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Old Dominion University
Norfolk, Virginia

NASA Conference on Large Space Antenna
Systems Technology - 1982

NASA Langley Research Center
Hampton, Virginia
November 30 - December 3, 1982

PROGRESS IN THERMOSTRUCTURAL ANALYSIS OF SPACE STRUCTURES

Earl A. Thornton, Pramote Dechaumphai, Jack Mahaney
and Ajay K. Pandey

Mechanical Engineering and Mechanics Department

Old Dominion University
Norfolk, Virginia

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INTRODUCTION

The authors are conducting finite element space structures research focused on the interdisciplinary problems of heating, thermal and structural analysis. Detailed results of recent research activities appear in references 1-3. In this paper two research studies in progress for improving analysis capabilities are described.

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RECENT PROGRESS IN THERMAL-STRUCTURAL ANALYSIS

- ODU SPACE STRUCTURES RESEARCH
  - –Finite element method
  - –Interdisciplinary problem of heating, thermal and structural analyses
- DESCRIBE TWO RESEARCH ACTIVITIES IN PROGRESS
  - –Slender member shadowing effects
  - –Cable-stiffened structures

Figure 1

SLENDER MEMBER SHADOWING EFFECTS

A video tape of a rotating space truss model in sunlight presented at the conference demonstrated qualitative aspects of slender member shadowing. Shadowing effects were shown to be in two categories: cross member and parallel member shadows. The tape demonstrated that cross member shadowing effects are highly transitory and that shadow widths are small compared to shadowed member lengths. Multiple shadows progressively moving across a shadowed member were demonstrated. Parallel member shadowing where complete member lengths are shadowed was demonstrated by the model and shadow durations were observed to be small in comparison to transit times for cross member shadows.

SLENDER MEMBER SHADOWING EFFECTS

- Video tape will show shadow characteristics
- Simplified analysis will demonstrate preliminary thermal-structural results

Figure 2

TYPICAL TRUSS SHADOWING

Studies are currently in progress to assess the effect of slender member shadows on the thermal-structural response of an orbiting truss. The thirty-six member graphite-epoxy truss shown in Figure 3 is used as the analytical model. Subsequent figures will present results of quantitative analyses of the cross member shadows cast by the four shadowing members on the shadowed member. The earth facing truss shown is assumed to be in a geosynchronous orbit in the ecliptic plane.

TYPICAL TRUSS SHADOWING

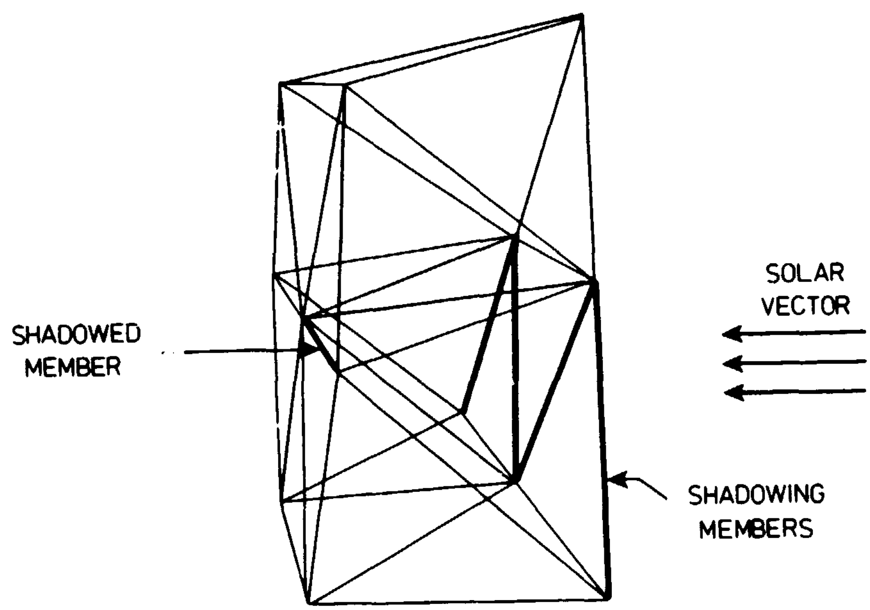

Figure 3

SLENDER MEMBER SHADOWING ANALYSIS

A numerical analysis procedure for shadowed space heating of sparse structures is presented in reference 4. The steps in this general approach are shown in Figure 4. If applied to a space truss with a large number of members, such an analysis will be very expensive. An objective of the current research is to determine if or when such highly detailed analyses are required to predict structural deformations accurately.

