



ESDU 03001

Issued December 2003

With Amendment A

February 2008

**Elastic buckling of long, flat,
symmetrically-laminated (AsBoDf),
composite stiffened panels and struts in
compression**

**Associated software:
ESDUpac A0301
ESDUpac B0301**



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ELASTIC BUCKLING OF LONG, FLAT, SYMMETRICALLY-LAMINATED (ASBODF), COMPOSITE STIFFENED PANELS AND STRUTS IN COMPRESSION

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ELASTIC BUCKLING OF LONG, FLAT, SYMMETRICALLY-LAMINATED (AsBoDf), COMPOSITE STIFFENED PANELS AND STRUTS IN COMPRESSION

1. INTRODUCTION, THEORY AND APPLICATION

1.1 INTRODUCTION

This Data Item accompanies ESDUpac A0301 which provides a Fortran computer program which calculates initial compressive buckling loads for long flat stiffened rectangular panels and struts made of composite materials. The method on which the program is based is the finite strip method (FSM), which is particularly well-suited to the analysis of prismatic structures that show periodic deformation patterns under loading. A brief outline of the finite strip method is presented in Section 1.3 of Data Item No. 98016*.

Table 1.1 gives a list of related ESDU Data Items, for some of which the program provides an alternative computational method for estimating the compressive buckling loads of panels or struts.

Despite the fact that the program is based on FEM-like discretization procedures, it possesses significant advantages in speed compared to a full-scale finite element approach.

Although there are several significant and fundamental differences regarding the analyses performed by the two programs of ESDUpacs A0301 and A9816, they are very similar in terms of actual use and all options provided in the latter are also available in program A0301. Section 1.3.2 summarizes these options. For further details on the predefined skin-stringer sections, skin-stringer joint models and types of analysis, see Appendix A of this Data Item and Section 1.3 and Appendices B and C of Data Item No. 98016.

The buckling analysis is only applicable to models of panels or struts constructed from composite laminates that fall into the category of balanced, or mid-plane symmetric, laminate lay-ups, that is, generally orthotropic laminates of the **AsBoDf** type, see Data Item No. 94003†. This restriction results from the basic requirement that a uniform pre-buckling state of strain must exist for the buckling condition, and hence the solution, to be applicable.

It is emphasized that the buckling stresses obtained for *generally* orthotropic laminates strictly apply to **long** panels; 'long' here means that the buckling half-wavelength should be small compared to the length between the panel end supports to allow many identical waves to develop and thus – essentially – render the buckling condition independent of the boundary conditions at the ends of the panel. No such restriction applies to *specialty* orthotropic panels and struts.

The computational capabilities of the program are demonstrated in Section 1.4; results are presented for selected examples that illustrate the scope of the program with regard to its ability to analyse models of stiffened panels made of composite material with generally orthotropic laminates.

Typical features that are inherent in the finite strip formulation used by the program are outlined in Section 1.4.4 of Data Item No. 98016 and apply equally to results obtained with program A0301.

Section 2 of the Data Item may be considered as a Program User's Manual. It consists of descriptions of the input and output files, interwoven with appropriate examples to explain or elucidate detailed aspects of the finite strip input and output models.

* Data Item No. 98016 "Elastic buckling of flat isotropic stiffened panels and struts in compression".

† Data Item No. 94003 "Stiffnesses of laminated flat plates".

TABLE 1.1 Relevant Data Items on Buckling of Flat Composite Plates and Panels

<i>Data Item No.</i>	<i>Volume No.</i>	<i>Title</i>
<i>Buckling</i>		
72012	2	Information on the use of Data Items on the buckling of plates and compression panels manufactured from isotropic materials
73015	13	Estimation of the local buckling stress under biaxial compression of an isotropic skin with fibre reinforced integral unflanged stiffeners
78021	11	Guide to Items on the strength and stability of struts
80023	13	Buckling of rectangular specially orthotropic plates
81047	13	Buckling of flat rectangular plates (Isotropic, orthotropic and laminated composite plates and sandwich panels)
89007	11	Flexural and torsional-flexural buckling of thin-walled open section struts
94005	13	Buckling of flat rectangular orthotropic plates
94006	17	Elastic buckling of unbalanced laminated fibre reinforced composite plates (Rectangular plates of AsBtDs type, all edges simply-supported under biaxial loading)
<i>Composite Material</i>		
94003	14	Stiffnesses of laminated flat plates.

1.1.1 General Scope and Limitations of the Method of ESDUpac A0301

ESDUpac A0301 has been written to compute the initial compressive buckling loads of models of panels that are presumed to behave within the realm of classical laminate thin plate theory. See Derivation 2 for the pertinent assumptions that are basic to that theory and Paragraph 2 of Section 1.1.1 of Data Item No. 98016 for a broader perspective of its application in the context of the finite strip method.

Because of the inherent freedom, on account of the finite strip formulation, for the buckling modes to develop across the panel, the scope of the computable modes includes the combined torsional-flexural mode. No particular fixed points of rotation of the section, or parts of the section, are presumed to exist, other than those enforced by the user through the imposition of zero-displacement conditions. A comprehensive account of local, flexural and torsional-flexural buckling may be found in Section 3 of Data Item No. 72012*. These modes may – in the present context – be combined with a skew deformation pattern as a result of non-zero bending-torsion coupling terms in the laminate $[ABD]$ matrix. The validity of this approach hinges on the presumption that the resulting buckling half-wavelength is small compared to the actual panel length, so that the assumption of periodicity holds.

* Data Item No. 72012 “Information on the use of Data Items on the buckling of plates and compression panels manufactured from isotropic materials”.

Thus, the present version of ESDUpac A0301 is able to compute the compressive buckling stresses and – if relevant – the associated modes for local, flexural and torsional or torsional-flexural buckling for panels and struts made of composite materials and subjected to pure compressive loading. It is emphasized, however, that the method presented has no capabilities to analyse the response of a panel loaded under axial compression into the post-buckling range. See Data Item No. 78021* for more information on that subject.

The analysis provides valid solutions for panels and struts consisting of generally orthotropic laminates of the **AsBoDf** type, see Data Item No. 94003. This aspect is briefly highlighted in Section 1.3.1.1. The types that are allowable is dictated by the requirement that a uniform pre-buckling state of stress exists, together with satisfaction of given boundary conditions.

In addition to those mentioned above, ESDUpac A0301 is subject to the same restrictions and limitations as ESDUpac A9816. Details of those restrictions and limitations are given in Data Item No. 98016 and, because of their importance, a brief summary is repeated here.

- (i) Although the buckling modes that may be computed are general in form, it should be noted that inter-rivet buckling is not treated. Data for such cases are provided in Data Items Nos Struct 02.01.08† and Struct 02.01.09‡.
- (ii) The plate strip element matrix is derived for flat elements. A buckling analysis for a model of a curved panel or shell-type geometry, where, amongst other things, significant membrane action could be expected as a result of its overall curvature, could be carried out, by approximating the curved geometry with flat strip elements, but this is not recommended. The main reason for this is the fact that the present program only treats ‘bifurcation’ buckling behaviour, whereas curved panels may well buckle or even collapse in a ‘limit point’ buckling mode, the prediction of which is beyond the scope of the program.

1.2 NOTATION

Both SI and British units are quoted but any coherent system of units may be used. Additional notation is defined where required.

A	cross-sectional area	m^2	in^2
A_c	equivalent axial stiffness, $A_c = A_{11} - \left(\frac{A_{12}^2}{A_{22}} \right)$	N/m	lbf/in
A_{ij}	elements of [A] -sub-matrix	N/m	lbf/in
B_{ij}	elements of [B] -sub-matrix	N	lbf
b, B	width	m	in
D	diameter	m	in
D_{ij}	elements of [D] -sub-matrix	N m	lbf in
d	width	m	in
E	Young’s modulus	N/m^2	lbf/in^2

* Data Item No. 78021 “Guide to Items on the strength and stability of struts”.

† Data Item No. Struct 02.01.08 “Buckling in compression of sheet between rivets”.

‡ Data Item No. Struct 02.01.09 “Inter-rivet buckling curves for specific materials”.

