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NASTRAN USERS' EXPERIENCE OF

AVCO AEROSTRUCTURES DIVISION

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SUMMARY

This paper discusses the NASTRAN experiences of a major structural design and fabrication subcontractor that has less engineering personnel and computer facilities than those available to large prime contractors. Efforts to obtain sufficient computer capacity and the development and implementation of auxiliary programs to reduce manpower requirements are described. Applications of the NASTRAN program for training users, checking out auxiliary programs, performing in-house research and development, and structurally analyzing an Avco designed and manufactured missile case are presented.

INTRODUCTION

The Avco Aerostructures Division has long been actively engaged in the research and development areas of structural analyses. Since 1966, particular emphasis has been placed on finite element techniques utilizing the displacement method. Such efforts yielded a static analysis program for both the IBM 360/Model 40 and IBM 1130 computers. Although the program was somewhat limited in the types of finite elements, the objective for solving structural problems containing a large number of degrees of freedom was achieved. This objective, however, was not obtained without the sacrifice of computer efficiency due to a requirement for large amounts of peripheral processing time. For example, the IBM 1130 could accommodate a structural model with nearly 1000 degrees of freedom, but approximately 10 hours were necessary for a solution. Run times of 3 and 4 hours were not uncommon for IBM 360/40 analyses. Only bar, triangular membrane plate, and rectangular membrane plate elements were available in the IBM 1130 program, but the IBM 360/40 program also included the triangular bending plate element. (Plate elements assumed constant stress conditions.) It became immediately apparent that the complete capability for performing structural analyses (i.e., static, vibration, buckling, etc.) by finite element techniques was not within the practical upper limits of Avco A/D's computer facilities.

In the latter part of 1970, Avco A/D became aware of the Industry Research Associate Program initiated by the NASA-Langley Research Center. The value of the program for providing a mutual interchange of technology was immediately recognized and Avco became an active participant in January 1971. The initial participation consisted of two engineering personnel being assigned to the Structures Division of the Structure Directorate. It was in this time period that the NASTRAN Systems Management Office (NSMO) was established in the Structures Division at NASA-Langley (October 4, 1970) and the first public release of NASTRAN through COSMIC occurred (November 1970). Since NASTRAN was being heavily used at NASA-Langley and other government centers for testing and evaluation, NASA-assigned Avco personnel could evaluate the program and become qualified users while performing their assigned tasks. This NASTRAN experience is one excellent example of the spin-off benefits from the NASA/Industry Research Associate Program.

It was obvious from the initial confrontation of the Avco associates with the NASTRAN program that it would enable us to attain our research and development goals. However, the in-house computer capacity at Avco A/D was still not adequate to accommodate the program. A survey of the local (Nashville) computing facilities was undertaken to determine if any computers, suitable for NASTRAN operations, were available. In-house terminals, as supplied by computer leasing services, were disregarded since the NASTRAN usage was unpredictable; operating costs could be excessive on a per run basis. A computer service, NLT Computer Services Corporation, which primarily serves the local banking and insurance interests, was found to have computers compatible with the NASTRAN program; namely, an IBM 360, Model 65 and an IBM 370, Model 155 computer. Arrangements were made with NLT for implementation of the level 12 NASTRAN on each of their computers. Further, it was decided that, whenever possible, auxiliary NASTRAN programs capable of generating and checking input data and manipulating output data (i.e., resizing routines) would be incorporated on the in-house IBM 360/40. The inconvenience of the data management problem presented by this approach was considered less undesirable than the economic problem of using the NLT computer services for all cases. Avco A/D acquired the NASTRAN program in October 1971 and had it operational on the NLT computers approximately one month later. The implementation of the program by NLT personnel will be discussed in this report. Further, this unique arrangement between the financial and technical community will be described with particular emphasis on the problems encountered due to different terminologies and concepts.

A description of Avco's auxiliary computer routines to be used with the NASTRAN analysis program is included in the paper. For example, the data generation programs described in references 1 and 2 have been converted from a CDC 6000 series computer to the IBM 360/40 computer with some modifications. Also, a program which checks the NASTRAN input data for format and syntax errors and incomplete and/or duplicate data and generates a tape for plotting undeformed structure has been developed. This check-out program is similar to the special NASTRAN program described in reference 3.

In addition, results obtained from various NASTRAN investigations of widely varying types of structure are presented. For each of the investigations, the results describe operational problems, run times, and core requirements (including comparisons of the IBM 360/65 and IBM 370/155 computers whenever possible) plus comparisons of the NASTRAN results with theoretical or experimental data.

The paper also discusses the importance of a NASTRAN type program to Avco Aerostructures Division as a major subcontractor to the prime aerospace contractors.

AVCO/NLT NASTRAN IMPLEMENTATION AND OPERATION

An interfacing of the capabilities and facilities of the Avco Aerostructures Division and the NLT Computer Services Corporation was required to accommodate the NASTRAN program. The acquisition (and updating) and execution of NASTRAN was the responsibility of Avco. The implementation and maintenance of NASTRAN was the responsibility of NLT. Obviously, NASTRAN bridges the gap that exists between the capabilities of the technical and financial communities; namely, scientific programmers.

