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ADVANCED X-RAY ASTROPHYSICS FACILITY - IMAGING (AXAF-I) THERMAL ANALYSES USING INTEGRATED THERMAL ANALYSIS SYSTEM (ITAS) PROGRAM

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ABSTRACT

The complex geometry and stringent thermal requirements associated with the Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) necessitate a detailed and accurate thermal analysis of the proposed system. A brief description of said geometry and thermal requirements is included in this paper. Among the tools considered for the aforementioned analysis is a PC-compatible version of the Integrated Thermal Analysis System (ITAS). Several bench-mark studies were performed to evaluate the capabilities of ITAS and to compare the corresponding results with those obtained using TRASYS and SINDA. Comparative studies were conducted for a typical Space Station module. Four models were developed using various combinations of the available software packages (i.e. ITAS, SINDA and TRASYS). Orbital heating and heat transfer calculations were performed to determine the temperature distributions along the surfaces of this module. A comparison of the temperature distributions obtained for each of the four cases is presented in this paper. Results of this investigation were used to verify the different ITAS modules including those used for model generation, steady state and transient orbital heating analyses, radiative and convective heat flow analyses, and SINDA/TRASYS model translation. The results suggest that ITAS is well suited to subsequent analyses of the AXAF-I.

INTRODUCTION

The Advanced X-ray Astrophysics Facility (AXAF-I), shown in Figure 1, is a proposed space observatory, designed to address several fundamental questions in astrophysics through celestial observations. The importance of AXAF-I stems from its selective sensitivity to x-rays. Recognizing that x-rays are emitted as a result of fundamental processes affecting the formation, destruction, and behavior of stellar objects, AXAF-I is expected to enhance man's understanding of the history of the universe.