E_c	$= \frac{A_c}{t}$, laminate apparent modulus of elasticity	N/m ²	lbf/in ²
e_1, e_2	edge widths, see Sketch A1.2	m	in
f	stress	N/m ²	lbf/in ²
G	shear modulus	N/m ²	lbf/in ²
h	height	m	in
I	second moment of area	m ⁴	in ⁴
ID_{type}	predefined skin-stringer section identifier		
I_{y0}	second moment of area of element about axis through its centroid and parallel to model y -axis (see Sketches A2.1 to A2.12 for location of y -axis)	m ⁴	in ⁴
I_{yy}	second moment of area of element about axis joining its node points	m ⁴	in ⁴
I_{zz}	second moment of area of element about axis through its centroid and perpendicular to axis joining its node points	m ⁴	in ⁴
i	counter or index		
k_1, k_2	boundary condition identifiers		
L	buckling half-wavelength	m	in
L_0	starting half-wavelength, see Section 1.3.3 and Table 2.2	m	in
LFT	Laminate file type specifier		
L_{inc}	incremental half-wavelength	m	in
L_p	panel length	m	in
L_s	specified half-wavelength	m	in
MC_i	material property code		
M_x, M_y, M_{xy}	moments per unit width	N m/m	lbf in/in
N_{st}	number of stringers		
N_x, N_y, N_{xy}	direct and shear loadings	N/m	lbf/in
OP	output specifier		
P	load	N	lbf

p	pitch	m	in
R	stringer corner inside bend radius	m	in
Runtype	run type specifier		
t	thickness	m	in
u, v, w	displacements in x -, y - and z -directions, respectively, in buckling mode, see Sketch 1.1	m	in
W_i	width	m	in
x, y, z	co-ordinates, see Sketch 1.1	m	in
z_{avg}	distance of centroid of element from y -axis	m	in
α, β	principal axes of orthotropy of a layer, see Sketch 2.1		
$\epsilon, \epsilon_x, \epsilon_y, \gamma_{xy}$	strains		
$\kappa_x, \kappa_y, \kappa_{xy}$	curvatures	m^{-1}	in^{-1}
ν	Poisson's ratio		
θ	angle of orientation of element about x -axis, measured anticlockwise from y -axis ('Theta' in program output)	rad	rad
σ	direct stress ('Sigma' in program output)	N/m^2	lbf/in^2
ϕ	rotational displacement about x -axis in buckling mode ('Phi' in program output), see Sketch 1.1	rad	rad
ψ	lay-up angle, see Sketch 2.1	deg	deg
ω	angle of inclination of web of top-hat and corrugated stringer sections, see Sketches A2.9, A2.11 and A2.12	rad	rad

1.2.1 Suffices

0	start value
1,2, ...	indices
a, adh	adhesive
avg	average
$chord$	chord of sector of stringer corner
cr	critical (or buckling)

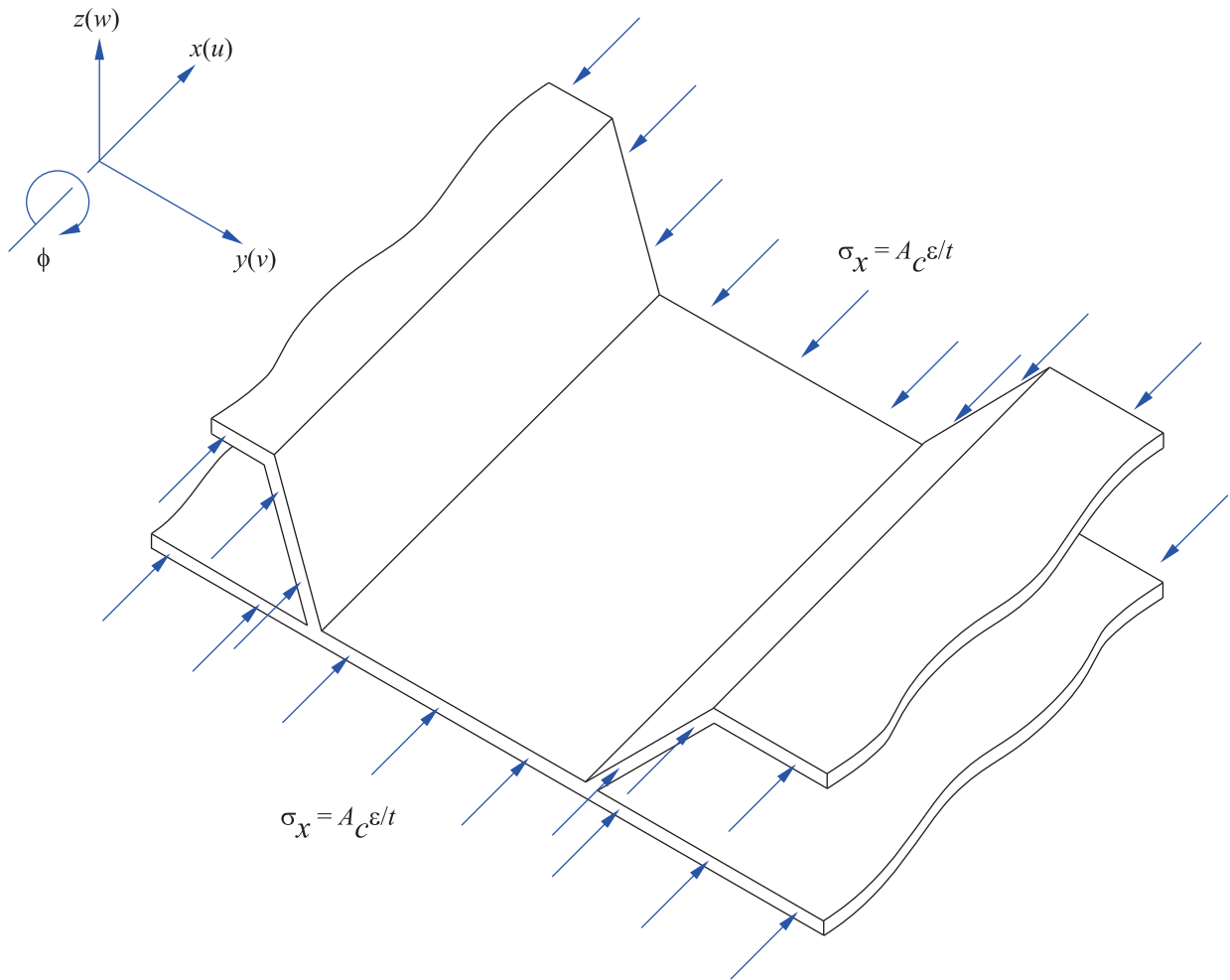
E	Euler
EL, El	element, elastic
f	flat (in this Data Item, a flat refers to any of the individual components that form part of a section)
i, j, k	indices
l, lb	layer, local, local buckling
Nf	number of flats
p	panel
r, riv	rivet
sk	skin
st	stringer
x, y	in x - and y -directions respectively
α	unidirectional layer axial direction
β	unidirectional layer transverse direction
$\alpha\beta$	unidirectional layer axial-transverse coupling

1.2.2 Matrix and Vector Notation

$[A]$	matrix
$\tilde{x}$	vector

1.2.3 Sign Convention

Tensile loads, stresses and strains are positive; compressive loads, stresses and strains are negative.



Sketch 1.1 Basic co-ordinate system

1.3 ASPECTS OF THE STRIP METHOD

1.3.1 Introduction

The finite strip method may be used to advantage for structural analysis in cases where the analysis pertains to models of prismatic structures that exhibit periodic deformation behaviour. These conditions prevail when considering buckling phenomena that occur in stiffened panels under compressive loading.

The uniformity of the pre-buckling state and the usually prismatic character of panels allow the adoption of the assumption of periodicity for the buckling deformations. This implies that the strip method – employed as a general formulation to solve the buckling problem for complicated strut and panel designs – can be utilized in the present application with similar advantages.

A more detailed account of the strip method is presented in Section 1.3 of Data Item No. 98016. Here it suffices to mention the fact that all formulations employed in ESDUpac A9816 for setting up the system matrices for the finite strip buckling problem have been utilized in ESDUpac A0301 without modification.

A major aspect of the formulation of the buckling condition for application to the treatment of composite panels and struts for buckling in axial compression is the more general form of the relation between stress

and strain that characterizes the behaviour of the strip elements of a panel or strut fabricated from composite material. This subject is briefly treated in the following sub-sections.

1.3.1.1 The set of allowable [ABD] matrices

The buckling condition utilized in computing the critical stress of composite panels and struts depends on the laminate lay-up properties which determine the membrane and bending stiffnesses of a laminate. These stiffnesses are contained in the so-called [ABD] matrix, which defines the relation between stress-resultants and strains (the generalized form of Hooke's law for general anisotropic materials):

$$\begin{bmatrix} \tilde{N} \\ \tilde{M} \end{bmatrix} = [ABD] \begin{bmatrix} \tilde{\epsilon} \\ \tilde{\kappa} \end{bmatrix} = \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{B}^T & \mathbf{D} \end{bmatrix} \begin{bmatrix} \tilde{\epsilon} \\ \tilde{\kappa} \end{bmatrix}. \quad (1.1)$$

Classical laminate theory furnishes the equations that can be used to compute the stiffnesses for a given lay-up and given unidirectional properties; those equations are given in Data Item No. 94003. In Table 7.1* of that Data Item a classification of the various lay-up types, or stacking sequences, in conjunction with the associated form of the [ABD] matrix, is also given.

