SURVEY OF COMPUTER PROGRAMS FOR HEAT TRANSFER ANALYSIS

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INTRODUCTION

The significant advances made in numerical discretization techniques, coupled with the rapid developments in computer hardware and software provided the foundation from which general-purpose programs for heat transfer analysis have evolved. After more than two decades of development, a wide variety of these programs are currently being used in government and industry for heat transfer analysis of practical problems. Depending on the criteria used for identifying general-purpose heat transfer analysis programs, estimates of their numbers vary between thirty and seventy. In addition, several special-purpose and research-oriented heat transfer programs are in existence. The potential user of a heat transfer analysis program is now faced with the problems of 1) getting information about, and sorting out, existing heat transfer analysis programs; and 2) identifying the program that is best suited for his particular needs.

While a number of bibliographies, data sheets and tables have been compiled about finite element software (see, for example, Refs. 1, 2 and 3), little has been published on the assessment of programs used for heat transfer analysis. The best known publication on this subject is Ref. 4 which was prepared by the Committee on Computer Technology of the ASME Pressure Vessels and Piping Division and includes information about eleven programs used for thermal analysis. The present paper goes well beyond the scope of Ref. 4. Specifically, the objective of this paper is to give an overview of the current capabilities of thirty-eight computer programs that can be used for solution of heat transfer problems. These programs range from the large, general-purpose codes with a broad spectrum of capabilities, large user community and comprehensive user support (e.g., ANSYS, MARC, MITAS II, MSC/NASTRAN, SESAM-69/NV-615) to the small, special purpose codes with limited user community such as ANDES, NNTB, SAHARA, SSPTA, TACO, TEPSA and TRUMP. The capabilities of the programs surveyed are listed in tabular form followed by a summary of the major features of each program. As with any survey of computer programs, the present one has the following limitations: a) It is useful only in the initial selection of the programs which are most suitable for a particular application. The final selection of the program to be used should, however, be based on a detailed examination of the documentation and the literature about the program; b) Since computer software continually changes, often at a rapid rate, some means must be found for updating this survey and maintaining some degree of currency. Nevertheless, the author feels that the present survey can serve as a focal point for the user community interested in heat transfer analysis.

Before listing the capabilities of the programs, some of the sources of information about computer programs and references on the background material needed for effectively using the programs are listed, and guidelines for selecting the code are discussed.

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SOURCES OF INFORMATION ABOUT COMPUTER PROGRAMS

A partial list of users groups and software dissemination services that provide information about computer programs for heat transfer analysis is given subsequently. A list of cooperative users groups and finite element software dissemination services can be found in Ref. 5.

- ASIAC - Aerospace Structures Information and Analysis Center, AFFDL/FBR, Wright Patterson Air Force Base, Ohio 45433
- COSMIC - Computer Software Management and Information Center, Suite 112, Barrow Hall, University of Georgia, Athens, Georgia 30602
- ICP - International Computer Programs, Inc., 9000 Keystone Crossing, Indianapolis, Indiana 46240
- National Energy Software Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439
- NTIS - National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

BACKGROUND MATERIAL NEEDED FOR EFFECTIVE EVALUATION AND USE OF COMPUTER PROGRAMS FOR HEAT TRANSFER ANALYSIS

The user of a computer program for heat transfer analysis is dependent on the detailed knowledge about the principles, algorithms and assumptions behind the program features for the proper selection of models and algorithms as well as for monitoring the solution process. There are also many heat transfer problems whose solution may require modifying (slightly) the program. Therefore, the effective evaluation and use of heat transfer programs, requires some knowledge about the following disciplines:

- Principles of heat transfer and formulation of thermal problems.
- Solution techniques for linear and nonlinear steady-state thermal problems.
- Temporal integration and solution techniques for nonlinear transient thermal problems.
- Considerations for the design of software systems for heat transfer analysis.

GUIDELINES FOR SELECTION OF A COMPUTER PROGRAM

The analysis capabilities and user features vary considerably from one code to the other, and therefore, it is often difficult to identify the proper code that meets a specific need. A number of factors which affect the selection of a code are enumerated in the succeeding paragraphs. The order in which the factors are listed does not necessarily reflect the priority which should be given each factor; this remains the responsibility of the user of the code. For a detailed discussion on the technical, operational and commercial criteria for selecting a code see Refs. 6 and 7.

1. *Analysis Capabilities*

These include the range of applications and limitations of the code. The limitations include both those implied by the formulation aspects and numerical solution procedures adopted by the code as well as the element library available in the code.

2. *Adequacy of User-Oriented Features*

For heat transfer analysis the user's features such as automatic (or semi-automatic) mesh (or model) generation, error checks, displays of original model and of various intermediate results, and mechanism for data transfer to other program packages (e.g., thermal stress analysis program) are essential for the effective use of the analysts' time.

3. *Maintainability*

Because of the rapid advances in computational methods, computer software and hardware technology, the maintenance of heat transfer codes usually includes updating the computational modules, extending the capabilities of the code and improving its performance. There exist well-established formal mechanisms of integration and quality assurance of software extensions. Maintenance of the code by personnel other than the developer (e.g., user's organization) can be quite expensive and time consuming.

