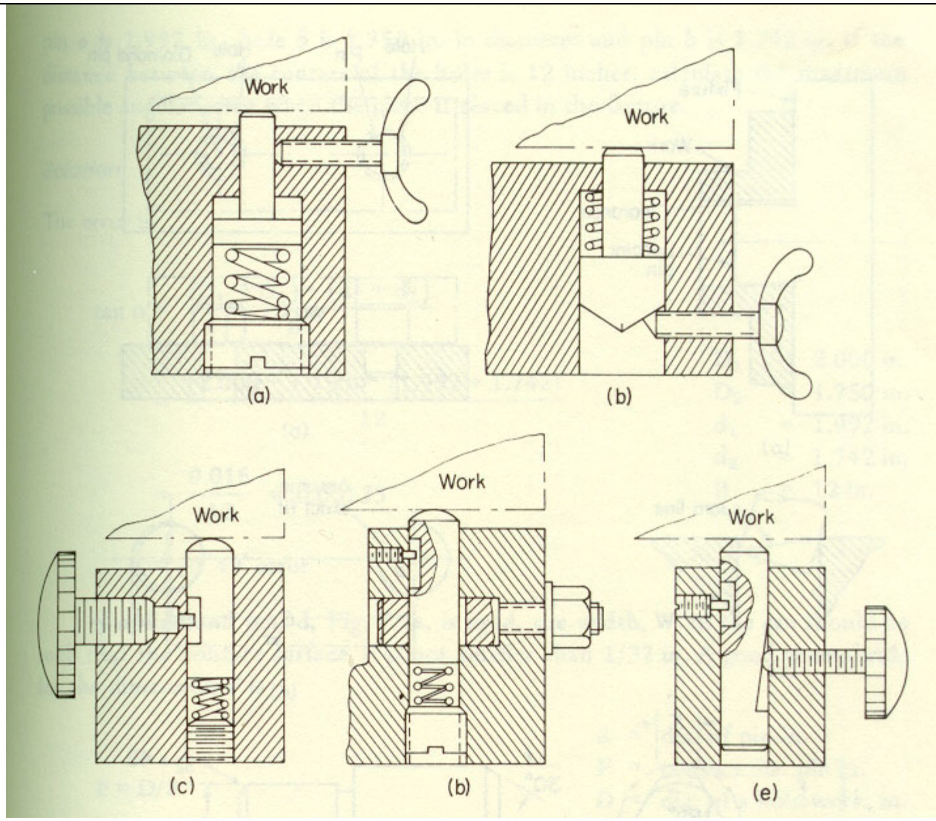
Feature:	Circular Pattern
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Configuration, Dimensions
Reference:	Kyriacou, 1998

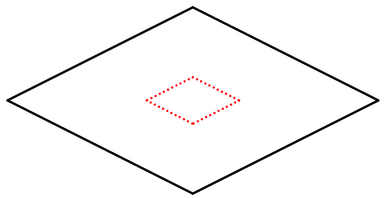
Feature:	Cone
Example(s):	 
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Pollack, 1976 and Dixon, 1998

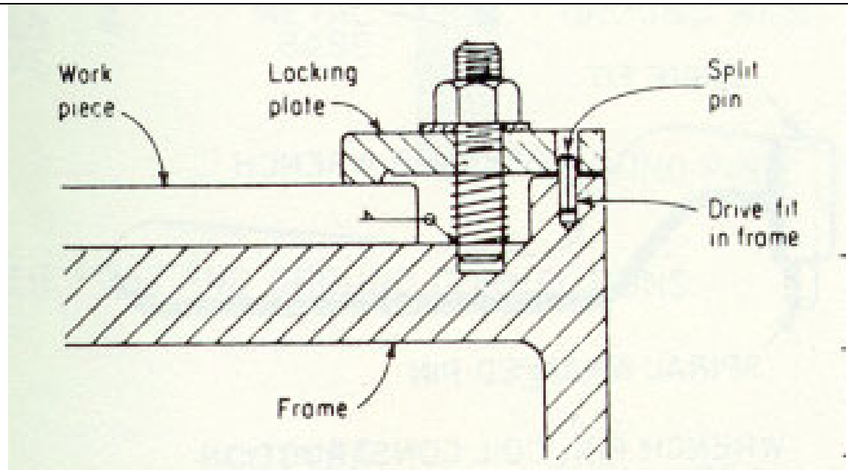
Feature:	Cylinder
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

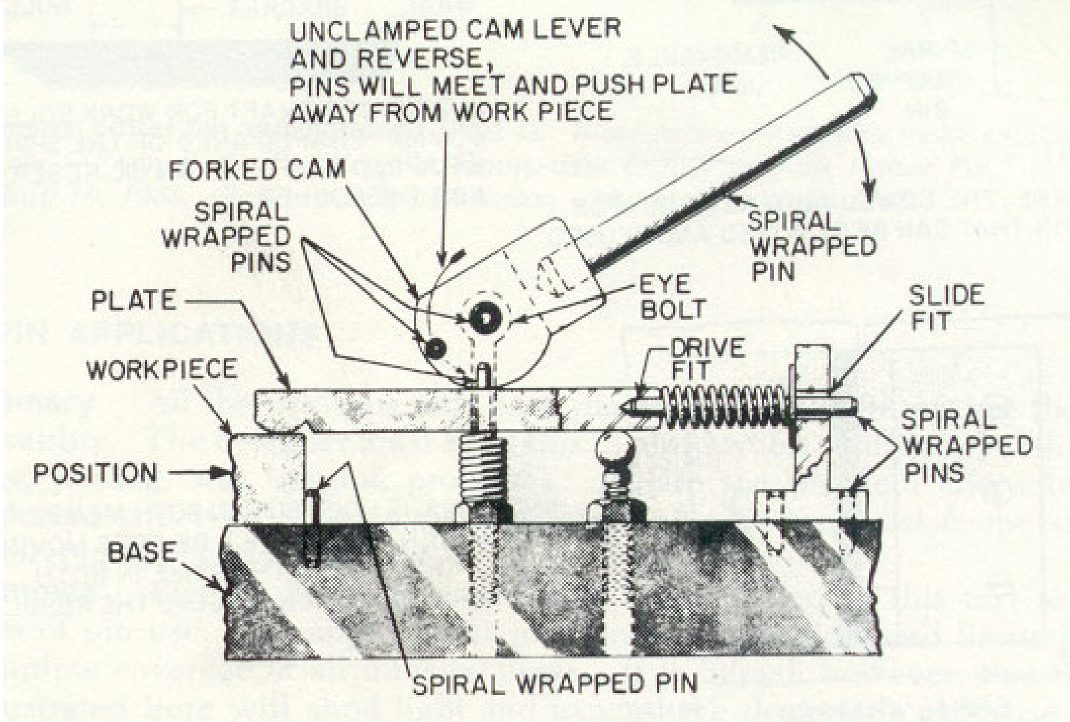
Feature:	Edge (Theodolite / Laser Radar / Photogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

Feature:	Pad
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Pollack, 1976

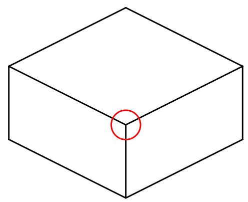
Feature:	Pin
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard / Soft
Feature Attributes:	Shape (Circular, Diamond, Equilateral, Bullet Nose), Dimensions
Reference:	Pollack, 1976; Dixon, 1998 and Parmley, 1989

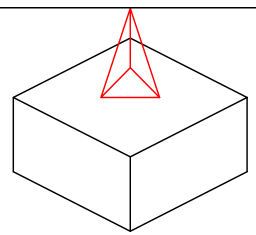
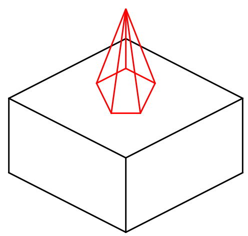
Feature:	Plane
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

Feature:	Plate
Example(s):	

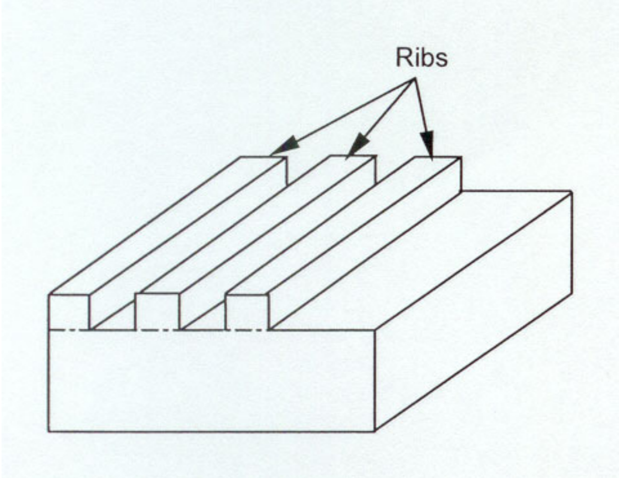


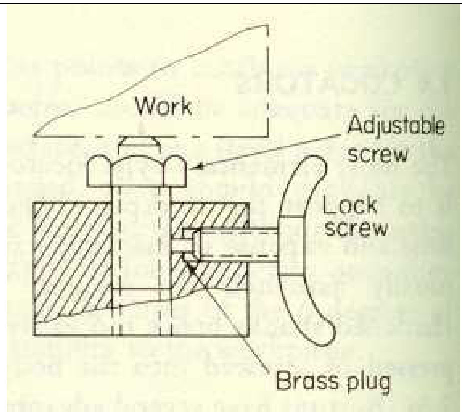
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Pollack, 1976

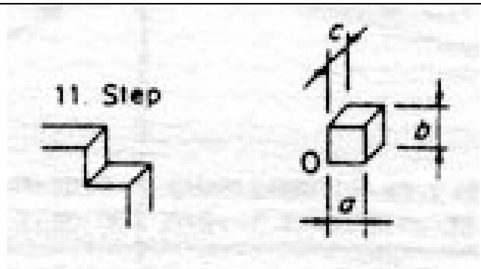
Feature:	Point (Theodolite / Laser Tracker / Photogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Leica Geosystems – Website

Feature:	Prism
Example(s):	 