SLENDER MEMBER SHADOWING ANALYSIS

GENERAL APPROACH (O'Neill, AIAA 81-1179)

1. Subdivide each member
2. Determine when sub-elements shadowed
3. Determine reduced solar heating
4. Compute transient member temperatures

Figure 4

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TRUSS MEMBER SHADOW MOVEMENT PREDICTIONS

Cross member shadow movements were analyzed by sub-dividing the shadowed member into 100 sub-elements. Predicted shadows and shadow movements are shown schematically in Figure 5. Shadow widths typically span three sub-elements for the truss analyzed. Thus when two shadows are traversing the shadowed member only six percent of the member length is shadowed.

TRUSS MEMBER SHADOW MOVEMENT PREDICTIONS

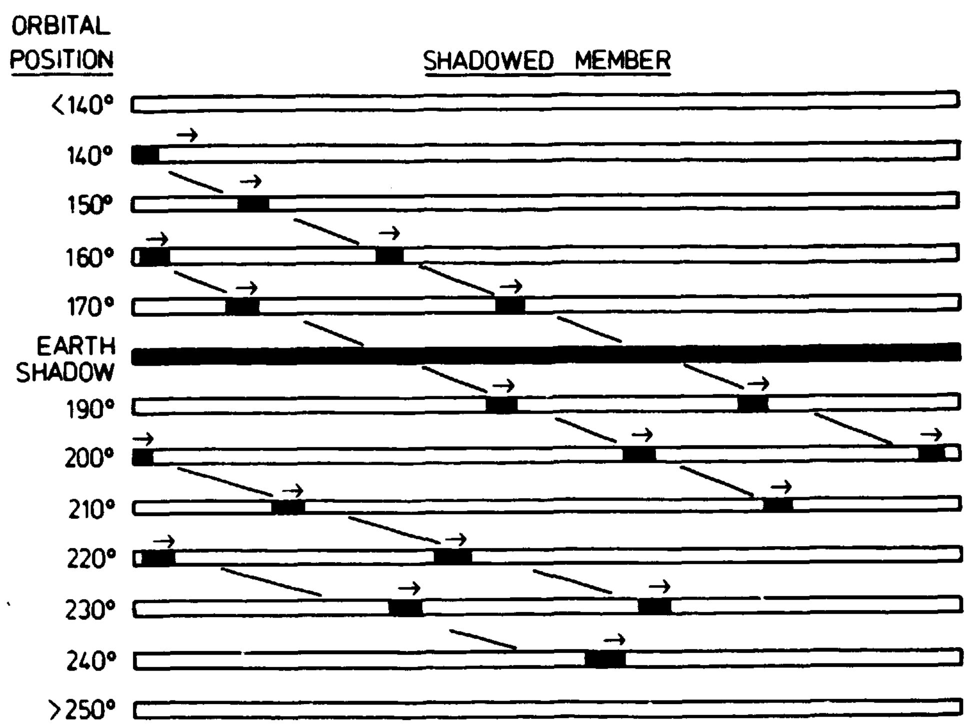

Figure 5

ASSESSMENT OF SHADOWING EFFECTS ON THERMAL RESPONSE

To assess the effects of the cross-member shadows on the shadowed member thermal response a simplified approach was employed. The simplified approach (Figure 6) gives insight into the member thermal-structural response without the programming complexity of the general approach. A "worst case" condition of complete (umbra) shadowing with fixed shadows is assumed for the heating analysis. Transient temperatures for the all graphite-epoxy member were computed considering combined conduction and radiation using 100 conventional (linear temperature distribution) finite elements.

ASSESSMENT OF SHADOWING EFFECTS ON THERMAL RESPONSE

SIMPLIFIED APPROACH

1. Subdivide member
2. Determine when sub-elements shadowed
3. – Neglect solar heating on shadowed sub-elements
   – Fix typical shadows on member
   – Apply shadows for proper duration
4 Compute transient member temperatures

Figure 6

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TRUSS MEMBER FIXED SHADOW MODEL

The fixed shadow model shown in Figure 7 simplifies the thermal analysis but maintains the proper shadow width, spacing and duration. Using this model, heating histories for the 100 sub-element model were computed for one orbit and used as input to compute the transient thermal response of the composite member.