Not all types of laminates are admissible for estimating the initial buckling stress with the theory utilized in the finite strip method. For instance, plates with general lay-ups are likely to show out-of-plane deflections before buckling occurs, due to coupling between bending and stretching (or compression) terms in the generalized stress-strain relation on account of a non-zero [B] sub-matrix. In the more general case of stringer-stiffened *panels*, it is perfectly conceivable that combinations of different lay-up types occur. This implies that the assumption of a uniform pre-buckling state, which is necessary for the bifurcation buckling condition to apply, cannot be satisfied in general. The types of laminate admissible for the composite panel buckling analysis presented in this Item are therefore restricted to those categorized as **AsBoDs** or **AsBoDf**.

From this arises the restriction that the [B] sub-matrices and elements A_{16} and A_{26} in the [A] sub-matrix be zero. This results in the following stress-strain relations.

$$\tilde{N} = \begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{21} & A_{22} & 0 \\ 0 & 0 & A_{66} \end{bmatrix} \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{bmatrix} = [\mathbf{A}] \tilde{\epsilon} \quad (1.2)$$

$$\text{and} \quad \tilde{M} = \begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{21} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{bmatrix} = [\mathbf{D}] \tilde{\kappa}. \quad (1.3)$$

In order to accommodate a skewed buckling mode to represent the skew deformation pattern that arises when D_{16} and D_{26} are non-zero, the function for the w -displacement of a strip element in the buckling mode, adopted in the finite strip formulation, is taken from Derivation 1 where it is used to formulate an

* Table I in the paper version of the Data Item.

approximate method for estimating the critical shear stress for isotropic plates. That deflection function may be written:

$$w = F_1(y) \sin\left(\frac{\pi x}{L}\right) + F_2(y) \cos\left(\frac{\pi x}{L}\right). \quad (1.4)$$

The first term is that utilized in the finite strip formulations of Data Items Nos 98016 and 01001*. The inclusion of the second term for this Data Item allows skew deformation patterns to be accommodated. Compatible functions for the u - and v -displacements are adopted to develop the stiffness matrices. Details may be found in Derivation 3.

1.3.2 Stringer Section Models

This section describes the various models that may be utilized to solve buckling problems for a variety of geometries. As mentioned in the introduction, although there are significant differences between the actual analyses performed, all these features are the same as those available in the program of Data Item No. 98016. Therefore, the following sections are condensed reproductions of what is presented in that Data Item.

1.3.2.1 Predefined skin-stringer sections

One of the features of the program is a pre-processor routine which simplifies the input of data for a number of commonly used skin-stringer sections by generating the strip model data file for a panel consisting of a skin and a number of stringers. This option frees the user from the need to generate a usually large strip model data file. The stringer types for which this feature is available are illustrated in Table 1.2. Detailed geometrical and model information for these skin-stringer sections is presented in Appendix A and input details are presented in Tables 2.2 and 2.3 of Section 2.3.2.

In most cases, use of the element meshes that are given for the predefined sections is expected to give reasonably accurate results; if, however, a very local buckling mode arises, it is suggested that the strip density in the region of the buckle is increased. See Section 1.4.2 of Data Item No. 98016 for more detailed comments on this aspect of the strip models.

1.3.2.2 General panel model

It is emphasized that the user may still generate the strip model data file for a panel or strut of completely arbitrary cross-section, without utilization of the predefined sections shown in Table 1.2. The input file definitions required in that case are provided in Section 2.4.2. When analysing struts it will often be necessary to generate the strip model data file in this way.

In many cases, however, modification of a strip model data file generated for one of the standard predefined sections may satisfy the user's needs. A detailed example of adapting such a file to specific requirements is presented in Appendix C of Data Item No. 98016, where the strip model data file for an I-section stiffened panel is modified.

1.3.2.3 Special single-stringer section – specially orthotropic (AsBoDs) laminates only

An added option for use with a predefined skin-stringer section consisting of **specially** orthotropic laminates is the possibility of representing a wide panel having many stringers by a special single skin-stringer model with predefined boundary conditions.

* Data Item No. 01001 "Elasto-plastic buckling of flat isotropic stiffened panels and struts in compression".

The special single-stringer model consists of a piece of skin of width equal to the stringer pitch with the web of the stringer located centrally (except for the top-hat sections which are simply located centrally on the skin).

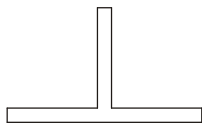
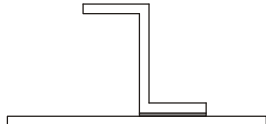
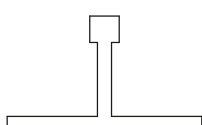
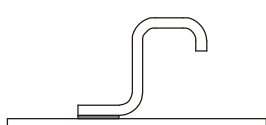
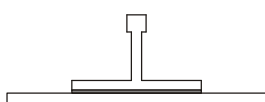
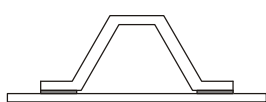
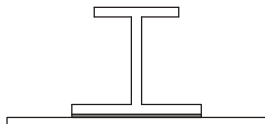
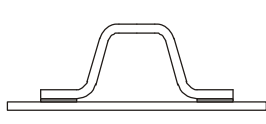
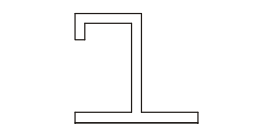
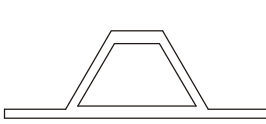
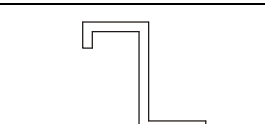
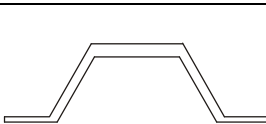
The predefined boundary conditions have been selected in such a way as to give complete freedom in the z -direction whilst not allowing lateral in-plane displacements and rotations in the buckling mode of the outer edges of the skin section, see Sketch 1.2 of Data Item No. 98016. This option allows quick exploration of the variation of compression buckling loads for ranges of geometrical and physical parameter values that may occur in a new design.

*Note that this 'special single-stringer model' is only applicable to models consisting strictly of **specially orthotropic** laminates that show rectangular – i.e. non-skew – buckling modes.*

Though useful for practical purposes, especially in cases where symmetric stringer sections are analysed, care should be exercised in cases where asymmetry of the section, or other irregularities, may give rise to buckling deformations for the full panel cross-section that do not fit the predefined boundary conditions for this special single-stringer case. This is shown more explicitly in the example problem in Section 1.4.4.2 of Data Item No. 98016. It is recommended that the results of special single-stringer analyses of panels with asymmetric stiffeners always be verified by a multi-stringer analysis.

A model for a single stringer with user-specified boundary conditions can obviously be analysed as well. The typical differences in the definitions for the two single-stringer models are discussed in Section [A1.1](#) of Appendix [A](#).

TABLE 1.2 Predefined Skin-stringer Sections

Type No.	Section	Relevant section of Appendix A	Type No.	Section	Relevant section of Appendix A
1		A2.1	7		A2.7
2		A2.2	8		A2.8
3		A2.3	9		A2.9
4		A2.4	10		A2.10
5		A2.5	11		A2.11
6		A2.6	12		A2.12

1.3.2.4 Sections having a large corner radius

Some of the predefined skin-stringer section types shown in Table 1.2 require the specification of the stringer corner radius. The section types for which this is the case are denoted in Table 2.3 by 'LR', for large radius. 'Large radius' here simply means that the stringer corner radius might not be negligible, and for these sections a finite strip model that takes the value of the bend radius into account is used for the stringer corners. This aspect is elaborated in Section A1.2 of Appendix A where information on how to model a corner when not using the predefined skin-stringer sections is provided. The effect of different bend radii on the critical stress is illustrated by the example in Section 1.4.4.1 of Data Item No. 98016.

1.3.2.5 Skin-stringer joint models

The use of the finite strip method allows the scope of the computational models to be extended with little additional effort. One way in which this has been done is through the development of adhesive layer and rivet line elements. These elements function as joining elements between the stringer flange and the skin and allow the creation of a more realistic panel model.

For the adhesive layer, simplified strain-displacement relationships are adopted on the basis that the stress distribution is assumed to be constant through the thickness of the adhesive layer. The strain energy can then be formulated in terms of the degrees of freedom of the two plate strips that constitute the joint. Also, in order to accommodate a wide range of adhesive tension/compression and shear stress-strain behaviour, the Young's modulus, E_{adh} , and shear modulus, G_{adh} , are uncoupled in the stress-strain relationship for the adhesive layer. A more detailed account of the specific features of the adhesive layer element, and of the mechanical joint model to be described next, may be found in Appendix B of Data Item No. 98016. The adhesive material behaviour is presumed to be elastic in all analyses.