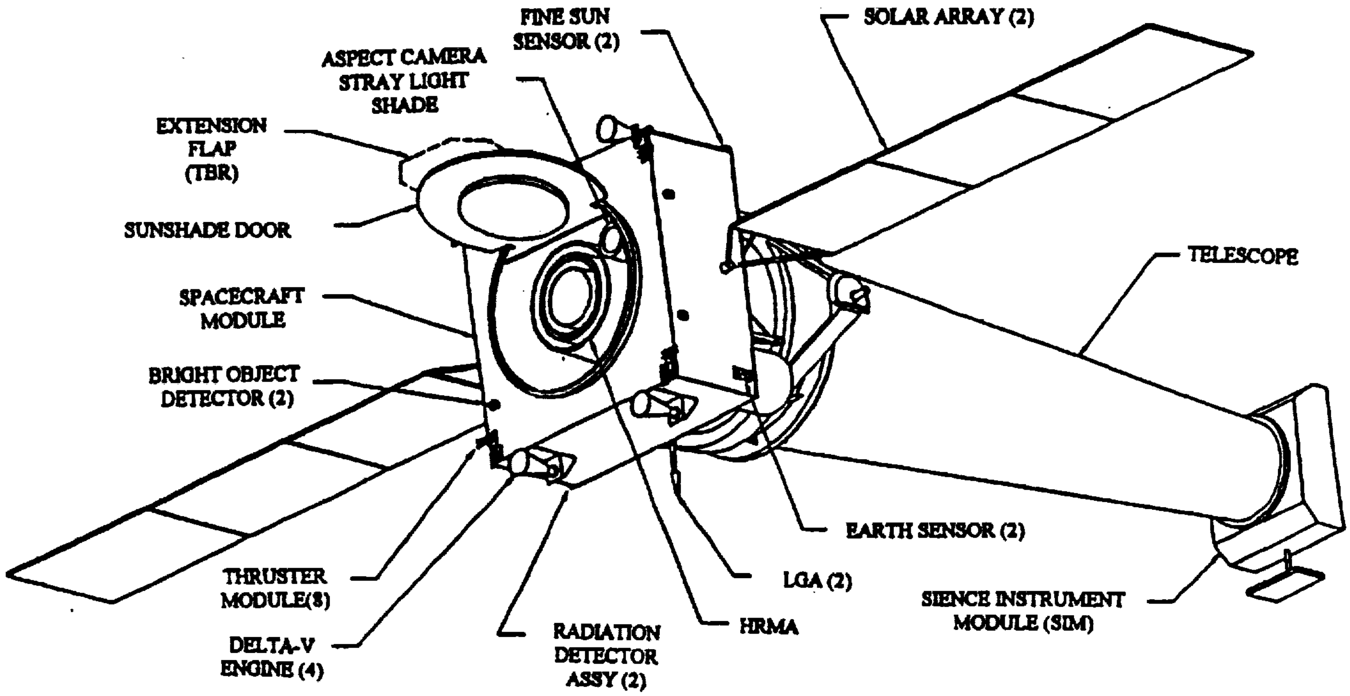

Figure 1: AXAF-I Flight Configuration

AXAF-I is the successor to the Einstein X-ray Observatory, flown between 1978 and 1981. Like the Einstein, AXAF-I will employ special mirrors, capable of projecting high-quality images of stellar objects. This new facility, however, will exceed the capabilities of the short-lived Einstein; AXAF-I will provide 10 times the resolution and 100 times the imaging sensitivity of Einstein. With a life expectancy exceeding 5 years, AXAF-I is scheduled for launch in 1998. The craft will follow an elliptical Earth orbit with minor and major axes of 10000 km and 100000 km, respectively. A 28.5^{o} angle of inclination will be maintained. Under the direction of NASA's Marshall Space Flight Center, the flight system is being developed by a broad-based industry team including TRW Inc. Eastman Kodak, Ball Aerospace, Perkin-Elmer Corporation, The Smithsonian Astrophysical Observatory, MIT, and Martin Marietta Aerospace.

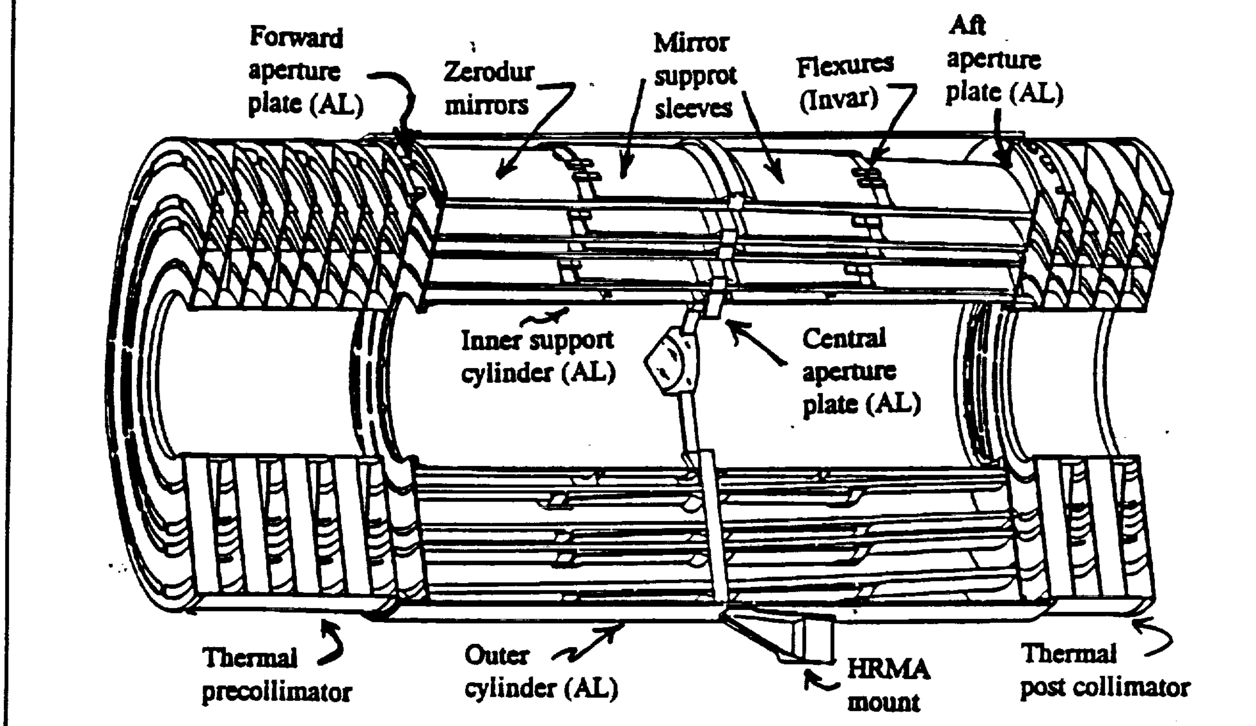

Figure 2: HRMA configuration must meet performance requirement with minimum thermal sensitivity and assembly/alignment risk