4. *Adequacy of User Support Facilities*

In addition to the printed documentation (user manuals, training manuals, programming manuals, sample problems and test cases), the following services are desirable: training courses, users meetings, hotline consulting, assistance by data centers and consulting organizations.

5. *Portability*

Although most of the heat transfer codes are written in standard FORTRAN IV language, a code developed on one computer system may not be entirely compatible with another system due to differences in I/O facilities, operating system, precision of the machine (e.g., UNIVAC versus CDC), etc.

Once a code is acquired and implemented on the user's computer system, it is important to establish its reliability by bench-mark problem runs. For a discussion of verification and qualification procedures see Ref. 8.

6. *Experience of Other Users*

This can be invaluable if the users are objective in their evaluation and are familiar with some of the other software packages.

PROGRAM SURVEY AND DESCRIPTION

This section gives an overview of the capabilities of thirty-eight computer programs for the solution of heat transfer problems. The majority of these programs use either finite elements or finite differences for the spatial discretization. Some of the programs have a much more limited scope than others. The information presented herein is based on a questionnaire sent to the developers of each program. The capabilities of the programs are listed in tabular form followed by a description of each program.

SURVEY OF COMPUTER PROGRAMS FOR HEAT TRANSFER ANALYSIS

Part I - Analytical Capabilities of the Program

		ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/NASTRAN	NNTB
1.	Goal of Program System																			
	General Purpose	•	•	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•
	Commercial	•	•			•	•	•									•		•	
	Research	•	•				•	•						•	•		•		•	
	Educational	•	•			•		•									•		•	
	Others (see program abstracts)																			
2.	Method of Analysis																			
	Finite Elements	•	•		•	•	•	•				•	•			•	•		•	
	Finite Differences			•										•	•			•		•
	Boundary Integral Method																		•	
	Perturbation Technique																			
	Hybrid Analytical - Numerical Technique (see program abstracts)								•	•	•									
	Others (see program abstracts)																			
3.	Space Dimensionality																			
	Three-Dimensional	•	•	•		•	•	•		•	•	•	•	•	•		•	•	•	•
	Two-Dimensional	•	•		•	•	•	•	•					•	•	•	•	•	•	•
	One-Dimensional	•	•		•	•	•	•						•	•	•	•	•	•	•

		NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
1.	Goal of Program System																			
	General Purpose	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●
	Commercial		●		●	●	●				●	●		●		●			●	●
	Research		●		●	●	●				●	●		●		●	●		●	●
	Educational		●			●	●							●		●				●
	Others (see program abstracts)								●											
2.	Method of Analysis																			
	Finite Elements	●	●		●	●		●		●				●	●	●				●
	Finite Differences			●			●		●		●	●	●				●	●	●	
	Boundary Integral Method		●																	
	Perturbation Technique																			
	Hybrid Analytical - Numerical Technique (see program abstracts)																			
	Others (see program abstracts)						●													
3.	Space Dimensionality																			
	Three-Dimensional		●	●	●	●	●	●	●			●	●	●			●	●	●	●
	Two-Dimensional	●	●	●	●		●	●	●	●	●			●	●	●			●	●
	One-Dimensional		●	●	●		●	●	●						●				●	●

Part I - Continued

		ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
	Solids of Revolution	•	•		•	•	•	•								•	•		•	
	Boundary Elements	•	•															•	•	
	Scalar Elements																•		•	
	Point Contact Elements	•				•											•		•	
	Others (see program abstracts)																			
4.	Range of Applications and Phenomena																			
	Linear Steady State	•	•		•	•	•	•						•	•	•	•	•	•	•
	Nonlinear Steady State	•	•	•	•	•	•	•						•	•	•	•	•	•	•
	Thermal Frequencies and Mode Shapes	•	•						•	•	•									
	Linear Transient Response	•	•		•	•	•	•					•	•	•	•	•	•	•	•
	Nonlinear Transient Response	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	•
	Others (see program abstracts)																			
5.	Formulation																			
	a) Fundamental Unknowns																			
	Temperatures	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	•
	Temperatures and Flux																	•		•
	Enthalpy	•																•	•	
	Others (see program abstracts)																			
	b) Elemental Matrices																			
	Conduction	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	•

		NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
	Solids of Revolution	•	•	•	•					•				•	•	•			•	•
	Boundary Elements	•	•	•	•			•											•	•
	Scalar Elements		•		•															
	Point Contact Elements		•		•														•	
	Others (see program abstracts)				•											•				
4.	Range of Applications and Phenomena										•	•								
	Linear Steady State		•	•	•	•	•	•	•	•	•	•		•	•				•	•
	Nonlinear Steady State	•	•	•	•	•	•	•	•	•				•	•	•		•	•	•
	Thermal Frequencies and Mode Shapes				•															
	Linear Transient Response		•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•
	Nonlinear Transient Response	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•
	Others (see program abstracts)																			
5.	Formulation																			
	a) Fundamental Unknowns																			
	Temperatures	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Temperatures and Flux				•			•	•										•	
	Enthalpy				•															
	Others (see program abstracts)						•													
	b) Elemental Matrices																			
	Conduction	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Part I - Continued

			ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
	Capacitance	a) Consistent	•	•		•	•	•	•								•	•		•	
		b) Lumped	•	•	•	•	•			•	•	•			•	•		•	•	•	•
	Convection	a) Free	•	•		•	•	•	•								•	•	•	•	
		b) Forced	•	•	•	•	•		•	•	•	•					•	•	•	•	
	Radiation		•	•		•	•	•	•	•	•	•					•	•	•	•	•
	Interelement Convection and Radiation		•			•	•	•	•	•	•	•					•		•	•	•
	User Supplied Elements (see program abstracts)																		•	•	
	Others (see program abstracts)						•		•												
6.	Material Properties and Material Models																				
	Isotropic		•	•	•	•	•	•	•				•	•	•	•	•	•	•	•	•
	Anisotropic		•	•		•	•	•	•						•	•	•	•		•	
	Multilayered		•	•											•	•	•		•		
	Temperature-Dependent Properties	Conductivity	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	
		Specific Heat	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•		
		Density	•		•	•	•	•	•	•	•	•			•	•	•			•	
		Absorptivity (Emissivity Factors)	•	•		•	•	•	•						•	•		•	•	•	•
		Convection Coefficients	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	
	Perfect Conductors (Via Multipoint Constraints)		•				•		•									•		•	
	Time Dependent Thermal Properties		•		•	•		•	•	•	•	•			•	•	•	•	•		

			NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
	Capacitance	a) Consistent	●	●		●	●		●		●				●	●			●		●
		b) Lumped	●		●	●	●	●	●	●	●	●	●	●		●	●	●		●	●
	Convection	a) Free	●	●	●		●	●	●	●	●				●	●			●	●	●
		b) Forced	●		●	●		●	●	●	●				●	●			●	●	●
	Radiation		●		●	●	●	●	●	●	●			●	●	●			●	●	●
	Interelement Convection and Radiation		●		●	●		●	●	●	●				●	●			●	●	●
	User Supplied Elements (see program abstracts)			●		●			●	●										●	●
	Others (see program abstracts)																				
6.	Material Properties and Material Models																				
	Isotropic			●	●	●	●	●	●	●	●				●	●	●	●	●	●	●
	Anisotropic			●		●		●	●	●	●	●	●		●	●	●	●		●	●
	Multilayered			●						●				●	●	●		●		●	
	Temperature-Dependent Properties	Conductivity	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●
		Specific Heat	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●
		Density	●	●		●		●	●			●	●		●	●	●	●			●
		Absorptivity (Emissivity Factors)				●		●	●		●	●	●		●	●		●	●		
		Convection Coefficients	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●
	Perfect Conductors (Via Multipoint Constraints)		●	●	●	●			●						●	●				●	●
	Time Dependent Thermal Properties		●	●	●	●	●	●	●		●	●	●		●	●		●		●	

Part I - Continued

			ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
	Latent Heat and Phase Change Effects		•	•	•	•	•		•						•	•		•	•		
	Material Added or Removed During Analysis		•	•														•	•		
	User Supplied (see program abstracts)														•	•		•			
	Others (see program abstracts)																	•			
7.	Initial Conditions																				
	Homogeneous		•	•		•	•	•	•						•	•	•	•		•	•
	Varying Throughout the Region		•	•		•		•	•						•	•	•	•		•	•
	Initial Enthalpy (for Phase Change)														•	•				•	
	User-Supplied		•		•			•	•	•	•	•		•	•	•	•	•	•	•	
	Others (see program abstracts)																				
8.	Boundary Conditions and Thermal Loads																				
	Prescribed Temperatures	a) Steady State	•	•		•	•	•	•						•	•	•	•	•	•	•
		b) Time Dependent	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	•
	Thermal Flux Input	a) Steady	•	•		•	•	•	•						•	•	•	•	•	•	•
		b) Temperature Dependent	•			•		•	•						•	•	•	•	•	•	
		c) Time Varying	•	•		•	•	•	•						•	•	•	•	•	•	•
	Convection from a Surface to Its Surroundings	a) Steady State	•	•		•	•	•	•						•	•	•	•	•	•	•
		b) Time Dependent	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	

			NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
	Latent Heat and Phase Change Effects					●		●									●		●	●	
	Material Added or Removed During Analysis					●		●							●						
	User Supplied (see program abstracts)					●		●			●	●	●					●		●	●
	Others (see program abstracts)								●												
7.	Initial Conditions																				
	Homogeneous			●	●	●	●	●	●	●	●				●	●	●	●		●	●
	Varying Throughout the Region		●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●
	Initial Enthalpy (for Phase Change)					●														●	
	User-Supplied			●		●	●	●	●	●		●	●		●			●		●	●
	Others (see program abstracts)					●															
8.	Boundary Conditions and Thermal Loads																				
	Prescribed Temperatures	a) Steady State		●	●	●	●	●	●	●	●				●	●	●			●	●
		b) Time Dependent	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●
	Thermal Flux Input	a) Steady		●	●	●	●	●	●	●	●				●	●				●	●
		b) Temperature Dependent	●			●		●	●		●				●	●		●		●	
		c) Time Varying	●	●	●	●	●	●	●	●	●				●	●		●	●	●	●
	Convection from a Surface to Its Surroundings	a) Steady State		●	●	●	●	●	●	●	●				●	●	●			●	●
		b) Time Dependent	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●