Before NASTRAN, NLT had provided a data processing service only and was completely inexperienced with respect to scientific computer programs. However, the program was implemented in approximately one week and operational in less than one month on the IBM 370, Model 155 and the IBM 360, Model 65 computers. The primary difficulty encountered in the implementation of the program was NLT personnel's lack of familarity with the OS operating system. (NLT uses the DOS operating system for their data processing services.) Minor problems occurred due to a reluctance to believe the disk space requirements of NASTRAN. Some check-out problems were encountered in the execution of the demonstration problems because of core size requirements. Further, the punched output for the restart deck of demonstration problem 1-1 was completely unexpected. Cpu times for the execution of certain demonstration problems on the IBM 370/155 computer are presented in table 1 along with compatible cpu times obtained from various computers as given in reference 4. Although more specific and concise documentation pertaining to the implementation would be desired, the ease in making NASTRAN operational has been substantiated. In all cases, COSMIC was very prompt in identifying user problems and giving a solution.

Some operational problems have been encountered due to the conflict of NASTRAN with the previous experience of NLT personnel. A limit of 900 cpu seconds was a standard NLT computer exit. This limit was based on previous experience which normally indicated the presence of a programming error (i.e., a 'hard DO loop'). Execution of NASTRAN has made them accustomed to exceeding the 900 cpu seconds restriction which is now deleted from all NASTRAN problems. The computer operator confused the OPTP (old problem tape) and NPTP (new problem tape) with the output and input tapes, respectively. Whether or not this contributed to an apparent problem of tape management was never identified.

It is believed that this arrangement permits smaller engineering departments to attain a structural analysis capability that may otherwise be impractical and uneconomical.

AUXILIARY PROGRAMS

Since the different physical locations of the Avco engineers and the NLT computers presented a data handling problem, it was decided that NASTRAN auxiliary programs would be installed on Avco A/D's in-house IBM 360, Model 40 computer. Further, those routines which would check hand generated input data or automatically generate the input data offer an economic advantage in the decrease of aborted analyses (computer cost) due to input errors and the reduction of manpower for data preparation.

A special NASTRAN program which checks the input data for mispunched data cards and incorrectly transcribed data and generates a tape for undeformed structure plots has been developed for the IBM 360/40 computer. This program is functionally equivalent to the check-out program for the CDC 6000 series computer described in reference 3. The program operates under the OS 360/PCP operating system and requires 210K bytes of a 256K byte core and a disk drive for peripheral storage. Only subroutine BTSTRP required a revision due to the necessary reduction in the length of a GINO buffer from 1803 to 250. This change caused a corresponding reduction in the default parameters of the block sizes contained on the PROC job control card to SP2=1, BLK1=1028, and BLK2=1032.

The automated input data generation routines, as described in references 1 and 2, have been converted from the CDC 6000 series computer to the IBM 360/40 computer. These routines offer a substantial reduction in the man-hours required for model generation since they require a minimum of input data which can be obtained from engineering drawings. This manpower reduction is particularly attractive to smaller engineering departments such as Avco A/D because a complex structural analysis can be performed by a minimum number of engineering personnel. In conducting some recent NASTRAN analyses, finite element models of a delta wing and a segment of a missile case were generated by these automated routines in less than 4 man-hours each. The generality of the routines was demonstrated in reference 2 and their versatility has permitted the modeling of a railroad passenger car by Avco A/D. Another routine which automatically generates a triangular or quadrilateral mesh about a circular cutout in a flat panel, as investigated in reference 5, was modified to yield punched NASTRAN input data. Presently, programs are being developed which will calculate the stiffness coefficients for specialized structural elements (i.e., reinforced concrete or integrally stiffened plate elements) and punch the data on cards with an input format consistent with NASTRAN.

The contour plotting routines that are described and demonstrated in reference 1 have been converted from the CDC 6000 series computers to the IBM 360/40 computer. Since Avco A/D lacks an in-house plotting capability, the plotting routine has been modified to yield a printed output of the planar coordinates of each contour line to permit manual plotting. A plotting service, similar to the Avco/NLT computer arrangement, could be obtained since plotters that are compatible with the routine and NASTRAN are available in the Nashville area.

Currently, a fully stressed design technique is being developed which is almost identical to the routine incorporated in the [illegible] program (ref. 6) and the SAVES program (ref. 2). The input and output formats for this routine are compatible with the NASTRAN output and input formats, respectively. A simplified design criterion for the sizing of rod and bar elements has been incorporated into the program.

APPLICATIONS

Since the acquisition of NASTRAN by Avco A/D in October 1971, it has been used for performing in-house research and development programs, check-out and verification of auxiliary routines, and analysis of existing structural designs. The following discussion is directed to three investigations of widely varying types of structure.

