A Parametric Study To Optimize A Complicated Stiffened Plate Structure In Buckling

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ABSTRACT

The buckling of a stiffened plate with discontinuity of stringers is verified in this paper. For this purpose, the results of a finite element model analysed by MSC/NASTRAN, Solution 5, were compared with those of a test. While the theoretical critical load calculated by finite element is different from the measured value, as it is expected, the analysis locates the exact place of buckling and its principal mode shape. Afterwards, the finite element model has been used to optimize the structure.

1-INTRODUCTION

There is a significant place for stiffened plates in structural design. Some of the examples are:

1) T-Beam systems in monolitic concrete floors;
2) Composite joists in steel structures;
3) Orthotropic bridges;
4) Skin-Stringer systems in aircraft, missiles and ships.

The functional purpose of the structure sometimes forces the designer to stop the stringers at a highly loaded location which makes the structure susceptible to buckling. To increase the critical load capability of the structure, one available solution is to reduce its effective length by adding a stiffener. Adding the stiffener may be the easiest way but it is not the most efficient one all the time.

To find the optimized solution, the critical load calculation by using finite element analysis cannot be considered as an exact index. The critical load of structure depends on the initial imperfections which are difficult to be modelled. Consequently the result of analysis is the upper bound to the the achievable buckling load. To overcome this obstacle, it is necessary to have a better understanding of the behaviour of the structure and to use that to optimize it.

2-THE STRUCTURE CONFIGURATION

The layout of the particular structure which is verified in this exercise is shown in Fig. 1 and 2. The structure consists of skin, stringers, ribs and two girders along the longitudinal sides of the skin. The skin is not completely flat and its thickness changes along the X (transversal) and Y (longitudinal) axes. Adding the stringers to skin along the Y axis produces an orthotropic structure which has higher strength along the Y than the X axis. The structure has a kink along station 42 where rib #3 is located. Consequently the stringers are not continuous at this location. Four ribs are located along stations 0,21,42 and 57 which are connected to the stringers and the girders.

3-BUCKLING BEHAVIOUR OF THE STRUCTURE

Any local change which disturbs the path of the load in a structure can induce undesired shear forces and bending moments. These undesired forces sometimes can control the design. One of the examples is the structure verified in this study. In this structure although the skin has enough strength to take the load without the help of the stringers over rib#3, it buckles at station 31 due to the bending moment induced by discontinuity of the stringers.

One of the stringers between ribs 1 and 4 is shown in Fig. 3. The resultant axial force passes through the centroid of skin-stringer assembly. At station 42 where the stringer is cut, the axial force in the stringer is zero. Consequently the stringer axial force has to be transferred to the skin before this station. The shift of the stringer axial force to the skin produces a bending moment which makes those bays adjacent to rib#3 more susceptible to buckling than other bays (a column with eccentric load buckles at a lower load than a similar column loaded by the same force, but concentrically). The buckling should likely happen between stations 21 and 42 because this panel is longer than the panel between stations 42 and 57.

To verify the above discussion, a finite element model of this structure has been analysed by MSC/NASTRAN, Solution 5. The first 6 eigenvalues are shown in Table 1. In this table , as well as the eigenvalues, the nodes and related degrees of freedom (D.O.F) which has zero stiffness are also shown. According to the type of D.O.F which has zero stiffness and the general path of the load in the structure, the primary and secondary modes of buckling can be defined.

A skin-stringer assembly transfers the load primarily by axial force and secondly by bending moment. If a translational D.O.F has zero stiffness, the structure cannot take any extra axial force and the primary path of the load fails. It is a primary mode of buckling. If a rotational D.O.F has zero stiffness, the structure at that D.O.F cannot take any extra moment and it is similar to a plastic hinge. In this case, each hinge reduces the structure degree of indeterminacy and also changes the boundary conditions for those parts of the structure adjacent to that location. But it does not mean that the structure fails. This mode of the buckling is called here as secondary.

As can be seen from Table 1, the first eigenvalue shows a primary mode of buckling. The related eigenvector is shown in Fig. 4. The analysis shows that the buckling occurs along stringer #9 and in the middle of the second bay (in Fig. 5 and 6 the eigenvector along stringer 9 and the middle of the second bay is shown). To confirm the result of the finite element analysis which is consistent with the expected behaviour, a test has been conducted.

In this test, a specimen which had the same configuration and dimensions as the finite element model was loaded in a way so as to have uniform pressure along the skin at stations 0 and 57. The pressure was increased until the structure failed. The failure was buckling of the skin at station 31. In Fig. 7, the structure after the failure is shown.