To make some allowance for a rivet line connection between the skin and stringer, a rivet line element is derived for the model depicted in Sketch B2.2 of Appendix B of Data Item No. 98016. The two-dimensional model of the panel cross-section allows the connection of adjacent skin and stringer nodes via a simple beam element. This element is presumed to function strictly as a tension-compression-bar/bending-in-two-directions beam element.

In practical cases, the rivet line is usually located about halfway across the skin flange of the stringer. Unless preventive measures are taken (see below), the finite strip approximation for the actual panel model may show a displacement pattern in the buckling mode in which the node point at the stringer heel or the node point at the flange tip displaces beyond the adjacent skin nodal point. In the real structure, that is not possible and the buckled shape is less extreme because the skin and flange constrain each other.

This freedom of the model stringer to rotate and for the edges to penetrate the skin will result in a conservative estimate of the buckling load, but will be physically unrealistic. Some alleviation of the phenomenon can be introduced by placing additional elements between the skin and the stringer, and over the otherwise unsupported nodes, to represent the contact stiffness or the stiffness of an adhesive or sealant layer when this is present.

Note that neither of these connection elements contributes to the load-carrying cross-sectional area of the panel.

It should be emphasized again here that no attempt has been made to equip the present version of the program with the means to analyse inter-rivet buckling phenomena.

1.3.3 Analysis Options

For all the models described in the previous sections, the following three analysis or runtime options for obtaining buckling loads are provided. Full details of the precise values of the buckling half-wavelengths used in the three options are given in Section 2.4.1.

- (1) Calculation of the buckling load for the buckle half-wavelength equal to the value, L_s , specified in the input. (Note that lower buckling loads associated with buckling half-wavelengths less than the specified value will be ignored.) A useful facility associated with this option is that it will provide details of the buckling mode.
- (2) Calculation of the complete P - L curve with L – the buckling half-wavelength – ranging from a small value up to the length, L_s , specified in the input.
- (3) A more precise search, starting from a user-specified value, L_0 , for a minimum in the load-buckling half-wavelength characteristic of the panel.

The use of the three options is demonstrated in Figure 1 which illustrates which option to use for what purpose. Detailed guidance on the use and interpretation of curves such as that shown in Figure 1 and other useful information on buckling in general are presented in Data Item No. 78021, "Guide to Items on the strength and stability of struts". A demonstration of the use of the three options is given in Section A1.6, notably its introduction and the subsequent listings of input and output files for all options.

It is emphasized that, in the case of models made with **generally** orthotropic laminates, essentially, only buckling stresses with associated half-wavelengths that are small compared to the strut or panel length measured between *rigid* end-supports can be considered accurate. The word 'small' here basically means that the value of L associated with the buckling stress should be less than $\sim L_p/4$. For example, the buckling stress for a long simply-supported panel with four or five intermediate floating frame supports, with an associated half-wavelength equal to the frame spacing, may be considered valid because it does not violate the requirement that the buckling half-wavelength be small compared to the panel length. The apparent restriction results from the character of the function selected for the buckling mode, see Section 1.1 and Equation (1.4), and it does not apply to **specialty** orthotropic panels and struts.

The second option is available because the buckling phenomenon may be rather complicated on account of the various deformation patterns that may occur at different load levels, such as overall panel buckling, torsional, flexural, or a combination of the last two, and/or local inter-stringer buckling, *et cetera*.

Although which option is used will depend on the nature of the problem under consideration, it is envisaged that, in cases where the first option does not provide sufficiently detailed results, or where there is a desire to investigate other buckling half-wavelengths, the second option will be used to identify areas of the $P-L$ curve that are of interest for a particular panel. The last option will then be used to perform more detailed analyses of these areas. If desired, the first option may then be used to provide details of the buckling mode.

A summary of the various models and analysis options is given in Table 1.3.

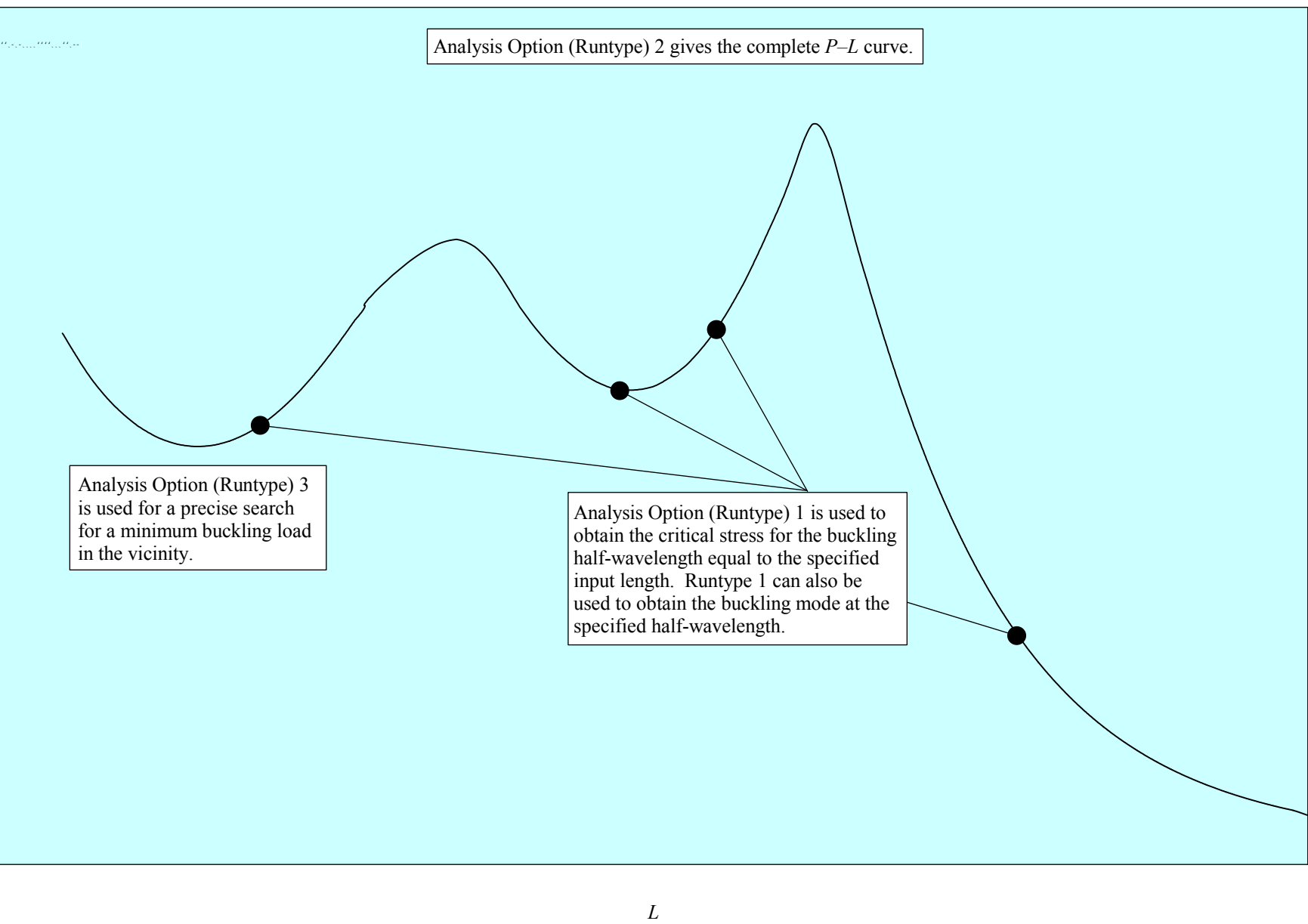


FIGURE 1 ILLUSTRATION OF ANALYSIS (RUNTYPE) OPTIONS (for the case of the channel-section strut of Figure 8 of Data Item No. 76023)

TABLE 1.3 Finite Strip Models for Panels and Struts

<i>Models</i>			
<i>Parameter/Feature</i>	<i>Predefined Skin-stringer Section</i>	<i>Panel of Arbitrary Geometry</i>	<i>Remarks</i>
<i>Number of Stringers</i>	- Special single-stringer as 'wide panel' model, specially orthotropic only, or N_{st} stringers with $N_{st} = 1$ to 10 - 18 (depending on stringer type, see Section 2.5.2)	User-defined	The maximum value of N_{st} depends on the program parameter constants (see Section 2.5.2)
<i>Boundary Conditions</i> *	Program-defined for the buckling displacements: - special single-stringer with 'wide panel' boundary conditions for specially orthotropic models, or - multi-stringer models, with panel edges – free, – simply-supported, or – clamped	User-defined	The user may create other types of support conditions by adding or removing nodal degrees of freedom
<i>Skin-stringer Joint Models</i>	Adhesive layer and/or rivet line/sealant layer		The user can modify a joint model generated for the predefined sections

* The enforcement of boundary conditions can only be effected for degrees of freedom along longitudinal edges, or intermediate nodal lines. The *a priori* choice for the trigonometric functions in Equation (1.4) means that no other conditions can be imposed at the panel ends, that is, at $x = 0$ and $x = L_p$.

