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NASTRAN STATIC AND BUCKLING ANALYSIS – COMPARISON WITH OTHER LARGE-CAPACITY PROGRAMS

by Lalit C. Shah
Rockwell International
B-1 Division
Los Angeles, California

SUMMARY

A square plate with clamped edges under a concentrated load was modeled using NASTRAN (reference 1) and ASKA (reference 2) finite element computer programs. Deflections were computed for various width-to-thickness ratios (b/t) of the plate element, and were compared against the classical theory to determine the b/t limitations.

A cylinder with simply supported ends was modeled using NASTRAN and STAGS (reference 3) computer programs for buckling analysis. The models were subjected to a uniform radial pressure loading. Several parameters were changed, and the effects of those variations are presented. Utilizing these data, a model which will produce results comparable to published empirical data can be constructed and processed for a minimized cost.

STATIC ANALYSIS

The user of finite element computer programs has numerous limitations to be considered when constructing a mathematical model of the structure to be analyzed. Although considerable information is available concerning the plate element aspect ratio (a/b) (i.e., length-to-width ratio), the effect of varying the width-to-thickness ratio (b/t) has not previously been presented. The effect of varying the plate element b/t ratio was investigated for the NASTRAN and ASKA finite element computer programs.

This investigation utilized a square plate with clamped edges. Two elements, CTRIA2 and CQUAD2, available in NASTRAN, were used in two separate models. One triangle-plate element, TRIB3, available in ASKA, was used in the third model. These models, shown in Figure 1, were 152.4 cm (60 inches) square plates with varied thickness to achieve the b/t ratio desired. The basic model mesh size was selected based upon previous experience. One model with mesh size reduced by a factor of 2 was processed, and the results were compared to verify that the basic model mesh size was valid.

One loading, which consisted of a concentrated load applied in the geometric center normal to the plate, was selected due to its ideal checks for the bending characteristics of any plate element. This loading was applied to each model processed.

The results of the two NASTRAN models and the ASKA model are summarized in table I. The resulting computed deflections for the three models are tabulated for the various b/t ratios investigated. Included in this table are the theoretical deflections based upon classical equations (reference 4). These deflection data are presented graphically in figures 2 through 4. The plot of the percentage difference between computed deflection and theoretical deflection is shown in figure 5 for the three models investigated. The two NASTRAN plate elements, CTRIA2 and CQUAD2, break down in regions of b/t less than five. The ASKA element, TRIB3, is quite consistent, even for extremely low values of b/t. It is apparent that a limitation on the value of b/t exists for the NASTRAN plate elements. This limitation should be considered along with the aspect ratio (a/b) limitations when constructing a model for the NASTRAN computer program.

BUCKLING ANALYSIS

Buckling analysis is an eigenvalue problem which may result in very high computer processing costs to achieve a valid solution. This report presents an investigation into the various modeling parameters that affect the solution and the computer cost. The results of this study reveal an approach to achieving a valid solution for minimized computer cost.

This investigation considered a cylinder under uniform radial pressure loading. According to Donnell's equation, under uniform radial pressure, the buckling stress of the cylinder is:

$$\sigma_{cr} = \frac{K_y \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{L}\right)^2$$

For moderately long cylinders, this equation gives quite good correlation with test data (reference 5). For this investigation, a data point was selected where the test result and the preceding equation value practically coincide. This cylinder model is shown in figure 6. The cylinder was modeled for

NASTRAN, a finite element computer program, and for STAGS, a finite difference computer program. Essentially, the same parameters were varied for both models in determining effects upon the solution validity and the computer costs.

The results of the NASTRAN and STAGS models are presented in tables II and III, respectively. These data are presented in figures 7 through 9. Appendix A contains the mode shapes for all the models studied in this investigation.

A significant parameter in modeling for either NASTRAN or STAGS is the circumferential spacing of grid points which determine the number of elements per half wave-length. As indicated in figure 7, an extremely narrow range of circumferential spacing may be considered in modeling in order for NASTRAN buckling analysis to achieve valid results. The NASTRAN model that is very fine is equally as erroneous as a model that is very coarse. These models that are outside this narrow band of acceptable circumferential spacing produced results that deviated from the theoretical value by up to 70 percent. The improper selection of the circumferential spacing for the STAGS program can result in extremely high errors, over 3,000 percent, as shown in figure 7. The results from the STAGS models indicate that the error percentage is directly related to the coarseness of the model, and as the circumferential spacing is reduced, the computed value approaches the theoretical solution. For this particular cylinder model to achieve a valid solution, the STAGS model required a 3-degree circumferential spacing, whereas the NASTRAN model required a 10-degree spacing.

The aspect ratio of the plate elements was considered as an important parameter in this investigation. Although most of the models utilized a constant number of uniformly spaced longitudinal cuts, a few were processed using nonuniformly spaced longitudinal cuts to determine the effects of varying the aspect ratio. It was a surprise to learn that the results did not change appreciably. Apparently the aspect ratio of the plate elements is not a critical parameter for NASTRAN buckling analysis. The data presented in figure 8 for extremely low and extremely high aspect ratios are related to the very coarse and the very fine circumferential spacing models, respectively. Therefore, the most probable reason for the results is due to the circumferential spacing.

The NASTRAN models were processed on IBM 370/165, and the STAGS models were processed on CDC 6600 computer system. The resulting machine time data are presented in tables IV and V. This information is converted to machine cost in dollars and presented in figure 9. Even the very fine model used in STAGS to achieve a valid solution resulted in less computer cost than any of the NASTRAN models processed. This may be partly attributed to the two computer systems used in the investigation. Although figure 9 presents the computer cost, a significant part of the total cost for buckling analysis is the man-hours required to construct the model and prepare the data. Also, the

NASTRAN program provides a lot more flexibility in modeling as compared to the STAGS program. The total cost data for this investigation are not available, but it is estimated that for a typical problem, the total cost would be nearly equal for these two programs.

CONCLUSIONS

In the static analysis investigation, it was determined that the NASTRAN plate element has a width-to-thickness ratio (b/t) limitation, as well as an aspect ratio limitation. These are both important parameters to be considered in modeling thick plate structures. Extra care should be exercised to avoid large aspect ratios and/or small (less than five) width-to-thickness ratios. The investigation did indicate that ASKA element TRIB3 is consistently valid for extremely low values of b/t. For those structures whose configuration requires modeling to b/t values less than five, it is recommended that they get processed using the ASKA program or use solid elements available in NASTRAN.