Not only the result of the test is consistent with the expected buckling mode but also it shows that the finite element model is working properly and can be used as an index to optimize the structure.

4-OPTIMIZATION

4-1 OPTIONS

To have an efficient structure with higher critical load, several options are available. Adding a stiffener along station 31 (the location of buckling) is the first option. The result of the finite element analysis for this case is shown in the second row of Table 1.

The first and second eigenvalues are related to the secondary modes of buckling and can be considered as local ones. Consequently the structure does not fail in these modes. The third eigenvalue represents a primary mode of buckling. If the eigenvalue of the first primary mode is considered as an index, it can be said that this structure has a critical load 19% higher than the first one. In this case, the buckling happens along stringer 10 at station 14.27. In Fig. 8 and 9 the eigenvector along stringer 10 and station 14.27 is shown.

If the real reason of the buckling in the second bay of the structure is the discontinuity of the stringers at station 42, it can be prevented by providing another path of the load for the stringers axial force at this station. In Fig. 10, this concept is shown by adding a strap to each side of the stringer over rib#3. The axial force of the stringer is transfered by straps from one side of the rib to the other side without shifting to the skin. By adding the straps to the original finite element model, this case has been examined.

As can be seen from Table 1, adding the straps increases the critical load by about 13.6% and moves the location of buckling to the first bay. The structure eigenvector as well as the eigenvector along stringer 9 and station 14.27 are shown in Fig. 11, 12 and 13 respectively.

The last option which has been chosen for this paper is the combination of the straps and the stiffener. The eigenvector for this case along stringer 9 and station 14.27 is shown in Fig. 14 and 15.

4-2 DISCUSSION

It was mentioned in section (4-1) that the primary buckling mode of the structure is considered as a failure index. Consequently it can be said that the original structure fails in the first buckling mode (Table 1). As can be seen from Fig. 5, which shows the eigenvector along the critical stringer, when the eigenvector value at the location of buckling is 1, its peak value is less than 0.65 at the other spans. This means that the stringer has residual stiffness everywhere except at the location of buckling. It shows a type of inefficient stiffness distribution along the stringer.

Adding the stiffener not only increases the eigenvalue of the primary mode (Table 1) but also provides a better distribution of the eigenvector along the critical stringer (Fig. 8).

The eigenvector along stringer 9, when the straps are added to the original structure, is shown in Fig. 12 . As mentioned before, adding the straps increases the critical load by about 13.6% and moves the location of buckling to station 14.27 . While the eigenvector has a value of 1 at this station, the peak in another span is about 0.95 . This structure has the most efficient stiffness distribution along the critical stringer.

Adding the straps as well as the stiffener provides the strongest structure. From Table 1, it can be concluded that the behaviour of this structure is dominantly controlled by the stiffener than the straps and consequently the stiffness distribution is not as efficient as the previous case.

5- CONCLUSION

The buckling behaviour of a stiffened plate structure with the discontinuity of stringers has been verified in this paper. It is believed that the undesired forces due to this local change are the reason for the buckling.

ACKNOWLEDGEMENT

The assistance provided by the stress department of Bombardier Inc., RJ division, is greatly appreciated.

REFERENCE

1- MSC/NASTRAN User's Manual, Version 65, The MacNeal-Schwendler Corporation, Los Angeles, CA, November 1988.

		MODE 1	MODE 2	MODE 3	MODE 4	MODE 5	MODE 6
ORIGINAL STRUCTURE	NODE #	10044	10170	10050	10211	10047	10172
	D.O.F	Dz	Ry	Dz	Rx	Dz	Ry
	EIGEN-VALUE	1.943	1.967	2.139	2.275	2.319	2.467
FIRST OPTION ADDING STIFFNER	NODE #	10170	10211	10108	10172	10205	10106
	D.O.F	Ry	Rx	Dz	Ry	Rx	Dz
	EIGEN-VALUE	1.947	2.285	2.313	2.446	2.517	2.716
SECOND OPTION ADDING STRAP	NODE #	10106	10211	10116	10112	10040	10167
	D.O.F	Dz	Rx	Dz	Dz	Rx	Ry
	EIGEN-VALUE	2.209	2.373	2.443	2.613	2.814	2.837
ADDING BOTH STIFFNER & STRAP	NODE #	10170	10211	10108	10040	10116	10167
	D.O.F	Ry	Rx	Dz	Rx	Dz	Ry
	EIGEN-VALUE	2.097	2.38	2.459	2.775	2.78	2.85