Reinforced Concrete Slab - The purpose of this study was to evaluate a method of modeling reinforced concrete with finite elements that are sufficiently accurate and economically feasible. Quadrilateral membrane and bending plate elements were used to represent the concrete slab and rod elements were used to model the reinforcing rods. The representation of each reinforcing rod would yield a finite element model with a maximum mesh size dictated by the reinforcement spacing. Since this spacing is relatively small, it is conventional to represent several reinforcement rods by a single rod element which is positioned between two nodes along the edge of a larger plate element. This method is commonly called the lumping technique and results in large rod elements at the neutral axis of the plate's cross sectional area. However, the reinforcement rods are usually displaced to the tension side of the neutral axis and thus cannot be included by the conventional lumping technique. For this study, continuity of the reinforcing rods and concrete (no slipping) was assumed. The elongations of the rods are considered equal to their normal displacements on the edgewise face of the plate element at the intersecting rods. A linear variation of the translational and rotational displacements is assumed between two nodes of a particular edge for computing the normal displacements. This computation of the normal displacement at the reinforcement rod position was accomplished by use of the multipoint constraint equations contained in NASTRAN.

The subject of the investigation was a square, simply supported, reinforced concrete slab with reinforcing rods spaced at 25.4 cm. intervals along each 609.6 cm. edge. The slab was 20.32 cm. thick and subjected to a dead weight loading. The reinforcement rods (diameter = 1.90 cm.) were at a depth of 3.49 cm. from the tension side of the concrete. The non-linear properties of the concrete due to its inability to withstand tensile stresses were neglected. Model mesh sizes of 4 x 4 and 6 x 6 (corresponding to element sizes of 152.4 x 152.4 cm. and 101.6 x 101.6 cm., respectively) were investigated. Figure 1 presents a comparison of the rod stresses for each NASTRAN analysis with the theoretical results determined from closed form equations on page 3[illegible]6 of reference 7. Figures 2 and 3 show a comparison of the maximum compressive stresses in the concrete and lateral displacement of the slab, respectively. Whenever necessary, NASTRAN results are extrapolated to the desired locations.

The coarse mesh model (4 x 4) required 218 cpu seconds for a solution on the IBM 370/155 computer and 260 cpu seconds were required for an IBM 360/65 computer solution of the fine mesh model (6 x 6) using Level 12 NASTRAN. Due to the difference in problem size, it was not possible to evaluate the computing speed of the different computers. However, the prohibitive time required for processing and manipulating multipoint constraint relationships was indicated by this investigation. Approximately 20% of the total cpu time was used on the multipoint constraints for each model. It is because of this time penalty that the previously mentioned auxiliary program for generating NASTRAN punched input of stiffness coefficients for specialized structural elements is being developed. The NASTRAN run time will be further reduced by the time required to calculate the stiffness. Obviously, the NASTRAN output would have to be used in an additional auxiliary program to determine the actual internal loads and stresses (i.e., axial stress in reinforcement rods).

These preliminary NASTRAN results show good agreement with theoretical results. Further validation of the computational efficiency and accuracy is required when the auxiliary routines become operational. This method is also applicable to integrally stiffened or semi-monocoque panels and other structures wherein an assemblage of finite elements is represented by a discrete structural element.

Structural Effects of Wing Camber Variations - This study was primarily initiated to check out the lifting surface data generation routine. To provide additional NASTRAN experience, it was decided to conduct a simple design study to evaluate the change in stiffness and strength due to camber variations of a wing. The wing has a delta planform and a modified diamond airfoil section with a 3% maximum thickness. A uniform pressure loading was applied to the structural model. For a maximum camber of 1.50% chord, the finite element model is identical to the lumped finite element model of the baseline wing structure used in the study described in reference 2. The normalized tip deflection and stress distribution in the lower surface skins near the wing-fuselage intersection for varying amounts of camber are shown in figure 4.

The finite element model of each wing configuration is identical except for the 'out of plane' geometry changes caused by camber variations. If everything remains the same except for wing configuration, the cpu time should be constant. Although there was some unexplained but minor variations in the cpu times, approximately 490 and 580 seconds were required for NASTRAN Level 12 solutions on the IBM 360/65 and IBM 370/155 computers, respectively. These times are contradictory and have not been explained by NLT systems personnel except to speculate that it could be due to the operating system. In all cases, the OS/MVT/HASP operating system was used.

Honeycomb Shell - This study was initiated to determine a possible cause for observable damage on Avco designed and manufactured missile case sections due to operational transportation conditions. The objective of the investigation was to determine the cause of the damage and study possible design changes in the transporter to prevent the re-occurrence of structural damage. The sections of concern are lightweight honeycomb shells with ring frames at the ends of each section. The damage occurred at one of the transporter's support saddles which was located such that the honeycomb shell would rest on it. The missile case sections were modeled by CQUAD2 elements for the shells and CBAR elements for the frames. The loads applied to the models were in accordance with loading conditions used for testing. Clamped boundary conditions were assumed at the intersection of the honeycomb structure and the relatively thick-walled back-up structure. Those grid points in contact with the saddle were not allowed to translate in the lateral direction. Results from a corresponding analysis and the test condition are shown in figure 5 in which the variation of the outer face sheet longitudinal (membrane) stress about the circumference of the shell is presented. The variation of the test data (+ θ and - θ) is due to the lack of symmetry of the structure caused by cutouts for doors and access ports. Although a good correlation of NASTRAN and test data was obtained, some variations should be expected since the cutouts were ignored in the finite element model. However, a NASTRAN analysis did predict a core shear failure at the exact location where observable damage did occur as indicated in figure 6.