The buckling analysis investigation revealed that modeling requirements are quite different from static analysis. The conventional rules for static analysis modeling are neither sufficient nor applicable for buckling analysis. Although the effect of varying aspect ratio is negligible, the effect of varying the number of elements per half wavelength is very critical to both a valid solution and the computer cost. The cost of performing a valid buckling analysis is very high measured by static analysis standards. Although STAGS computer cost is quite low, the man-hour cost is quite high, compared to NASTRAN costs. The evaluation of the buckling analysis performed in this investigation has revealed that it is very difficult to separate a reasonable solution from an erroneous solution. The NASTRAN models indicate an extremely narrow band of circumferential spacing (number of elements per half wavelength) may be selected for a valid solution, whereas the STAGS models indicate the finer models produced an acceptable solution.

ACKNOWLEDGEMENT

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SYMBOLS

θ	Circumferential spacing
ℓ	Length of cylinder element
a	Length of plate
b	Width of plate
t	Thickness of plate or cylinder
R	Cylinder radius
P_{cr}	Critical buckling load – program output
P	Critical buckling load – theoretical value
σ_{cr}	Critical buckling stress – theoretical value

REFERENCES

1. The NASTRAN User's Manual (Level 15), NASA SP-222(01), June 1972.

2. ASKA User's Reference Manual, ISD Report No. 73, Institute for Statics and Dynamics, University of Stuttgart, 1971.

3. Almroth, B. O., Brogan, F. A., Meller, E., and Zele, F., User's Manual for STAGS Computer Code, LMSC-D266611A, Lockheed Missiles & Space Co., Inc., April 1972.

4. Timoshenko, S.; and Woinowsky-Krieger, S.: Theory of Plates and Shells. Second ed., McGraw-Hill Book Co., Inc., 1959.

5. Gerrad, George, and Becker, Herbert, Handbook of Structural Stability, Part III, NACA TN 3783, August 1957.

Table I

STATIC ANALYSIS - DEFLECTION DATA

Plate Thickness t (cm)	b/t	NASTRAN CQUAD2	NASTRAN CTRIA2	ASKA TRIB3	Theoretical (Ref 4)
1.27	20.0	15.00×10^{-1}	13.64×10^{-1}	13.39×10^{-1}	14.91×10^{-1}
5.08	5.0	24.0×10^{-3}	22.07×10^{-3}	20.9×10^{-3}	23.37×10^{-3}
10.16	2.5	3.2×10^{-3}	2.97×10^{-3}	2.62×10^{-3}	2.92×10^{-3}
15.24	1.67	10.39×10^{-4}	9.73×10^{-4}	7.82×10^{-4}	8.61×10^{-4}
20.32	1.25	4.93×10^{-4}	4.65×10^{-4}	NA	3.63×10^{-4}
25.4	1.00	2.87×10^{-4}	2.72×10^{-4}	16.74×10^{-5}	18.54×10^{-5}

Table II

BUCKLING ANALYSIS - EIGENVALUE DATA NASTRAN MODEL

Shell	Mesh Size		P_{cr}/P	Degree of Freedom*
	θ, deg	ℓ, cm		
90	2	25.4	1.6434	T_1
90	5	25.4	1.5409	T_1
90	9	25.4	1.3614	R_2
90	10	25.4	1.0390	R_2
90	11	25.4	.7844	R_2
180	20	25.4	.5568	R_3
180	30	25.4	.3079	R_3

*Eigenvectors are normalized with respect to this degree of freedom.

Table III

BUCKLING ANALYSIS - EIGENVALUE DATA STAGS MODEL

Shell	Mesh Size		P_{cr}/P	Degree of Freedom*
	θ, deg	ℓ, cm		
90	3.1	4.24	1.08	T_1
90	3.1	9.53	1.09	T_1
90	3.1	19.05	1.11	T_1
90	3.1	38.1	.37	T_1
90	5.3	4.24	1.27	T_1
90	11.25	12.7	2.78	T_1
90	22.5	12.7	29.9	T_1

*Eigenvectors are normalized with respect to this degree of freedom.

Table IV

BUCKLING ANALYSIS - MACHINE TIME DATA NASTRAN MODEL IBM 370/165

Number of Grid Points	CPU Time (sec)	Channel Time (sec)	Billing Units
184	222.432	114.732	28.9015
76	80.208	93.438	12.9706
44	57.732	91.212	10.4553
40	63.23	102 72	12.1796
40	54.63	93.75	10.8106
36	58.398	104.118	11.5798
28	43.662	95.358	9.6276

Table V

BUCKLING ANALYSIS - MACHINE TIME DATA STAGS MODEL CDC 6600

Number of Grid Points	CPU Time (sec)	I/O Time (sec)	System Sec
300	46.228	105.800	72.678
180	18.469	40.9	28.694
150	19.176	48.626	31.332
90	11.312	33.816	19.766
60	7.858	30.624	15.514
36	3.227	21.162	8.517
20	2.036	23.259	7.85

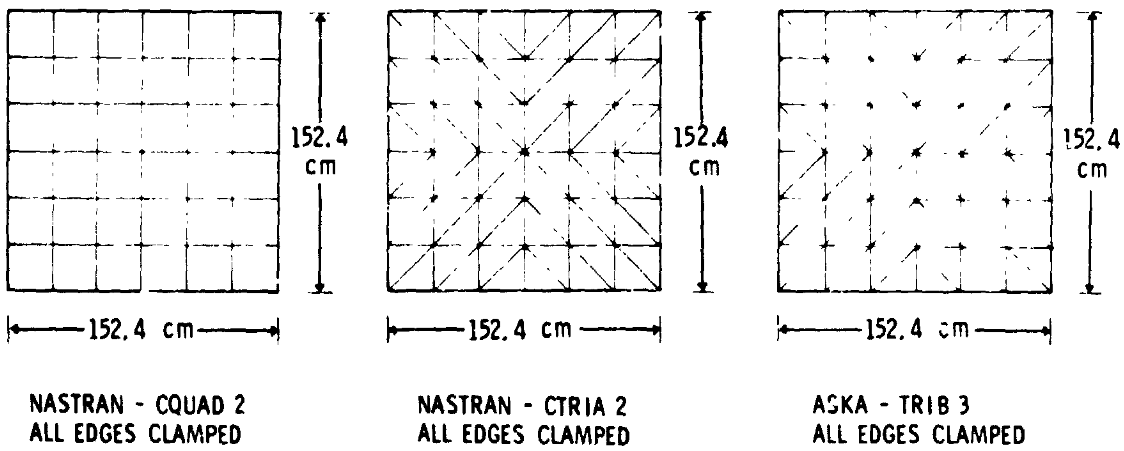

Figure 1. Static analysis - basic model geometry.