Part I - Continued

		ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
Convection from Surroundings to a Surface	a) Steady State	•	•		•	•	•	•						•	•	•	•	•	•	•
	b) Time Dependent	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	
Forced Convection		•	•	•		•		•	•	•	•					•	•	•	•	
Radiation from a Surface to Its Surroundings	a) Steady State	•	•		•	•	•	•	•	•	•			•	•	•	•	•	•	•
	b) Time Dependent	•	•	•	•	•	•	•						•	•	•	•	•	•	
Radiation from Surroundings to a Surface	a) Steady State	•	•		•	•	•	•	•	•	•		•	•	•	•	•	•	•	•
	b) Time Dependent	•	•	•	•	•	•	•						•	•	•	•	•	•	
Radiation Between Narrow Gaps		•				•	•	•						•	•	•	•	•	•	
Radiation Between n Surfaces with	a) User-Supplied View Factors			•	•	•		•						•	•			•	•	•
	b) Internally Calculated View Factors											•				•			•	
Prescribed Fluid Flow				•	•	•		•								•		•	•	
Boundary Layer Convection			•				•		•	•	•						•		•	
Volumetric Heat Generation	a) On Element Level	•	•		•	•	•	•								•	•	•	•	
	b) On Node Level		•	•	•		•							•	•	•	•	•	•	
Gap (Thermal Resistance)						•		•								•	•	•	•	
Boundary Conditions/Loads Added or Removed During Analysis		•	•	•	•	•	•	•								•	•	•	•	
Others (see program abstracts)															•					

		NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
Convection from Surroundings to a Surface	a) Steady State		●	●	●	●	●	●	●	●				●	●	●			●	●
	b) Time Dependent	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●
Forced Convection					●		●	●	●	●	●	●		●		●			●	●
Radiation from a Surface to Its Surroundings	a) Steady State			●	●		●	●	●	●				●	●	●			●	●
	b) Time Dependent	●		●	●		●	●	●	●	●	●		●	●	●	●	●	●	●
Radiation from Surroundings to a Surface	a) Steady State			●	●		●	●	●	●				●	●	●			●	●
	b) Time Dependent	●		●	●		●	●	●	●	●	●		●	●	●	●	●	●	●
Radiation Between Narrow Gaps					●		●		●	●	●	●		●			●		●	●
Radiation Between n Surfaces with	a) User-Supplied View Factors	●		●	●		●	●	●	●					●	●		●	●	●
	b) Internally Calculated View Factors								●	●	●	●		●						
Prescribed Fluid Flow		●		●	●		●	●			●	●		●	●				●	
Boundary Layer Convection				●				●											●	
Volumetric Heat Generation	a) On Element Level	●		●	●			●		●				●	●	●		●		●
	b) On Node Level	●	●				●	●	●		●	●		●	●		●		●	●
Gap (Thermal Resistance)				●	●		●	●	●	●	●	●		●		●		●	●	
Boundary Conditions/Loads Added or Removed During Analysis				●	●		●	●	●		●	●		●	●				●	●
Others (see program abstracts)																				

Part I - Continued

				ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
9.	Solution Techniques																					
	Linear Steady State	a) Direct		●	●		●	●	●	●							●	●	●		●	●
		b) Iterative					●									●	●			●		
		c) Others (see abstracts)																			●	
	Nonlinear Steady State	a) Incremental		●	●		●												●			
		b) Iterative		●	●		●	●	●	●						●	●	●	●	●	●	
		c) Others (see abstracts)																				●
	Transient	a) Thermal Mode Superposition																			●	
		b) Direct Integration	i) Explicit		●	●								●	●	●	●			●		
			ii) Implicit — User Specified Time Step	●	●		●	●	●	●						●	●		●	●	●	
			ii) Implicit — Automatic Time Step Selection	●			●	●	●							●	●	●	●			●
			iii) Combined Explicit/Implicit																		●	
		c) Finite Elements in the Time Domain																				
		d) Moving - Deforming Grids																				
		e) Others (see program abstracts)									●	●	●									
10.	Other Capabilities																					
	Thermal Stress Analysis Capability	a) Uncoupled		●	●		●		●	●									●			
		b) Coupled		●			●	●											●		●	

	Capability	Technique	NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
9.	Solution Techniques																				
	Linear Steady State	a) Direct	•	•		•	•		•		•				•	•	•			•	•
		b) Iterative			•			•		•		•	•							•	
		c) Others (see abstracts)				•														•	
	Nonlinear Steady State	a) Incremental		•													•			•	•
		b) Iterative	•		•	•		•	•	•	•	•	•		•	•			•	•	•
		c) Others (see abstracts)				•	•													•	
	Transient	a) Thermal Mode Superposition				•															
		b) Direct Integration: i) Explicit				•		•	•	•							•			•	
		b) Direct Integration: ii) Implicit: User Specified Time Step	•		•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•
		b) Direct Integration: ii) Implicit: Automatic Time Step Selection							•		•				•					•	•
		b) Direct Integration: iii) Combined Explicit/Implicit		•				•		•										•	
		c) Finite Elements in the Time Domain																		•	
		d) Moving - Deforming Grids				•											•				
		e) Others (see program abstracts)																			
10.	Other Capabilities																				
	Thermal Stress Analysis Capability	a) Uncoupled		•		•			•						•				•		•
		b) Coupled															•				