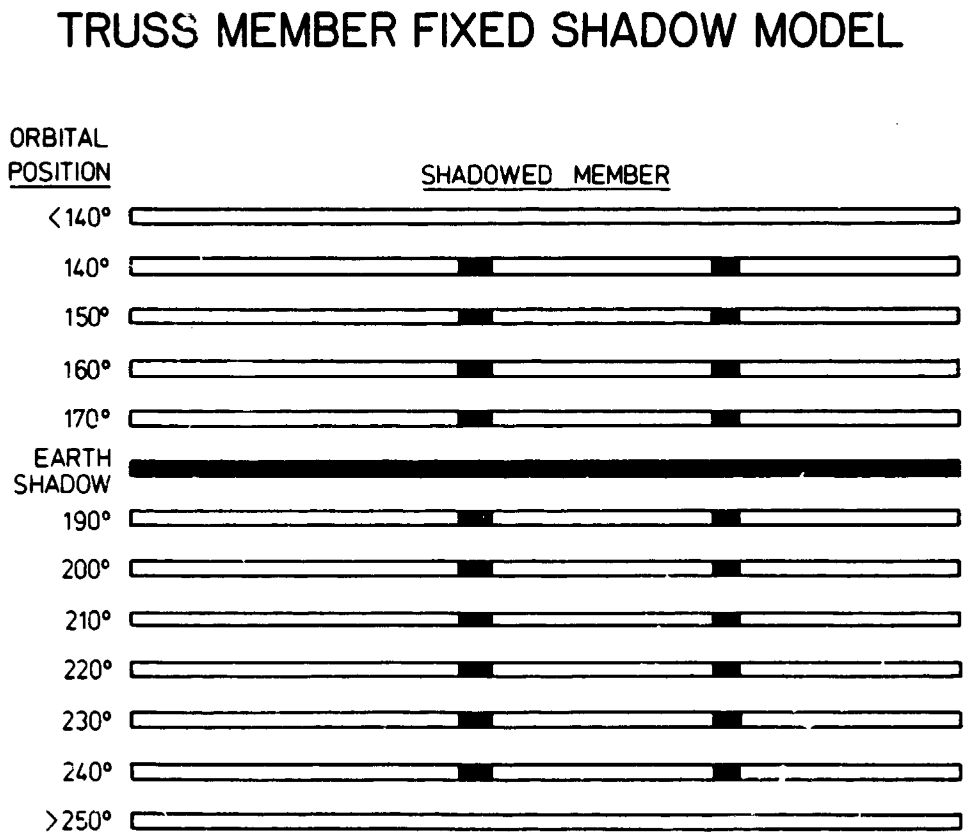

Figure 7

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SHADOWED MEMBER THERMAL RESPONSE

The temperature history for a typical shadowed sub-element is shown by the solid line in Figure 8. The dashed line shows the temperature history of a typical unshadowed sub-element. The figure shows that there is a significant alteration of the temperature history during the local shadowing duration, although this result probably exaggerates the shadow effect on the thermal response because of the assumptions of fixed, umbra shadows.