1.4 RESULTS

1.4.1 Introduction

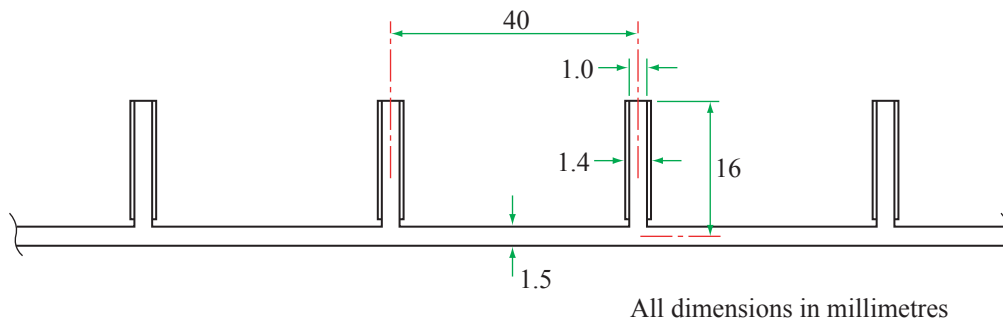
In the following sub-sections, the results of computations with the program of ESDUpac A0301 are presented. Section 1.4.2 lists results for the example problem of Data Item No. 73015*, the local buckling in axial compression of a CFRP blade-stiffened panel, whilst Section 1.4.3 summarizes results obtained for panel models reported in NASA TP 2215 (Reference 6) which treats blade-stiffened, hat-stiffened and corrugated composite panels under both compressive and shear loading.

* Data Item No. 73015 "Estimation of the local buckling stress under biaxial compression of an isotropic skin with fibre reinforced integral unflanged stiffeners".

1.4.2 Example Problem from Data Item No. 73015

The example problem in Data Item No. 73015 presents the results of estimating the local buckling stress in axial compression of an aluminium alloy blade-stiffened panel, in which the blades have been reinforced with CFRP layers. The lay-up consists of five layers of unidirectional material on each side of the blade with the following orientations: 0° , -15° , 0° , 15° , 0° . This stacking sequence leads to an **[ABD]** matrix with a fully populated **[D]** sub-matrix. Material properties are specified below. The cross-sectional dimensions of the panel are given in Sketch 1.2.

Aluminium Alloy	Carbon fibre
$E = 73\,000 \text{ N/mm}^2$	$E_\alpha = 207\,000 \text{ N/mm}^2$
$G = 28\,100 \text{ N/mm}^2$	$E_\beta = 7600 \text{ N/mm}^2$
$\nu = 0.3$	$G_{\alpha\beta} = 5000 \text{ N/mm}^2$
	$\nu_{\alpha\beta} = 0.3$



Sketch 1.2 Blade-stiffened panel of Data Item No. 73015

The critical stress found in Data Item No. 73015 is calculated with the method presented in Data Items Nos Struct 02.01.28* and 73007†. The method is based on a few simplifying assumptions, which have been incorporated in the B0301 model. Below, two results are presented for comparison with the Data Item value of the critical axial loading for local buckling. First, the stress obtained when the torsion-bending coupling terms are ignored, to give a (quasi) specially orthotropic laminate for the blade stiffener. Second, a straightforward computation via the local buckling option – Runtype 3 – with the ‘real’ **[ABD]** matrix, which includes the non-zero D_{16} and D_{26} terms, provides the B0301 value for the buckling stress. These results are brought together in Table 1.4.

* Data Item No. Struct 02.01.28 “Information on the use of Item No. 73007”.

† Data Item No. 73007 “Stiffness of loaded flat strips under sinusoidally distributed bending couples at their edges (for use in local buckling calculations)”.

TABLE 1.4 CFRP Blade-stiffened Panel – Local Buckling in Axial Compression

	Critical Loading, N_x N/mm	
	<i>B0301</i>	<i>Data Item No. 73015</i>
Simplified model (D_{16} , D_{26} zero)	567	570
‘Real’ model (D_{16} , D_{26} non-zero)	611	–

1.4.3 Other Stiffened Panels

1.4.3.1 Buckling of blade- and hat-stiffened and corrugated panels

In NASA Technical Paper 2215 (Reference 6) several analytical procedures for estimating critical compressive and/or shear stresses for stiffened panels are examined. The report lists results from both finite strip and finite element programs. Critical stresses for composite blade-stiffened, hat-stiffened and corrugated panels are reported. The panel lay-up definitions, material properties and results for all panels are presented below.

All laminates used for constructing the panels are of the **AsBoDf** type and satisfy the requirements stated in Section 1.3.1.1.

The graphite-epoxy unidirectional material properties used in the calculations are as follows.

$$\begin{aligned}
 E_{\alpha} &= 131\,000 \text{ N/mm}^2 \\
 E_{\beta} &= 13\,000 \text{ N/mm}^2 \\
 G_{\alpha\beta} &= 6410 \text{ N/mm}^2 \\
 \nu_{\alpha\beta} &= 0.38 \\
 \nu_{\beta\alpha} &= 0.0378
 \end{aligned}$$

The lay-up definitions for the various example cases are given in Table 1.5.

TABLE 1.5 Lay-up Data

<i>Panel</i>	<i>Element</i>	<i>Layer Angles (°) and Stacking Sequence</i>	<i>Layer thicknesses* mm</i>
Blade-stiffened panel (see Sketch A2.1)	Skin (p_{st})	[45, -45, -45, 45, 0, 90]s	$t_l = 0.1397$ (0°, ±45°) $t_l = 1.2573$ (90°)
	Blade (W_1)	[45, -45, -45, 45, 0]s	$t_l = 0.2974$ (0°) $t_l = 0.1397$ (±45°)
Hat-stiffened panel (see Sketch A2.11)	Skin between stringers (p_{st})	[45, -45, -45, 45, 0]s	$t_l = 0.262\ 00$ (±45°) $t_l = 0.252\ 81$ (0°)
	Skin under hat (W_3)	[45, -45, 0]s	$t_l = 0.262\ 00$ (±45°) $t_l = 0.430\ 66$ (0°)
	Webs (W_1)	[45, -45]s	$t_l = 0.262\ 00$ (±45°)
	Top (W_2)	[45, -45, 0]s	$t_l = 0.262\ 00$ (±45°) $t_l = 0.644\ 73$ (0°)
Corrugated panel (see Sketch A2.12)	Skin (p_{st}) and top (W_2)	[45, -45, -45, 45, 0]s	$t_l = 0.139\ 17$ (±45°) $t_l = 0.427\ 63$ (0°)
	Inclined webs (W_1)	[45, -45, -45, 45]s	$t_l = 0.139\ 17$ (±45°)

* The large numbers of significant figures come from the reference where equally many are used.

Table 1.6 presents the B0301 results and lists the comparison values, which were read from the figures in the reference which present plots for critical combinations of N_x and N_{xy} for a fixed buckling half-wavelength of $L = 762$ mm.

TABLE 1.6 Comparison of Results

<i>Panel</i>	<i>Critical Loading, N_x N/mm</i>	
	<i>B0301</i>	<i>Reference 6</i>
Blade-stiffened panel (ID _{type} = 1)	172.2	~174
Hat-stiffened panel (ID _{type} = 11)	531.8	~528
Corrugated panel (ID _{type} = 12)	260.6	~260

1.4.3.2 Local buckling of an inverted-T-section-stiffened panel

In Paper AIAA-98-1993 (Reference 8) results of local buckling computations obtained with the PANDA2 (see Reference 7) and STAGS (see Reference 9) analysis codes for an $ID_{type} = 3$ stiffened panel are reported.

The stacking sequences for the skin and stringer laminates are as follows.

Skin $[\pm 45_4, \pm 45_3, 90_2, \pm 45_3]_s$
 Stringer web and flange $[\pm 45_2, (\pm 45/0_4)_2, 90_2, 0_4, (\pm 45, 0_2)_2, 0_2, \pm 45]_s$

The unidirectional material properties are as follows.

