NASTRAN NONLINEAR ANALYSIS OF STIFFENED WING PANELS

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Abstract

MSC/NASTRAN nonlinear analysis capability has been studied by many investigators. In this paper, Solution 66 of MSC/NASTRAN Version 64A is used to analyze stiffened panels of the wing in a large transport aircraft. Material nonlinearity is considered. The complete stress-strain function of each material used in the panel is input through MATS1 and TABLES1 data cards. QUAD4 elements are used to model the panel. The nonlinear buckling result, obtained from Solution 66 and its DMAP Alter for nonlinear eigenvalue extraction, shows substantial agreement with the experimental test data of stiffened panel under compression. The paper also addresses the application of nonlinear analysis of MSC/NASTRAN in material evaluation and selection of structures.

1. INTRODUCTION

MSC/NASTRAN has been used in Douglas as one of the major computer programs in analysis of structures to support production of large transport airplanes such as the MD-80 series, the MD-11, and the DC-9. In addition, it is used in investigation of advanced materials, both composites and metals, for application to existing or future aircraft.

This paper presents a comparison of test data with the results of MSC/NASTRAN nonlinear analysis of stiffened wing panels under compression using a new metal such as Al-Li versus a conventional aluminum alloy. Two types of the following wing panels were investigated: (1) aluminum panel using Al 7075-T6 plate as skin and stringers (Reference 1) and (2) Al-Li panel using Alcoa Al-Li 2090 plate as skin and stringers (Reference 2). The geometry of both panels is identical, as shown in Figure 1. Each of the panels consisted of three extruded and machined J-shaped stringers, slug-riveted to the skin through the inner flanges. The 1,100,000-pound Baldwin testing machine was utilized to apply compressive loads to the panels. The machine consists of two massive crossheads and a hydraulic ram. The test panel was placed between the crosshead and ram for testing. Pressurizing the hydraulic ram moved it toward the lower crosshead, thus imparting a uniformly compressive loading on the test panel.

2. MSC/NASTRAN NONLINEAR BUCKLING ANALYSIS

One of the advantages of nonlinear analysis of Solution 66 in MSC/NASTRAN is using a similar approach in linear static analysis. Both the finite-element models require the same basic grid points, element data, and unique load case except that nonlinear properties of the materials are specified with addi-

A	B	C	D	E	F
47.911	22.652	1.937	9.493	9.489	1.714

STRINGER NO.	G	H	K	M	N	P	R
S1	1.370	0.298	2.509	0.2505	0.2945	1.687	3.630
S2	1.367	0.298	2.498	0.250	0.295	1.685	3.627
S3	1.371	0.297	2.508	0.250	0.295	1.684	3.629

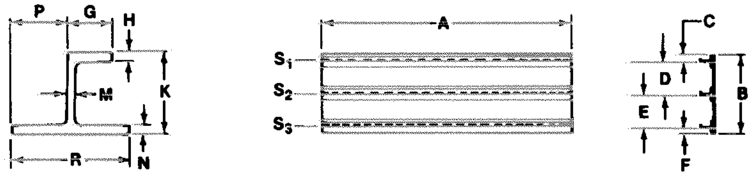


FIGURE 1. GEOMETRY OF THE STIFFENED WING PANEL

tional material data and the nonlinear solution requires a search/iteration/increment strategy. The eigenvalue problem for the nonlinear buckling analysis used in Solution 66 and its DMAP Alter for nonlinear eigenvalue extraction may be expressed as follows (Reference 3):

Let (K_n) and (K_{n-1}) be the stiffness matrices evaluated at the known solution points in the vicinity of the instability of the panels.

$$(K_n + \lambda \Delta K)\{\phi\} = \{0\} \tag{1}$$

with

$$\Delta K = K_n - K_{n-1} \text{ in the } n^{th} \text{ iteration.}$$

The critical displacements matrix upon instability may be estimated as

$$\{U_{cr}\} = \{U_n\} + \lambda\{\Delta U\} \tag{2}$$

where

$$\{\Delta U\} = \{U_n\} - \{U_{n-1}\}$$

Let $\{P_{cr}\}$ be the critical buckling load of the panel. Then, based on the virtual work principle,

$$\{\Delta U\}^T\{P_{cr}\} = \{\Delta U\}^T\{(F_{cr}\}$$

where

$$F_{cr} = F_n + \int_{U_n}^{U_{cr}} K du = F_n + \int_0^{\lambda} K(\lambda)\Delta U d\lambda = F_n + \lambda\ [K_n + (1/2)\ \lambda \Delta K]\ \Delta U$$

and

$\{F_n\}$ is the element force matrix.