AXAF DESIGN AND SYSTEM REQUIREMENTS

The High Resolution Mirror Assembly (HRMA) comprises x-ray imaging mirrors of a special type known as "Wolter, type-1, grazing incidence mirrors." Simply stated, X-rays approaching the mirrors with an angle of incidence between a few degrees and the normal are absorbed (i.e. transmitted) by the mirrors. For angles of less than a few degrees, "soft" x-rays of a few angstroms in wavelength are reflected and imaged using specialized optics. These mirrors are thin-walled cylinders constructed of Zerodur material. The primary mirrors are parabolic whereas the secondary mirrors are hyperbolic. Because the grazing angle of incidence is low, the collection area of Wolter-type optics is necessarily small. The effective collecting area is increased by nesting concentric sets of mirrors. The AXAF-I HRMA uses four sets of grazing incidence optics, radially and axially parafocalized to a 10 m focal length. The largest parabolic mirror has an inner diameter of 1.2 m; the smallest is 0.68 m. Each mirror is 83.8 cm in length. To satisfy the encircled energy requirement, the polished mirrors must be mounted in a strain-free configuration and assembled to small alignment tolerances. These tolerances must, of course, be maintained during ascent and in the orbital environment. A central aperture plate is the primary structural element in the HRMA; this plate is fabricated using a high-strength aluminum alloy, so chosen because it's high thermal conductivity minimizes temperature gradients which can misalign the mirrors. The forward and aft aperture plates are equipped with ghost image control baffles and multi-zone heater tapes which maintain the assembly at a temperature of 20C. Pre- and post-collimators narrow the view factors (i.e. to cold space and to the 10 C telescope) and minimize heat losses and axial temperature gradients. Heater tapes located on the quarter-point flanges and circumferential MLI blankets minimize diametrical thermal gradients (the HRMA isothermal spatial temperature variation must be maintained to within 2.5 F of the orbital thermistor control set point). The axial, diametrical, and radial temperature gradients must also be maintained to within 1.5 F, 0.5 F, and 1.0 F, respectively.

AXAF-I has provisions for two focal plane Science Instruments (SI's); these include a High Resolution Camera (HRC) and an AXAF CCD (Charge Coupled Device) Imaging Spectrometer (ACIS). The HRMA remains stationary and the SIM will have the capability to move and position the appropriate SI at the focal plane of the HRMA.

In order to make on-orbit observations with the precision required to meet the established scientific objectives, ground calibration of the HRMA in conjunction with the SI's, must be performed. Calibration will take place in the X-ray Calibration Facility (XRCF), at the Marshall Space Flight Center .

OBJECTIVE OF STUDY

A complex geometry, coupled with the need to maintain a strictly defined thermal environment, justify the need for a detailed thermal model of the AXAF-I. Furthermore, the HRMA and other specularly reflective surfaces require an analysis tool that may be used to determine specular (ray tracing/Monte Carlo) view factors/Script-F components of radiation conductors. Among the tools considered for this analysis is an interactive, menu driven, PC-based thermal analysis package known as PC-ITAS. Complex models can be quickly generated using a comprehensive set of integrated surface geometry generation primitives. Figure 3 shows an ITAS-generated representation of the AXAF-I. While the preliminary evaluations of ITAS were particularly encouraging, further studies were needed to determine whether this software is suitable for the task at hand. Therefore, a series of bench-mark studies was performed using a geometry for which the results are accepted and documented. In this case, a Space Station module was considered. Results obtained using TRASYS and SINDA were compared with those obtained from ITAS.