TABLE 1

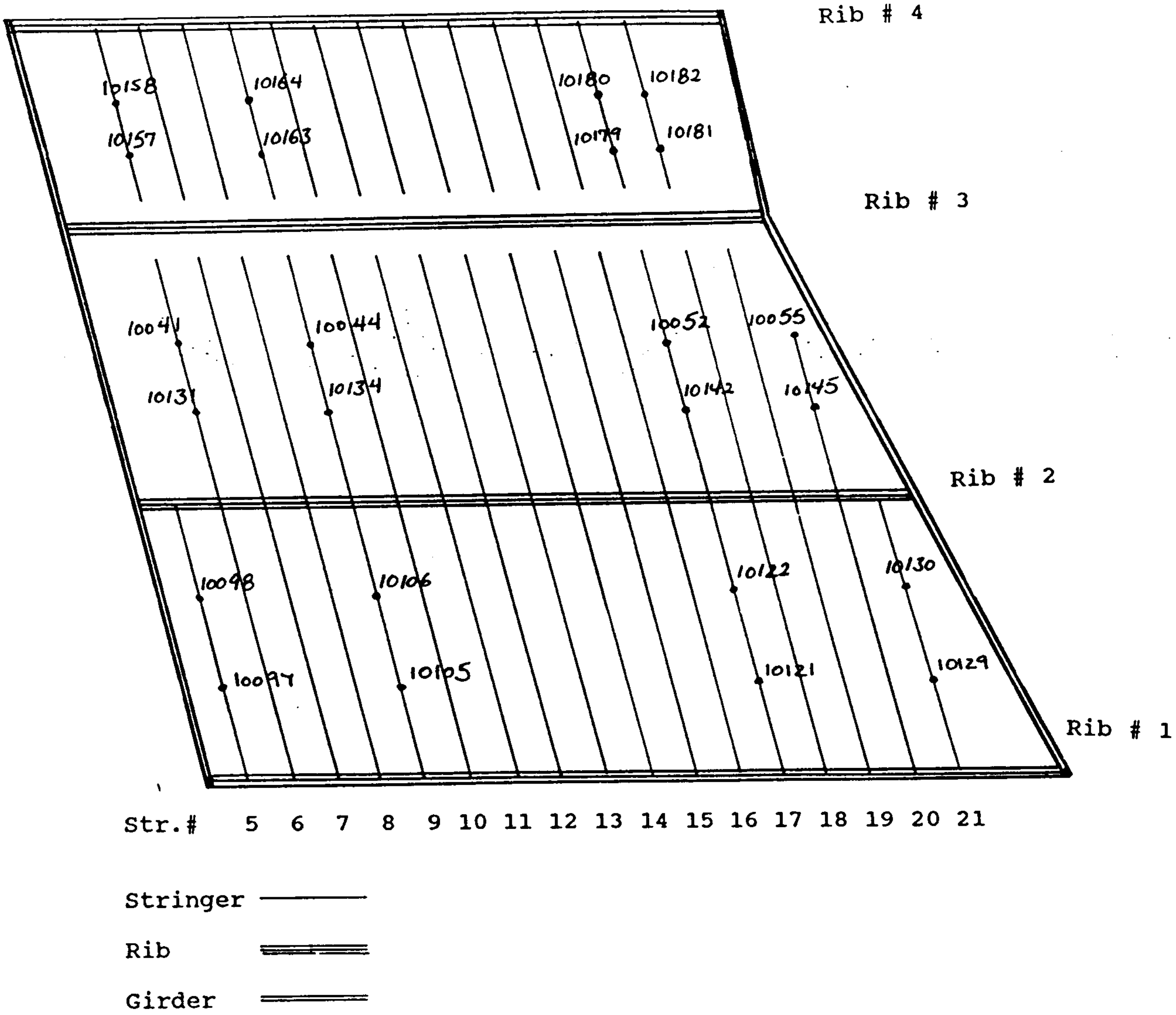

Fig. 1 Arrangement of stringers, ribs and girders

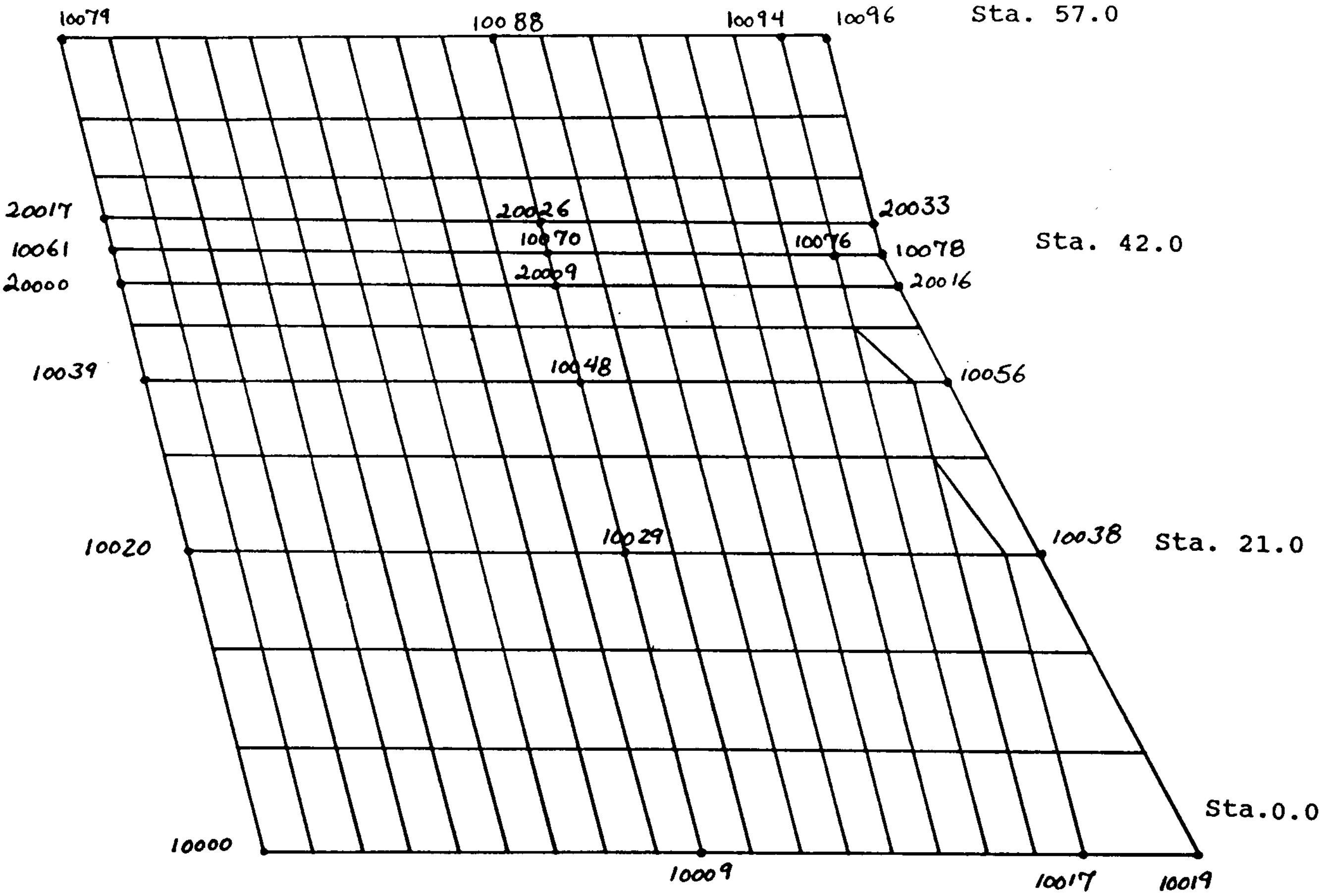

Fig. 2 Skin mesh