Then, the critical buckling load may be calculated by

$$\{P_{cr}\} = \{P_n\} + \alpha\{\Delta P\} \tag{3}$$

where

$$\{\Delta P\} = \{P_n\} - \{P_{n-1}\},$$

and

$$\alpha = \frac{\lambda\{\Delta U\}^T[K_n + (1/2)\lambda\Delta K]\{\Delta U\}}{\{\Delta U\}^T\{\Delta P\}} \tag{4}$$

The α value provided on the program output is used to calculate the critical buckling load through Equation (3).

The NASTRAN finite-element model, consisting of QUAD4 elements, is shown in Figure 2. This model illustrates the use of the nonlinear buckling analysis of the Type 1 stiffened panel under compression. The compression load applied to the panel was introduced by a set of uniform displacement using the SPCD data card. A uniform displacement of 0.19 inch was applied in Subcase 1, which was subdivided into two increments. Additional uniform displacement of 0.29 inch was applied in Subcase 2 and 0.52 inch in Subcase 3. Subcase 2 was subdivided into six increments and Subcase 3 was subdivided into four increments. The nonlinear properties were input through MATS1 and TABLES1 data cards. The type of material nonlinearity was specified as PLASTIC. The Von Mises yield function and isotropic hardening rule were selected. The stress-strain curves of Al 7075-T6 (Reference 4) and Alcoa Al-Li 2090 (Reference 5) were input in TABLES1.

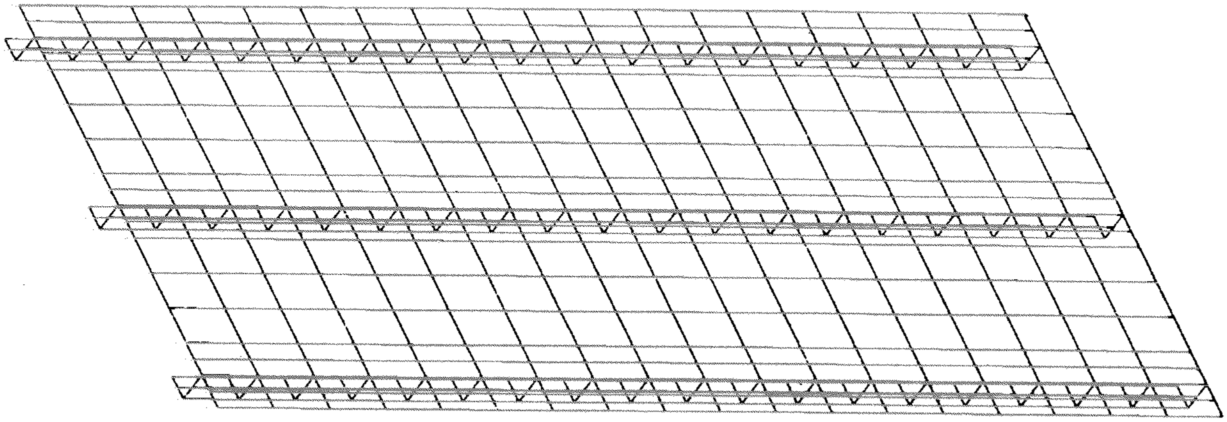


FIGURE 2. NASTRAN MODEL OF THE WING PANEL USING QUAD4

The primary solution operations in Solution 66 were controlled with the NLPARM data card for applied load increments, internal force equilibrium iterations, and element stiffness matrix updates. Solution 66 provides a great advantage by specifying error tolerance numbers in the NLPARM card to control the accuracy and by specifying the limit numbers to control cost.

Solution 66 for static analysis was first performed in a cold-start run to create a data base. The AUTO option for KMETHOD specified in the NLPARM card allowed the program to select automatically the most efficient iteration strategy based on the convergence rate. At each iteration, the program examined whether it was more efficient to perform a stiffness update. The maximum number of iterations, MAXITER, allowed for each load increment was specified as 10.