$E_\alpha = 18\,500\,000$ lbf/in²
 $E_\beta = 1640\,000$ lbf/in²
 $G_{\alpha\beta} = 870\,000$ lbf/in²
 $\nu_{\alpha\beta} = 0.3$
 $t_l = 0.0052$ in

The run for local buckling – Runtype = 3 – gives the following results.

Results for Local Buckling				
Step	L in	Eps-cr	Sigma-cr lbf/in ²	Buckling Load lbf
1	0.2000D+01	-0.017348	-0.136506D+06	-0.193126D+07
2	0.3540D+01	-0.011612	-0.913728D+05	-0.129272D+07
3	0.5080D+01	-0.008505	-0.669184D+05	-0.946748D+06
4	0.6620D+01	-0.007199	-0.566421D+05	-0.801361D+06
5	0.8160D+01	-0.006674	-0.525170D+05	-0.743000D+06
6	0.9700D+01	-0.006532	-0.514009D+05	-0.727210D+06
7	0.1124D+02	-0.006614	-0.520403D+05	-0.736255D+06

The minimum critical load is 727 210 lbf, which corresponds to a load per unit width of $N_x = 22\,725$ lbf/in for a width of 32 in. Table 1.7 presents this result along with that obtained with the STAGS code.

TABLE 1.7 Critical load factor for local buckling. Base loading is 20 000 lbf/in

Code	B0301	STAGS	
Element type	FSM	FEM 480*	FEM 411*
Load factor	1.136	1.168	1.296

* 411 is a quadrilateral cubic shell element; 480 includes transverse shear deformation modes.

No specific information is given in the paper with regard to the material properties of the adhesive used to bond the stringer to the skin, other than that it is isotropic with a thickness of 0.0121 in. The above result was obtained with estimated base values of $G_{adh} = 72\,500$ lbf/in² and $E_{adh} = 188\,500$. The sensitivity of the model to variation in these values is given below.

1000

1.5.1 Derivation

1.5.2 References

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2. ESDUpac A0301

2.1 INTRODUCTION TO THE PROGRAM

ESDUpac A0301 contains a Fortran 77 computer program for calculating the initial elastic buckling loads of composite stiffened panels and struts under compressive loading. The basis of the program is explained in Part 1 of this Item. Throughout this section of the Item the text refers mostly to panels but this should be taken to include struts where appropriate.

This Data Item relates to Version 1.1 of ESDUpac A0301V11 and Fortran program A0301V11. Both the ESDUpac number and the program number contain the version number encoded in the three characters V11. Throughout this Data Item the ESDUpac and the program are referred to by the number A0301 and Version 1.1 is taken to apply. The Contents page of the Series Software Volume states the current version number. The program is available in the form of a Fortran 77 source code and corresponding executable file. Section 2.3 gives notes on running the program and details of the input data required. Both the source code and the executable file, along with all the files that have been used to obtain the results from the program that are quoted in this Data Item, can be found in ESDUscope (the electronic version of the Series), on the internet version of the Series, and on CD in the Series Software Volume.

An alternative version of the program, ESDUpac B0301V11, accompanies this Data Item and can also be found in ESDUscope, on the internet, and on CD in the Series Software Volume. Program B0301V11 uses identical input files to program A0301V11 and performs identical calculations, the only difference being the manner in which the file names associated with a particular run are handled; this is described in Section 2.3.1.2.2. There is only that small difference between the two versions and all references to program A0301V11, with the exceptions of those in Sections 2.3.1.2.1 and 2.5.4, may be taken to apply equally to program B0301V11.

Every reasonable effort has been made to ensure that the program of ESDUpac A0301 performs the intended calculations satisfactorily. If, however, any problems are encountered in its use, please inform ESDU and every effort will be made to overcome the difficulties. In common with other software producers, ESDU makes no representation as to the suitability or fitness of the program for any particular purpose and no liability for any loss occasioned by any persons as a direct or indirect result of use of the program, whether arising from negligence or otherwise, can be accepted. In no event shall ESDU or any individuals associated with the development of the program be liable for any damages, including loss of profit or consequential loss, arising out of or in connection with the program.

2.2 PROGRAM OPTIONS AND LIMITATIONS

Version 1.1 of ESDUpac A0301 is capable of the following.

- (i) Elastic analysis for initial buckling of composite stiffened panels and struts loaded in compression, with the following options:

buckling load calculation for buckling half-wavelength equal to a specified length, L_s ,
analysis to obtain complete P - L curve of the panel, or
computation of local buckling minima.

In all cases either minimal or extended output may be selected. For details of the output and of the analysis options themselves, see Section 2.4.1.

- (ii) The user is not restricted to data models created with the predefined skin-stringer sections listed in Table 2.3. Any other section may be analysed for buckling, though the strip model data file must then be prepared by the user. See **B** and **C** of Section 2.3.1.3 and Entry 4 of Table 2.2.
- (iii) Analysis of panels with skin-stringer joint elements modelling adhesive or riveted connections.
- (iv) Analysis of models fabricated from up to fifty different generally orthotropic materials, which includes isotropic materials, as described in Section 2.3.3, per model. Section 2.5 gives directions for increasing the number of different materials that can be handled by the program.
- (v) Skin and stringer elements, such as flanges, webs *et cetera*, may consist of different laminates.
- (vi) For the predefined skin-stringer sections with large corner radii the thickness and laminate lay-up are presumed to be the same for all flats.
- (vii) The program is limited to the analysis of data models that comprise up to approximately 10 to 18 stringers. This restriction depends on the value of the relevant constants in the program. Larger models require adaptation of these values. The constants and their values are described in Section 2.5.

2.3 RUNNING THE FORTRAN PROGRAM

2.3.1 Overview

In order to run program A0301 it is necessary to prepare the input files and decide on a running strategy; these aspects are discussed in the following sections. Definitions of the four files that will be encountered in a program run and their naming conventions are given in Sections 2.3.1.1 and 2.3.1.2.

There are three basic approaches to running the program and these are described in Section 2.3.1.3.

Detailed descriptions of the two basic input files are given in Sections 2.3.2 and 2.3.3. The output from the program is described in Section 2.4.

2.3.1.1 File definitions

The four files that are utilized when running program A0301 are defined in Table 2.1. Note that the extensions are optional; those quoted are used throughout this Data Item.

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TABLE 2.1 File Definitions

<i>File type</i>	<i>Extension</i>	<i>For details, refer to</i>	<i>Description</i>
Panel Geometry Definition file	PGD	Section 2.3.2, Tables 2.2 and 2.3	A short, user-prepared file containing all the basic geometrical information required to describe a panel or strut.
Laminate Data file	LAM	Section 2.3.3	A user-prepared file containing layer properties and lay-up definitions or [ABD] matrices.
Strip Model Data file	STO	Section 2.4.2 and Appendix C of Data Item No. 98016	A file, usually large, that stores all the detailed model information. This file may be generated by the program from the information contained in the PGD file or it may be prepared by the user, depending on the type of run, see Section 2.3.1.3.
Results file	PRT	Section 2.4.1	An output file containing the results of a particular run.

2.3.1.2 Naming input and output files

2.3.1.2.1 ESDUpac A0301

ESDUpac A0301 is run using list-directed input/output, as described in Section 4.4 of the 'Introduction to ESDUpacs' in the Series Software Volume. In running the program in this way, the paths and names of the Panel Geometry Definition (PGD) file and the Results (PRT) file are specified at the command (DOS) prompt by the user.

As mentioned above, two further files are utilized when running the program; those files are the Strip Model Data (STO) file and the Laminate Data (LAM) file. Lines 4 and 5 of the PGD file are used to name the STO and LAM files as follows.

On the third line of the PGD file must be entered the name of that (the PGD) file. This line may not be left blank.

On the fourth line of the PGD file may be entered the name of the STO file. Alternatively, this line may be left blank in which case the program will name the STO file by taking the stem of the PGD file name and appending to it the extension STO.

On the fifth line of the PGD file may be entered the name of the LAM file. Alternatively, if the LAM file to be used for the run has been named using the stem of the PGD file name and the extension 'LAM', this line may be left blank.

Any file names that are specified should consist of a string of up to 70 alpha-numeric characters followed by an extension of up to three characters and the total length should not exceed 72 characters (that is to say, if the initial string is 70 characters long, the extension can only be one character long (the point between the stem and the extension accounts for the other character); alternatively, if the stem is 69 characters long,

the extension can only be two characters long). If the files being used for a particular run are in a different location to the program itself, the file names should include their paths.

See, for examples, the PGD files in Appendix A.

2.3.1.2 ESDUpac B0301

When running program B0301 the user is prompted to choose one of two options for the naming of the input and output files. These options are as follows.