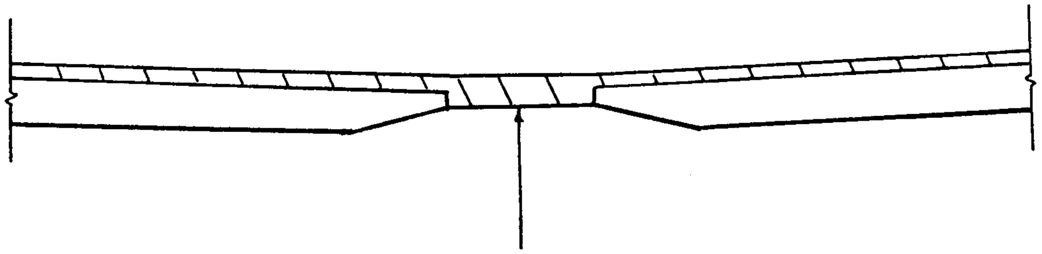

Fig. 3 Discontinuity of stringer over rib # 3

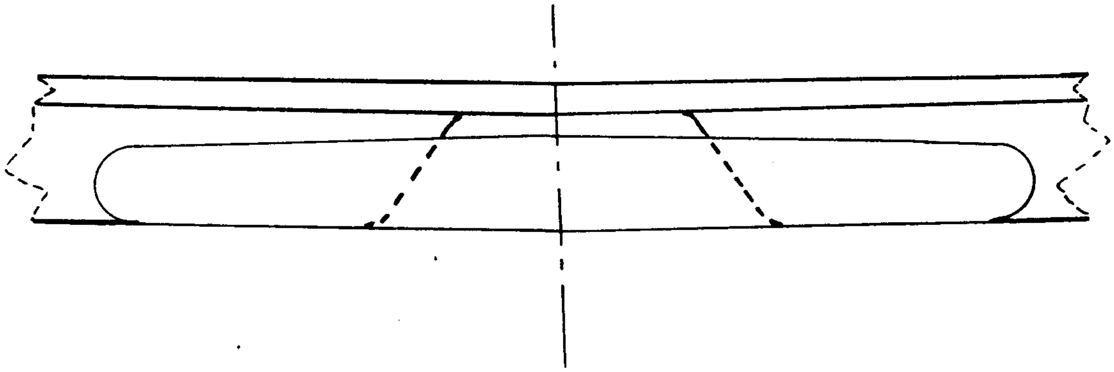

