



Prediction of loads in shear cleat attachments



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PREDICTION OF LOADS IN SHEAR CLEAT ATTACHMENTS

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PREDICTION OF LOADS IN SHEAR CLEAT ATTACHMENTS

1. INTRODUCTION

This Data Item presents graphs to enable the prediction of the critical attachment loads for cleats. The graphs are based on two analyses which relate to elastic and plastic behaviour respectively. The theory on which the item is based is given in Appendix B. The Data Item also discusses the proper function of cleats and aspects of good design practice.

Structural cleats (or clips in the USA) are amongst the most common airframe components. Many thousands of cleats can be found in a typical aircraft structure. They come in a variety of forms and styles, of which four common types are identified herein, relating to the number and layout of their respective identical attachments, see Sections 2.1 to 2.4.



Harrier fin internal cleated structure
Photograph courtesy of the University of Hertfordshire

A cleat is frequently fabricated as a formed angle in sheet metal, or as a similar machined angle, being a separate item or integrally formed as part of another component. The angle to which the cleat is formed is immaterial to the analysis. The principal purpose of a structural cleat is to transmit a shear force between two adjacent webs or into a flange, acting in the direction of the cleat bend-line. Where additional normal loading must be resisted across the bend-line of the cleat, reinforcement in the form of a stress pad secured by a bolt might well be necessary to provide local bending stiffness.

A well-designed cleat is ideally of a thickness at least equal to that of the thinner of the two webs that it is joining. Good design practice should minimise the offsets of the attachments from the bend-line of the cleat to minimise the attachment loads.

In the case of individual rivets or bolts, failure can arise in the proof or ultimate mode. In the proof mode the deformation of the hole becomes unacceptable. An elongation of the hole by 1 per cent of its diameter is the criterion usually adopted in the aerospace industry. In the ultimate mode, possibly following extensive permanent deformation, the attachments cease to sustain the applied load often with the failure in shear of several or all of the attachments. Transitional failure in both proof and ultimate modes can arise in ductile structures.

The elastic analysis is based on a linear relationship between the applied load and the individual attachment loads. There is a point about which one component rotates relative to the other and the attachment loads are taken to be proportional to their distance from that centre of rotation. The method is intended to be used in situations where significant permanent deformation is not permitted, for example for brittle materials, including GRP and CFRP. It should also be used in estimating the proof strength in aerospace applications (essentially a condition in which the airframe structure has to remain airworthy)*.

The plastic analysis is based on a non-linear theory in which the loads on the attachments most remote from the centre of rotation are partially redistributed, see Section 3 Method and Applications. This implies a degree of permanent deformation in these attachments and in the material local to them. The plastic analysis is intended to be used for estimating the failure load after significant permanent deformation may have taken place in ductile materials, known as the ultimate strength in aerospace applications (the condition above which load structural collapse is anticipated).

The plastic analysis is an adaptation of the elastic analysis in which the stiffness of the most heavily stressed attachments is progressively reduced with the object of equalising their loads (or strength).

