N89-24628

LOCAL STIFFENER AND SKIN POCKET BUCKLING PREDICTION BY SPECIAL PASCO MODELING TECHNIQUE: CORRELATION TO TEST DATA

Dah N. Yin, Vu M. Tran, and Patrick M. Swift
Rockwell International, Space Transportation Systems Division
Downey, California

INTEGRALLY MACHINED WAFFLE PANELS

Waffle panels are often used on fuselage shell structures such as that of the Space Shuttle. There are a number of advantages to using waffle paneling. The waffle panel design is an efficient design for carrying biaxial, in-plane and shear loads. The geometry of the waffle panel pockets can be adjusted to account for variability of loading in the principle directions. The stiffeners of the waffle panel readily provide attachment support for secondary systems, an important consideration for aerospace structures. The waffle panel also represents the simplest integrally machined panel design to manufacture. Figure 1 shows a typical waffle panel design. The integrally machined waffle panel is constructed with a fillet radius between the vertical stiffener and the plate. This fillet radius provides additional stability and load carrying capability to the structure. Present analysis techniques for waffle type structures include classical theory of plate buckling, introduced here as the Rockwell-developed program WAFFLE, and the NASA-developed stress analysis program--Panel Analysis and Sizing Code (PASCO). This paper discusses the application of the PASCO program in conjunction with the WAFFLE program to account for both the fillet radius and the presence of stiffeners in both directions. The results of the tests are used to verify that these adjustments are valid and necessary if accurate analysis of the waffle panel is to be achieved.