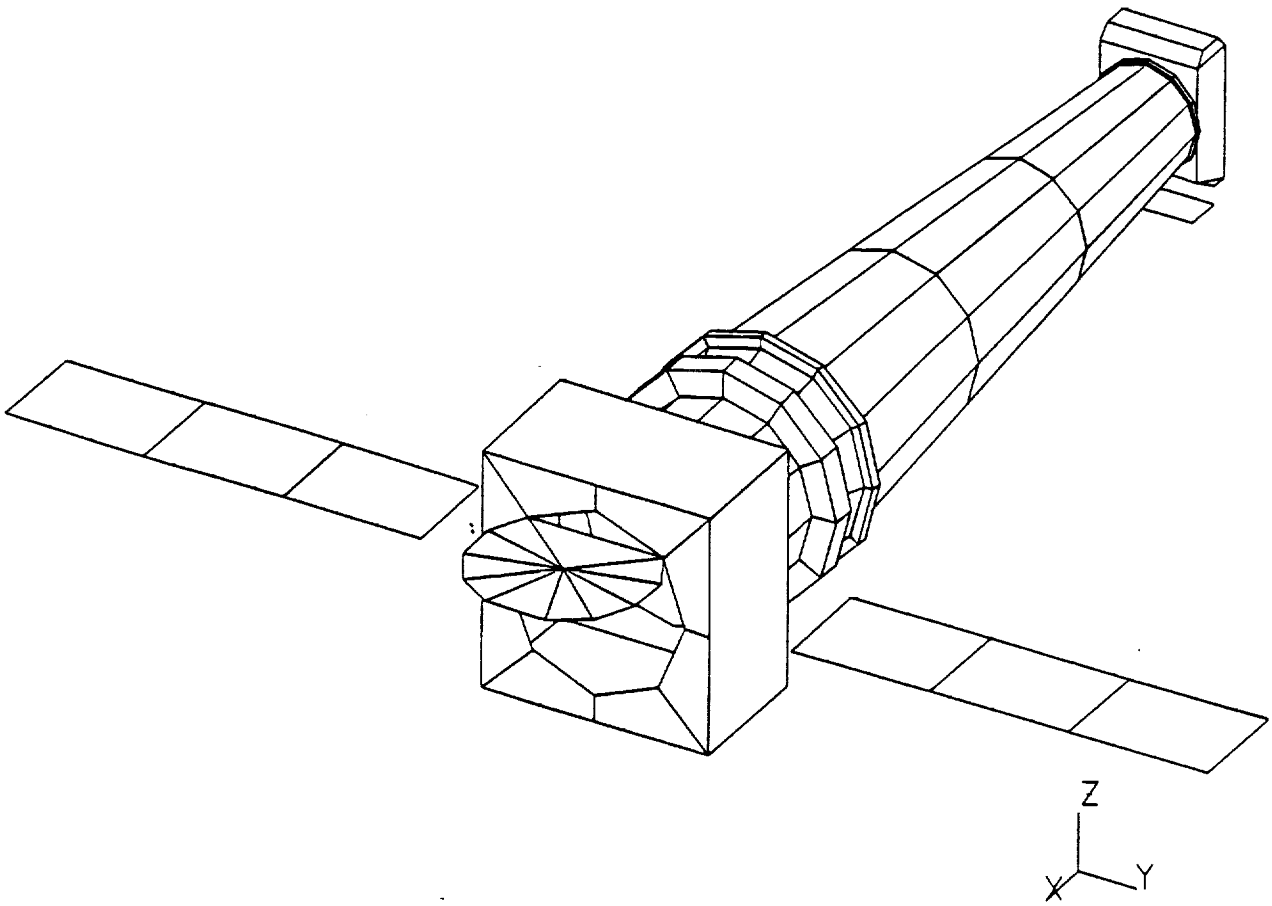

Figure 3: ITAS generated AXAF-I exterior model

METHOD OF EVALUATION

As stated in the previous section, a study was conducted to evaluate PC-ITAS and to compare the performance of this package with that of TRASYS and SINDA. The test case chosen for this evaluation involved a Space Station module in a 250-n.mi., circular earth orbit. A beta-angle of 38°, with respect to the Sun, was assumed for this orbit. Values used for the absorptivity and emissivity of the MLI-covered exterior surfaces of the module were 0.30 and 0.40, respectively. The 0.156-inch-thick Aluminum skin which separates the inner layer of insulation from the interior of the spacecraft was included in the model. An effective emissivity of 0.02 was assumed between interior and exterior surfaces of the spacecraft. Finally, interior surfaces were assumed to exchange heat, via convection, at a rate of 0.20 Btu/sq.ft.hr. to an environment at 70 F. Radiation heat transfer was considered between interior walls of the module, for which the emissivity was assigned a constant value of 0.90. Figure 4 shows a schematic of the model that was generated using ITAS.

Four sets of analyses were conducted. In the first case, ITAS was used (exclusively) to generate a model of the module and to perform orbital heating and subsequent heat flow calculations;

results of these calculations were then used to predict interior and exterior surface temperatures. In the second and third cases, ITAS translators were used to generate SINDA and TRASYS input decks (i.e. using the very same model developed for case one). For the second case, SINDA was run without modifying the respective input deck. In the third case, however, heat fluxes obtained using the ITAS-generated TRASYS input deck were integrated with the ITAS- generated SINDA model. In the fourth and final case, TRASYS and SINDA files were generated and analyzed, independent of ITAS.

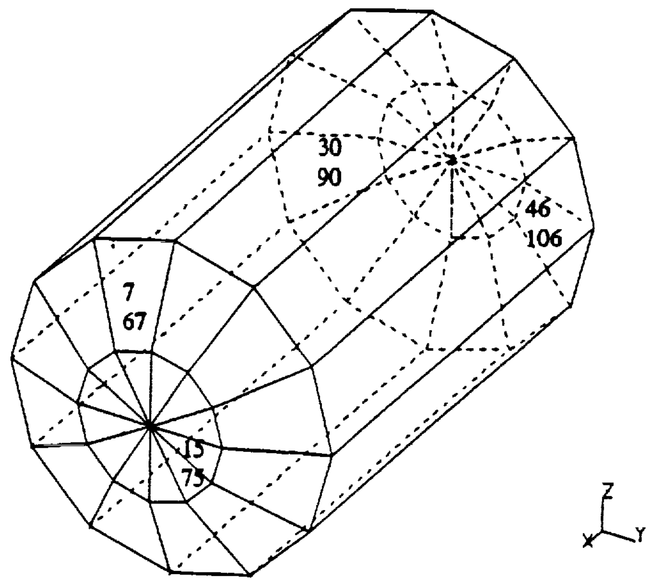

Figure 4: ITAS generated schematic of the space station model.