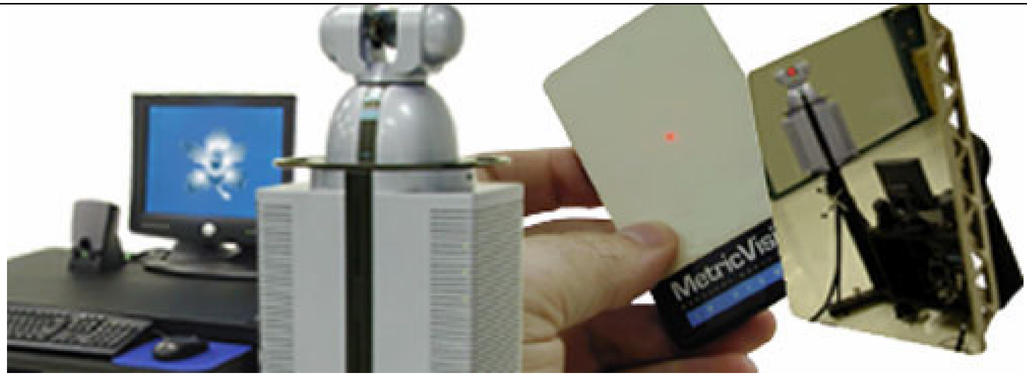
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Shape (N-gonal), Dimensions
Reference:	Burley et al, 1999b

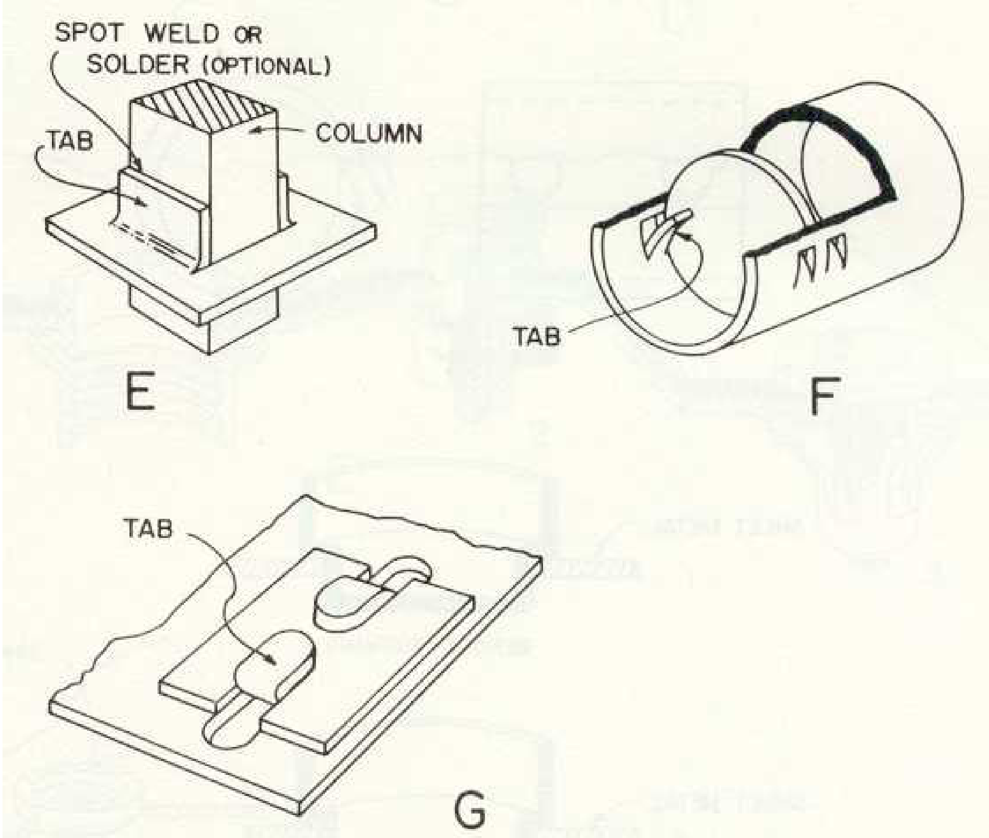
Feature:	Rib
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Kyriacou, 1998

Feature:	Screw
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Type (Banking, Adjustable), Dimensions
Reference:	Pollack, 1976

Feature:	Step
Example(s):	
Pre- / User Defined	Pre-Defined

Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

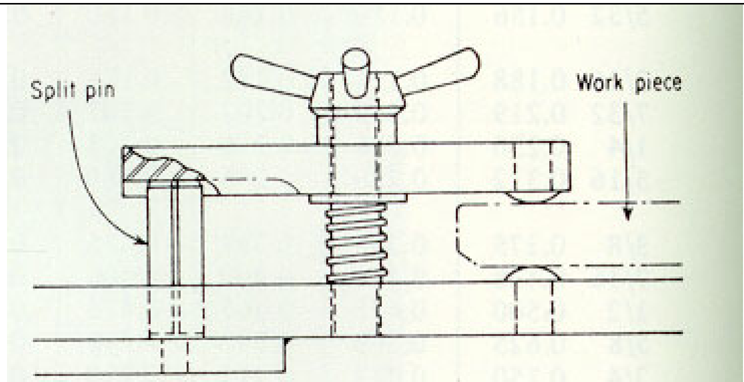
Feature:	Surface (Laser Radar / Photogrammetry)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	MetricVision – Website

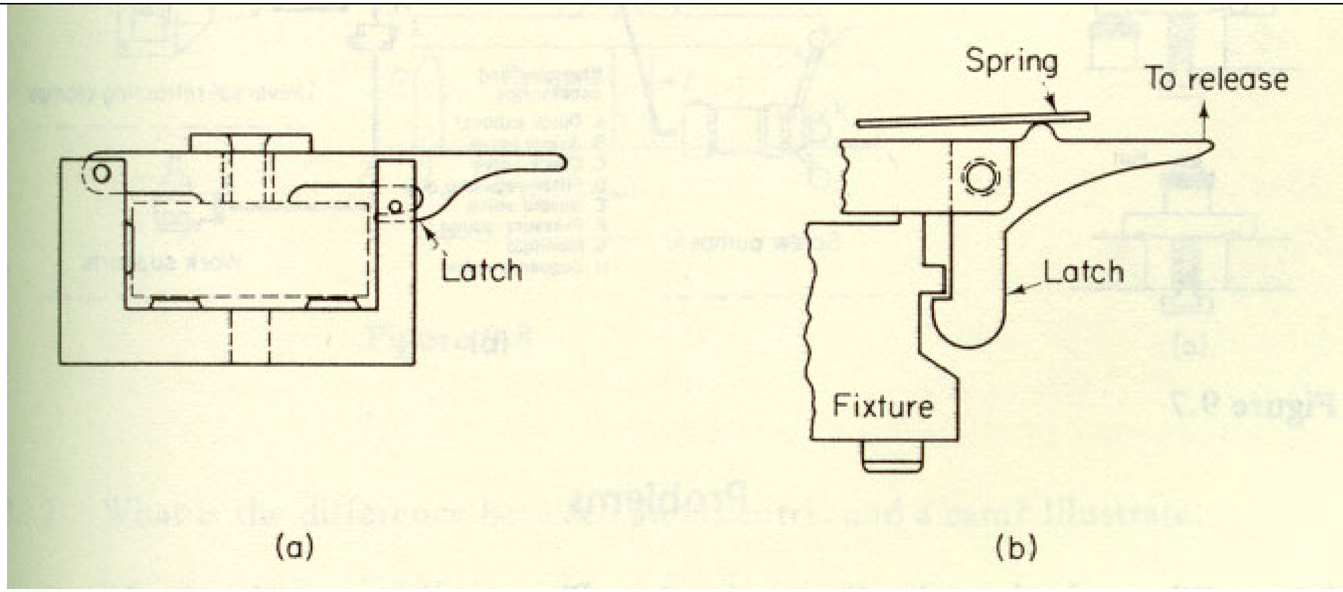
Feature:	Tabs
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Lanced, Alignment), Dimensions
Reference:	Parmley, 1989

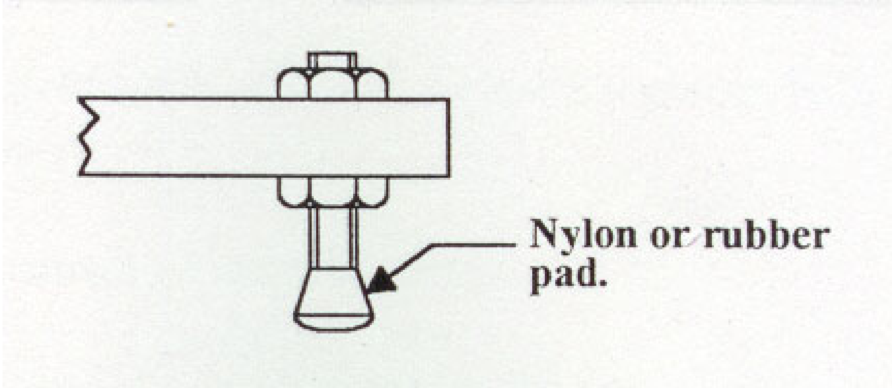
Feature:	XXX-SF*1*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Hard
Feature Attributes:	S1, S2, S3
Reference:	

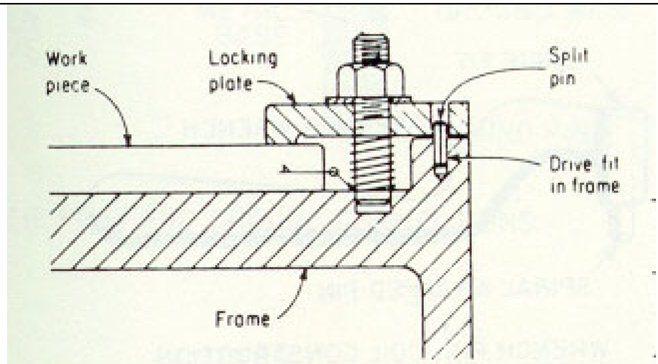
Feature:	XXX-SF*2*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Soft
Feature Attributes:	S4, S5, S6
Reference:	