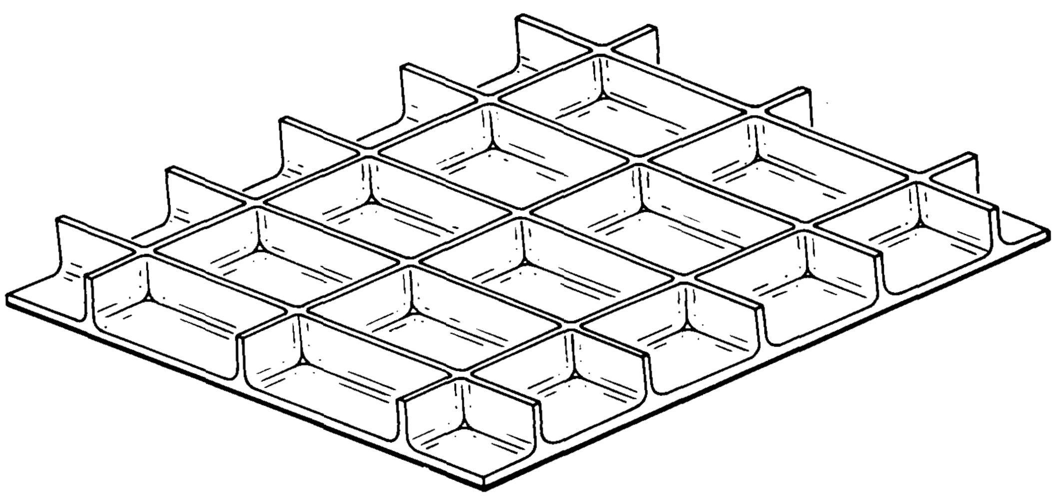


Figure 1

THE WAFFLE PROGRAM

The WAFFLE program was developed at Rockwell for application on waffle panels. It is based on NACA Technical Notes (refs. 1, 2, 3, 4, and 5). The critical stresses are determined on the basis of the principle that during buckling, the elastic strain energy stored in a structure is equal to the work done by the applied loads. The deflection function is expressed exactly by means of a two-dimensional infinite Fourier series. The Raleigh-Ritz method is applied to obtain an infinite set of homogeneous linear equations needed to solve for the Fourier coefficients. The solutions of these equations that give Fourier coefficients not all equal to zero exist only for those combinations of shear and direct stress for which the buckled plate is in neutral equilibrium. The matrix iteration method was then applied to solve for the 10 most important equations that best satisfy the loading condition. Input load includes in-plane and moment loads in both directions, shear loading, and lateral pressure. Thermal stress caused by temperature gradients is also calculated. The effect of the combined loadings is reflected in the general instability margin of safety. Local instability of the waffle panel is also taken into account by computing the crippling and buckling allowables of the stiffener as well as pocket skin buckling allowable (ref. 6). It should be noted that although it is the same plate buckling theory that is used to obtain the buckling allowable of the whole panel as well as the buckling allowable of the pocket skin, the bending stiffness formulation of the former reflects the orthotropic effects presented by the biaxial stiffeners. WAFFLE therefore represents a comprehensive stress analysis of the waffle panel. Figure 2 shows a sample output of the program.

```
COMPRESSION TEST
PANEL GEOMETRY AND PROPERTIES AT 70. DEG. TEMPERATURE:
A    =20.00     B    =18.00     BSX =4.00       BSY =3.00
TS   =.0660     H    =.800      TWX=.086        TWY=.086
TEX  =.0921     TEY  =.0856     IX   =.003530   IY   =.002775
RAD  =.1875     FCY  =57037.      E=10.9E+06
APPLIED LOADS: (+ IS COMPRESSION AND - IS TENSION)
NX   =2000.     NY  =    0.     NXY =    0.     PRESS =.00
TEMP =  70.0    TDX =  .00      TDY =  .00
POCKET STABILITY: (LBS/IN.)
NXP =1434.      NYP =0.         NXYP=0.             M.S.=-.03
STIFFENER STABILITY: (PSI)
FCSX=21722.     FCWX=21722.                         M.S.=1.48
FCSY=      0.   FCWY=      0.                       (NO LOADS)
GENERAL STABILITY:
GRX=.9010       GRXY.0000                           M.S.= ..11
RTX=.0000       RTV  .0000
```

Figure 2

THE PASCO PROGRAM

The PASCO program was developed by M.S. Anderson and W.J. Stroud of NASA. It was designed for analyzing and sizing uniaxially stiffened panels. Buckling and vibration analyses are carried out with a linked plate analysis computer code denoted VIPASA, which is incorporated into PASCO (refs. 7, 8, and 9). Typical loading conditions for an uniaxially stiffened panel include longitudinal and transverse loads, shear load, bending moment, lateral pressure, temperature, and a bow-type imperfection (fig. 3). PASCO ordinarily models a cross section by assuming there is a repetition of substructures. The substructure is composed of an arbitrary assemblage of thin, flat, rectangular plate elements that are connected together along their longitudinal edges. The loads on each plate element are calculated under the assumption of uniform longitudinal strain. In addition, transverse load is assumed to be carried by the skin elements.