Part I - Continued

			ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
	Temperature Field Data Transmitted Directly from Heat Transfer Modules to Thermal Stress Modules		•	•		•	•	•	•								•	•		•	
	Enclosure Radiation with View Factor Calculation												•				•			•	
	Heat Input/Output at Constrained Boundaries		•	•			•	•	•								•	•	•	•	•
	Cyclic Symmetry																			•	
	Substructuring	a) Repeated Use of Identical Substructures	•				•													•	
		b) Mixing Linear and Nonlinear Substructures						•												•	
		c) Mixing Substructures with Different Types of Nonlinearities					•	•													
	Restart Capability		•	•	•	•	•	•	•				•		•	•		•	•	•	•
	Others (see program abstracts)								•											•	
11.	Program Operational On																				
	CDC		•	•		•	•			•	•	•			•			•	•	•	
	IBM		•	•	•		•	•	•	•	•	•	•	•	•	•	•	•		•	•
	UNIVAC		•	•			•	•	•									•		•	
	Honeywell			•			•	•													
	Telefunken			•																	
	AMDAHL		•	•			•		•									•		•	
	SIEMENS			•																	
	ICL								•								•				

			NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
	Temperature Field Data Transmitted Directly from Heat Transfer Modules to Thermal Stress Modules			•		•	•		•		•				•		•		•		•
	Enclosure Radiation with View Factor Calculation									•	•				•						
	Heat Input/Output at Constrained Boundaries		•			•			•	•					•	•				•	
	Cyclic Symmetry			•											•				•	•	
	Substructuring	a) Repeated Use of Identical Substructures		•		•	•													•	•
		b) Mixing Linear and Nonlinear Substructures		•		•	•			•											
		c) Mixing Substructures with Different Types of Nonlinearities				•	•														•
	Restart Capability		•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•
	Others (see program abstracts)					•															
11.	Program Operational On																				
	CDC		•	•	•	•		•	•		•					•	•		•	•	•
	IBM			•		•		•		•				•	•		•	•		•	
	UNIVAC			•		•	•	•	•			•	•						•	•	
	Honeywell			•		•													•		
	Telefunken																				
	AMDAHL													•			•				
	SIEMENS					•															
	ICL			•											•						

Part I - Concluded

		ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
	Minicomputers (see program abstracts)	•	•			•	•	•									•		•	•
	Supercomputers (see program abstracts)	•	•			•											•		•	
	Others (see program abstracts)																•			
12.	Documentation																			
	Programmer's Manual	•	•	•	•		•	•	•	•	•			•	•		•		•	
	Theoretical Manual	•	•	•		•	•	•	•	•	•	•		•	•		•		•	•
	Data Preparation - Users' Manual	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Example Problem Manual	•	•	•	•	•	•	•	•	•	•						•	•	•	
	Verification/Validation Manual	•	•			•	•	•	•	•	•						•		•	
	Pre- and Post-Processors' Manual	•		•	•	•	•	•									•		•	

		NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
	Minicomputers (see program abstracts)		•		•		•													
	Supercomputers (see program abstracts)		•	•			•			•									•	
	Others (see program abstracts)				•				•										•	
12.	Documentation																			
	Programmer's Manual	•	•			•	•				•	•	•		•			•	•	
	Theoretical Manual		•		•	•		•	•	•			•			•	•	•	•	
	Data Preparation - Users' Manual		•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•
	Example Problem Manual	•	•	•	•	•		•	•	•			•	•	•	•		•	•	
	Verification/Validation Manual		•		•	•					•			•		•			•	•
	Pre- and Post-Processors' Manual		•	•	•	•	•			•				•	•			•	•	•

Part II - User Interface and Modeling Capabilities

	ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
1. Input Form and Sequence																			
a) Input Form																			
Fixed Format	•	•	•				•	•	•	•	•	•	•			•		•	•
Free Form-List Directed Format	•			•	•	•	•							•	•	•	•	•	
Problem Oriented Language	•						•								•		•	•	
Others (see program abstracts)																			
b) Input Sequence																			
User Directed	•	•	•		•			•	•	•				•	•	•			
System Directed				•		•	•				•	•	•				•	•	•
User Supplied Subroutines (see program abstracts)	•		•													•	•	•	
2. Model Generation and Checking																			
a) Automatic or Semi-Automatic Generator for:																			
Nodal Point Coordinates	•	•		•	•	•	•			•			•	•	•	•		•	
Element Connectivities	•	•		•	•	•	•			•			•	•	•	•		•	
Constraints, Symmetry and Boundary Conditions	•	•	•		•	•	•	•	•	•			•	•		•		•	
Substructure Connectivity						•											•	•	
Repetition of Identical Segments	•	•	•	•	•		•			•						•	•	•	
Others (see program abstracts)																			

		NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
1.	Input Form and Sequence																			
	a) Input Form																			
	Fixed Format			●	●	●				●	●	●	●			●	●		●	●
	Free Form-List Directed Format	●	●		●			●						●	●			●		
	Problem Oriented Language						●		●					●						
	Others (see program abstracts)							●					●							
	b) Input Sequence																			
	User Directed		●	●	●			●	●	●			●	●		●		●	●	●
	System Directed	●				●	●	●			●	●			●		●			
	User Supplied Subroutines (see program abstracts)						●	●			●	●								
2.	Model Generation and Checking																			
	a) Automatic or Semi-Automatic Generator for:		●																	
	Nodal Point Coordinates	●	●	●	●	●		●		●	●	●	●	●	●	●	●	●	●	●
	Element Connectivities	●	●	●	●	●		●		●			●	●	●	●	●	●		●
	Constraints, Symmetry and Boundary Conditions		●		●	●				●			●	●			●	●	●	●
	Substructure Connectivity		●			●							●			●			●	●
	Repetition of Identical Segments	●	●		●	●							●	●	●			●	●	●
	Others (see program abstracts)							●	●										●	

Part II - Continued

	ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/NASTRAN	NNTB
b) Automatic or Semi-Automatic Generator for:																			
One-Dimensional Elements	•	•		•	•	•	•									•		•	
Triangular Elements		•		•	•	•	•			•						•		•	
Quadrilateral Elements	•	•		•	•	•	•			•						•		•	
Body or Shell of Revolution Elements	•	•		•	•	•	•		•	•						•			
Three-Dimensional Solid Elements	•	•			•	•	•			•						•		•	
Two-Dimensional Shell Elements	•				•	•	•											•	
Curvilinear Finite Difference Grids																			
Others (see program abstracts)								•	•	•									
c) Data Checking Facilities																			
Line Printer	•		•	•	•	•	•				•	•	•	•	•	•	•	•	
Plotter	•			•	•	•	•						•	•	•	•	•	•	
Interactive Graphics			•	•	•	•	•			•	•					•		•	
Others (see program abstracts)		•																	
d) Plots and Graphics Display of Model													•	•					
Complete Analysis Region	•			•	•	•	•			•	•		•	•	•	•		•	
Part of Analysis Region	•			•	•	•	•						•	•	•	•		•	
"Blow-Up" Option	•			•	•	•	•						•	•	•	•		•	

	NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
b) Automatic or Semi-Automatic Generator for:																			
One-Dimensional Elements	•	•	•	•			•							•				•	•
Triangular Elements	•	•		•			•					•	•	•					•
Quadrilateral Elements	•	•	•	•			•		•			•	•	•	•			•	•
Body or Shell of Revolution Elements		•	•	•				•	•				•	•	•			•	•
Three-Dimensional Solid Elements		•	•	•	•		•	•				•	•				•	•	•
Two-Dimensional Shell Elements		•		•														•	•
Curvilinear Finite Difference Grids																			
Others (see program abstracts)																			
c) Data Checking Facilities																			
Line Printer	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•
Plotter	•	•		•	•	•	•	•					•	•			•	•	•
Interactive Graphics	•	•	•	•			•					•		•			•		•
Others (see program abstracts)													•						
d) Plots and Graphics Display of Model																			
Complete Analysis Region	•	•	•	•	•		•		•			•	•	•			•	•	•
Part of Analysis Region	•	•	•	•	•		•	•	•				•	•			•	•	•
"Blow-Up" Option	•	•	•	•			•	•	•				•	•			•	•	•

Part II - Continued

		ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
	Hidden Lines or Surfaces				•	•	•	•			•	•					•		•	
	Orthographic Views	•			•	•	•	•			•								•	
	Perspective and Isometric Views	•			•	•	•	•			•	•					•		•	
	Section View on Arbitrary Plane	•			•	•	•				•						•		•	
	Others (see program abstracts)		•					•												
	e) Other Facilities																			
	Digitizer Input					•		•			•	•								
	Automatic Renumbering of Nodes, Elements or Equations					•		•			•					•	•		•	
	Table Lookup of Data	•		•		•			•	•	•		•					•		
	Others (see program abstracts)																	•		
3.	Results Output Form																			
	a) Tabular Output				•		•	•	•	•	•									
	Fixed Set	•	•		•	•	•	•				•				•	•	•		•
	User Defined Set and Sequences	•		•	•	•		•					•	•	•		•	•	•	
	Maximum and Minimum Quantities				•	•		•						•	•			•	•	
	Average and Maxima for Blocks of Nodes															•		•		
	Temperature or Flux Exceedances					•		•										•	•	
	Others (see program abstracts)																			

		NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
	Hidden Lines or Surfaces	●	●										●	●	●					●
	Orthographic Views	●			●			●	●				●	●	●					●
	Perspective and Isometric Views	●	●		●	●		●	●				●	●	●			●		●
	Section View on Arbitrary Plane	●	●										●		●					●
	Others (see program abstracts)		●																	
	e) Other Facilities																		●	
	Digitizer Input		●										●					●		●
	Automatic Renumbering of Nodes, Elements or Equations		●		●			●		●			●	●	●			●		●
	Table Lookup of Data		●					●		●								●	●	
	Others (see program abstracts)				●														●	
3.	Results Output Form																			
	a) Tabular Output		●					●								●			●	
	Fixed Set	●		●	●	●	●	●	●	●			●	●	●	●	●		●	●
	User Defined Set and Sequences	●		●	●	●	●	●			●	●		●	●	●		●	●	
	Maximum and Minimum Quantities		●	●			●	●											●	●
	Average and Maxima for Blocks of Nodes							●											●	
	Temperature or Flux Exceedances							●								●			●	
	Others (see program abstracts)																		●	

Part II - Concluded

		ABAQUS	ADINAT	AGTAP	ANDES	ANSYS	ASASHEAT	BERSAFE FLHE	CAVE I	CAVE II	CAVE III	CONFAC	FLUX2	HEATING5	HEATING6	HEATRAN	MARC	MITAS II	MSC/ NASTRAN	NNTB
	b) File Output for User Post-Processing and Plotting	•	•	•		•	•	•	•	•	•	•	•	•	•		•	•	•	
	c) Plots																			
	Isotherm Plots (Contours) of Temperatures/Flux	•		•	•	•	•	•						•	•	•	•		•	
	Surface Functions							•											•	
	Selective Output (e.g., by Elements or Regions)	•		•	•	•		•						•	•		•	•	•	
	Histories (e.g., Time History)	•		•	•	•		•						•	•	•	•	•	•	
	Others (see program abstracts)															•			•	
4.	Interactive Input and Control																			
	Parameter Specicification (e.g., Flux or Time Steps)					•												•		
	Singularity Check						•										•			
	Error Correction/Recovery	•		•		•														
	User Control of Matrix Decomposition						•													
	Others (see program abstracts)																			

		NTEMP	PAFEC	SAHARA	SAMCEF (THERNL)	SESAM-69 (NV-615)	SINDA	SPAR	SSPTA	TACO	TAC2D	TAC3D	TANG	TAU	TEMP	TEPSA	THAC-SIP-3D	THTD	TRUMP	WECAN
	b) File Output for User Post-Processing and Plotting		•	•	•	•	•	•	•	•			•	•			•		•	•
	c) Plots																			
	Isotherm Plots (Contours) of Temperatures/Flux	•	•		•	•				•				•	•		•	•	•	•
	Surface Functions																	•		•
	Selective Output (e.g., by Elements or Regions)		•		•	•				•				•			•		•	•
	Histories (e.g., Time History)		•	•	•		•		•	•				•	•		•	•	•	•
	Others (see program abstracts)		•	•					•	•			•	•						
4.	Interactive Input and Control																			
	Parameter Specification (e.g., Flux or Time Steps)		•		•			•										•	•	
	Singularity Check		•		•			•								•				
	Error Correction/Recovery		•		•			•					•						•	
	User Control of Matrix Decomposition		•					•											•	
	Others (see program abstracts)							•											•	

ABAQUS

Descriptive Program Title: General Purpose Structural and Heat Transfer Program

Program Developer: Hibbitt, Karlsson and Sorensen, Inc., 35 South Angell Street, Providence, Rhode Island 02906.

Date of First Release and Most Recent Update: 1979 and 1981

General Information:
ABAQUS is a general purpose, structural and heat analysis code developed and maintained by Hibbitt, Karlsson and Sorensen, Inc.

Program Capability and Scope of Analysis:
ABAQUS provides a complete capability for linear and nonlinear analysis. In addition to a general heat transfer capability, static, dynamic, eigenvalue buckling and soil consolidation procedures are included in the code. Also, a procedure for Eully coupled heat/stress analysis is operational.

User Interface and Modeling Capabilities:
- The ABAQUS pre-processor is designed to simplify the task of data specification. Data may be entered in fixed or free format and are identified by leading keyword cards. Extensive data consistency checks are built into the code and clear messages are printed whenever errors are encountered.
- ABAQUS provides a complete range of plotting: mesh plotting, contour and displaced plots at specified points in an analysis may be requested, and time history plots are directly obtained. Each of these plotting capabilities permits detailed 'blow-ups', viewpoints, etc.
- A very general printed/file output is provided as well as a flexible restart capability.

Solution Methods:
- Nonlinear transient response - Backward difference scheme.
- Nonlinear steady state - Newton-Raphson technique.
- Eigenvalue extraction - Subspace iteration procedure.
- Linear equation solver - Wavefront technique.

Notable Items and Limitations:
All solution procedures include automatic time stepping capability. These self-adaptive schemes choose time (loading) increments based on user set tolerances to provide solutions of uniform accuracy. Automatic loading can avoid excessive restarting to obtain convergence and thus generally saves computer costs.

Programming Language: ANSI FORTRAN

Hardware/Operating System: CDC 6600, 7600, CYBER 175, 176, CDC 203, CRAY, IBM 370, 3033, AMDAHL, UNIVAC 1100 series, VAX.