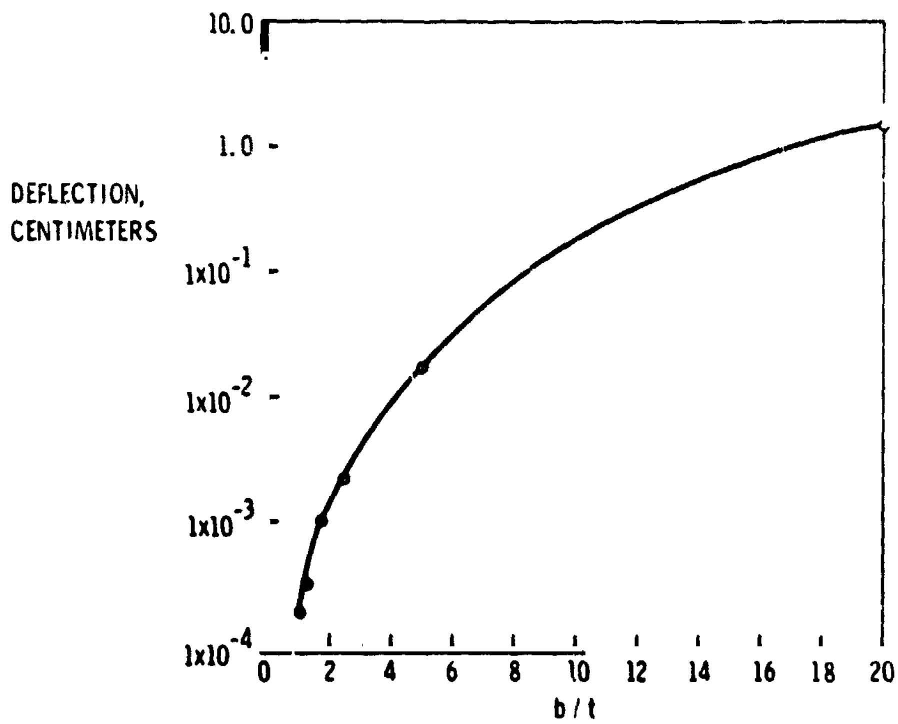

Figure 2. Deflection vs thickness ratio, NASTRAN - CQUAD2.

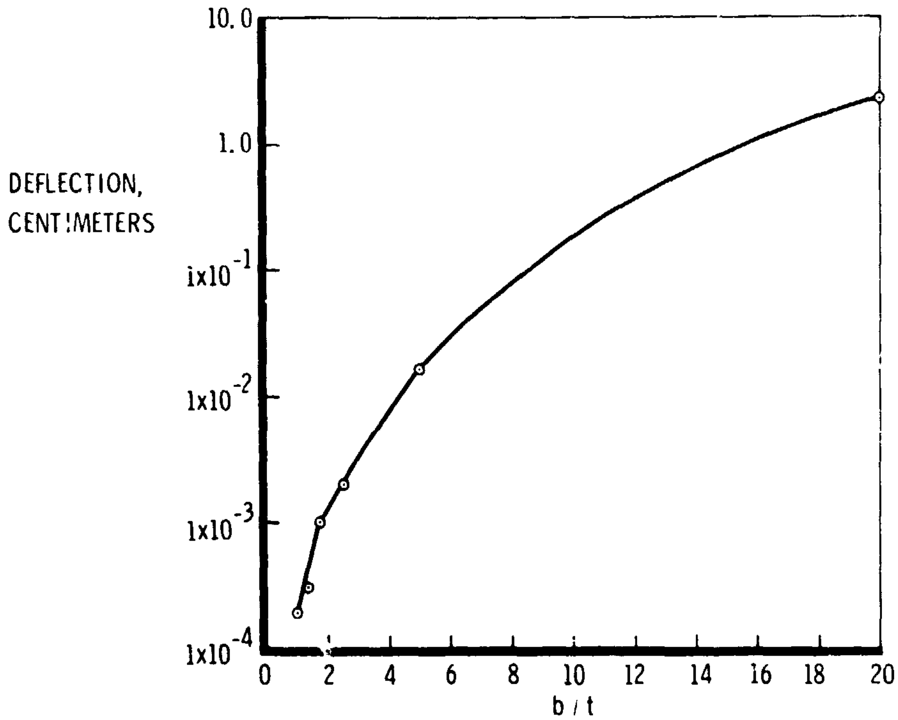

Figure 3. Deflection vs thickness ratio, NASTRAN - CTRIA2.

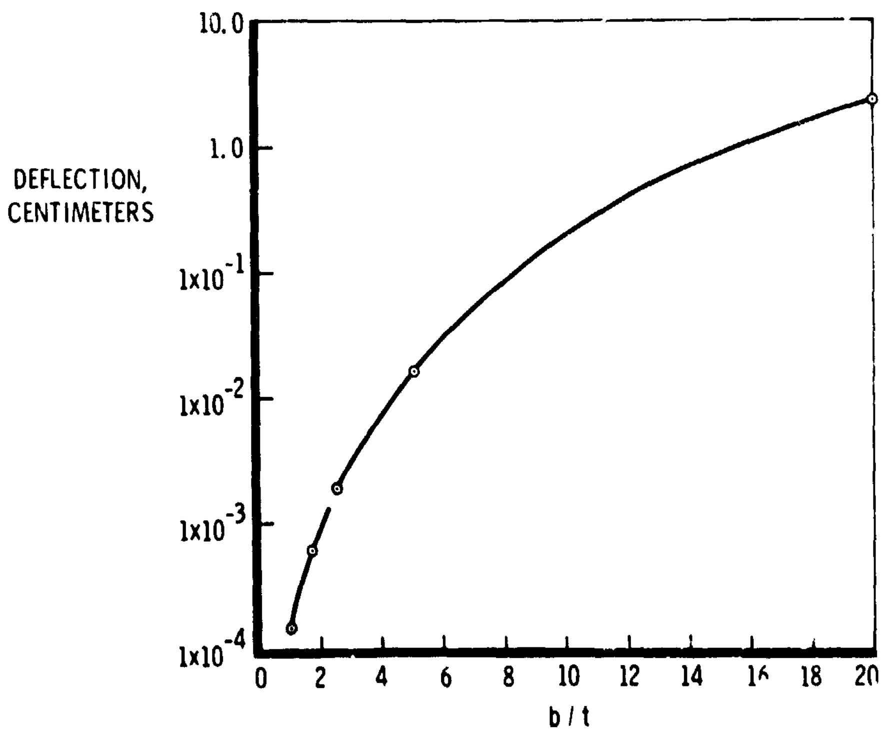

Figure 4. Deflection vs thickness ratio, ASKA - TRIB3.