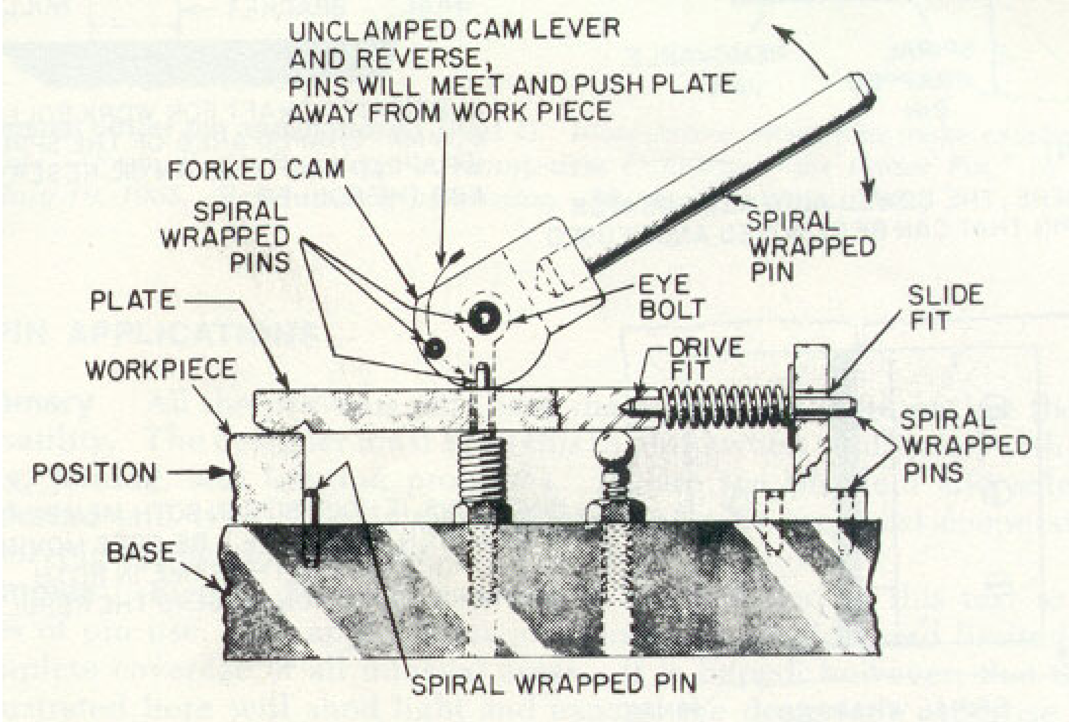
B.3 Clamping Features

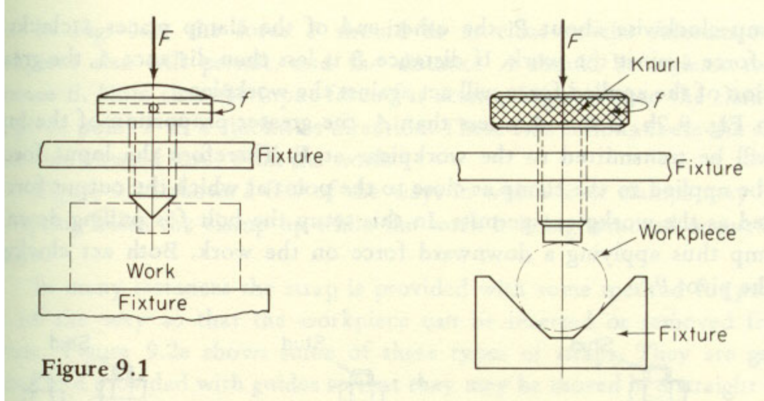
Feature:	Bead
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions, Clamping Force
Reference:	Parmley, 1989

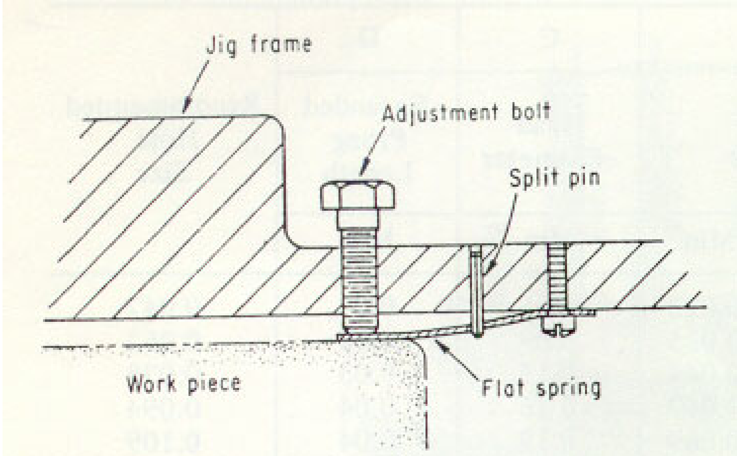
Feature:	Latch
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Cam-action Hook, Self-Locking Hook), Dimensions, Clamping Force
Reference:	Pollack, 1976

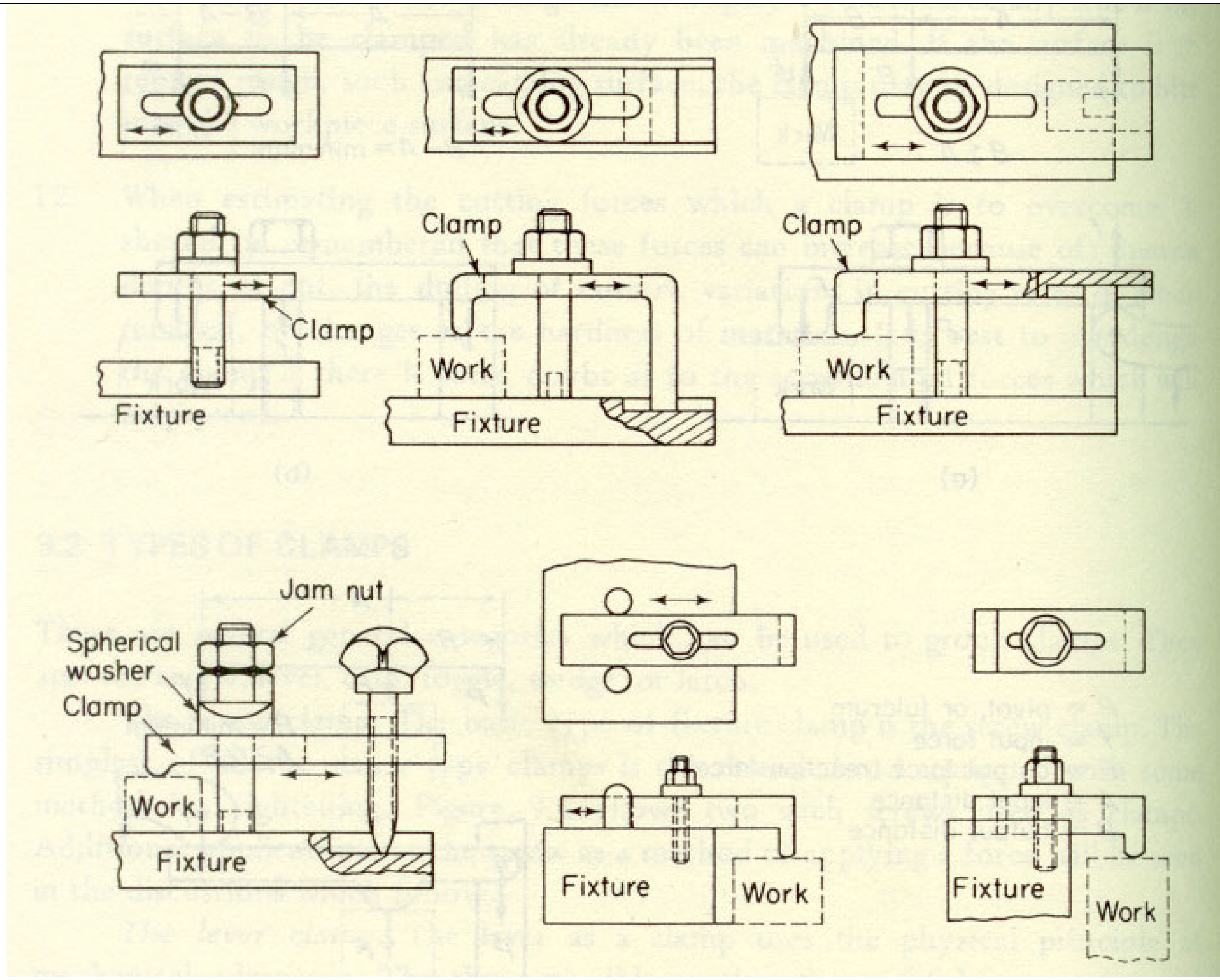
Feature:	Pad
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Material (Nylon, Rubber), Dimensions, Clamping Force
Reference:	Dixon, 1998

Feature:	Plate
Example(s):	

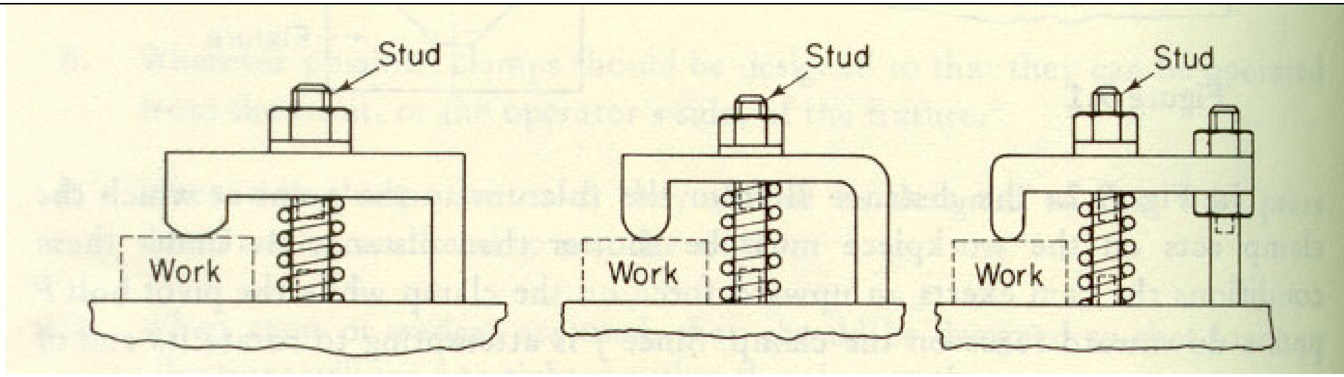
	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions, Clamping Force
Reference:	Pollack, 1976