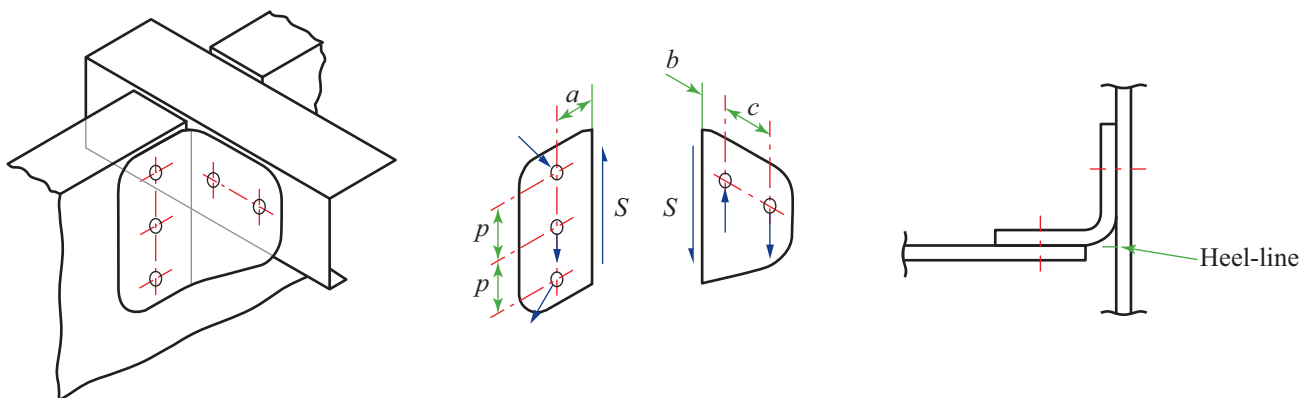
1.1 Notation

Both SI and British units are quoted but any coherent system of units may be used. Note that in the passage above and in this notation ‘attachments’ refers to the particular fastener in use.

<i>a</i>	offset dimension for multiple in-line attachments, see Sketch 1.1	m	in
<i>b</i>	offset dimension normal to heel-line, see Sketch 1.1	m	in
<i>c</i>	pitch dimension normal to heel-line, see Sketch 1.1	in	
<i>d</i>	diameter of rivet or bolt attachment	m	in
<i>k_e</i>	elastic load factor		

* The allowable proof bearing deformation at a hole is normally taken to be a 1 per cent elongation of the diameter. The associated proof bearing stress based upon the hole diameter (*d*) and the local plate thickness (*t*) in which the bearing load is acting is known as *b₁₀*. Thus the proof bearing strength *F_b* = *dtb₁₀*.

k_p	plastic load factor		
F_{exp}	experimental rivet ultimate shear strength	N	lbf
F_b	proof bearing strength of attachment	N	lbf
F_p	maximum attachment load transmitted under elastic conditions	N	lbf
F_e	maximum attachment load transmitted under plastic conditions	N	lbf
F_s	ultimate shear strength of attachment	N	lbf
N	number of attachments per face		
p	pitch dimension parallel to heel-line, see Sketch 1.1	m	in
S	total shear force transmitted by cleat, see Sketch 1.1	N	lbf
S_e	Limiting total shear force under elastic conditions	N	lbf
S_p	Limiting total shear force under plastic conditions	N	lbf
t	thickness of cleat material	m	in



Sketch 1.1 Cleat dimensions and general form

2. NOTES

A cleat transmits a shear force almost entirely by the stiffest route available, that is to say loads arise essentially in the two planes of the cleat separately, thus avoiding bending through the thickness of the material. The common axis to both faces is the heel-line and therefore this is the axis along which the shear force is constrained to act. The attachments, in the form of rivets or bolts in each face, must therefore handle this force and account for the load offset in each face separately.

An important rule emerging from this understanding of the structural cleat is that at least two attachments per face must be provided, see the photograph below. Where only two attachments are present, their individual loads can often be determined by application of the principles of equilibrium, although this can lead to an over-simplification of the problem. When three or more attachments are present, it is usually necessary to adopt an analytical approach. This is implemented as described in this Data Item.



Structural cleat – illustrating the principle of fitting a minimum of two attachments per face

In the approach adopted the limiting cleat shear load is expressed in terms of the critical attachment load(s) and an elastic or plastic load factor as appropriate:

For the elastic condition: $S_e = F_e N/k_e$

and for the plastic condition: $S_p = F_p N/k_p$

Four types of common cleat, each with identical attachments, are identified and dealt with in this Data Item as given in the following sections.

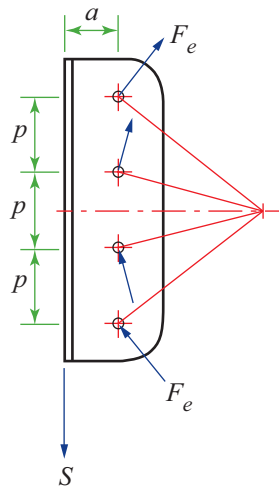
2.1 Type 1 – Multiple in-line, identical attachments

The attachments are equi-pitched and have equal nominal strength, which is the most common type of cleat style; an example is given in Sketch 2.1. Where the offset a/p is small and there are ten or more attachments, the critical individual attachment load differs little from the average value, S/N .