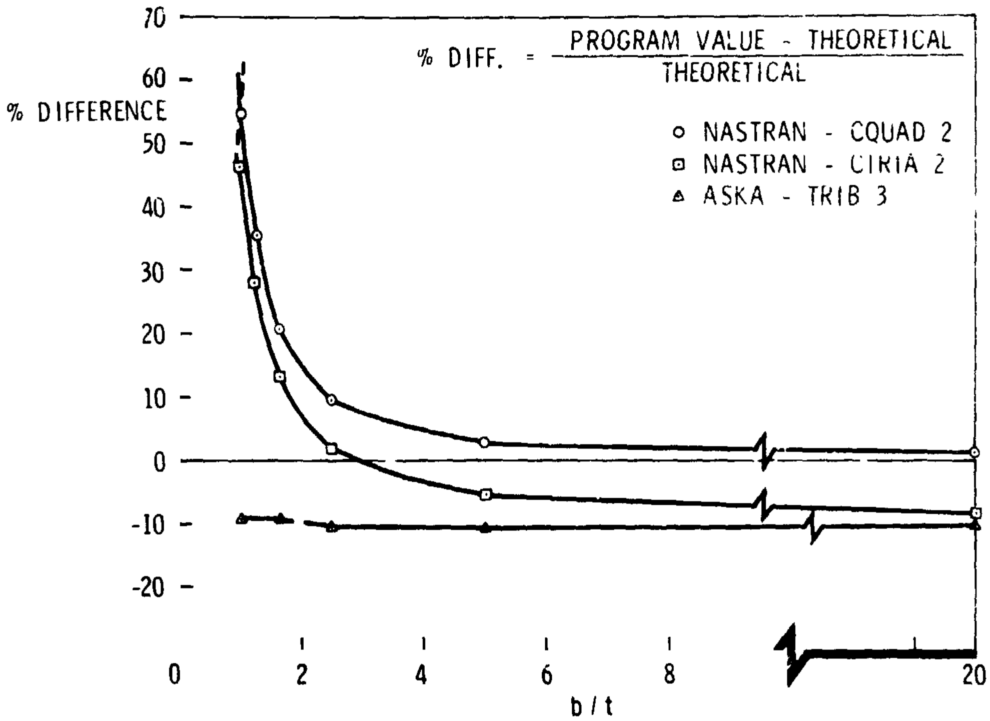

Figure 5. % difference vs thickness ratio.

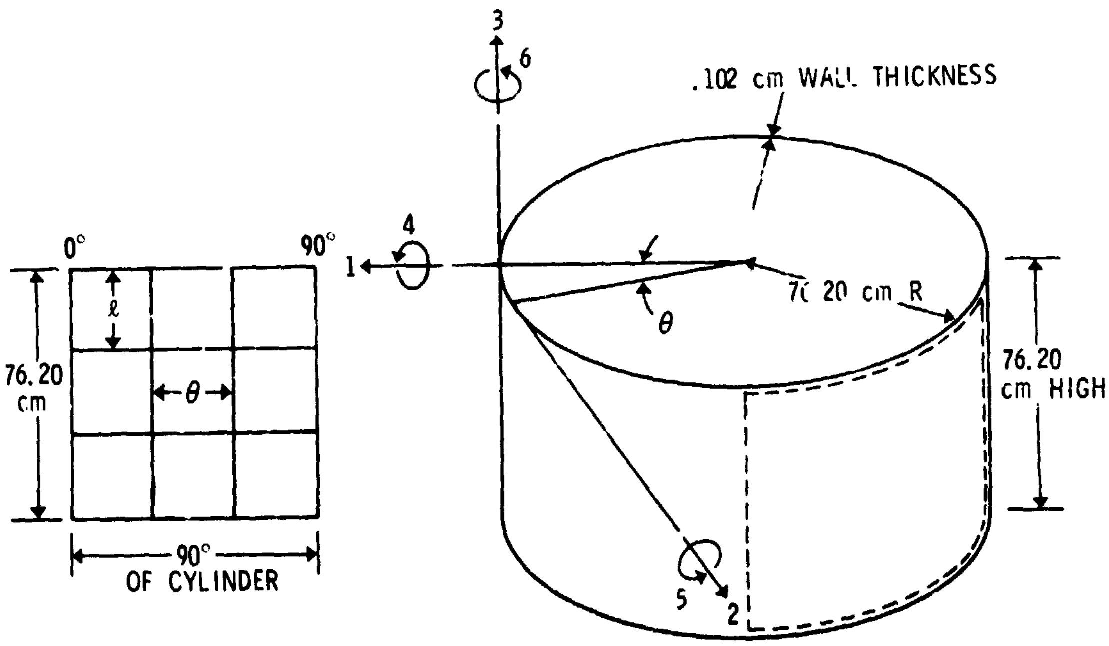

Figure 6. Buckling analysis - basic model geometry.

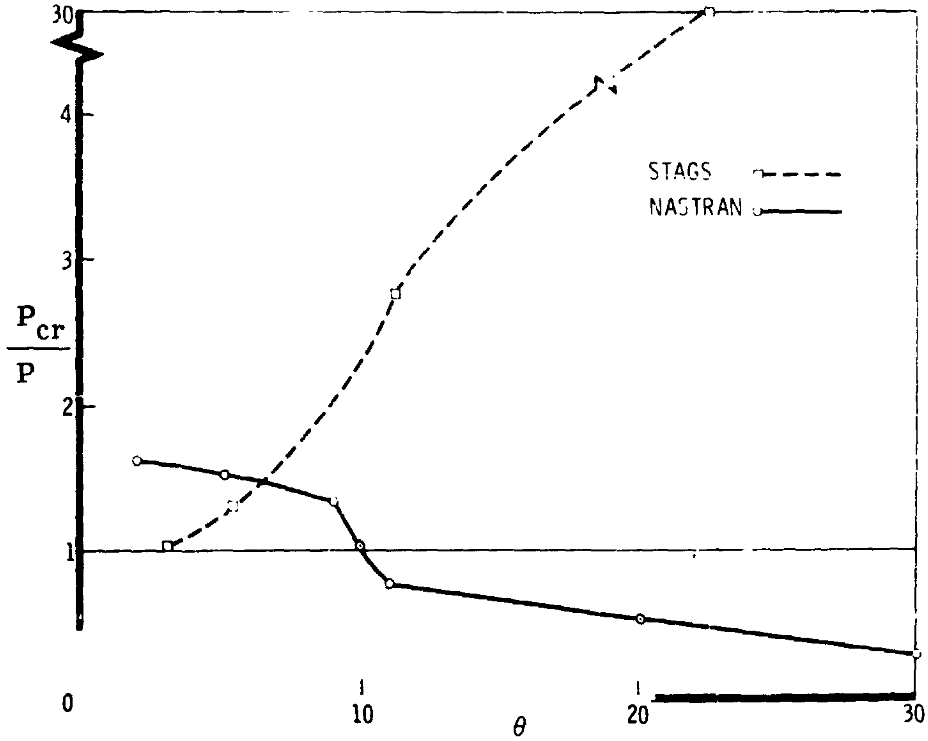

Figure 7. Effect of varying circumferential spacing.