Fig. 10 Attachment of strap to stringer

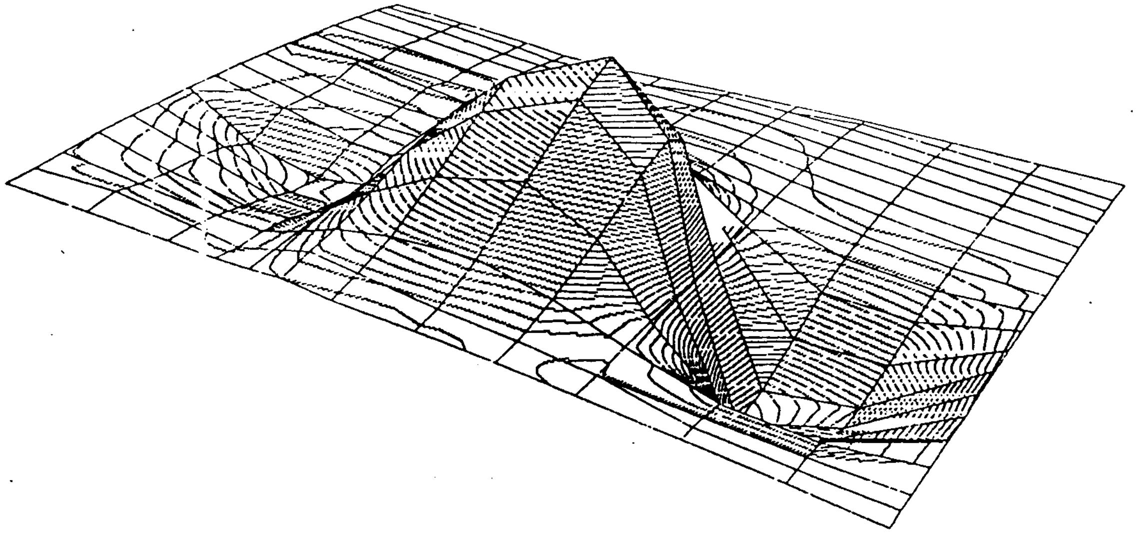

Fig. 4 The eigenvector related to the first primary mode of the original structure