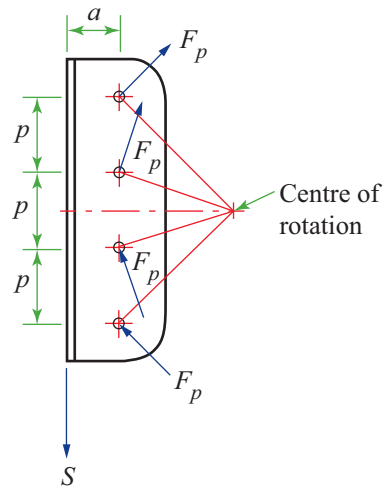
On Figure 1a, values of the elastic load factor, k_e , derived using the elastic analysis, are plotted against a/p over the range 0 to 1.0 for $N = 2$ to 8. The critical attachments are those at the ends of the joint, see Sketch 2.1a.

On Figure 1b, values of the plastic load factor, k_p , are plotted against a/p . Yielding, commencing at the outer attachments, is assumed to occur with a progressive reduction of attachment stiffness, until failure of the joint arises, see Sketch 2.1b. The method is further discussed in Section B2.1. Within the range of this data item the limiting stiffness reduction (ARF = 0.5) is reached only with $N = 3$ rivets when $a/p = 1.0$. These results are consistent with test evidence discussed in Appendix A.

For $N = 2$, the elastic and plastic load factors are the same.



Sketch 2.1a



Sketch 2.1b

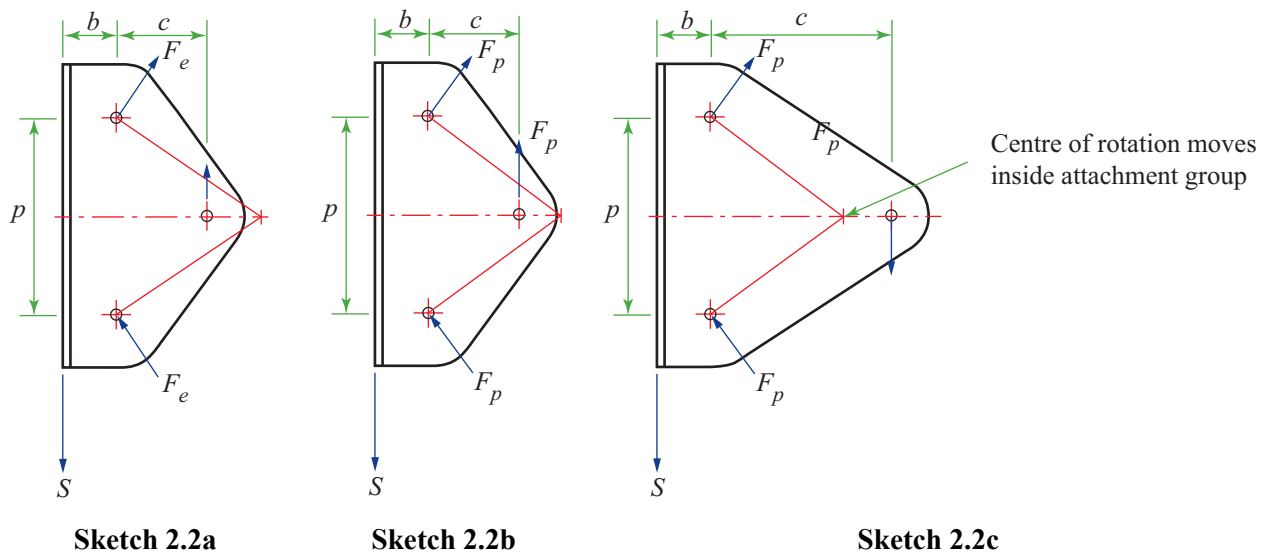
Sketch 2.1 Cleats with multiple in-line identical attachments

2.2 Type 2 – Symmetrical arrangement of three identical attachments

The three attachments have equal strength. This arrangement is useful where geometrical limitations prevent the attachments being in-line with sufficient pitch. Provided c/p can be kept small, say less than 0.4, the central attachment assists the load transfer directly, see Sketch 2.2a. On Figure 2, values of the elastic load factor, k_e , derived using the elastic analysis, are plotted against c/p over the range 0 to 5.0, for values of b/p between 0 and 1.0.