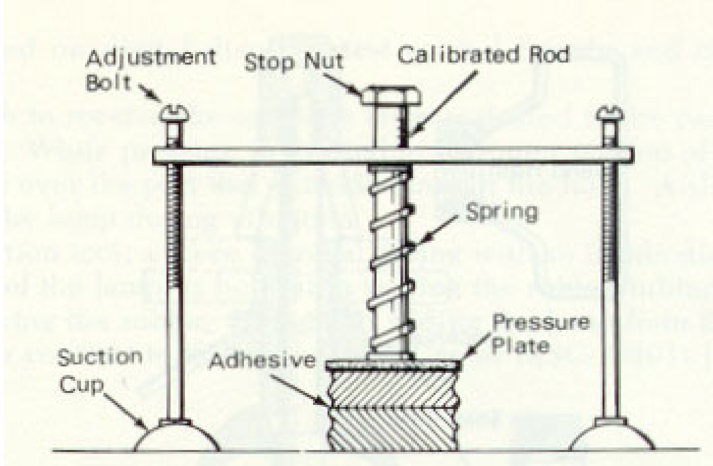
Feature:	Screw
Example(s):	 Figure 9.1
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Banking, Adjustable), Dimensions, Clamping Force
Reference:	Pollack, 1976

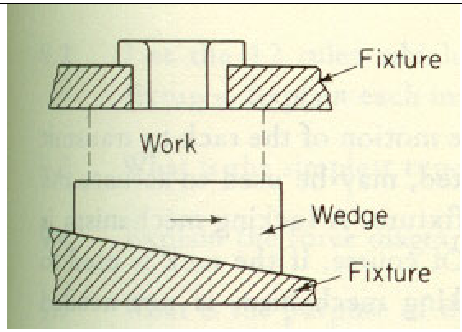
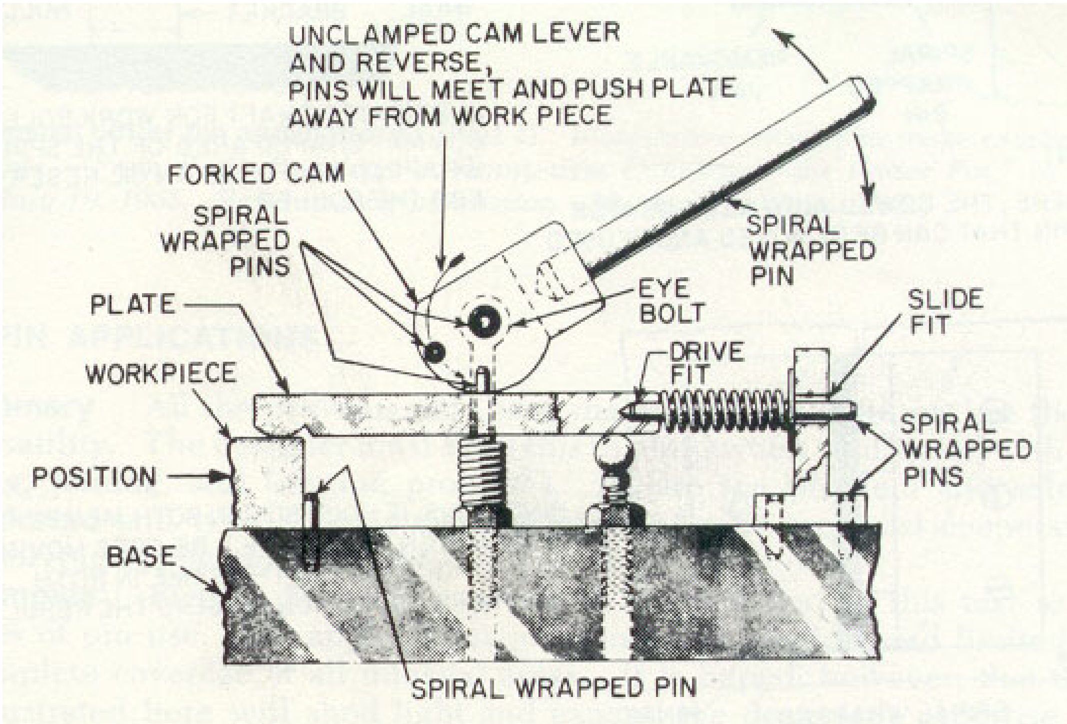
Feature:	Spring
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions, Clamping Force
Reference:	Parmley, 1989

Feature:	Strap
Example(s):	

Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions, Clamping Force
Reference:	Pollack, 1976

Feature:	Stud (with Nut)
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions, Clamping Force
Reference:	Pollack, 1976

Feature:	Suction Cups
Example(s):	
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Dimensions, Clamping Force
Reference:	Parmley, 1989

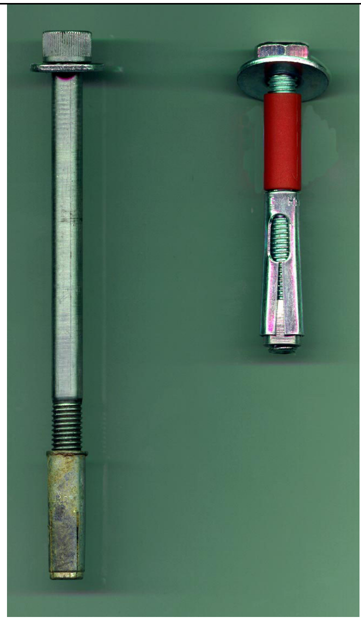
Feature:	Wedge
Example(s):	 

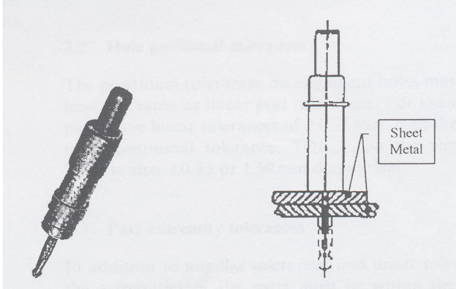
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions, Clamping Force
Reference:	Pollack, 1976 and Parmley, 1989

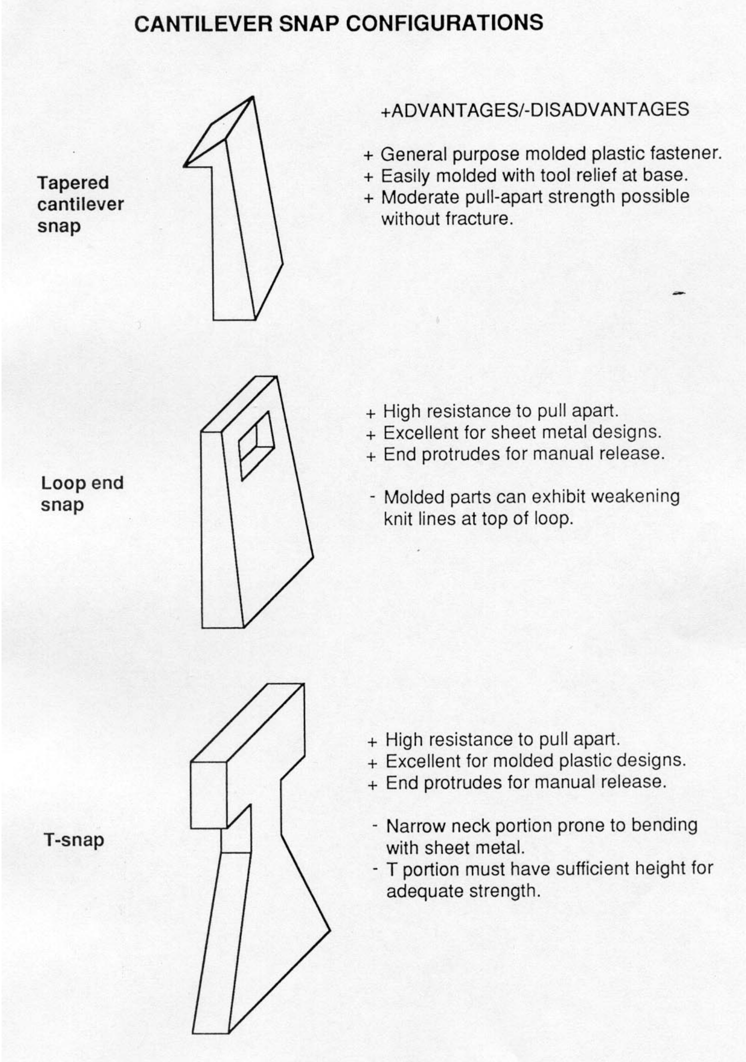
Feature:	XXX-CF*1*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Hard
Feature Attributes:	C1, C2, C3
Reference:	

Feature:	XXX-CF*2*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Soft
Feature Attributes:	C4, C5, C6
Reference:	

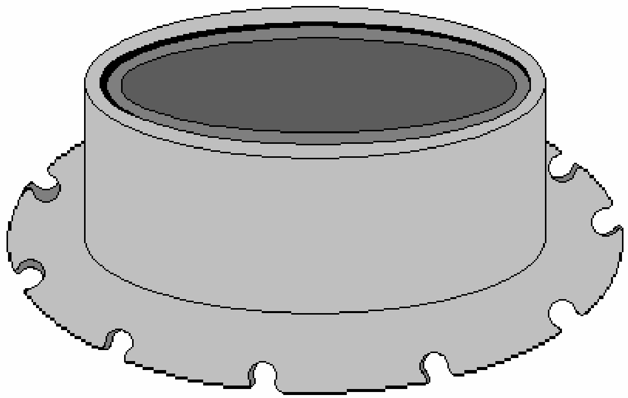
B.4 Fastening Features

Feature:	Bolt
Example(s):	
Temporary / Permanent	Temporary
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Burley et al, 1999b

Feature:	Cleco Pins
Example(s):	
Temporary / Permanent	Temporary
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Dimensions
Reference:	Monogram Aerospace Fasteners, 1990