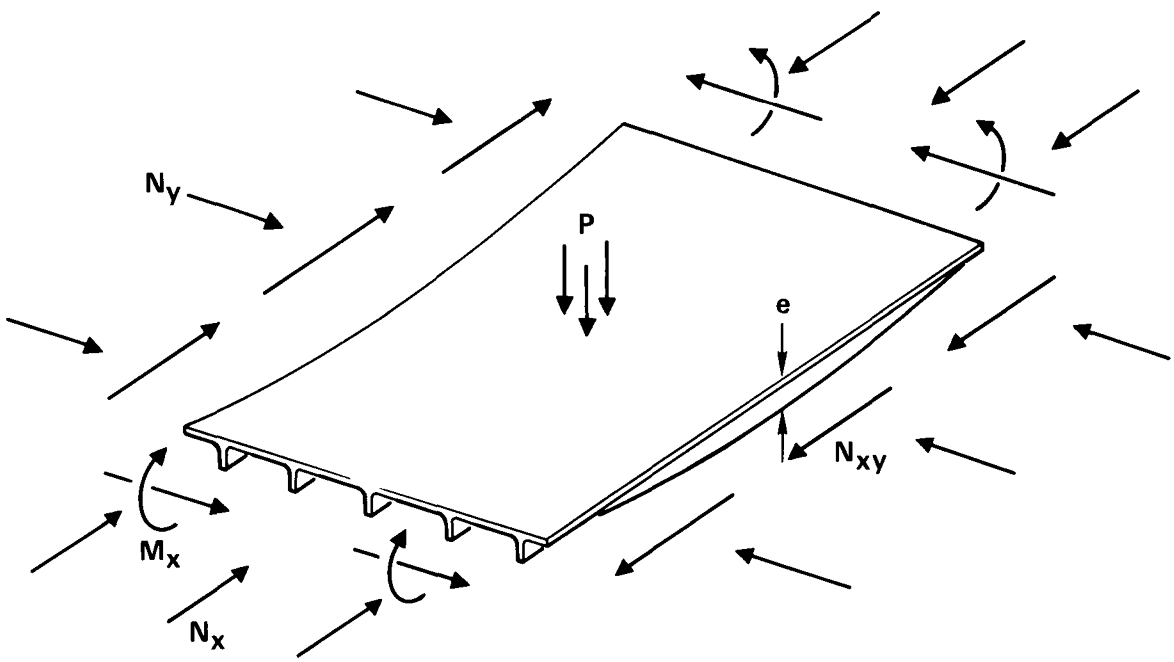


Figure 3

PASCO MODELS

PASCO's capability is limited to uniaxially stiffened panels. Biaxially stiffened panels such as waffle panels, however, can be analyzed by assuming that the waffle is made up of a series of uniaxially stiffened panels whose interface lines are the location of the transverse stiffeners. Boundary conditions along the longitudinal edges can be simply supported or clamped. Boundary conditions can not be prescribed on the ends (transverse edges) of the panel. PASCO, however, implicitly assumes that the end lines remain straight after buckling. Thus, in effect, PASCO imposes a simply support condition on the ends. Since the real waffle panel behaves neither as simply supported or clamped edge condition at the interface lines, we would expect a conservative result. A more accurate model would apply a bending moment at the interface. This bending moment can be determined from WAFFLE program. Additional loading because of the thermal gradient could indirectly be determined by WAFFLE and be input into PASCO. Two PASCO models were run and the results were compared with the actual test result. Panel geometry, loading, and boundary conditions similar to the actual test were made. In one of the PASCO models, five small elements stacked on top of each other simulated the fillet radii. The total area of these elements added up to the total area of the real fillet. Plots of the two models are shown in figure 4.

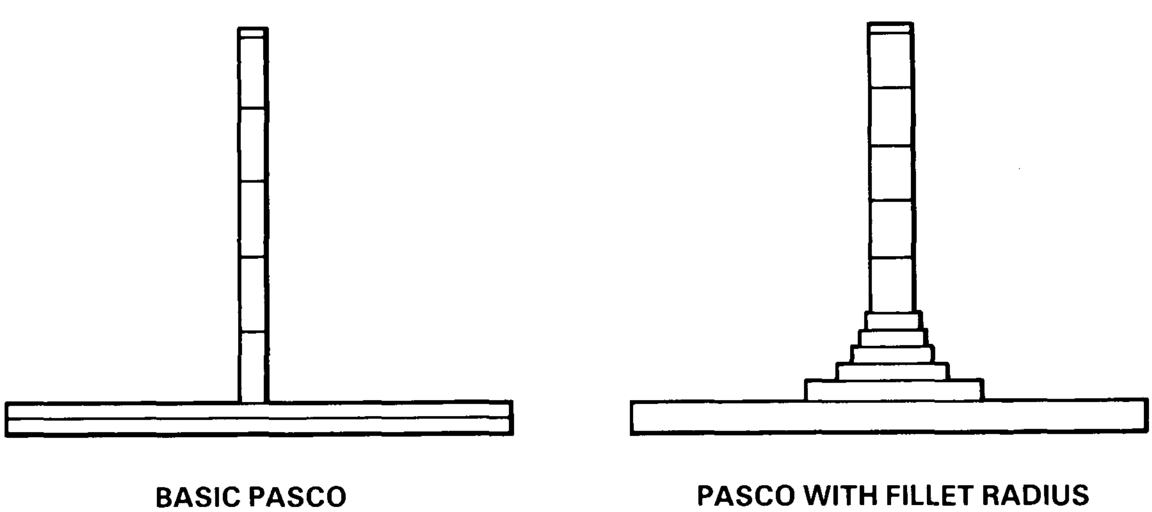
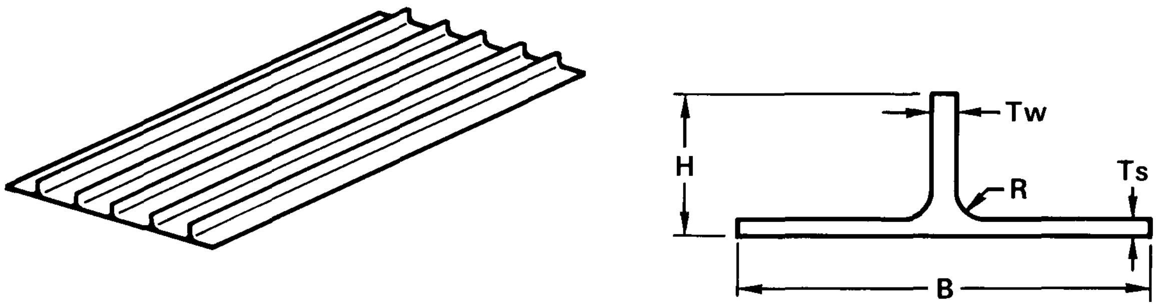