RECOMMENDATIONS AND CONCLUSIONS

Based on the NASTRAN experience obtained to date at Avco A/D, the following changes or improvements would be desired.

1. The development of a mathematical technique for estimating the time and core requirements for finite element models of various sizes and degrees of complexity would reduce turn around time. This technique could be in the form of empirical relationships amenable to programming on an office size computer.

2. Since the static analysis portion of NASTRAN receives the greater usage, a mini NASTRAN which only contains the rigid format 1 and reduced buffer sizes to allow for execution on smaller computers (i.e., IBM 360/40) would probably prove economical.

3. The margin of safety pertaining to compression members is not conventional since a positive margin of safety is understrength and vice versa for a NASTRAN analysis. This may be corrected by using a negative number to designate the allowable compressive stress on the materials property card.

In conclusion, the development and continuing maintenance and improvement of the NASTRAN program has made it possible for companies with limited engineering manpower and computer facilities to attain a proficiency in structural analysis. Prior to NASTRAN, a large amount of the independent research and development funds was expended on the development of structural analysis methods based on finite element techniques. This effort can now be directed to structural research utilizing NASTRAN as the analysis tool. Further, the implementation of NASTRAN by systems personnel who are completely inexperienced with scientific programs and comprehension of the program by new users attests to its usability.

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TABLE 1. COMPARISON OF LEVEL 12 EXECUTION TIMES (CPU SECONDS) FOR NASTRAN DEMONSTRATION PROBLEMS

Problem No.	Form & Version	Computer Configuration/Series/Model IBM 370/155	IBM 360/95	IBM 360/67	CDC 6600	UNIVAC 1108
1-1	U	116	60	108	31	72
1-1A	R	72	30	102	24	24
1-2	U	166	84	264	72	60
1-3	U	242	114	336	120	96
1-4	U-1	1022	020	1464	666	1020
1-4	U-2	2665	380	--	--	--
1-5	U	1505	660	1800	--	1080
1-6	U	68	48	132	30	24
1-7	U	251	60	270	120	90
2-1	U	88	72	168	30	24
3-1	U-1	1567	720	3900	828	660
3-1	U-2	3088	610	--	--	--
4-1	U	328	168	486	144	90
5-1	U	863	408	1134	486	318