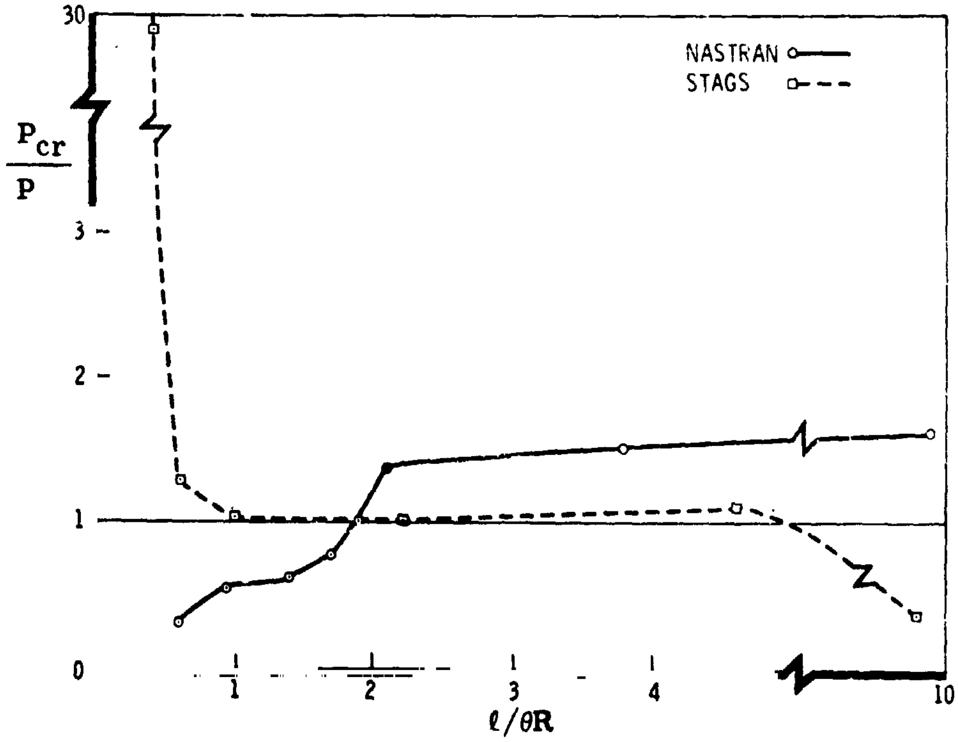

Figure 8. Effect of varying aspect ratio.

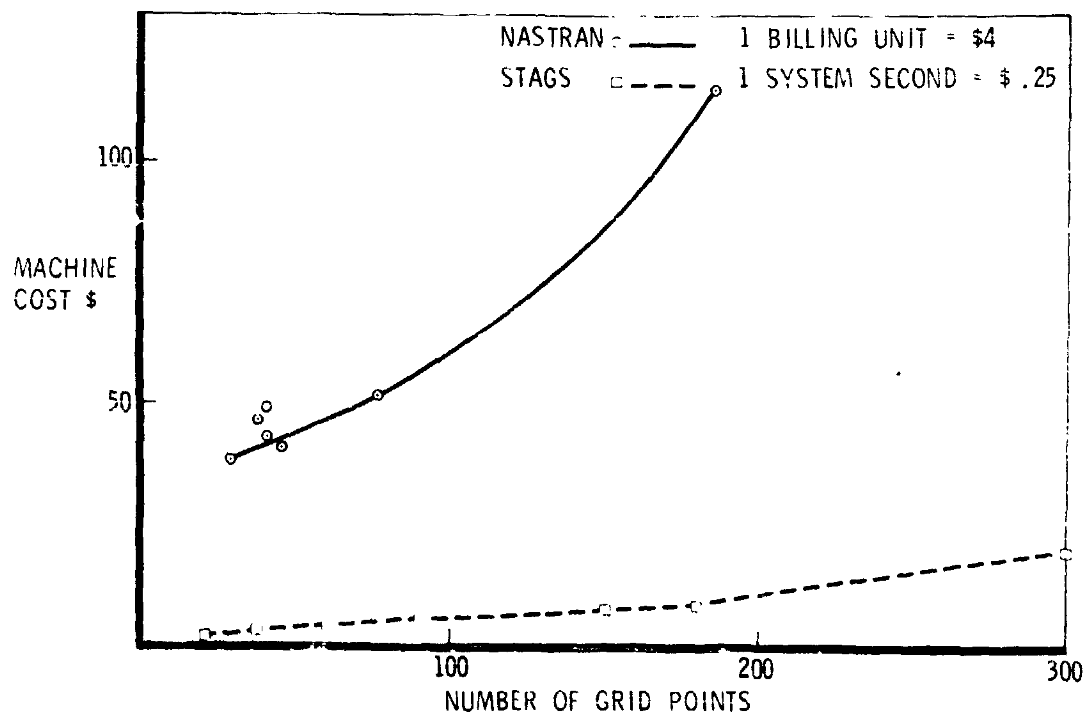

Figure 9. Cost comparison between NASTRAN and STAGS.

$P_{cr}/P = 1.6434$; $\ell = 25.4$ cm; $\theta = 2^{\circ}$

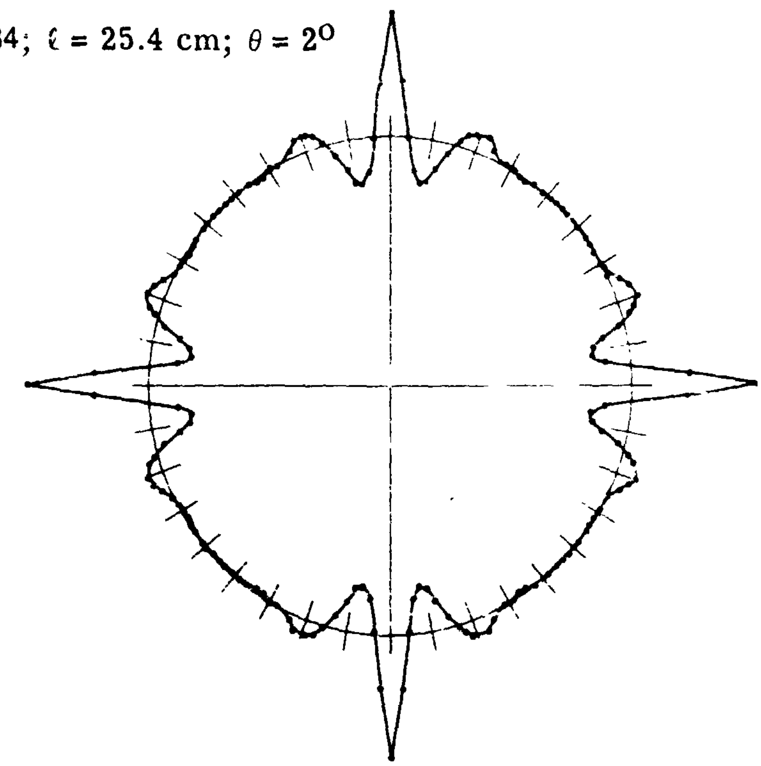

Figure A-1. Mode shape - NASTRAN model.