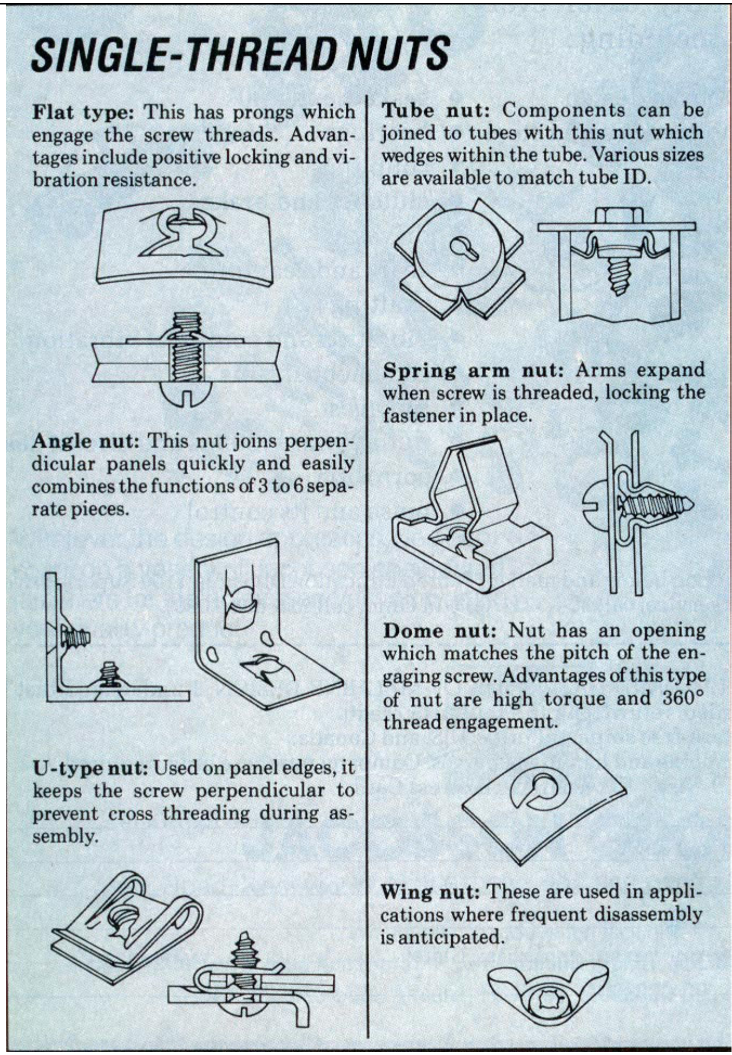
Feature:	Clip
Example(s):	

Temporary / Permanent	Temporary
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Burley et al, 1999b

Feature:	Double-Eccentric Bolt
Example(s):	
Temporary / Permanent	Temporary
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Soft
Feature Attributes:	Eccentricity, Dimensions
Reference:	Burley et al, 1999b

Feature:	Nut

Example(s):



SINGLE-THREAD NUTS

Flat type: This has prongs which engage the screw threads. Advantages include positive locking and vibration resistance.

Angle nut: This nut joins perpendicular panels quickly and easily combines the functions of 3 to 6 separate pieces.

U-type nut: Used on panel edges, it keeps the screw perpendicular to prevent cross threading during assembly.

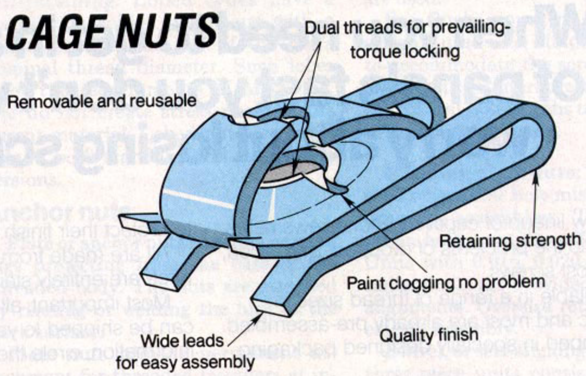
Tube nut: Components can be joined to tubes with this nut which wedges within the tube. Various sizes are available to match tube ID.

Spring arm nut: Arms expand when screw is threaded, locking the fastener in place.

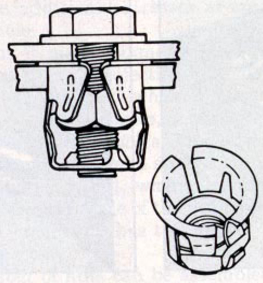
Dome nut: Nut has an opening which matches the pitch of the engaging screw. Advantages of this type of nut are high torque and 360° thread engagement.

Wing nut: These are used in applications where frequent disassembly is anticipated.

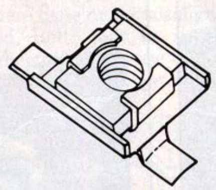
CAGE NUTS



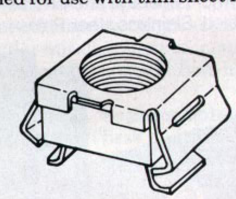
Heavy-duty caged nut: This is used in applications with round, blind holes. Driving the screw causes the locking lugs to engage.



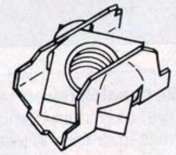
Square-hold cage nut: Lugs lock behind the panel.



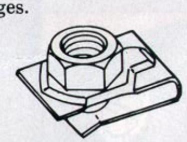
Full-cage retainer: Lugs are designed for use with thin sheet metal.



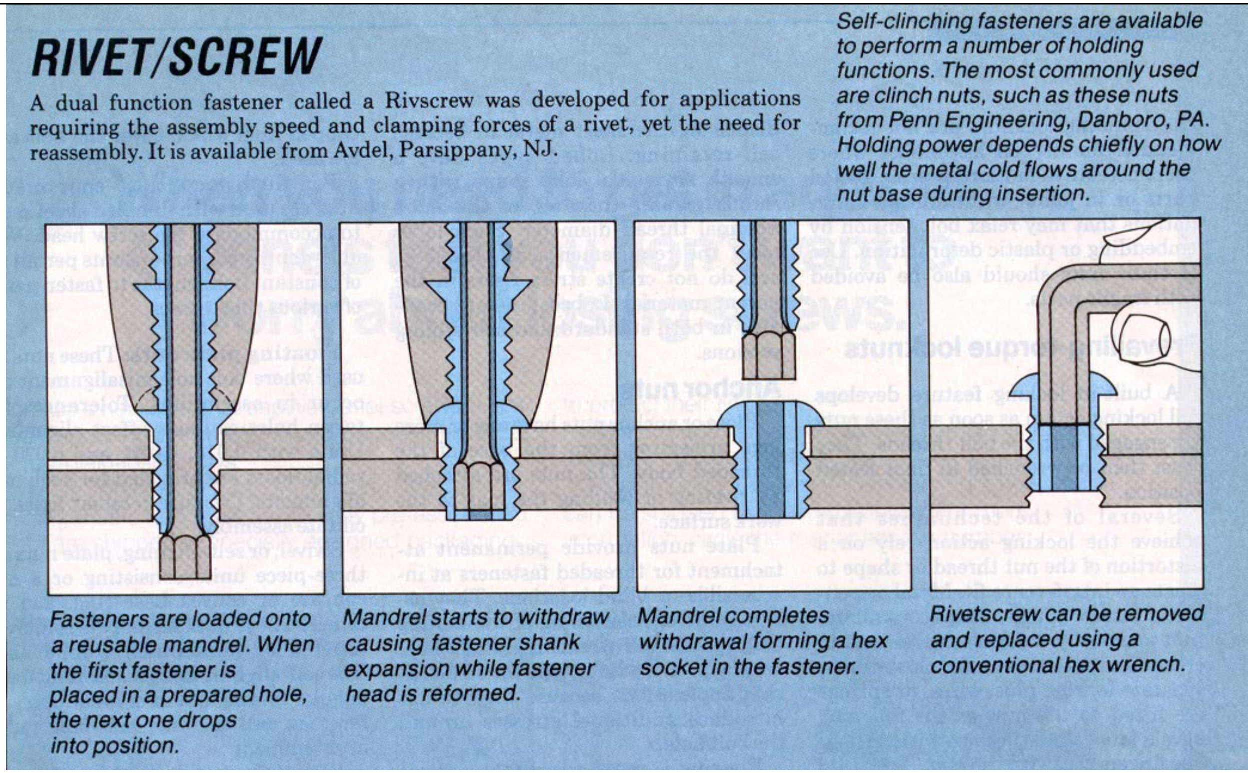
Prevailing-torque: Cage nut has lugs which engage and lock the screw thread.



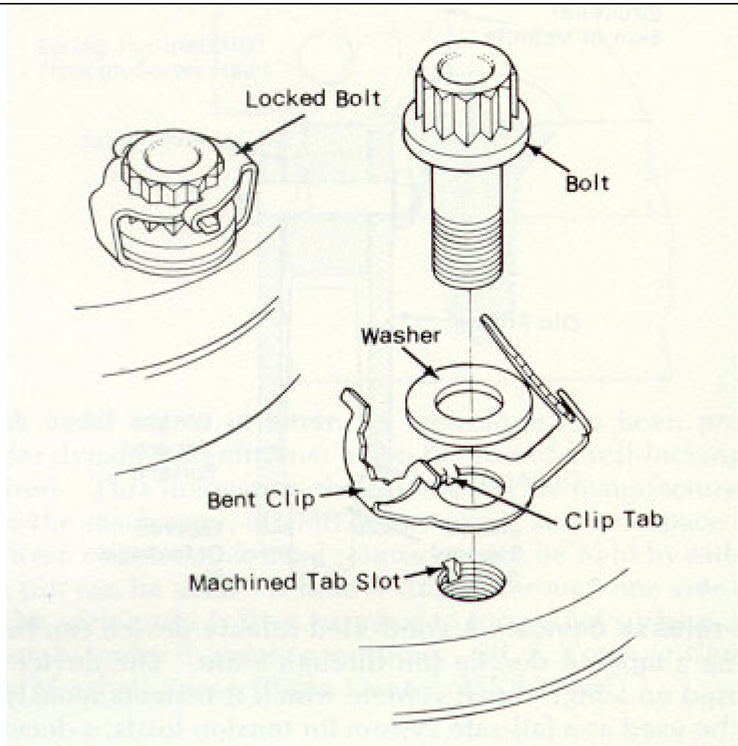
Nut retainer: Design is used on panel edges.