NOTES 1. STRESSES AT Y= 0, NORMALIZED ON MAXIMUM THEORETICAL AT X=0

2. ROD SPACING = 25.4 CM. SEMI-SPAN, A = 304.8 CM.

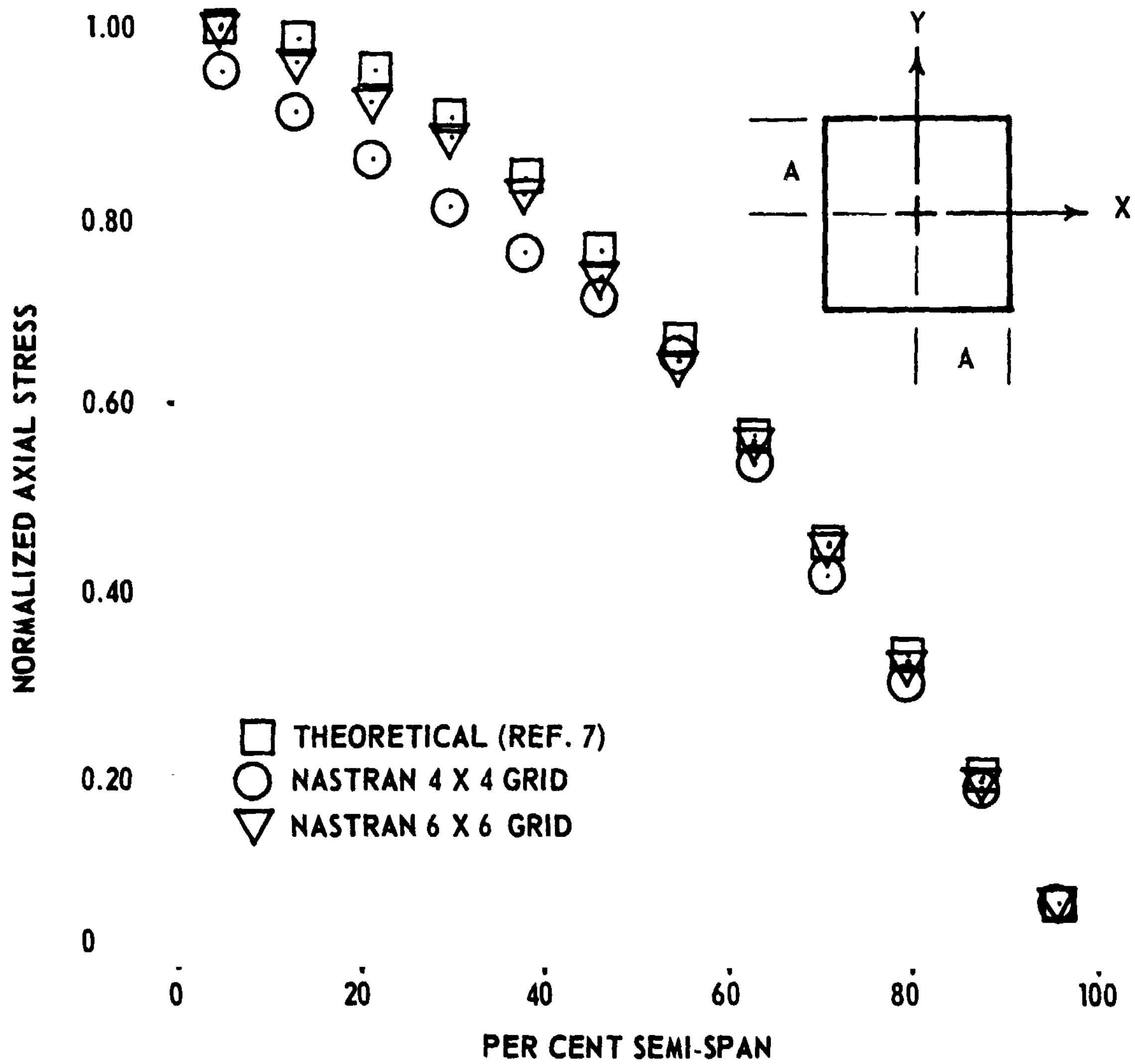

Figure 1. · Variation of rod axial stresses in a square, simply supported, reinforced concrete slab subjected to a dead weight loading.

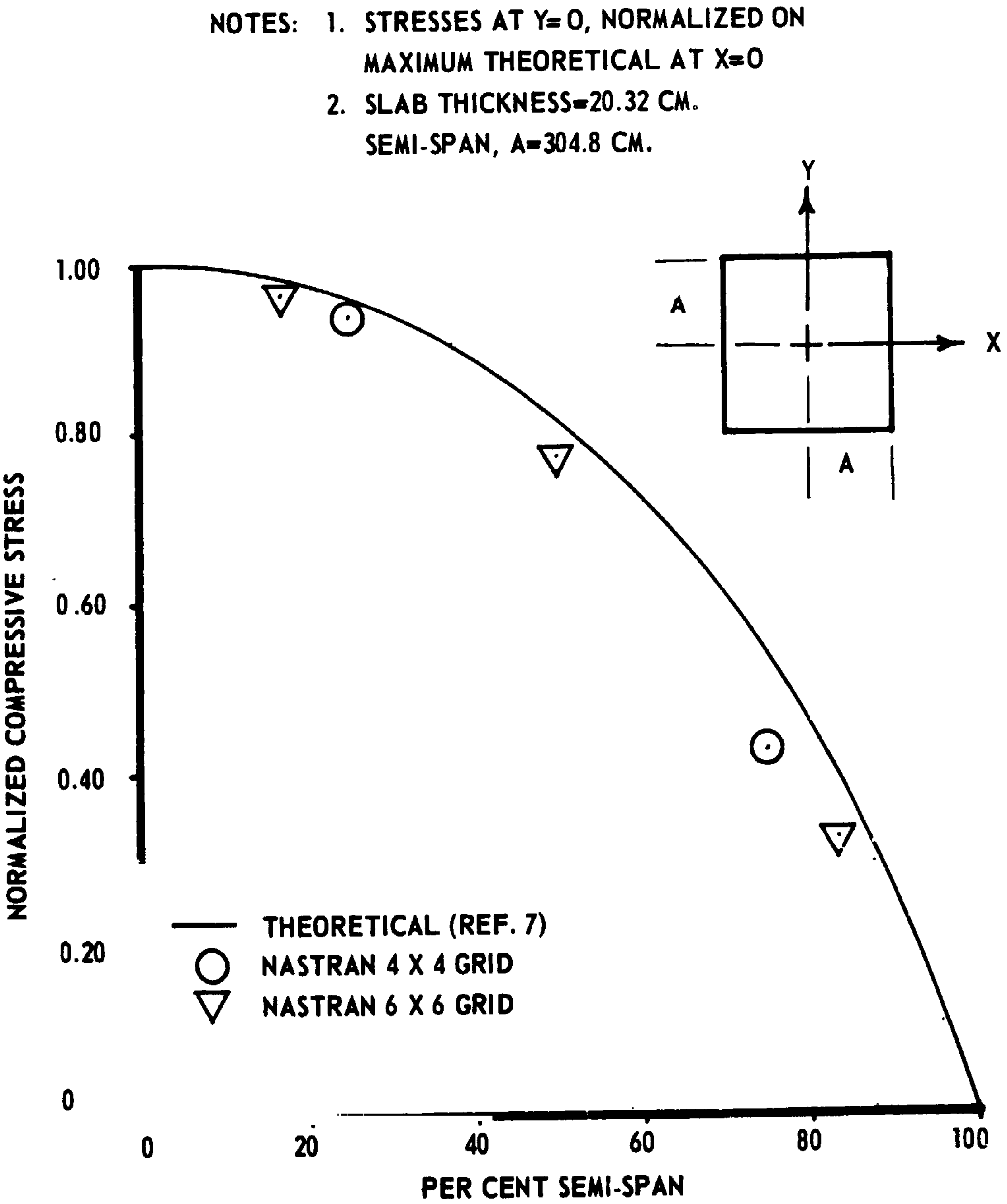

Figure 2. - Variation of concrete compressive stresses in a square, simply supported, reinforced concrete slab subjected to a dead weight loading.