$P_{cr}/P = 1.5409$; $\ell = 25.4$ cm; $\theta = 5^{\circ}$

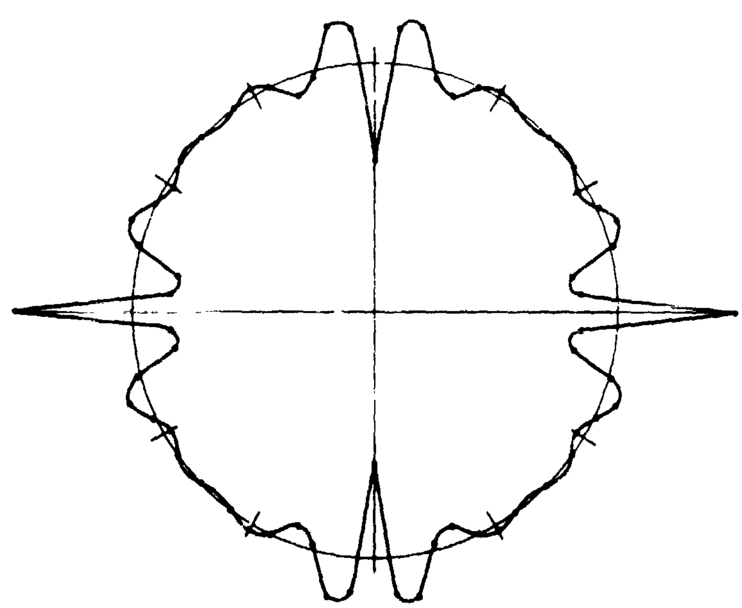

Figure A-2. Mode shape - NASTRAN model.

$P_{cr}/P = 1.3614$; $\ell = 25.4$ cm; $\theta = 9^{o}$

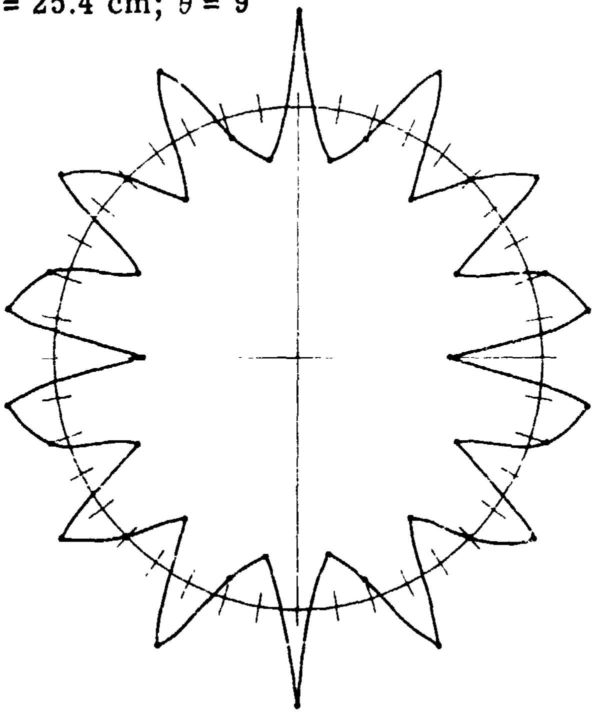

Figure A-3. Mode shape - NASTRAN model.

$P_{cr}/P = 1.039$; $\ell = 25.4$ cm; $\theta = 10^{o}$

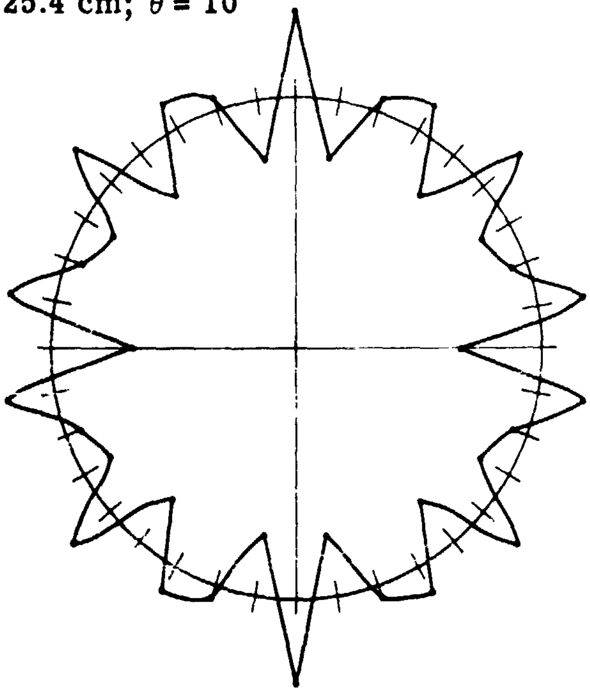

Figure A-4. Mode shape - NASTRAN model.

$P_{cr}/P = 0.7844$; $\ell = 25.4$ cm; $\theta = 11^{\circ}$

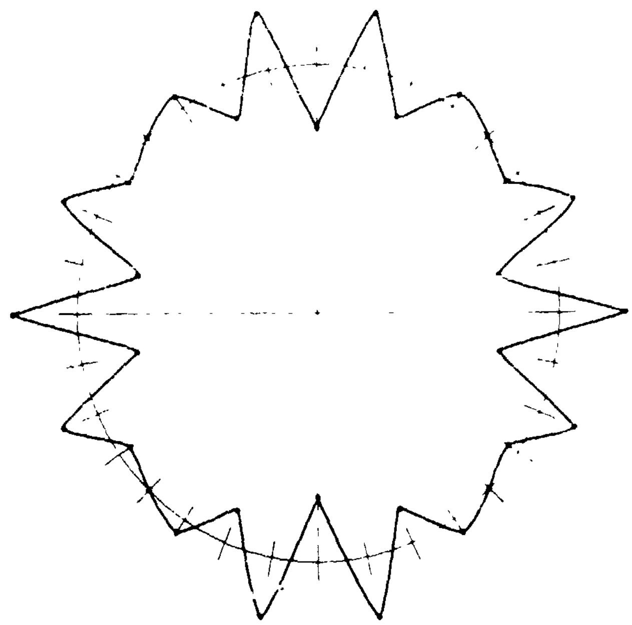

Figure A-5. Mode shape - NASTRAN model.