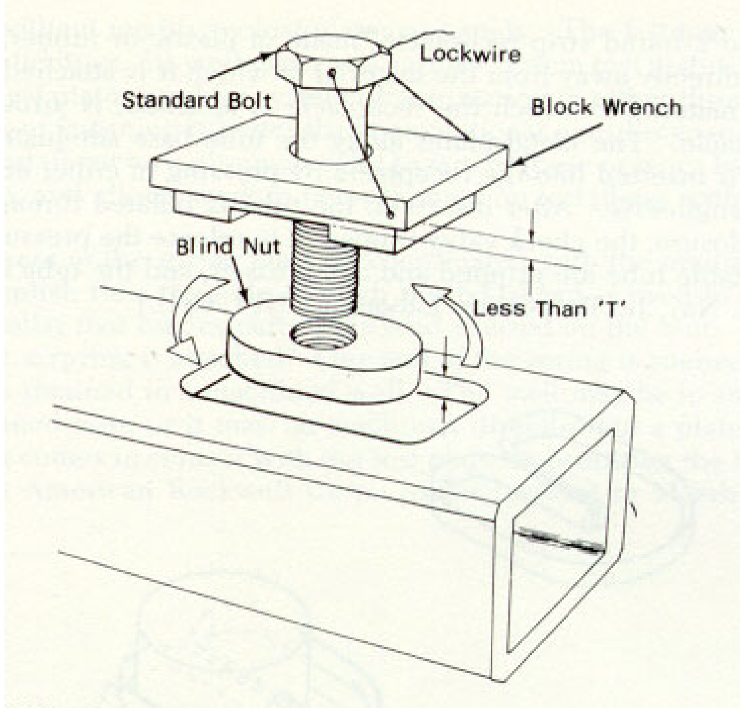


Temporary / Permanent	Temporary
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Eccentricity, Dimensions
Reference:	Burley et al, 1999b

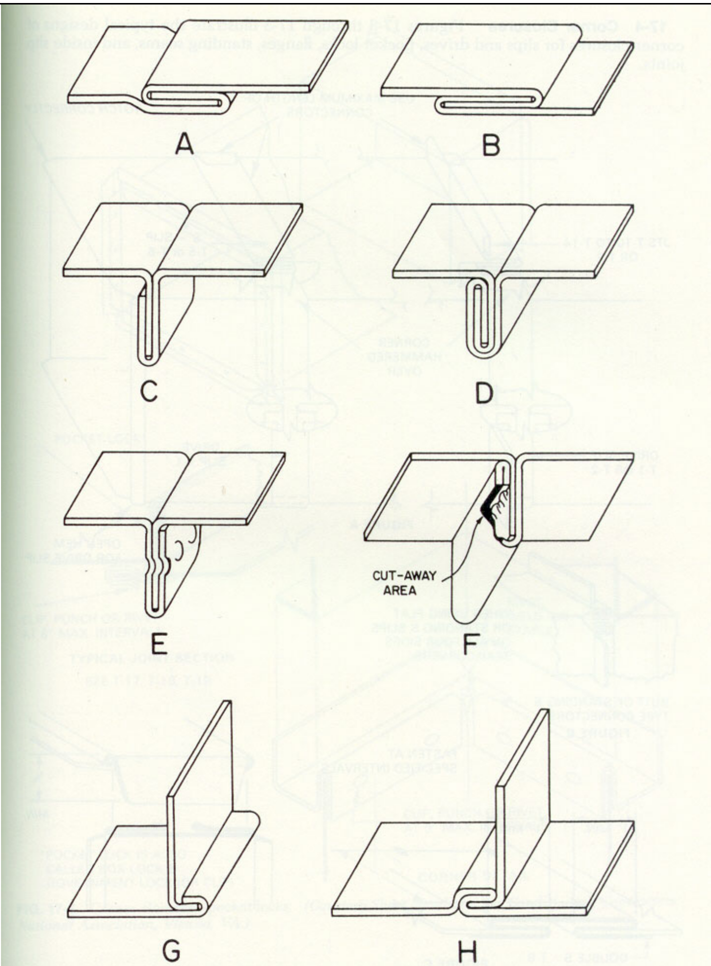
Feature:	Rivet / Screw
Example(s):	

Temporary / Permanent	Temporary
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Burley et al, 1999b

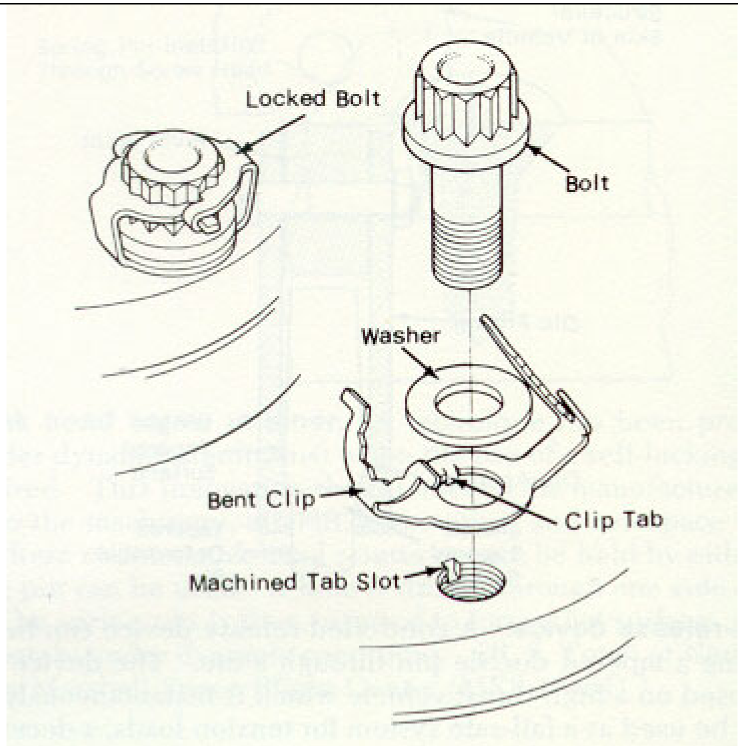
Feature:	Bolt
Example(s):	

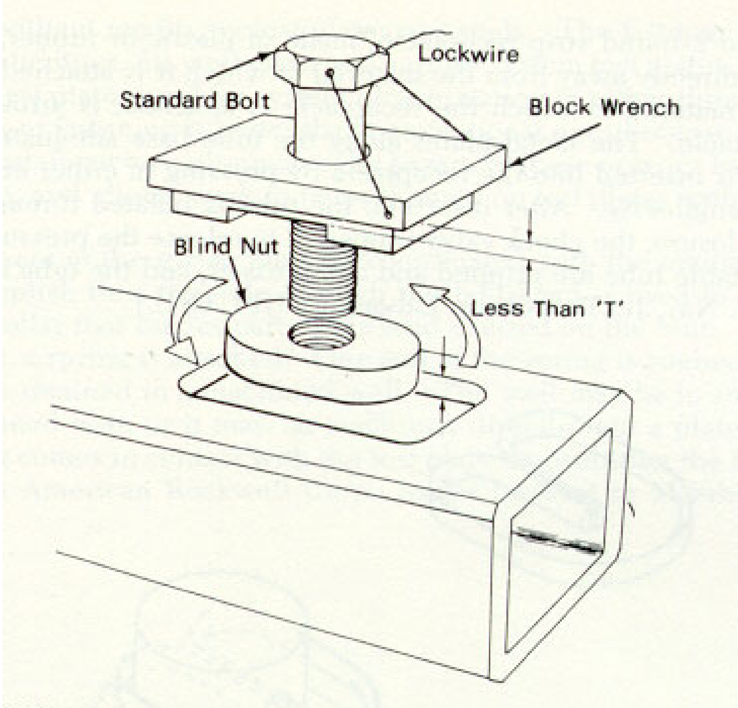


Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Parmley, 1989 and Burley et al, 1999b

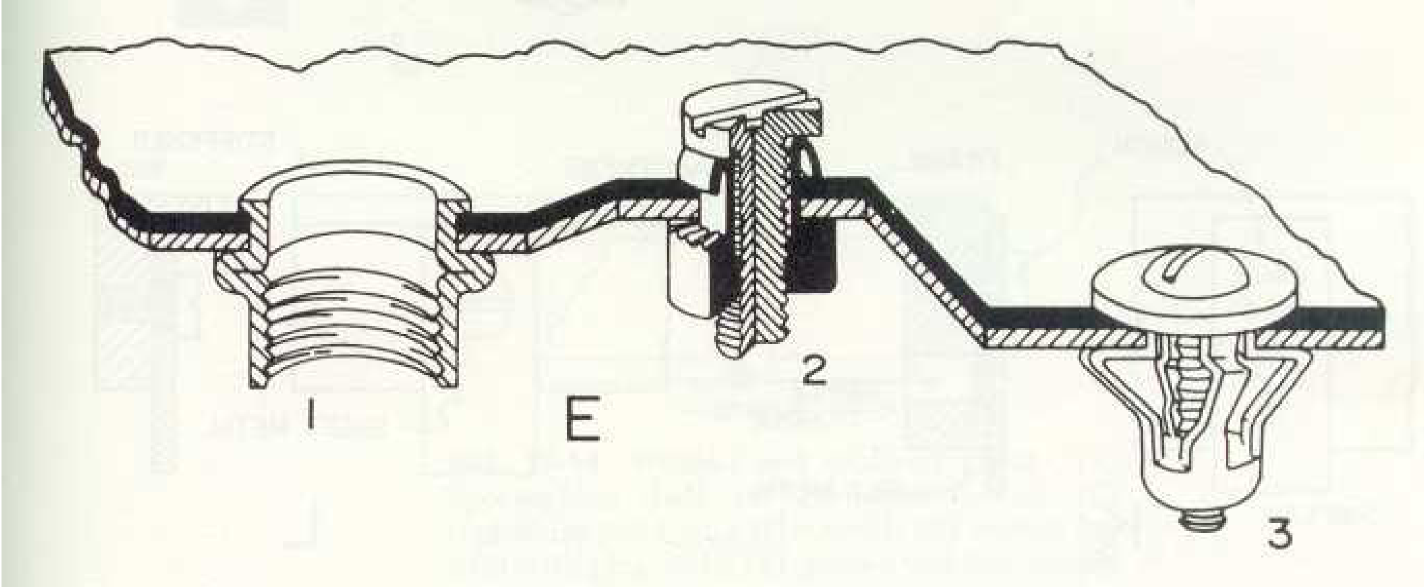
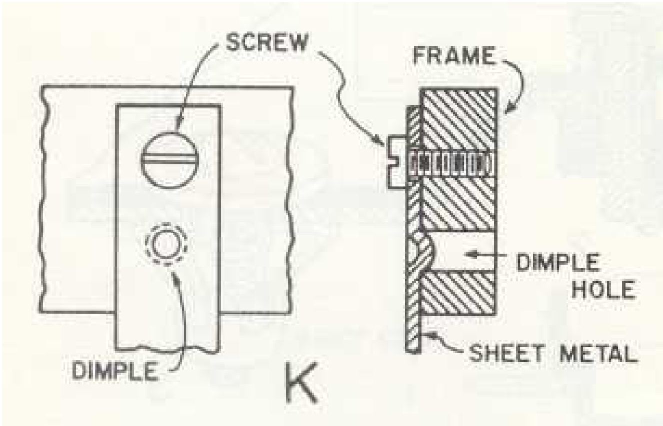
Feature:	Longitudinal Seam Joint
Example(s):	 **FIG. 17-2** Standard longitudinal seam joints. *(A)* Grooved single-lock seam; *(B)* single-lock seam; *(C)* standing seam; *(D)* double-lock standing seam; *(E)* dimpled standing seam; *(F)* self-locking standing seam; *(G)* folded-over seam; *(H)* modified folded-over seam.