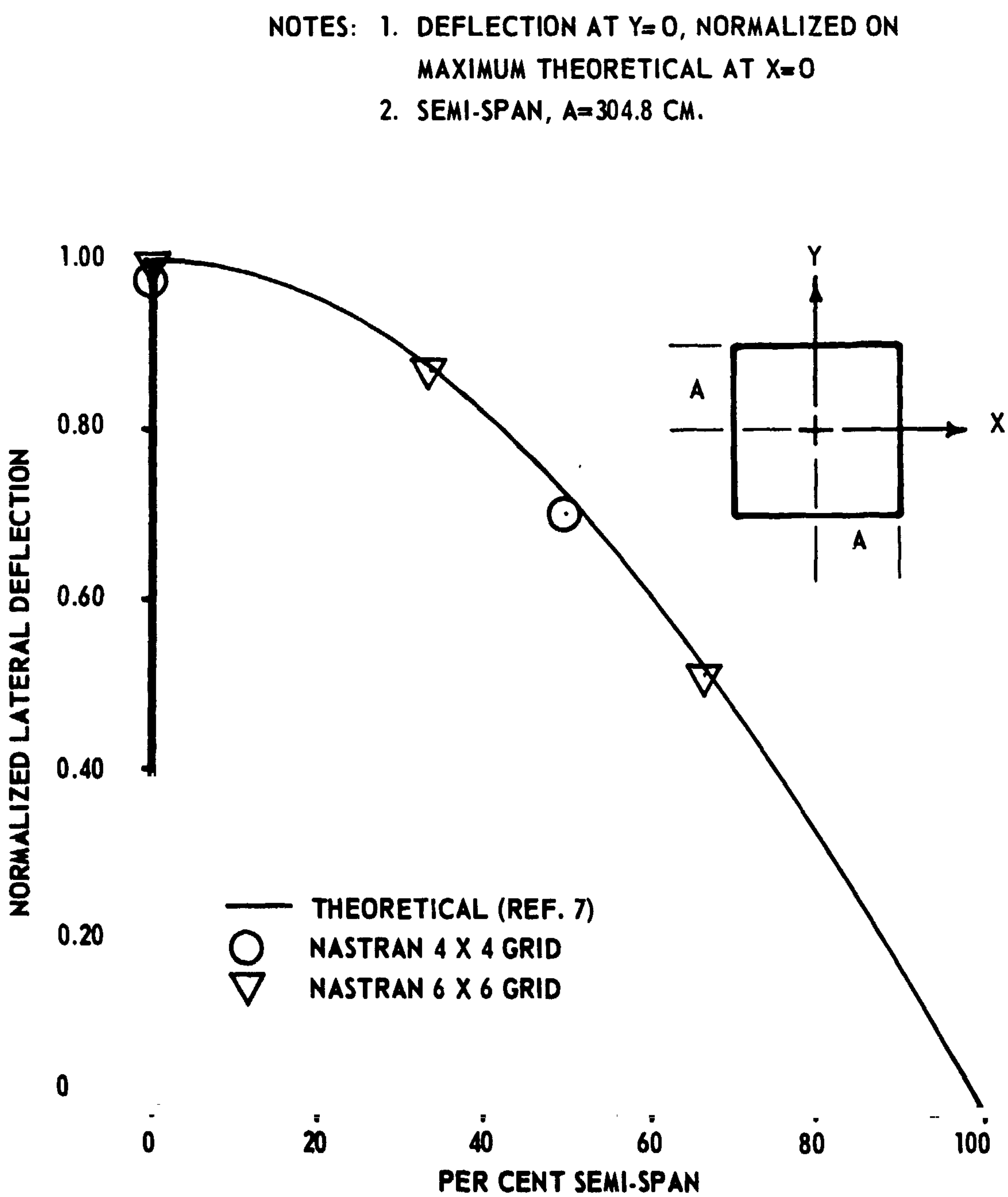

Figure 3. - Variation in lateral deflection of a square, simply supported, reinforced concrete slab subjected to a dead weight loading.