Figure 4

EXPERIMENTAL

Two full scale tests were run on the integrally machined waffle panels (ref. 10). For both tests, a series of uniaxial strain gages were used to determine the stress in the expected area of failure. The gages were placed in the pockets and, where applicable, on the base, sides, and tip of the stiffeners. The first test was a study of the pocket buckling allowable for the waffle skin panel. In this test the stiffener was machined so that the skin was critical. The second test was a study of the stiffener buckling allowable. In this test, the stiffener was undercut to make the stiffener critical. The test panels were 19 by 20 inches and 14 by 20 inches, respectively. They were installed on a Tinius Olsen Compression Test Machine, which can deliver up to 440,000 pounds of load. The load was applied in the longitudinal direction. The panels were placed vertically on the test machine. A metal slab sandwiched between the panel ends and the test bed uniformly distributed the compressive load. In order to simulate simply support condition, I-beams were firmly placed, but not clamped, along the longitudinal edges. In both tests the load was increased incrementally by 5,000 pounds to the point of failure with stress readings taken at the end of each interval. The stress readings were tabulated with the corresponding applied loads. Geometry dimensions used in the two tests are shown in figure 5. A picture of the test setup is shown in figure 6.



GEOMETRY	TEST 1	TEST 2
B	3.00 IN.	2.24 IN.
H	0.80 IN.	1.13 IN.
Ts	0.066 IN.	0.070 IN.
Tw	0.086 IN.	0.058 IN.
R	0.19 IN.	0.19 IN.
L	4.00 IN.	3.38 IN.
a × b	19 × 20 IN.	14 × 20 IN.