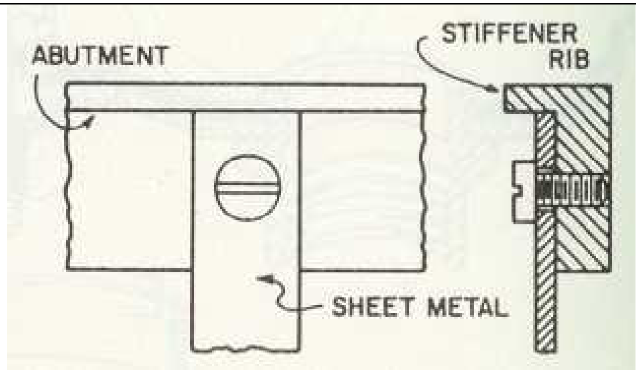
Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Parmley, 1989

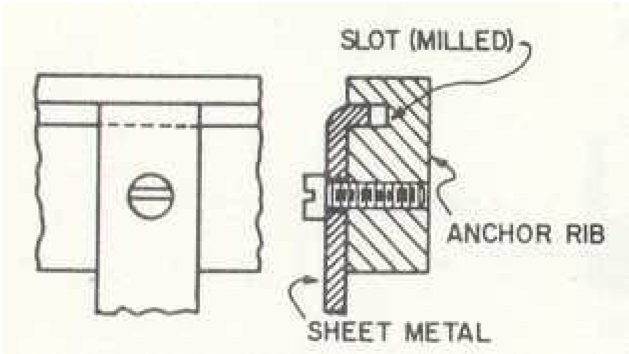
Feature:	Nut
Example(s):	

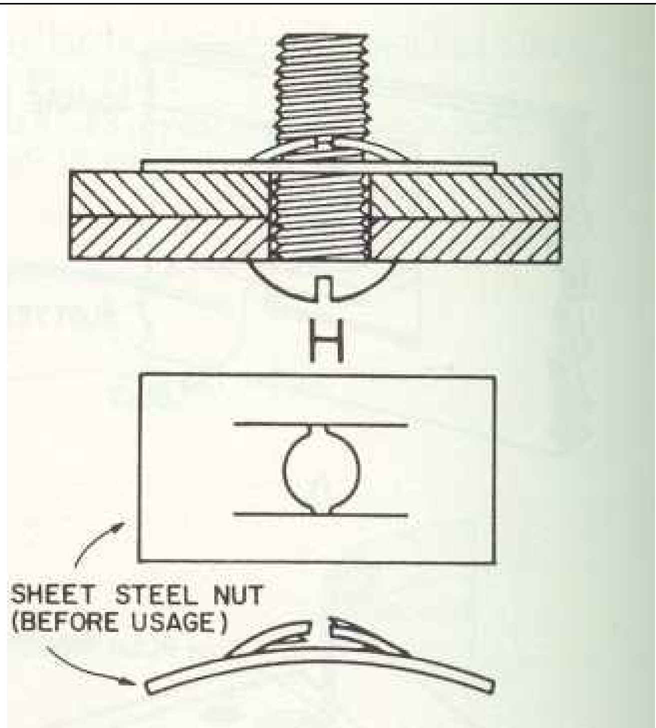


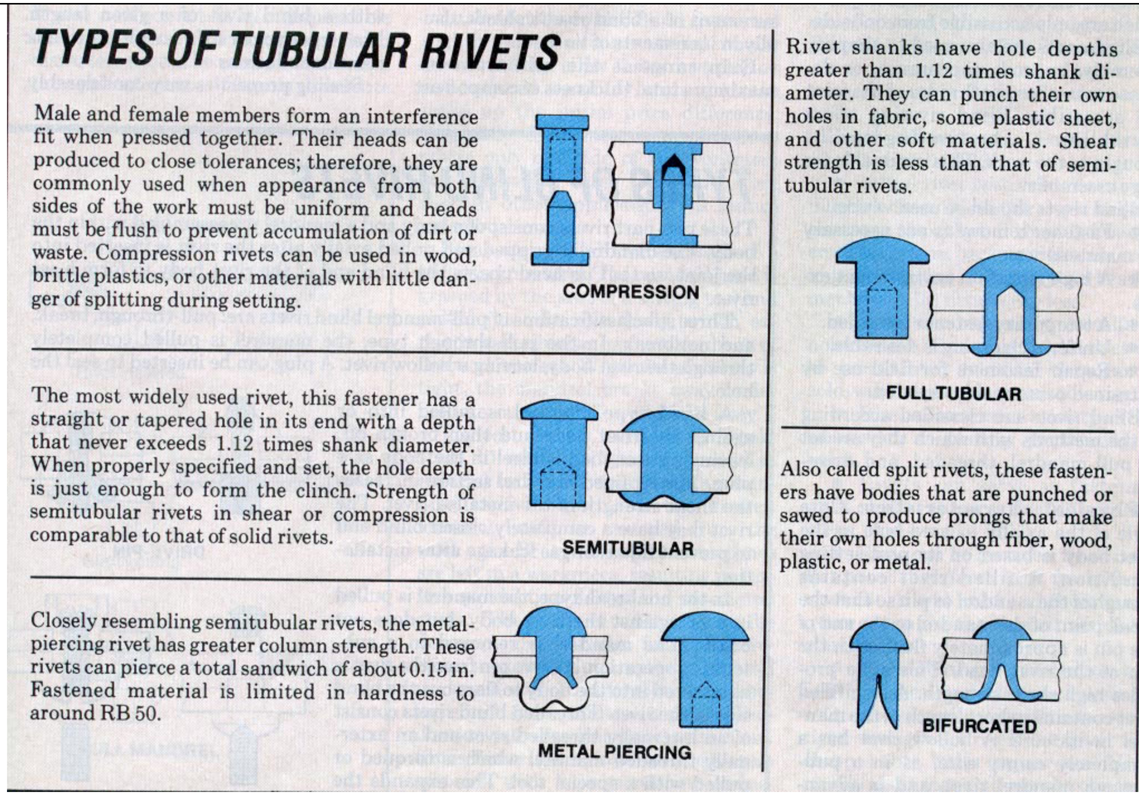
Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Parmley, 1989 and Burley et al, 1999b

Feature:	Screw
Example(s):	 


ABUTMENT
STIFFENER RIB
SHEET METAL


SLOT (MILLED)
ANCHOR RIB
SHEET METAL

	
Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Parmley, 1989 and Burley et al, 1999b

Feature:	Rivet
Example(s):	

TYPES OF TUBULAR RIVETS

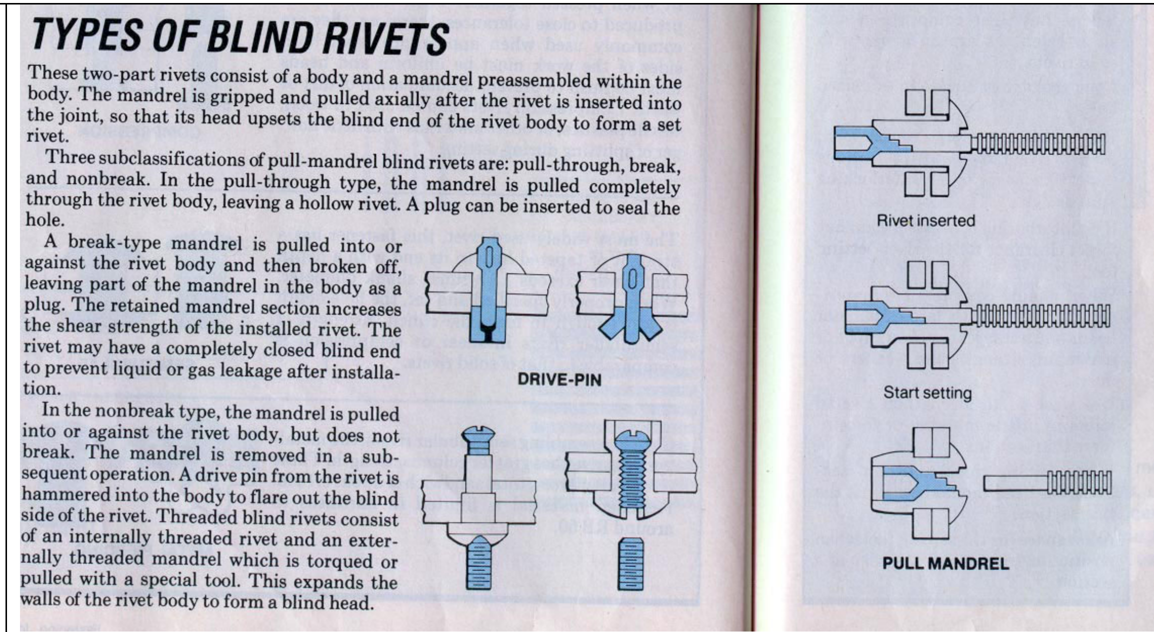
Male and female members form an interference fit when pressed together. Their heads can be produced to close tolerances; therefore, they are commonly used when appearance from both sides of the work must be uniform and heads must be flush to prevent accumulation of dirt or waste. Compression rivets can be used in wood, brittle plastics, or other materials with little danger of splitting during setting.