The program was restarted into Subcase 2 at load increment 2 through parameters SUBID, LOADINC, and LOOPID in the NLPARM card and the data base which was created in the cold-start run. At each step, the number of iterations required to converge was estimated. The error tolerance limits for determining convergence were EPSU = 1.0 E-2, EPSP = 1.0 E-3, and EPSW = 1.0 E-4. The execution was terminated after two consecutive diverging solutions with stiffness updating. Results of the analysis, as shown in Table 1 and Figure 3, are very close to the test data. The buckling load as well as the postbuckling load is known to be quite sensitive to the modeling sophistication in the skin-stiffener region (Reference 6). In order to investigate the influence of modeling technique on the result of buckling load using MSC/NASTRAN Solution 66, various models with different element configurations at the skin-stiffener regions were studied, as shown in Table 2. The study showed that Model No. 4 gave the closest solution to the test result. However, results from other models provided similar substantial agreement with the test data. FAR Sec. 25.307 (Proof of Structure) states: "Structural analysis may be used only if the structure conforms to those for which experience has shown this method to be reliable." The substantial agreement with the test data would qualify the nonlinear analysis as a reliable method, which is in agreement with current literature (Reference 7).

TABLE 1
COMPARISON OF TEST DATA AND RESULT FROM NASTRAN NONLINEAR ANALYSIS

TYPE OF PANELS	TEST DATA (LB)	NASTRAN NONLINEAR ANALYSIS	
		BUCKLING LOAD (LB)	DEVIATION FROM TEST DATA (PERCENT)
TYPE 1 PANEL	890,000	930,000	4.5
TYPE 2 PANEL	920,000	966,000	5

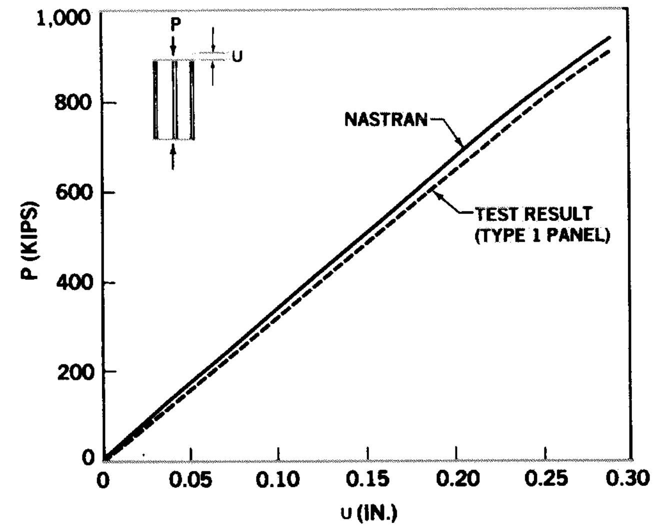


FIGURE 3. NASTRAN AND TEST RESULT OF THE LOAD-DEFLECTION CURVES OF TYPE 1 PANEL

TABLE 2
INFLUENCE OF NASTRAN MODELS ON BUCKLING LOAD

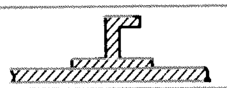
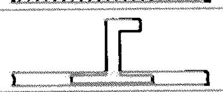
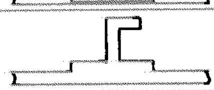
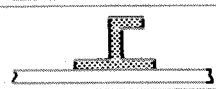
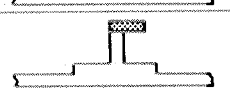
NASTRAN MODEL	ELEMENT OF TYPICAL SKIN-STIFFENER REGION	DEVIATION OF BUCKLING LOAD FROM TEST DATA (PERCENT)
REAL PANEL		TEST DATA 0
MODEL 1		5
MODEL 2		6
MODEL 3		6
MODEL 4		4

PLATE ELEMENT
BEAM ELEMENT

3. SAMPLE APPLICATION OF MSC/NASTRAN

Where testing is not conducted, either for reasons of cost or applicability, MSC/NASTRAN analysis would be a reliable method to use to select a material for a complicated structure. The selection of Al-Li alloy instead of Al 7075-T6 would be of benefit, increasing 3.9 percent of the buckling strength based on the nonlinear buckling analysis, as shown in Table 1.