Figure 5

TEST SETUP

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

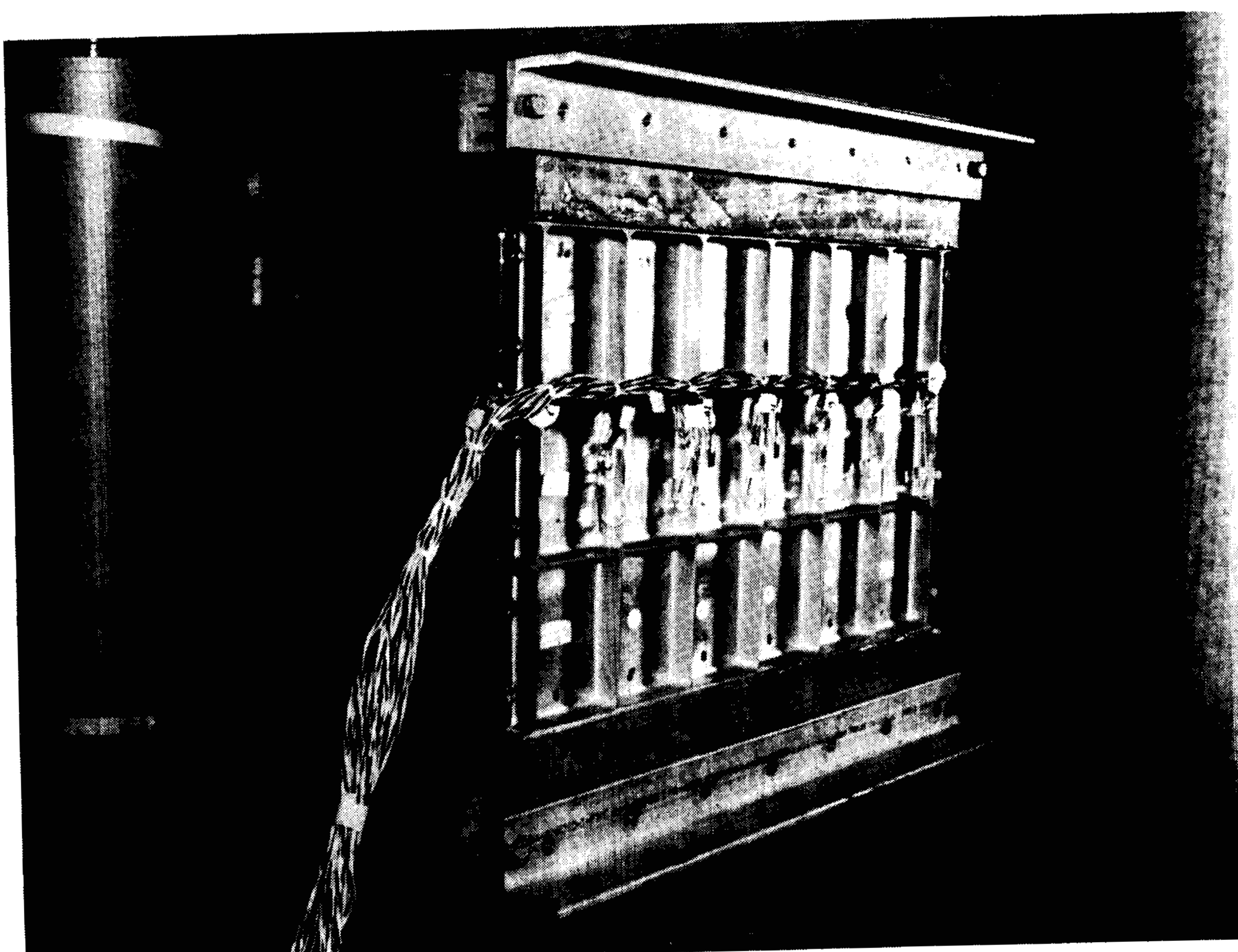


Figure 6

RESULTS

Plots of stress versus longitudinal compressive load are shown in figure 7. The relationship between the applied load and the induced stress is, as expected, very close to linear. Stress readings were taken from the appropriate strain gages mounted in the buckled areas (pocket skin in the first test and the stiffener in the second test). The results of the tests as well as the results predicted by WAFFLE and PASCO are shown in the following chart. The actual test result in each test is the average of the two strain gages.

Method	Test 1 Buckling Half-Wavelength		Test 2 Buckling Half-Wavelength	
	λ = L/2	λ = L	λ = L/2	λ = L
WAFFLE	N/A	21,121 psi	N/A	15,259 psi
PASCO without fillet	24,492 psi	23,127 psi	26,316 psi	31,205 psi
PASCO with fillet	28,805 psi	33,319 psi	38,067 psi	43,473 psi
Actual test	30,000 psi	N/A	39,750 psi	N/A