The most widely used rivet, this fastener has a straight or tapered hole in its end with a depth that never exceeds 1.12 times shank diameter. When properly specified and set, the hole depth is just enough to form the clinch. Strength of semitubular rivets in shear or compression is comparable to that of solid rivets.

Closely resembling semitubular rivets, the metal-piercing rivet has greater column strength. These rivets can pierce a total sandwich of about 0.15 in. Fastened material is limited in hardness to around RB 50.

Rivet shanks have hole depths greater than 1.12 times shank diameter. They can punch their own holes in fabric, some plastic sheet, and other soft materials. Shear strength is less than that of semitubular rivets.

Also called split rivets, these fasteners have bodies that are punched or sawed to produce prongs that make their own holes through fiber, wood, plastic, or metal.



TYPES OF BLIND RIVETS

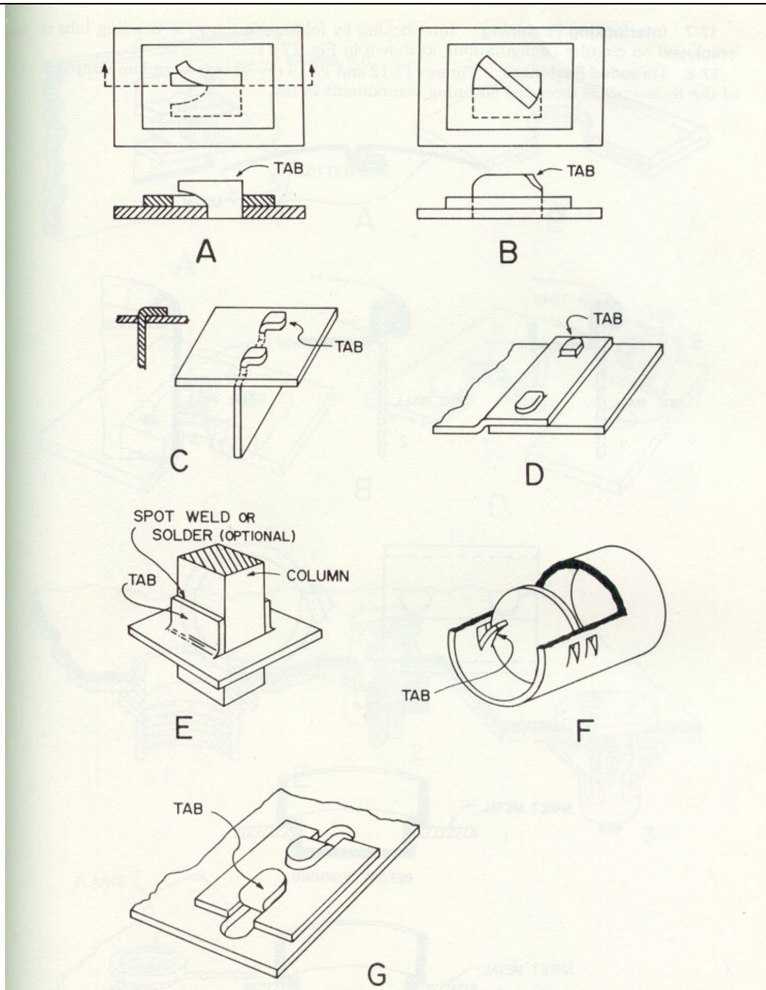
These two-part rivets consist of a body and a mandrel preassembled within the body. The mandrel is gripped and pulled axially after the rivet is inserted into the joint, so that its head upsets the blind end of the rivet body to form a set rivet.

Three subclassifications of pull-mandrel blind rivets are: pull-through, break, and nonbreak. In the pull-through type, the mandrel is pulled completely through the rivet body, leaving a hollow rivet. A plug can be inserted to seal the hole.

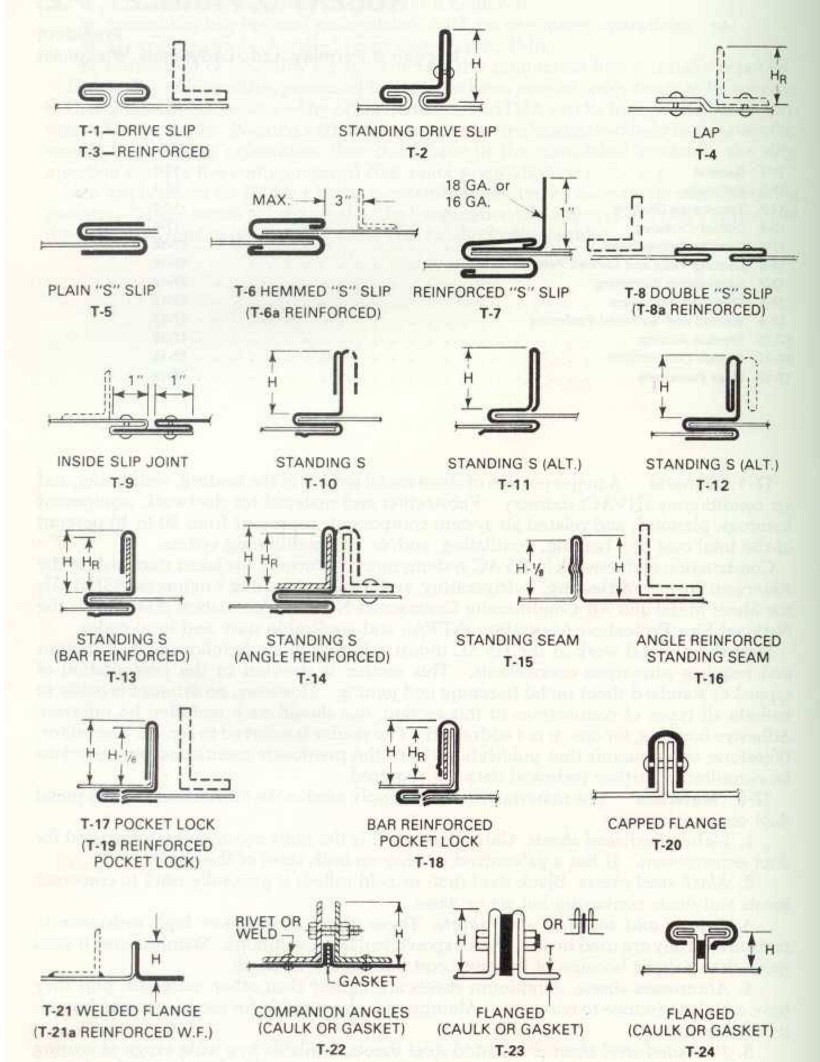
A break-type mandrel is pulled into or against the rivet body and then broken off, leaving part of the mandrel in the body as a plug. The retained mandrel section increases the shear strength of the installed rivet. The rivet may have a completely closed blind end to prevent liquid or gas leakage after installation.

In the nonbreak type, the mandrel is pulled into or against the rivet body, but does not break. The mandrel is removed in a subsequent operation. A drive pin from the rivet is hammered into the body to flare out the blind side of the rivet. Threaded blind rivets consist of an internally threaded rivet and an externally threaded mandrel which is torqued or pulled with a special tool. This expands the walls of the rivet body to form a blind head.

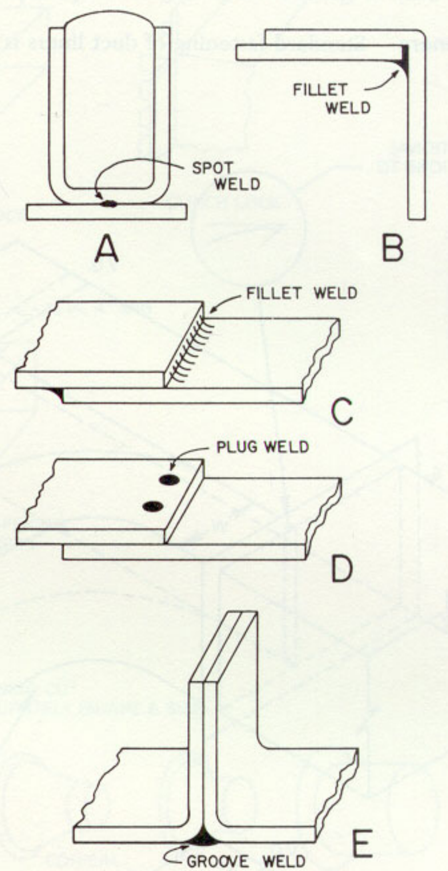
Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Parmley, 1989 and Burley et al, 1999b

Feature:	Tab
Example(s):	 **FIG. 17-10** Locking tabs and lanced parts. *(A)* Single-twisted tab; *(B)* double-twisted tab; *(C)* folded tabs; *(D)* opposite folded tabs; *(E)* lanced flaps; *(F)* locator tabs; *(G)* alignment and bent-over tabs.

Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Parmley, 1989

Feature:	Transverse Joint
Example(s):	

Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type, Dimensions
Reference:	Parmley, 1989

Feature:	Weld
Example(s):	 **FIG. 17-14** Welded and soldered joints. *(A)* Spot-welded shell; *(B)* corner-reinforced; *(C)* typical lap joint with fillet weld; *(D)* typical lap joint with plug weld; *(E)* groove weld for simple standing rib.

Temporary / Permanent	Permanent
Pre- / User Defined	Pre-Defined
Hard / Soft Feature:	Hard
Feature Attributes:	Type (Spot, Fillet, Plug, Groove, etc.), Dimensions
Reference:	Parmley, 1989 and Burley et al, 1999b

Feature:	XXX-FF*1*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Hard
Feature Attributes:	F1, F2, F3
Reference:	

Feature:	XXX-FF*2*
Example(s):	
Pre- / User Defined	User Defined
Hard / Soft Feature:	Soft
Feature Attributes:	F4, F5, F6
Reference:	