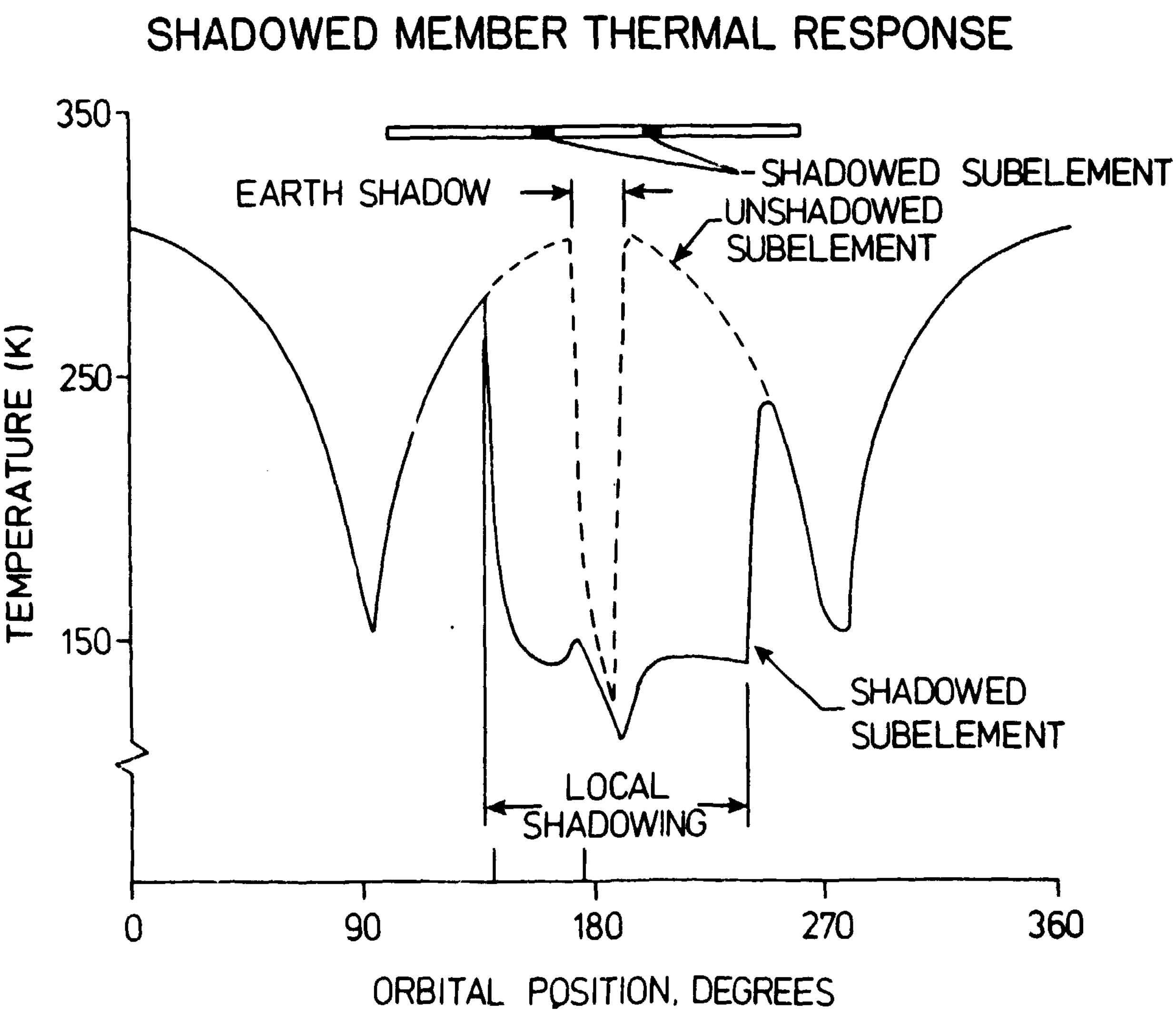

Figure 8

SHADOWED TRUSS MEMBER TEMPERATURE DISTRIBUTION

The shadowed member temperature distributions at the 140° and 175° orbit positions are shown in Figure 9. There are two significant results to be observed. The loss of heating in the shadowed sub-elements causes temperature to drop in these sub-elements, but the temperature drops are confined to only the shadowed sub-elements. The reason that the temperature drops are locally confined is the low thermal conductivity of the composite material which minimizes member axial heat conduction. Thus only about six percent (the percent length shadowed) of the member experiences a temperature drop. The figure shows the average temperature of the member is reduced only slightly, consequently the structural response will be affected only slightly by the cross-member shadowing.