$P_{cr}/P = 0.5568$; $\ell = 25.4$ cm; $\theta = 20^{\circ}$

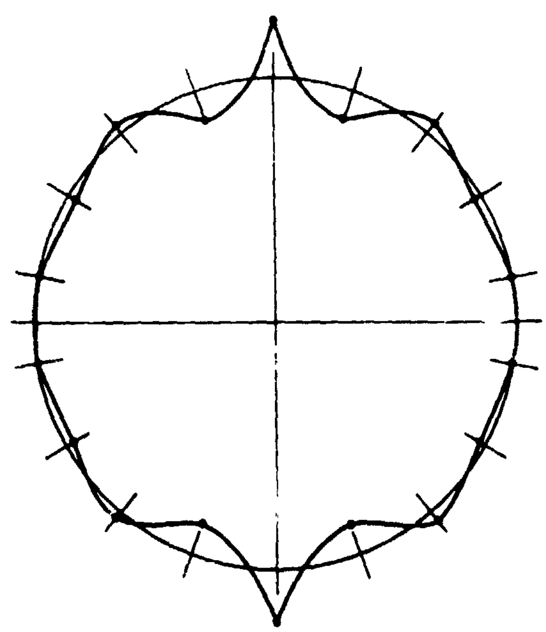

Figure A-6. Mode shape - NASTRAN model.

$P_{cr}/P = 0.3079$; $\ell = 25.4$ cm; $\theta = 30^{\circ}$

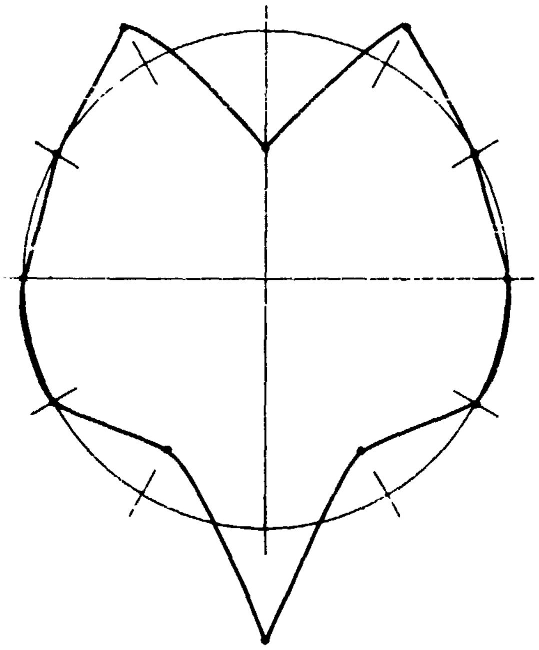

Figure A-7. Mode shape - NASTRAN model.

$P_{cr}/P = 1.08$; $\ell = 4.24$ cm; $\theta = 3.1^{\circ}$

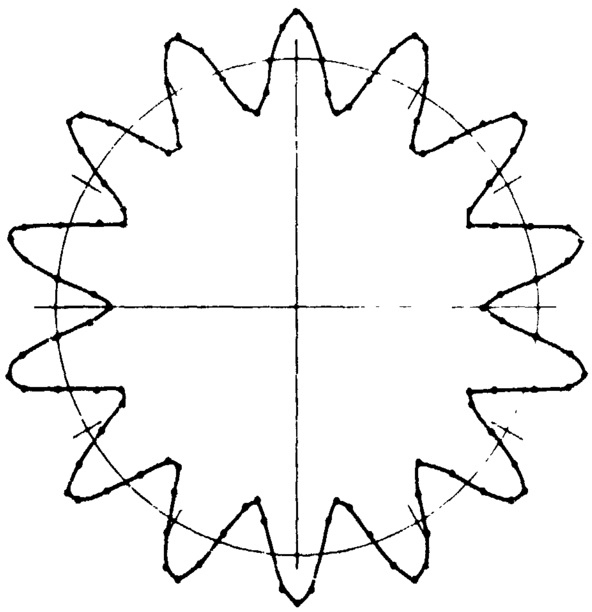

Figure A-8. Mode shape - STAGS model.

$P_{cr}/P = 1.09$; $\ell = 9.53$ cm; $\theta = 3.1^{\circ}$

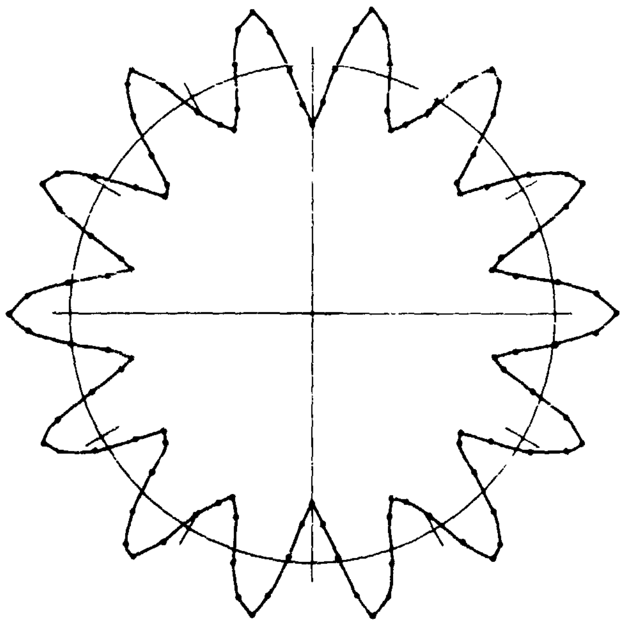

Figure A-9. Mode shape - STAGS model.