RESULTS AND DISCUSSION

The temperatures of selected nodes, shown in figure 4, are depicted in Figures 5 through 12. Nodes 7 and 15 are the exterior nodes on the end-cone and have no view of the earth. i.e. the contributing heat source and sink are the solar heat flux and radiation to deep space. Node 30 is on the main cylindrical portion of the module and has partial view of the earth. Node 46 is the exterior node on the other end-cone which is pointing at the earth. Nodes 67, 75, 90 and 106 are the corresponding interior nodes to the above mentioned exterior nodes. As shown in the figures 5 through 12, results corresponding to each of the four cases were in general agreement; hence, the findings of this study suggest that the performance of ITAS is acceptable, at least for cases in which diffuse surface properties may be assumed. These results serve to verify the model definition, steady state and transient orbital heating analysis, radiative and convective heat flow analysis, and translator modules included in the ITAS package.

Additional studies are underway to verify other features of ITAS including the capability for ray tracing and specular surface radiation modeling. These features are of particular interest because they are not accurately handled by COSMIC TRASYS.

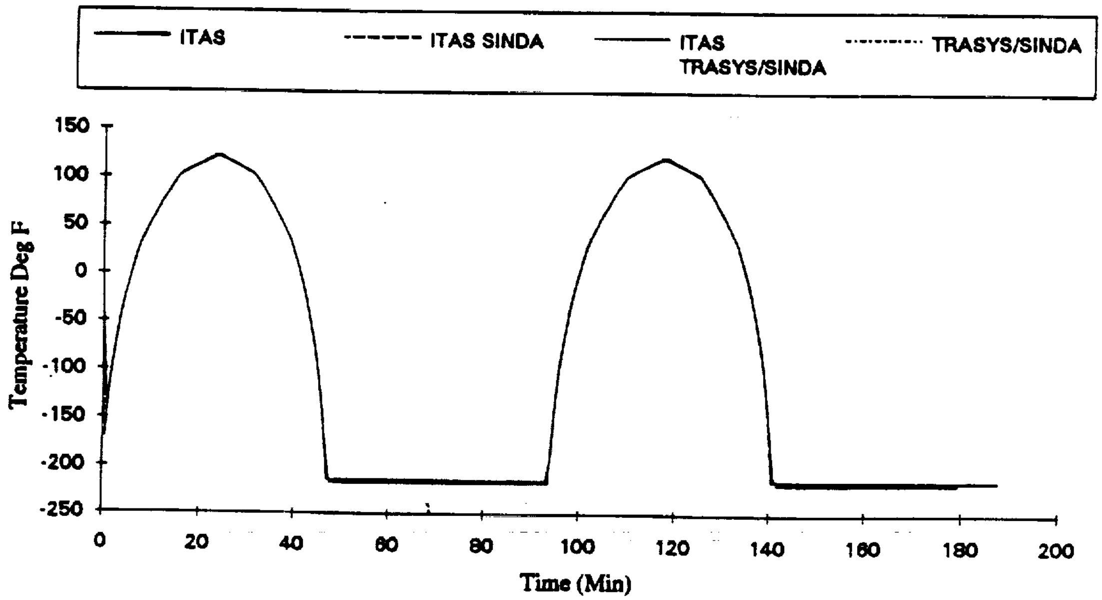

Figure 5: Temperature comparison for interior node 7

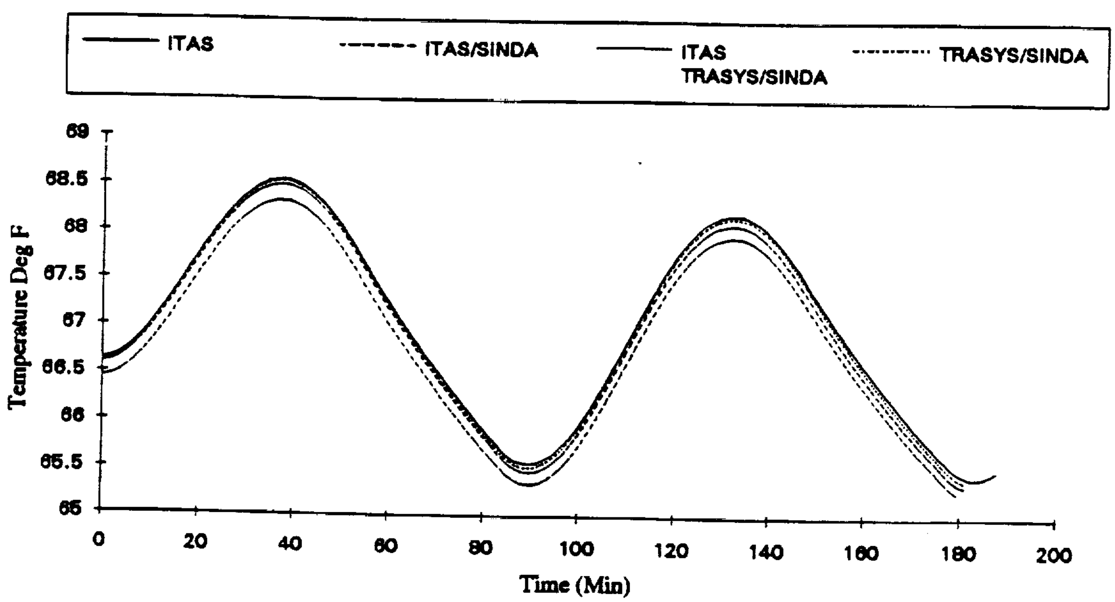

Figure 6: Temperature comparison for interior node 67

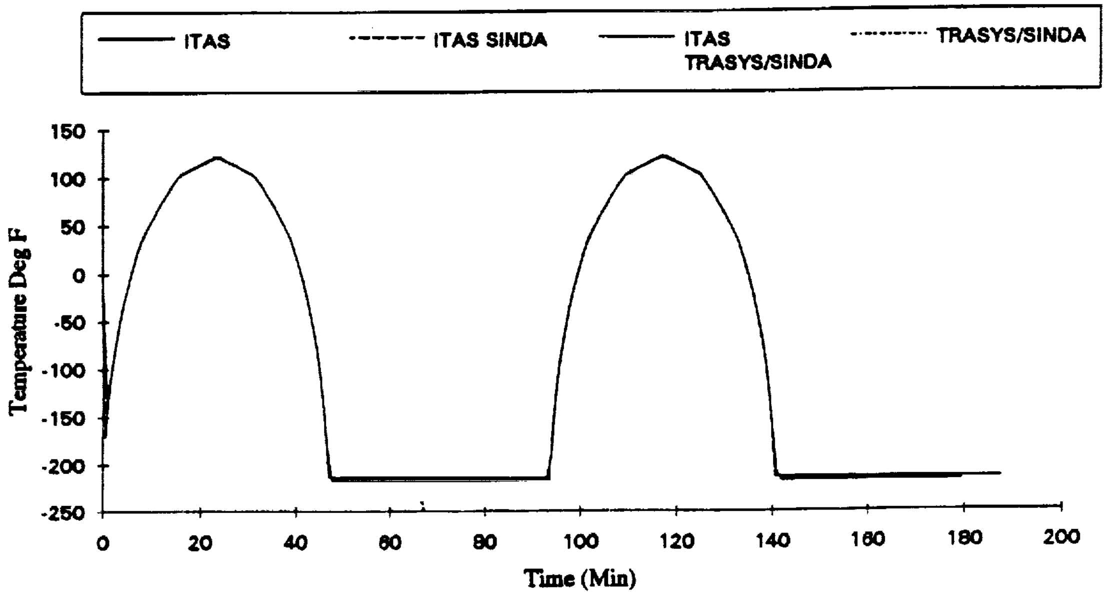