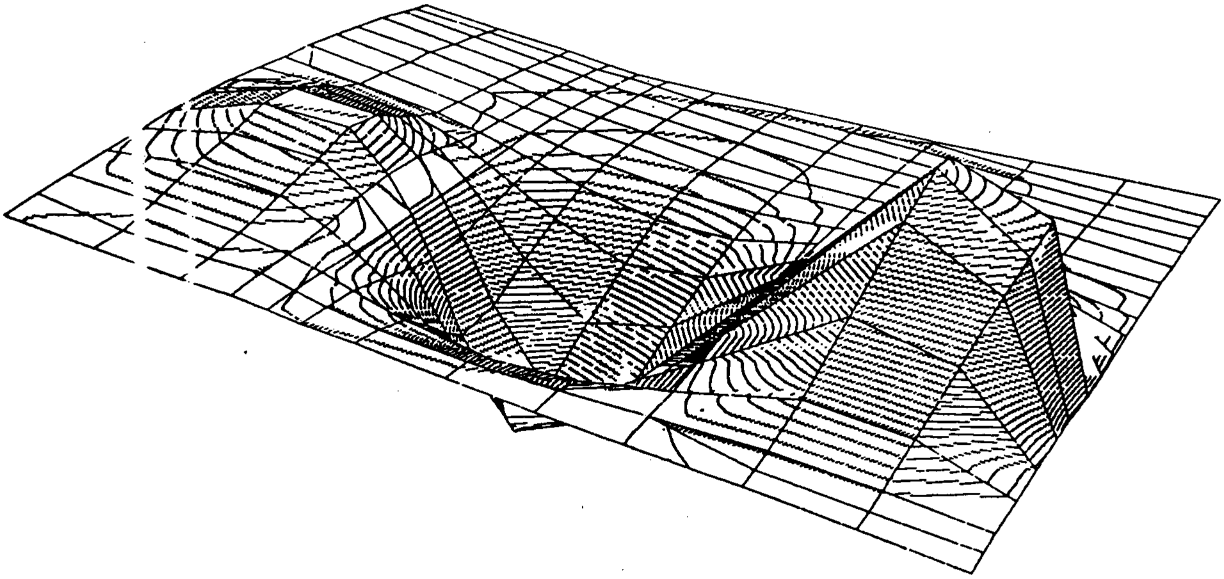

Fig. 11 The eigenvector related to the first primary mode of the structure after adding the straps

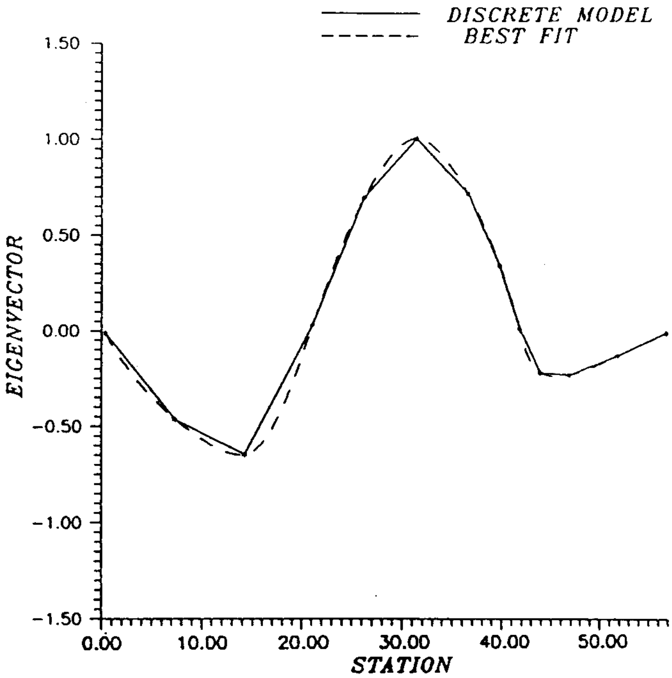

Fig. 5 Eigenvector along the critical stringer (Str. 9)