$P_{cr}/P = 1.11$; $\ell = 19.05$ cm; $\theta = 3.1^{\circ}$

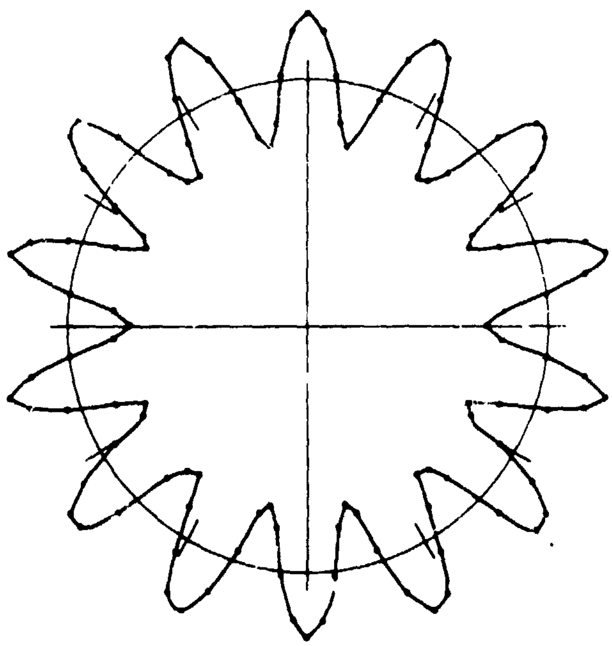

Figure A-10. Mode shape - STAGS model.

$P_{cr}/P = 0.37$; $\ell = 38.1$ cm; $\theta = 3.1^{o}$

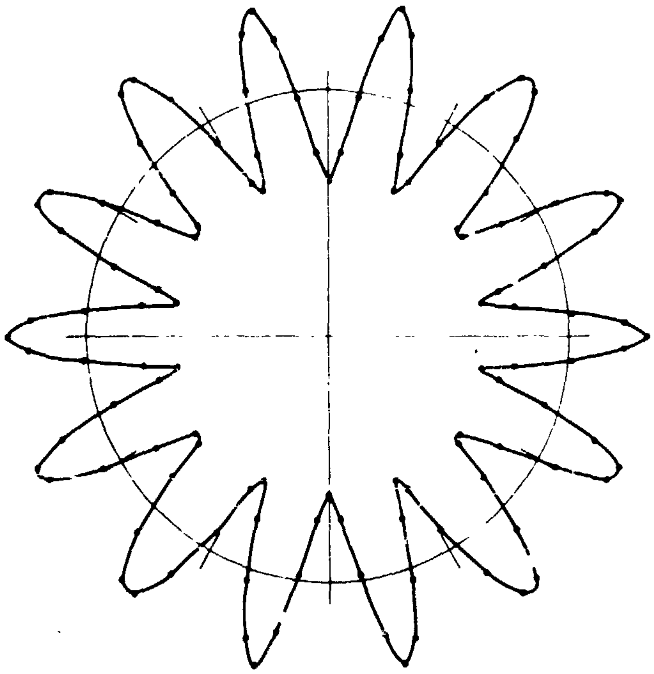

Figure A-11. Mode shape - STAGS model.

$P_{cr}/P = 1.27$; $\ell = 4.24$ cm; $\theta = 5.3^{o}$

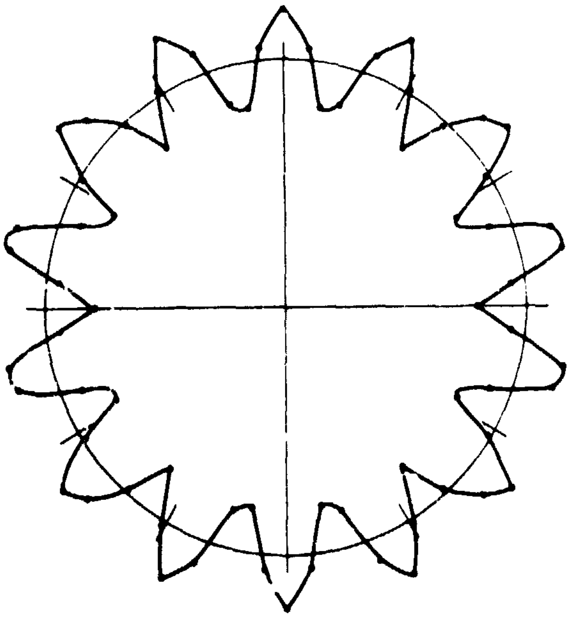

Figure A-12. Mode shape - STAGS model.

$P_{cr}/P = 2.78$; $\ell = 12.7$ cm; $\theta = 11.25^{\circ}$

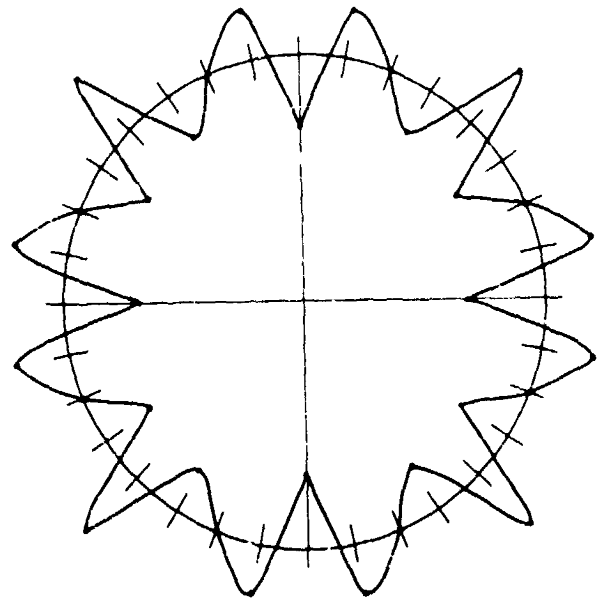

Figure A-13. Mode shape - STAGS model.

$P_{cr}/P = 29.9$; $\ell = 12.7$ cm; $\theta = 22.5^{\circ}$

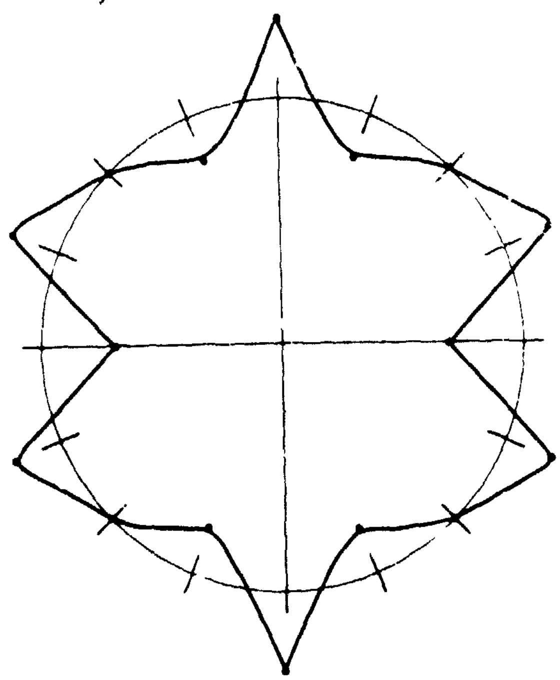

Figure A-14. Mode shape - STACS model.