Also on Figure 2, as dashed curves, values of the plastic load factor, k_p , derived using the plastic analysis, are plotted against c/p for the same values of b/p . For very low values of c/p , yielding occurs to the extent that all three attachments approach their failing load simultaneously, see Sketch 2.2b, shown on the concave upwards curves.

For higher values of c/p the remote attachment load reverses direction and it has been found that k_p becomes very close to k_e . When the inner attachments fail the joint may be anticipated to swing about the outer attachment see Sketch 2.2c. A summary of the theory is given in Section B2.2.

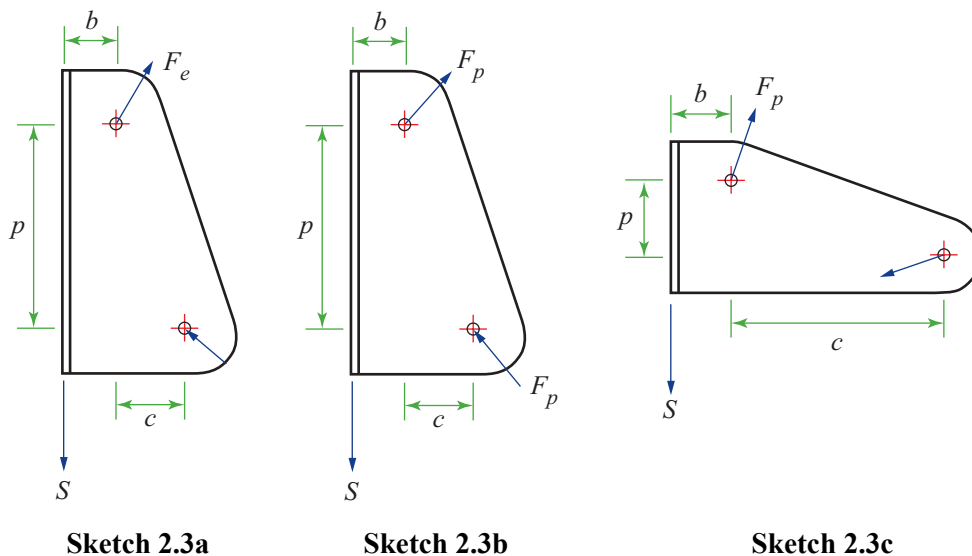


Sketch 2.2 Symmetrical arrangement of three identical attachments

2.3 Type 3 – Slanting arrangement of a pair of identical attachments

Here two attachments of equal strength are arranged on a line slanting from the heel-line. This can be useful where geometric limitations prevent the attachments being in-line as in Type 1. However, the inner attachment tends to attract the greater load elastically, see Sketch 2.3a. On Figure 3, values of the elastic load factor, k_e , for the inner attachment, derived using the elastic analysis, are plotted against c/p over the range 0 to 5.0, for values of b/p between 0.1 and 1.0.

Also on Figure 3, values of the plastic load factor, k_p , derived using the plastic analysis, are plotted against c/p for the same range of values of b/p . For low values of c/p , yielding causes both attachment loads to become equal in the region of the concave upwards curves of Figure 3. See also Sketch 2.3b. For larger values of c/p , the inner rivet attracts the greater load leading to its failure, leaving the joint to swing about the outer attachment, see Sketch 2.3c. A summary of the theory is given in Section B2.3.



Sketch 2.3 Slanting arrangement of a pair of attachments of equal strength