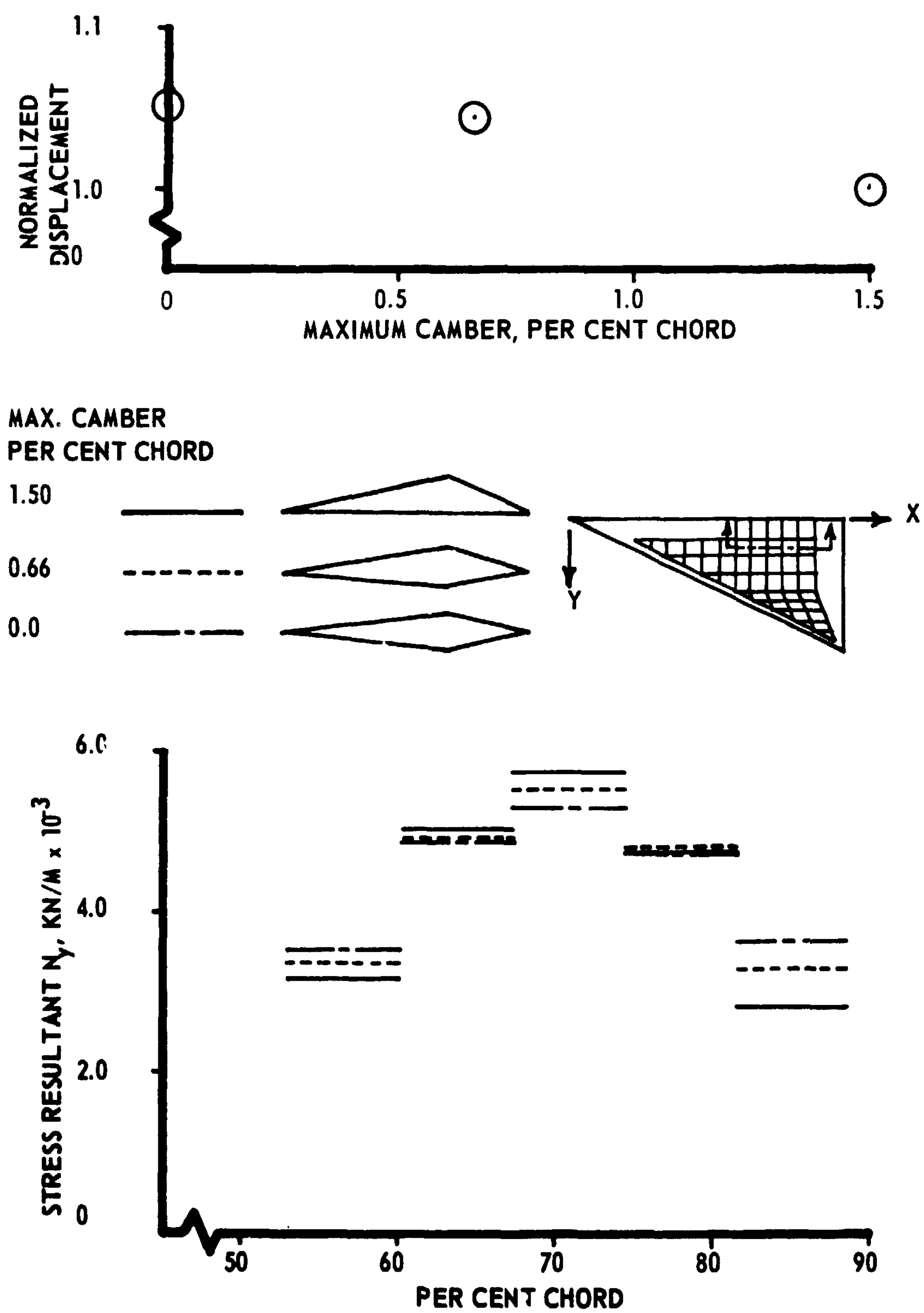

Figure 4. - Stress distribution near wing-fuselage intersection and normalized tip deflection for varying degrees of camber.