- (a) The user enters one string of up to eight alpha-numeric characters, for example, ABCD1234. The four files associated with a particular run are then named by adding to this stem each of the four extensions, PGD, LAM, STO and PRT.
- (b) The user enters four file names, one for each of the files associated with a particular run. The only restrictions on these file names are that the stem be no longer than eight characters and the extension be no longer than three characters.

2.3.1.3 Approaches to running the program

There are three basic ways of running the Fortran program. (Note that these should not be confused with the three analysis options defined in (i) of Section 2.2 and described in Section 2.4.1.) The first option, **A**, applies to the analysis of panels consisting of skin and a number of any one of the predefined sections listed in Tables 1.3 and 2.3. Approaches **B** and **C** are two ways of constructing a model for a panel of arbitrary cross-section. **B** is likely to be more appropriate if a model for a completely new section is to be constructed, whereas **C** would be the simpler option if a model for a panel using stringers with sections resembling closely one of the predefined sections is to be constructed. Details of the three approaches are given below.

- A** This is the simplest way of running the program. It makes use of the predefined skin-stringer sections listed in Tables 1.3 and 2.3 (additional details of the predefined sections are also given in Appendix A) and consequently cannot be used to analyse directly panels of arbitrary cross-section* (an arbitrary cross-section here being any cross-section that is not represented in Table 1.3). The user prepares the Panel Geometry Definition (PGD) file according to Table 2.2 and the Laminate Data (LAM) file according to Section 2.3.3. Using the information in the PGD file the program generates the Strip Model Data (STO) file and the Results (PRT) file is produced.
- B** Using Section 2.4.2 the user creates the complete Strip Model Data (STO) file for the panel. The user also creates the PGD file, noting that the first value in Entry 4 (line 8) of the PGD file must be negative to indicate that the STO file already exists, see Table 2.2. (Because, in this case, the program is taking the input directly from the STO file rather than from the PGD file, Entries 5 to 11 of the PGD file are not used by the program and may therefore be left blank or given any values.) The user creates the LAM file. The program is then run and outputs the PRT file.
- C** Initially, the program is run as in **A**, the main purpose being the generation of the STO file. Once this has been done the STO file is adapted/manipulated using the directions given in Section 2.4.2 to represent a panel of the required geometry. The first value in Entry 4 (line 8) of the PGD file is then given a negative value to indicate that the STO file already exists. Either the LAM file that was created by the user for the initial program run is used, or the user may create another LAM file. The program is then run and outputs the PRT file. A detailed example of running the program in this way is given in Appendix C of Data Item No. 98016.

* This option can, however, be used to generate an STO file which can then be modified to describe a panel of arbitrary cross-section.

2.3.2 Panel Geometry Definition File

This section describes in detail the preparation of the panel geometry definition (PGD) file required when running the program according to **A** in Section 2.3.1.3. The PGD file consists of eleven sub-sections which are briefly described as follows.

- 1 Two lines of text for run identification details or notes.
- 2 Three lines for the specification of the names of the PGD, STO and LAM files.
- 3 Two lines of text for the definition of units.
- 4 Definition of stringer type and the number of stringers in the panel.
- 5 Properties of the adhesive layer.
- 6 Properties of the rivet line connection.
- 7 A list of stringer dimensions such as flat widths, thicknesses and material codes.
- 8 Definition of stringer pitch, skin thickness and material code.
- 9 Specification of edge widths and support conditions of panel longitudinal edges.
- 10 Buckling half-wavelength, starting half-wavelength for the local buckling calculation, and the stringer corner bend radius.
- 11 Run type and output type specifiers.

Table 2.2 lists all the input requirements. Table 2.3 complements Table 2.2 by giving relevant details of the predefined skin-stringer sections. An example and a few explanatory notes follow Table 2.3. Further information and additional details of the predefined sections, such as explicit definitions of the various widths and thicknesses, may be found in Appendix A, the section number of that appendix appropriate to each stringer type being given in the final column of Table 2.3. All input data are accepted in free format.

The program checks the input from the panel geometry definition file and gives appropriate messages if errors are detected. In addition, checks are carried out as required on the strip model data (STO) file when either of approaches **B** or **C** described above is employed.

2.3.2.1 Units

As can be seen from Tables 2.2 and 2.7, lines 6 and 7 of the input are provided for the specification of units. The first line is for the specification of the unit of force, for example N or lbf, and the second line is for the specification of the unit of length, for example mm or in. The input units are echoed in the output where they are quoted appropriately for all the output values. It is therefore essential to provide all the input data in a coherent set of units that agrees with the units declared. Irrespective of what is entered in these two lines, the results will be in the same units as the input data and will be correct provided that the input data are all in a coherent set of units. In the event that no units are declared, no units appear in the output.

TABLE 2.2 Program Input Data

Entry order	Entry	Enter the numerical values for the quantities indicated in free format. The entries must be in the order shown below and made on a separate line with no blank line in between (except Entries 1 to 3). The values given for each entry on a single line must have a space or a comma between them.
1	Text	Enter run identification data or notes. Two lines 72 characters wide are allotted. Any lines that are not used must be left blank.
2	PGD file name STO file name MAT file name	Enter the names of the PGD, STO and MAT files. Three lines 72 characters wide are allotted. Enter the name of the PGD file on the first line followed by the name of the STO file on the second line followed by the name of the MAT file on the third line. The first line must not be left blank; the second and third lines may be left blank. See Section 2.3.1.2.1 for more details.
3	Unit of force Unit of length	Enter details of units used for the input data. Two lines three characters wide are allotted. Enter unit of force on the first line followed by unit of length on the second line. Any lines that are not used must be left blank.
4	ID_{type} N_{st}	Enter a number, ID_{type} , indicating which skin-stringer type from Table 2.3 is to be used. If the STO file is already available, enter a negative number. On the same line, enter N_{st} , the number of stringers in the model. If N_{st} is given a negative value, a strip model data (STO) file for a special single skin-stringer model is generated. (See Sections 1.3.2.3 and A1.1.)
If the STO file is already available, that is, ID_{type} has been given a negative value in Entry 4, the remaining entries may be left blank or given any values.		
5	G_{adh} E_{adh} t_{adh}	Enter, on the same line, the shear modulus, Young's modulus and thickness of the adhesive. If the adhesive thickness is entered as zero, no adhesive layer element is included in the analysis*. For integral stringers, enter zeros. For footnotes, see end of table.
6	D_{riv} p_{riv} E_{riv}	Enter, on the same line, the rivet diameter, rivet pitch and rivet material Young's modulus. If the rivet diameter is entered as zero, no rivet line element is included in the analysis*. For integral stringers, enter zeros. For footnotes, see end of table.
7	W_1 t_1 MC_1 W_2 t_2 MC_2 and so on up to W_{Nf} t_{Nf} MC_{Nf}	Enter the width, thickness and material code of each of the flats that form the stringer section in the order given in Table 2.3. The three values for each flat should be on the same line. See Appendix A for additional dimensional details and Section 2.3.3 for notes on the material codes.
8	p_{st} t_{sk} MC_{sk}	Enter, on the same line, the stringer pitch, the skin thickness and the skin material code.
9	e_1 k_1 e_2 k_2	Enter, on the same line, the edge width and support specifier for the 'left-hand' edge of the panel (subscript 1) followed, on the next line by those for the 'right-hand' edge of the panel (subscript 2). See Section A1.5 in Appendix A. The possible values for the support specifier, k_i , are as follows: 0 – free edge, 1 – simply-supported edge, 2 – clamped edge. If N_{st} is negative, e_1 and e_2 and k_1 and k_2 are ignored but must still be given values.
10	L_s L_0 R	Enter the half-wavelength (note that, although the length L_s is only used when Runtype = 0, 1 or 2, some value must still be entered when Runtype = 3). Next, on the same line, enter the initial or starting value of the length in the Runtype = 3 option, see Section 2.4.1. (Note that, although L_0 is only used when Runtype = 3, some value must still be entered when Runtype = 0, 1 or 2.) Next, on the same line, enter the stringer corner inside bend radius, see Sketch A1.1. Note that the value of R is only used by the program when either stringer type 8 or 10 is specified and in all other cases must still be entered but may be given any value.
11	Runtype OP	Runtype: Enter a number, 0, 1, 2 or 3, specifying the run type required, see Section 2.4.1. 0 – input check only; no buckling calculations, 1 – single buckling load calculation, 2 – complete P - L curve, or 3 – local buckling analysis. OP: Enter a number, 0 or 1, specifying the type of output required, see Section 2.4.1. 0 – minimal output: run identification, panel area, panel centroid, panel moment of area, critical strain, stress and load, or 1 – extended output: as for 0 but with an echo of the input data and results depending on the value of the Runtype specifier.