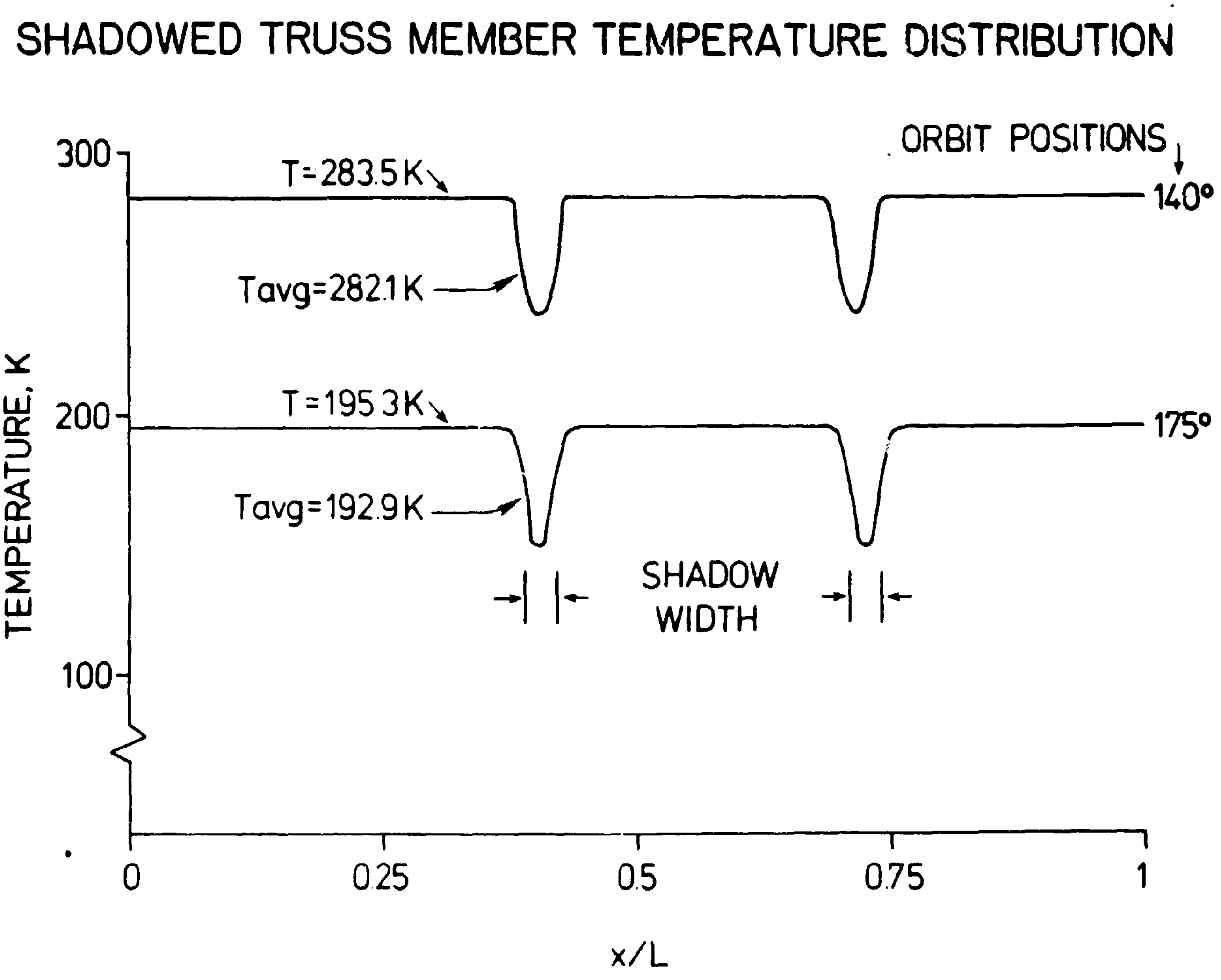

Figure 9

FINITE ELEMENT MODELING OF CABLE-STIFFENED STRUCTURES

Thermal-structural analysis of orbiting cable-stiffened structures depends on effective modeling of both the thermal and structural behavior (Figure 10). The thermal response depends strongly on the structural materials and following figures will demonstrate effective finite element thermal models. The structural response depends strongly on the cable behavior. Standard finite element production programs can analyze small deflection problems, but only a few proprietary programs (e.g. MSC NASTRAN AND ANSYS) are available to perform the nonlinear analysis required when cables experience large transverse deformations.

FINITE ELEMENT MODELING OF CABLE–STIFFENED STRUCTURES

- THERMAL RESPONSE DEPENDS STRONGLY ON MATERIAL
  - –Member temperature distributions different for aluminum and composites
  - –Specialized finite element thermal models effective
- STRUCTURAL RESPONSE DEPENDS STRONGLY ON CABLE BEHAVIOR
  - –Cable elongation primary deformation (no slackening)

    Rod element–linear analysis
  - –Cable elongation with large transverse displacement

    Cable element–nonlinear analysis

Figure 10

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THERMAL RESPONSE OF STAYED COLUMN

To demonstrate two finite element thermal models a stayed column (Figure 11) is analyzed. The stayed column consists of composite spokes, battens and cables with a column of either aluminum or graphite-epoxy. The analyses to be described assume the stayed column to be earth-facing in a geosynchronous orbit in the ecliptic plane.