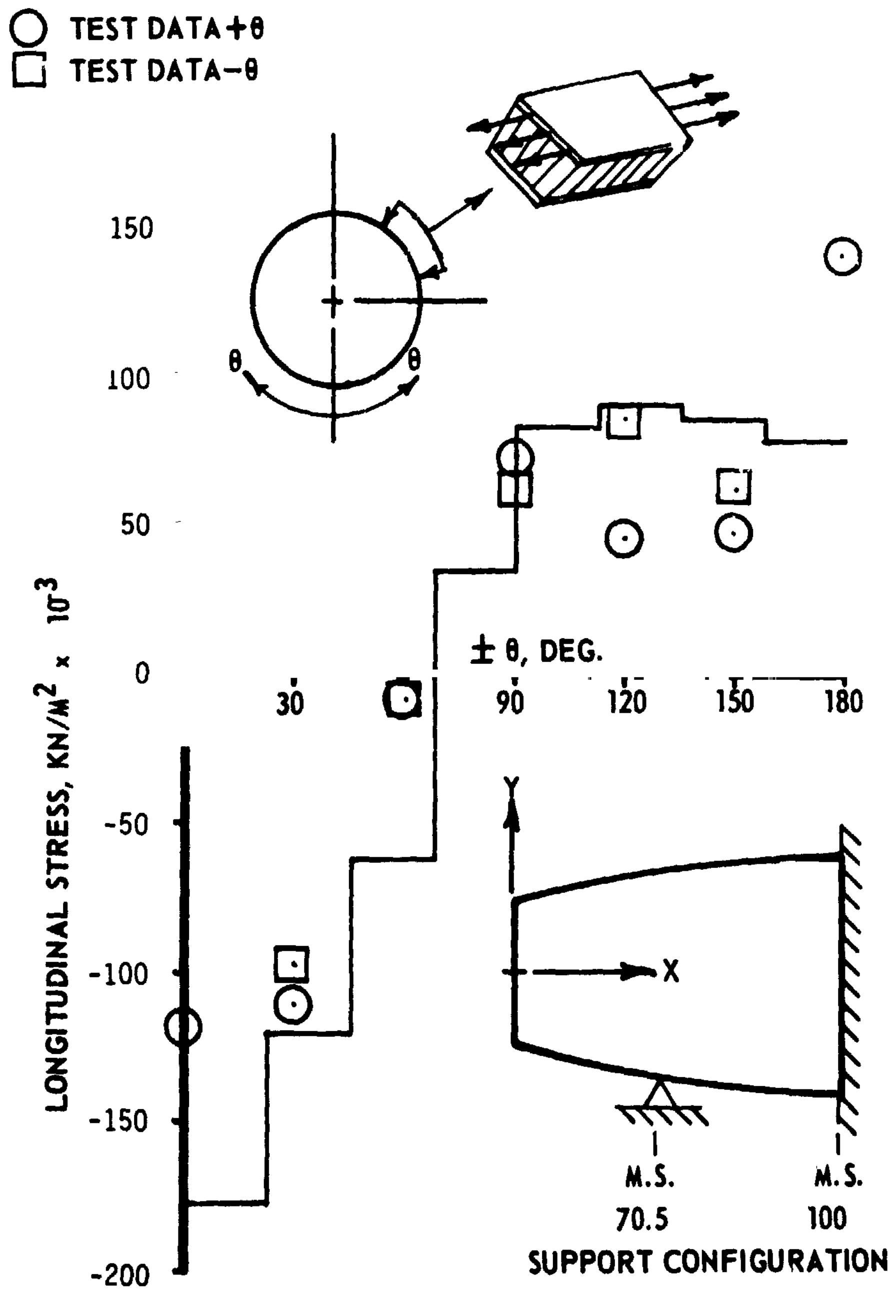

Figure 5. - Variation of outer face sheet longitudinal stress at M.S. 70.5 for symmetric vertical loading.

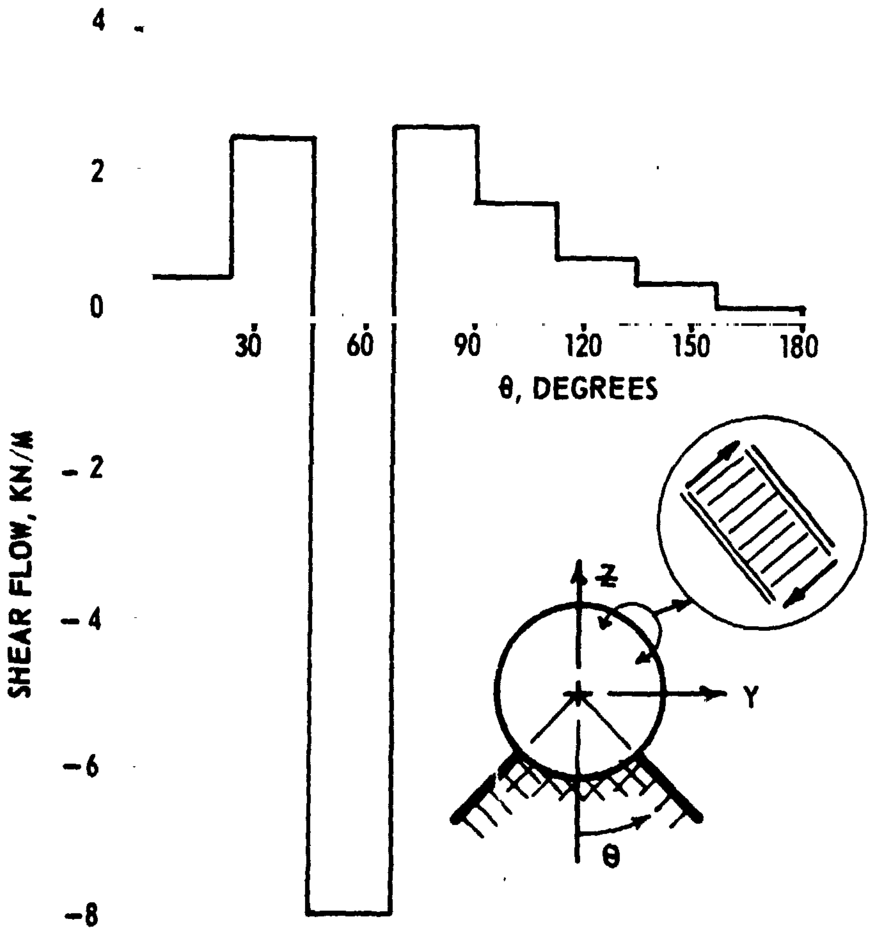

Figure 6. - Circumferential transverse shear flow (core) for cradle support enclosed angle = 90°