* This means that if t_{adh} or D_{riv} are not equal to zero, but other properties are, the element matrix will still be generated.

TABLE 2.3 Stringer Type Specification

<i>Stringer ID_{type} Number</i>	<i>Description*</i>	<i>Number of Flats</i>	<i>Flat Data Entry Order</i>	<i>Relevant Section of Appendix A</i>
1	Integral blade	1	Blade, W_1	A2.1
2	Integral beaded blade	2	Blade, W_1 Bead, W_2	A2.2
3	Beaded T-section	3	Height, W_1 Flange, W_2 Bead, W_3	A2.3
4	I-section	3	Top flange, W_1 Height, W_2 Skin flange, W_3	A2.4
5	Lipped J-section	4	Lip, W_1 Top flange, W_2 Height, W_3 Skin flange, W_4	A2.5
6	Lipped Z-section	4	Lip, W_1 Top flange, W_2 Height, W_3 Skin flange, W_4	A2.6
7	Unlipped Z-section	3	Top flange, W_1 Height, W_2 Skin flange, W_3	A2.7
8	Lipped LR [†]	4	Lip, W_1 Top flange, W_2 Height, W_3 Skin flange, W_4	A2.8[‡]
9	Top-hat	4	Skin flange, W_1 Height, W_2 Top, W_3 Skin under hat, W_4	A2.9
10	Top-hat LR [†]	4	Skin flange, W_1 Height, W_2 Top, W_3 Skin under hat, W_4	A2.10[‡]
11	Integral hat	3	Height, W_1 Top, W_2 Skin under hat, W_3	A2.11
12	Corrugation	3	Height, W_1 Top, W_2 Width under top, W_3	A2.12

* For all non-integral sections, adhesive layer and/or rivet line joint elements are available.

† All 'LR' sections, that is 'large radius' types, require the specification of a finite value for the corner radius.

‡ 'LR' sections have a large bend radius between flats. Limitations hold for the widths of the remaining flat parts of the flanges and webs.

The beads that are mentioned for types 2 and 3 are simple small thick parts at the ends of the outstands to increase the moments of area of the sections. Types 1 to 10 are identical to those included in Data Items Nos 98016 and 01001. Types 11 and 12 are specific to this Data Item.

2.3.2.2 Example panel geometry definition file

Below is an example panel geometry definition (PGD) file. The text in square brackets, which need not form part of the input file, corresponds to that used in Table 2.2.

Example from NACA TP 2215	[General text
Simple blade section	]
TP2215.pgd	[PGD file name]
	[STO file name = TP2215.STO]
TP2215.lam	[LAM file name]
N	[Unit of force]
mm	[Unit of length]
1 6	[ID _{type} N _{st}]
0.0 0.0 0.0	[G _{adh} E _{adh} t _{adh}]
0.0 0.0 0.0	[D _{riv} p _{riv} E _{riv}]
32.38 1.6764 2	[W ₁ t ₁ MC ₁]
127.00 3.9116 1	[W ₂ t ₂ MC ₂]
62.66 1	[e ₁ k ₁]
62.66 1	[e ₂ k ₂]
762.0 10.0 0.5	[L _s L ₀ R]
1 0	[Runtype OP]

This file describes the layout of a panel with six blade-section, ID_{type} = 1, stringers. The blade width is 32.38 mm, with thickness of 1.6764 mm its material code is 2. The stringer pitch is 127 mm, which implies, together with the specified edge width values for e_1 and e_2 of 62.66 mm, that the panel width amounts to ~760 mm ($e_1 + 4$ pitches + e_2 , see Sketch A1.2). The skin thickness is 3.9116 mm. The longitudinal edges are simply supported, meaning that the w -displacements along these edges are to be equal to zero. The buckling half-wavelength is 762 mm. The corner radius is a dummy parameter in this case (because the section is not an LR (large radius) section, that is, ID_{type} ≠ 8 or 10). The calculation of the buckling load for overall buckling with a half-wavelength of L_s is requested and the output specifier of zero will give minimal output.

Note that the number of decimal places in the values of the various thicknesses does not imply high accuracy, but arises from simply summing the layer thicknesses that occur in the laminate lay-up. The values read from the PGD – or STO file, see the next section – are used to ascertain correct handling of data from the LAM file.

2.3.3 Laminate Data File

The laminate stiffness properties of the strip elements are read from a separate file, the Laminate Data (LAM) file. The laminate data may be provided in either of two formats, the value of LFT (the laminate file type specifier, see Entry 11 of Table 2.2) determining the form in which the program expects the laminate data to be presented. The two options for the form of the laminate data and the corresponding values of LFT are as follows.

LFT = 1 individual layer properties accompanied by stacking sequences, see Section 2.3.3.1

LFT = 2 laminate [ABD] matrices, see Section 2.3.3.2

A Note on Laminate Thicknesses

Regarding laminate thicknesses, it is of the essence to realize the following.

- When $LFT = 1$, the laminate thickness is calculated by summing the individual layer thicknesses given in the laminate data (LAM) file.
- When $LFT = 2$, the laminate thickness is read directly from the laminate data (LAM) file.

It is emphasized that it is *these* thicknesses that are utilized in the program to generate related model data. In the case where the thicknesses read from either the PGD file or the STO file differ from those read from the LAM file, a warning is issued. See the note on message 172, which follows Table 2.8 in Section 2.5.3. In addition it is emphasized that panel or strut cross-section node point co-ordinates depend directly on the strip – or laminate – thicknesses. Hence, modifying LAM file entries may have consequences for either the PGD file or the STO file.

A Note on Units

Note that all the data used for a particular program run must be in the same system of units. Note also, however, that not all the layer/laminate data in a particular file need be defined in the same system of units. Details of the units used for the data in each layer/laminate entry may be appended to the right-hand ends of the lines in the file as appropriate (a space must be left between the rightmost entry on the line and any notes that are added). Note that those details are not used in any way by the program and the numerical values present in the LAM file will be used by the program irrespective of the units given at the ends of the rows.

2.3.3.1 Layer properties and stacking sequences, $LFT = 1$

If the laminate data are to be provided in the form of individual layer properties accompanied by stacking sequences, the laminate data file must be in the format defined in Table 2.4 (which is similar to that used in Data Item No. 94007*). When the data are presented in this form, the program computes the $[ABD]$ matrix and the thickness for all the specified laminates.

* Data Item No. 94007 “Elastic buckling of cylindrically curved fibre reinforced composite panels with all edges simply supported under biaxial loading”.

TABLE 2.4 Laminate Data for LFT = 1

Entry no.	Entry	Enter the numerical values for the quantities indicated in free format. Each entry must be in the order shown below and made on a separate line with no blank line in between. The values given for each entry on a single line must have a space or a comma between them.
1	LFT N	Enter LFT = 1 to identify the laminate file type and N for the number of different laminates to be defined (the maximum value of N is 10) for the current run.
2	C	Enter the number of layers for which properties are to be entered. The maximum value for C is 50.
3	$1 \quad \psi_1 \quad t_1 \quad E_{\alpha 1} \quad E_{\beta 1} \quad G_{\alpha \beta 1} \quad \nu_{\alpha \beta 1}$ $2 \quad \psi_2 \quad t_2 \quad E_{\alpha 2} \quad E_{\beta 2} \quad G_{\alpha \beta 1} \quad \nu_{\alpha \beta 1}$ and so on up to $C \quad \psi_C \quad t_C \quad E_{\alpha C} \quad E_{\beta C} \quad G_{\alpha \beta C} \quad \nu_{\alpha \beta C}$	Enter the properties and geometry of each layer. For the number of layers specified in Entry 2, enter, on the same line, the layer number, the angle of the principal axis of orthotropy, its thickness, the Young's moduli in the α - and β -directions, the shear modulus and the Poisson's ratio. Note that the value of the angle of orientation entered here should always be positive; where necessary, a negative angle can be specified in Entry 4.
4	$MC_1 \quad n_1$ Sequence of n_1 layer types for laminate 1 $MC_2 \quad n_2$ Sequence of n_2 layer types for laminate 2 and so on up to $MC_N \quad n_N$ Sequence of n_N layer types for laminate N	Enter the laminate material code, number of layers and stacking sequence. For the number of laminates specified in Entry 1, enter the material code followed, on the same line, by the number of layers in the laminate. On the next line, enter the laminate stacking sequence in terms of the layer numbers used in Entry 3*. The sequences should start at the uppermost layer in the laminate. If a negative layer angle is to be specified, the appropriate layer number should be prefixed with a minus sign. The maximum value for n_i is 100.

* Note that despite the mid-plane symmetric character of the acceptable laminate lay-ups, the complete stacking sequence(s) has to be given in Entry 4.