Figure 4 shows a variation of MSC/NASTRAN buckling loads of wing panels using a new alloy; e.g., Alcoa Al-Li 2090. The module of elasticity, E, was varied in the different position of the stringers. The base panel consisted of homogeneous E_b in the stringers. The second panel consisted of stringers where the E of the outer flanges was 20 percent less than that of the base panel, and the E of inner flange and web was kept the same as for the base panel. The third panel consisted of stringers where the E of the web was 20 percent less than that of the base panel and the E of flanges was kept the same as for the base panel. Similarly, in the fourth panel, the E of the inner flange of the stringers was 20 percent less than that of the base panel and the E of the outer flange and web was kept the same for the base panel. The solid section of the figure represents the baseline E_b and the dotted section represents 0.8 E_b. It is shown that the No. 3 panel has the highest change of percentage of buckling load; i.e., 91 percent of the baseline panel. The buckling load of the No. 4 panel has the least effect due to the change of E in the inner flange, even though the area of the inner flange occupies 60 percent of the total area of the stringer.

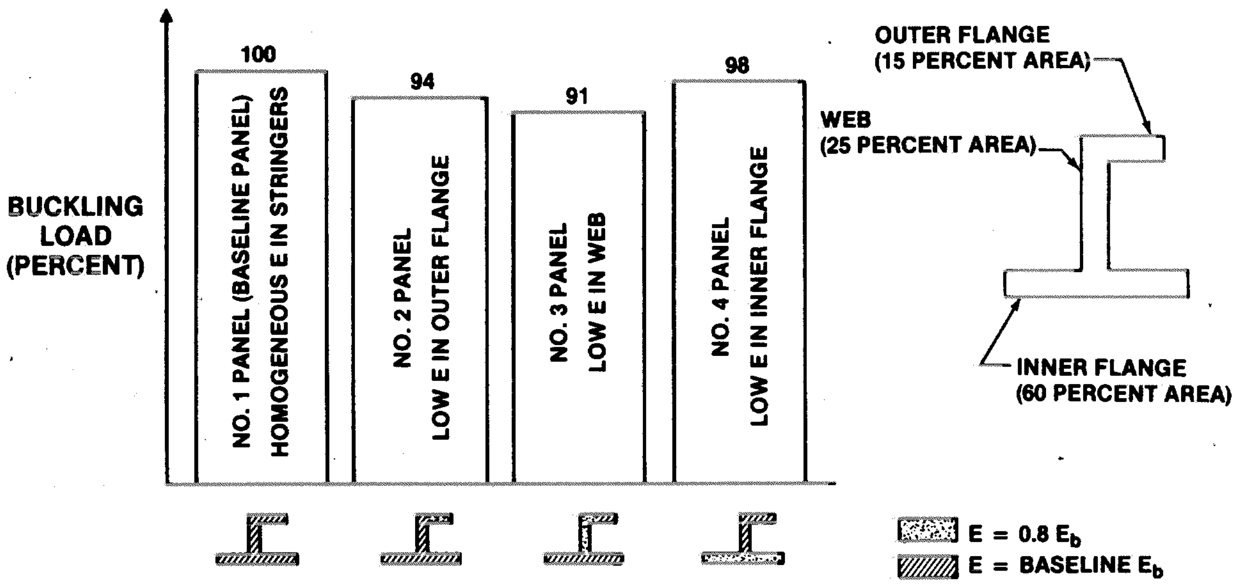


FIGURE 4. VARIATION OF BUCKLING LOADS OF WING PANELS

Thus, from the above analysis, it is important to have quality control of the material property at the web or outer flanges rather than the inner flange of the extruded J-shaped stringer on the panel under compression. From a designer's point of view, the J-section could be more effective if the area of inner flange is decreased and the area of web or outer flange is increased.

4. CONCLUSIONS

The nonlinear buckling result obtained from Solution 66 and its DMAP Alter for nonlinear eigenvalue extraction shows substantial agreement with the experimental test data of stiffened panel under compression. The close agreement of the analysis and test data provides confidence in using the MSC/NASTRAN as a reliable method of analyzing structures for certification of a large transport aircraft with either the FAA or DoD.

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