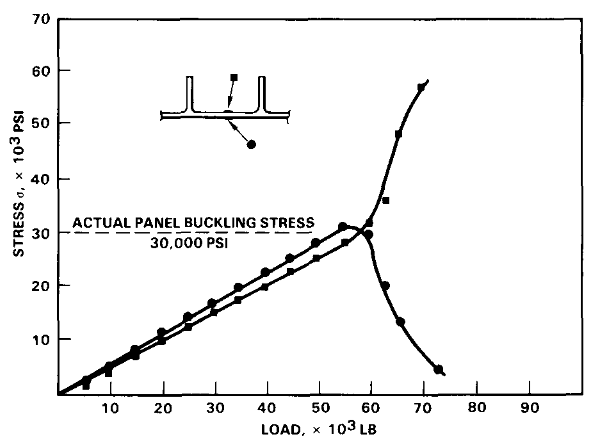


FIGURE 7. RESULTS

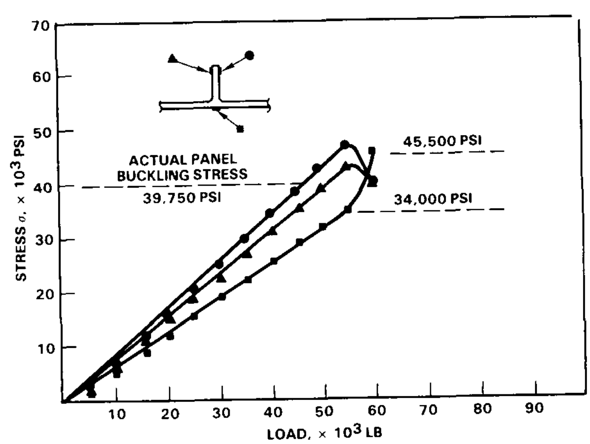


FIGURE 7. RESULTS (CONT)

Figure 7

REFERENCES

1. Gerald, George and Becker, Herbert: Handbook of Structural Stability, Part I, Buckling of Flat Plate. NACA Technical Note 3781, July 1957.

2. Becker, Herbert: Handbook of Structural Stability, Part II, Buckling of Composite Elements. NACA Technical Note 3782, July 1957.

3. Gerald, George: Handbook of Structural Stability, Part IV, Failure of Plates and Composite Elements. NACA Technical Note 3784, August 1957.

4. Gerald, George: Handbook of Structural Stability, Part V, Compressive Strength of Flat Stiffened Panels. NACA Technical Note 3785, August 1957.

5. Gerald, George and Becker, Herbert: Handbook of Structural Stability, Part VII, Strength of Thin Wing construction. NACA Technical Note D-162, September 1959.

6. Yin, Dah N.: Integrally Machined Panel With Longitudinal and Transverse Stiffeners. WAFFLE Analysis Program (to be published). Rockwell International, Space Transportation Systems Division.

7. Stroud, W. Jefferson and Anderson, Melvin S.: PASCO: Structural Panel Analysis and Sizing Code, Capability and Analytical Foundations, Langley Research Center, Hampton, Virginia. Memorandum 80181, November 1981.

8. Anderson, Melvin S.: Stroud, W. Jefferson; Durling, Barbara J.; and Hennessy, Katherine W. PASCO: Structural Panel Analysis and Sizing Code, User's Manual Langley Research Center, Hampton, Virginia. NASA Technical Memorandum 80182, November 1981.

9. Stroud, W. Jefferson; Greene, William H.; and Anderson, Melvin S.: Buckling Loads of Stiffened Panels Subjected to Combined Longitudinal Compression and Shear: Results Obtained With PASCO, EAL, and STAGS Computer Programs Langley Research Center, Hampton, Virginia. NASA Technical Paper 2215, 1984.

10. Local Stiffener and Skin Pocket Buckling of Integrally Machined Stiffened Panel Test Report. Rockwell International, Space Transportation Systems Division, December 1980.

11. Timoshenko, Stephen P. and Gere, James M.: Theory of Elastic Stability. McGraw-Hill Book Company, Inc. Second Edition, 1961.

12. Dow, Norris F.; Libove, Charles; and Hubka, Ralph E.: Formulas for Elastic Constants of Plates With Integral Waffle-Like Stiffening. NACA Report 1195, 1954.