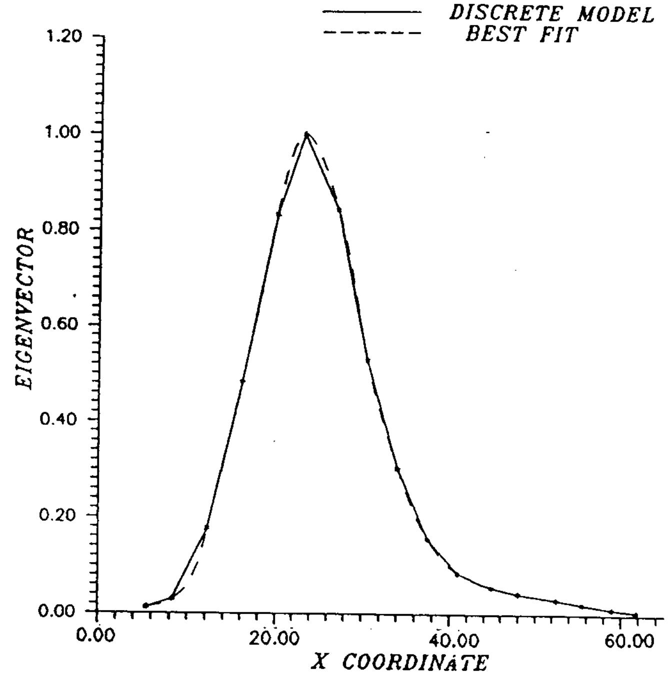

Fig. 6 Eigenvector along the wing at station 31.6

Fig. 7 Structure after the buckling

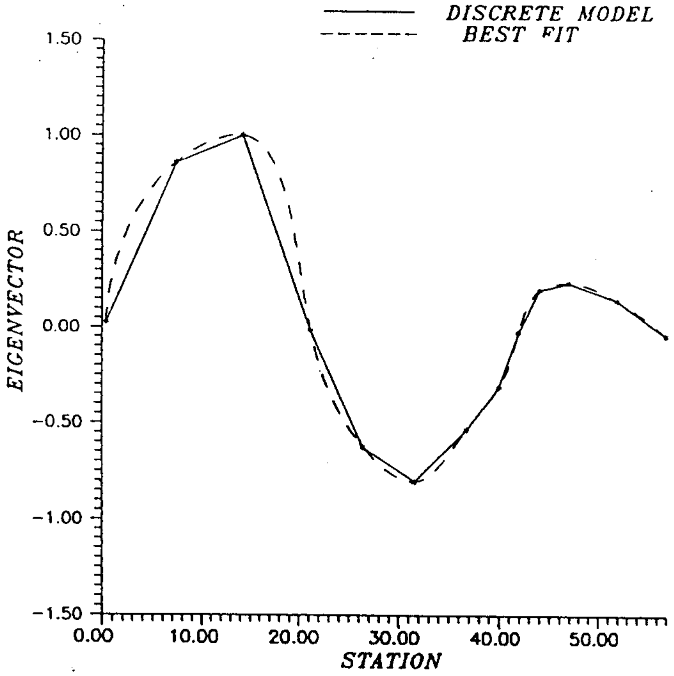

Fig. 8 Eigenvector along the critical stringer (Str. 10)

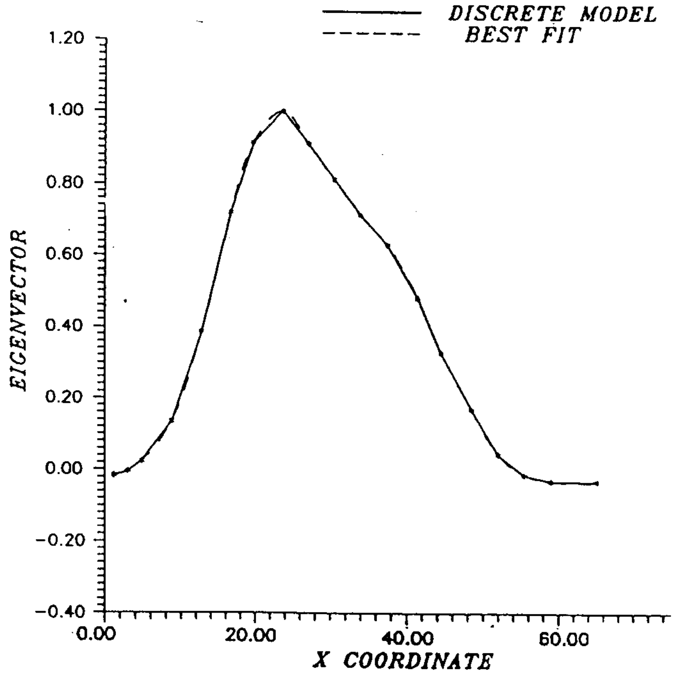

Fig. 9 Eigenvector along the wing at station 14.27

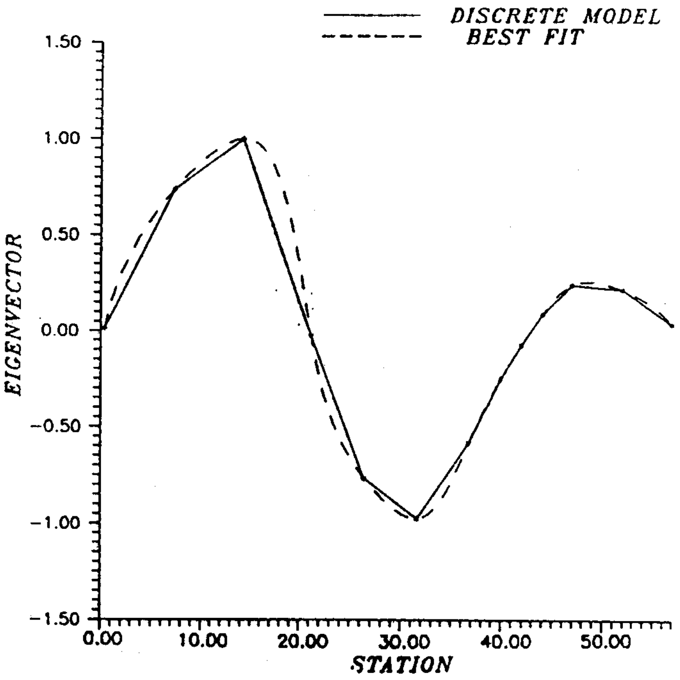

Fig. 12 Eigenvector along the critical stringer (Str. 9)