Analytical and experimental studies of the vibration and buckling behavior of the stayed column (reference 5) have shown that stay (cable) pretension and slackening have significant effect upon the structural response. The thermal analyses to be demonstrated are a first step in a determination of the role of thermal effects on the vibration and buckling behavior of the stayed column.

THERMAL RESPONSE OF STAYED COLUMN

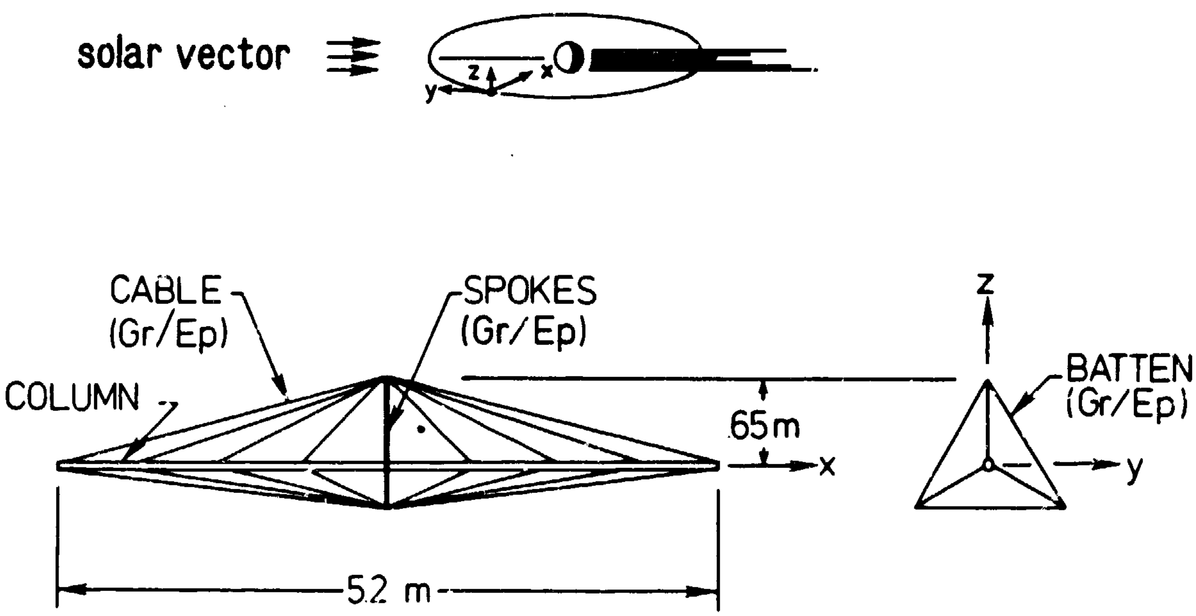

Figure 11

ALUMINUM COLUMN TEMPERATURE DISTRIBUTION

A stayed column design consisting of an aluminum column with composite cables, spokes and battens was thermally analyzed with a refined mesh of 380 conventional (linear temperature distribution) finite elements. The solid line in Figure 12 shows the temperature distribution in the aluminum column. The scalloped temperature distribution results from the relatively high thermal conductivity of the aluminum. Low points on the curve occur at cable attachment points indicating heat conduction to the cable. The stayed column was also analyzed with a nodeless variable (quadratic temperature distribution) finite element (see reference 2 for details) thermal model with 38 elements. The dashed line shows the good agreement between the predicted temperature distributions. Use of the nodeless variable elements reduces computer costs by a factor of about ten and permits use of a common discretization for an integrated structural analysis.