Figure 7: Temperature comparison for interior node 15

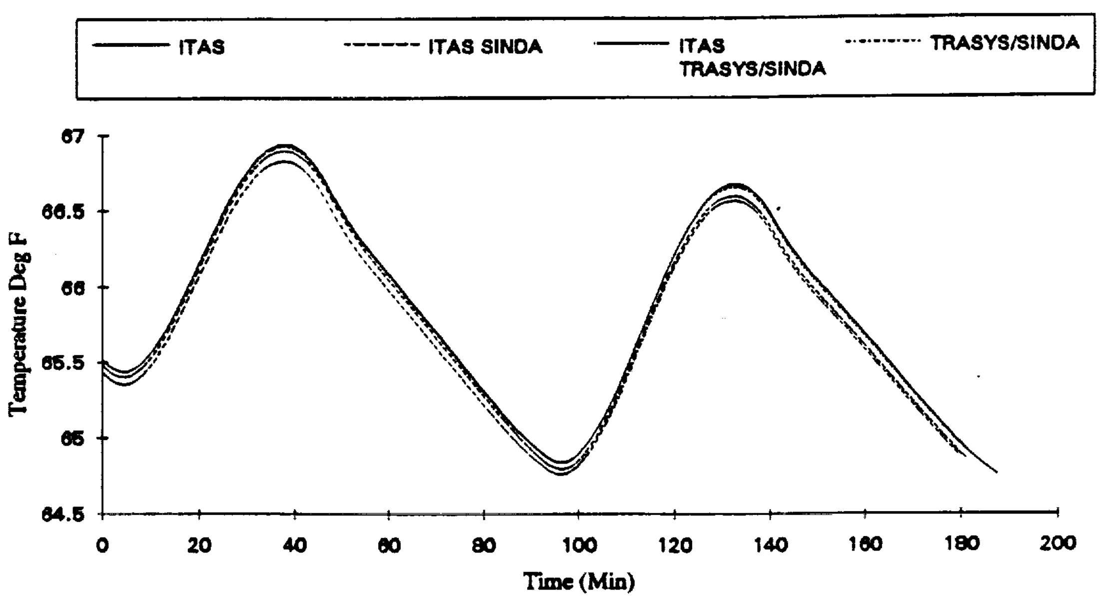

Figure 8: Temperature comparison for interior node 75

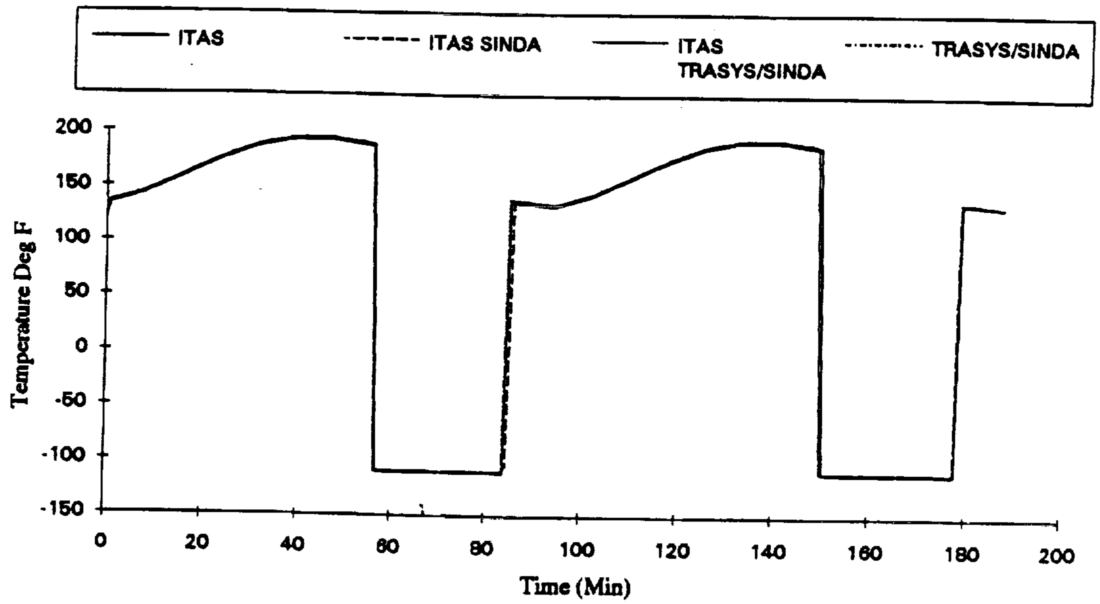

Figure 9: Temperature comparison for interior node 30

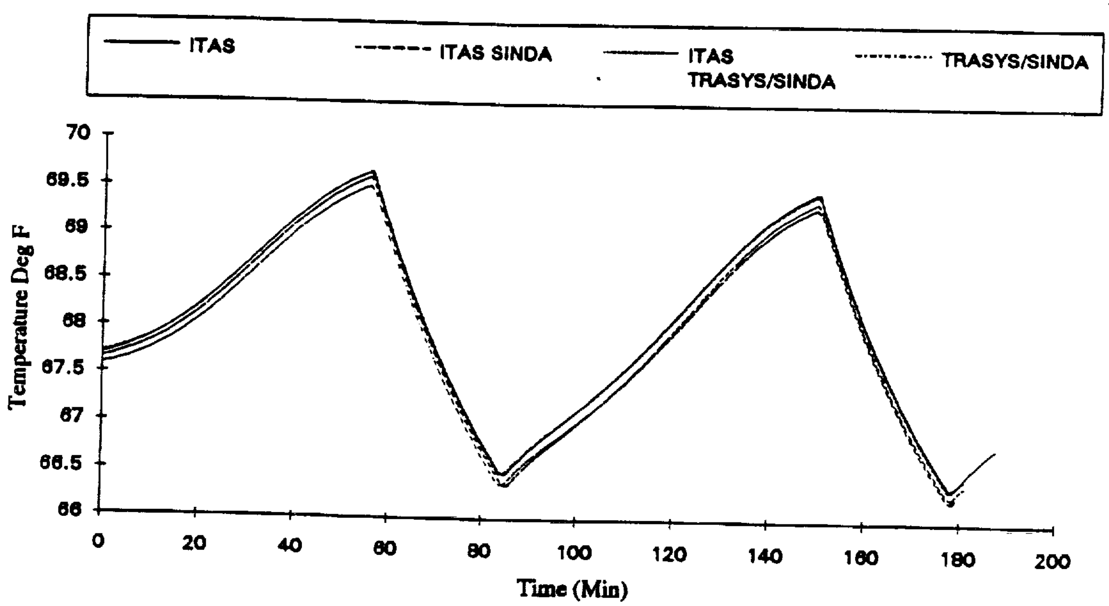

Figure 10: Temperature comparison for interior node 90

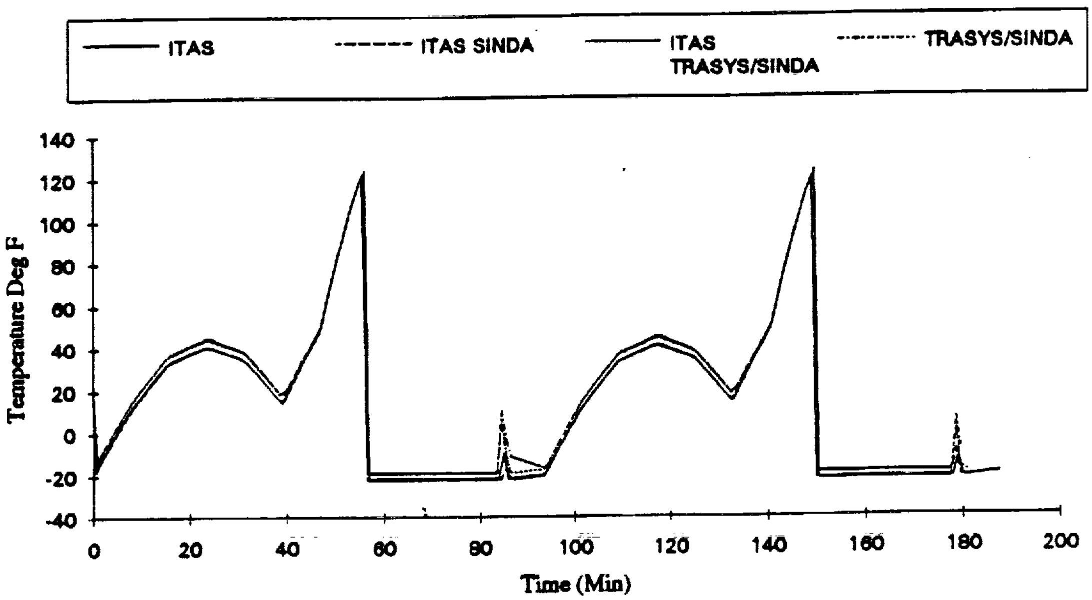

Figure 11: Temperature comparison for interior node 46

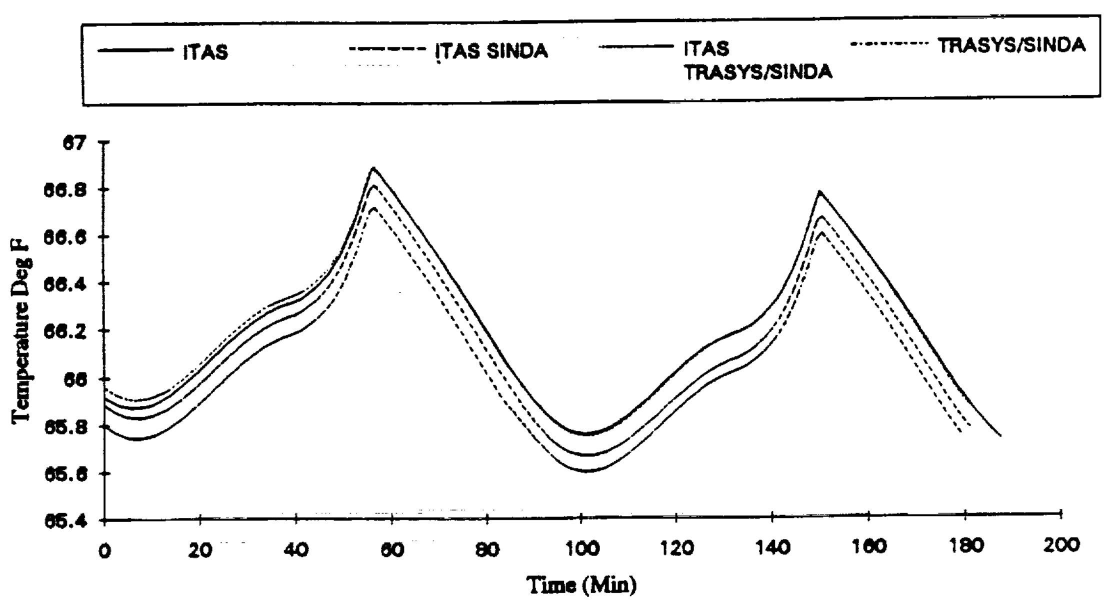

Figure 12: Temperature comparison for interior node 106