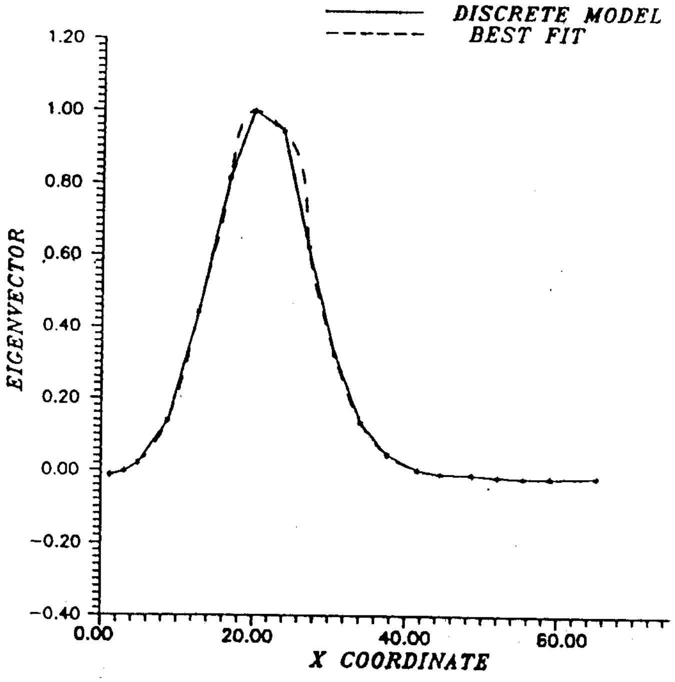

Fig. 13 Eigenvector along the wing at station 14.27

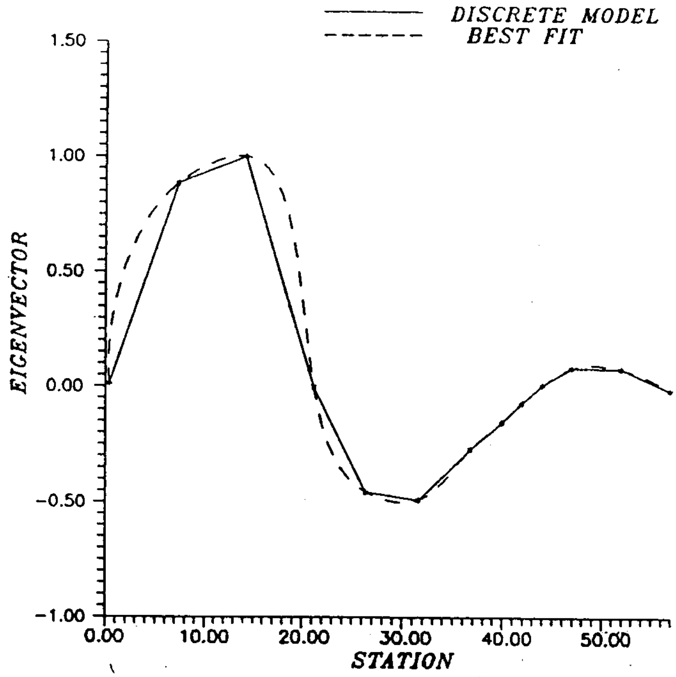

Fig. 14 Eigenvector along the critical stringer (Str. 10)

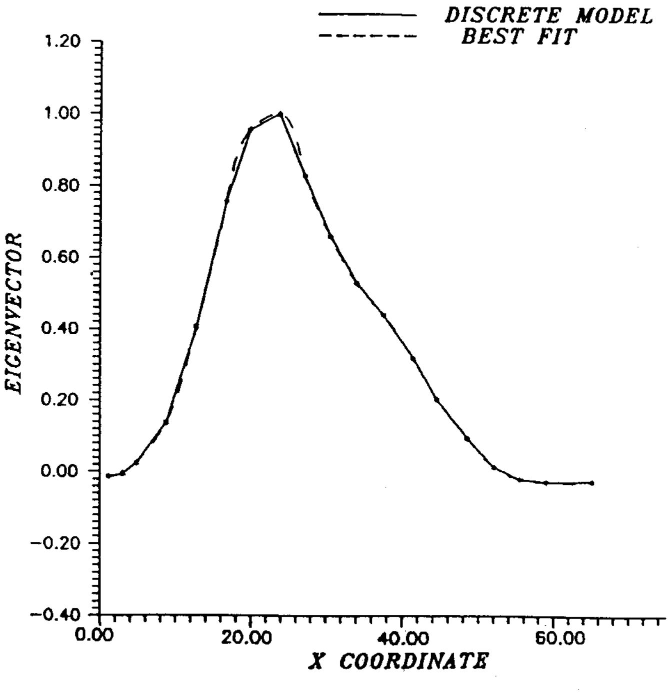

Fig. 15 Eigenvector along the wing at station 14.27