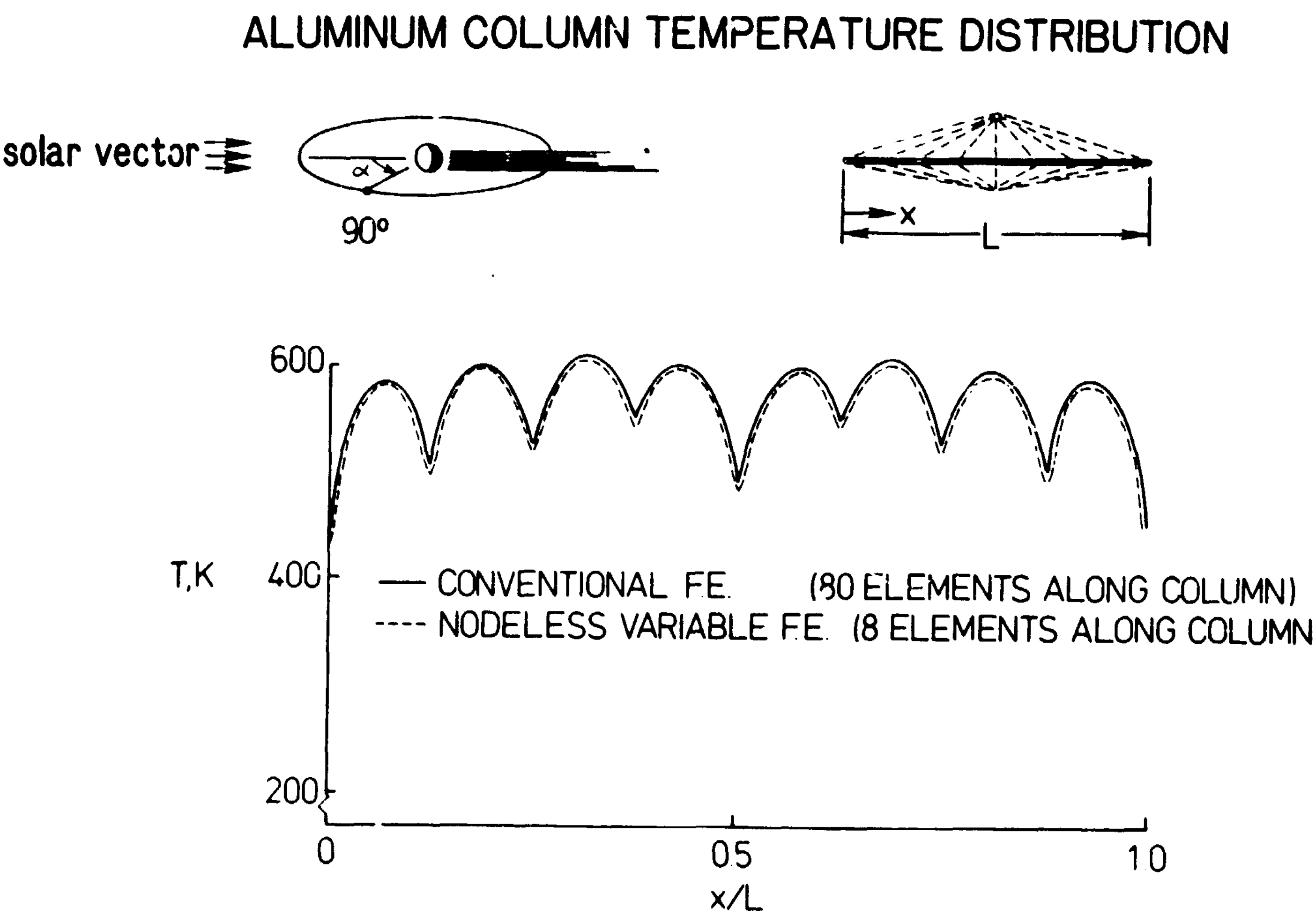

Figure 12

GRAPHITE/EPOXY COLUMN TEMPERATURE DISTRIBUTION

A stayed column design (Figure 13) consisting of all composite components was analyzed with the refined conventional thermal element model (380 elements) and with a mesh of 38 isothermal elements. Isothermal elements (references 1-2) neglect member conduction heat transfer and permit efficient analyses for average member temperatures. The dashed line shows the good agreement between the predicted temperature distributions along the column. The column temperature is almost constant and temperatures computed by the isothermal element are in excellent agreement with the refined conventional element solution. The use of isothermal elements reduces computer costs significantly (by about 100 for this problem) and also permits use of a common discretization for an integrated structural analysis.

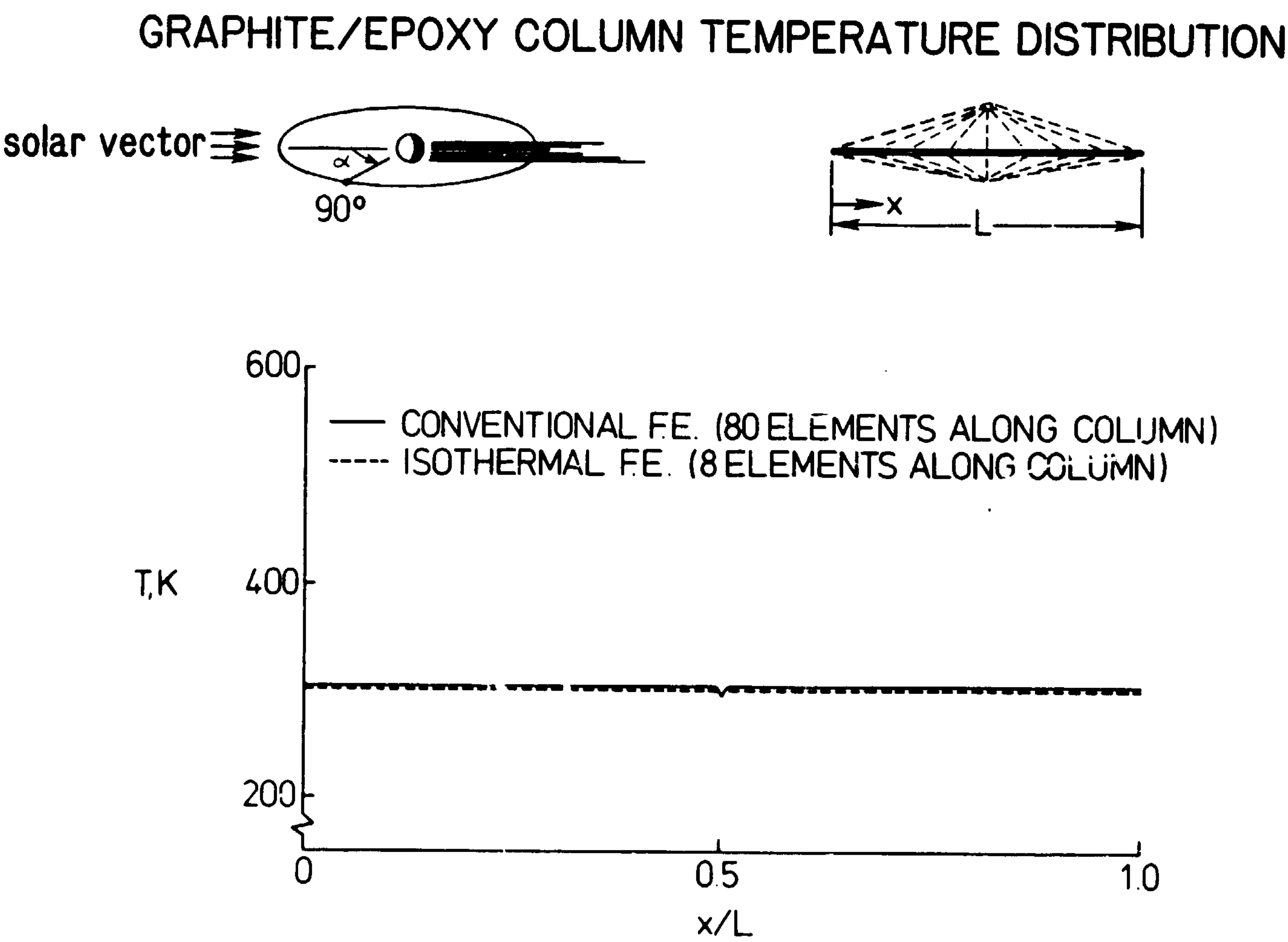

Figure 13

CONCLUDING REMARKS

As structural designs for complex large space antenna systems evolve, greater reliance than ever before is being placed on analysis methods implemented in large computer codes. It is becoming increasingly important to understand the limitations and uncertainties of the analytical methods and the computer programs. Recent research aimed at understanding two interdisciplinary problems of heating, thermal and structural analysis of orbiting space structures was described briefly in this paper. Work on these problems continues with the goal of removing uncertainties in thermal-structural modeling and analysis.

CONCLUDING REMARKS

- THERMAL–STRUCTURAL RESEARCH DESCRIBED
  - –Slender member shadowing effects
  - –Cable stiffened structures
- SLENDER MEMBER SHADOWING
  - –Cross member shadow effects appear small
  - –Work continues including parallel member shadowing
- CABLE STIFFENED STRUCTURES
  - –Specialized thermal models effective
  - –Need further study on nonlinear structural response with cable elements

Figure 14

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