Program Size (Heat Transfer Modules Only): Pre-processors 25,000; Main 50,000 executable statements. Programs load as libraries, so that small problems can be fitted in quite small machine memories.

Documentation: See Ref. 9

Program Availability: The program may be obtained from the developer:
Hibbitt, Karlsson and Sorensen, Inc.
35 South Angell Street
Providence, Rhode Island 02906

It may also be accessed commercially through the CYBERNET System.

ADINAT

Descriptive Program Title: ADINAT - A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis of Temperatures

Program Developer: Professor K. J. Bathe, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

Date of First Release and Most Recent Update: 1977 and 1981

General Information:
ADINAT is part of the ADINA system together with the general purpose code ADINA and the pre- and post-processor ADINA-PLOT. ADINAT is a proprietary code which is maintained and further developed by ADINA Engineering with offices in Västerås, Sweden, and Boston, Massachusetts. The code is available for a fee and members of the users group obtain the source code and all new developments as long as they remain members of the group. The source code is transmitted with sample data cases and their solutions.

Program Capability and Scope of Analysis:
ADINAT is a general purpose linear and nonlinear finite element analysis program for steady-state and transient heat transfer and analogous field problems. The nonlinearities may be due to temperature-dependent material properties including latent heat effects, element birth and death options or boundary convection and radiation conditions. The program can be used to restart at pre-selected time steps. Thermal frequencies and mode shapes can be calculated. Both concentrated and distributed heat flows can be applied.

User Interface and Modeling Capabilities:
The ADINA system includes ADINA-PLOT for pre- and post-processing. At present the capabilities of ADINA-PLOT are oriented towards ADINA but a temperature tape can be output from ADINAT for further processing in ADINA-PLOT with printing and plotting of selected results in the form of tables, curve plots, etc.

Solution Methods:

- Nonlinear transient response - Implicit and explicit time integration, Euler backward and forward method, trapezoidal rule and the α-family method. Equilibrium iteration.
- Nonlinear steady-state problems - Incremental solution, modified Newton-Raphson method.
- Equation solver for linear equations - Compacted out-of-core solver.
- Extraction of frequencies and mode shapes - Determinant search method.

Notable Items and Limitations:
ADINAT offers a very large range of applications in linear and nonlinear analysis with relatively few effective elements, a good library of material models and effective numerical methods. The program can be employed effectively in linear

analysis and then, with only a few input changes, in relatively simple and very complex nonlinear analyses.

Programming Language: FORTRAN IV

Hardware/Operating System: Among mini- and supercomputers, installations are VAX, PRIME, CYBER 203, and CRAY.

Program Size: Approximately 12,000 source statements of the core program; ADINA 45,000 statements.

Documentation: See Refs. 10 to 13

Program Availability: Source program of ADINAT is available by joining the ADINA Users Group (for a fee). Contact:

ADINA Engineering AB
Munkgatan 20 D
S-722 12 Västerås
Sweden
Tel. 021-14 40 50
Telex 40630 ADINA S

AGTAP

Descriptive Program Title: Abbreviated General Thermal Analyzer Program

Program Developer: Grumman Aerospace Corporation, Bethpage, New York 11714

Date of First Release and Most Recent Update: 1965 and 1980

General Information:
AGTAP is a general thermal analyzer designed to solve both simple problems requiring rapid solution and unconventional problems for which extensive supplementary calculations are necessary.

Program Capability and Scope of Analysis:
This program is capable of solving thermal models of up to 1,000 nodes with 2,000 conduction and 2,000 radiation connectivities.

User Interface and Modeling Capabilities:
The preprocessor code TANG provides model generation capability with output formats compatible with AGTAP. A post-processor plotting capability is also available.

Solution Methods:
The solution technique employs a "lumped parameter" approximation of the problem which is solved by a finite difference iterative procedure.

Notable Items and Limitations:
The program features three options to insert specialized calculations into the solution. Evaluation of the maximum critical time step is provided, but not internally controlled.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 370 (OS/VS)

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
The most recent version contains 905 source statements.

Documentation: Informal report describing method of solution, program operation, data preparation and sample problems is available.

Program Availability: For further information contact:
Dr. John G. Roukis
Mail Stop B22/35
Grumman Aerospace Corporation
Bethpage, New York 11714

ANDES

Descriptive Program Title: Acoustic Non-Destructive Evaluation Stress Analysis

Program Developer: Dr. A. F. Emery, Department of Mechanical Engineering, University of Washington, Seattle, Washington 98195.

Date of First Release and Most Recent Update: September 1980 and September 1981

General Information:
ANDES is designed to calculate stresses and residual stresses for comparison with acoustic experimental tests. Phase changes, temperature-dependent properties, time-dependent properties, and time-dependent boundary conditions are treated. Dynamic core allocation.

Program Capability and Scope of Analysis:
Two-dimensional and axisymmetric problems. Transient with nonlinear boundary conditions.

User Interface and Modeling Capabilities:
Batch processing. Interactive graphic input of mesh. Separate mesh generator or internal generation of simple meshes.

Solution Method:
Direct solution of equations with incremental iteration for nonlinear problems. SOR method if specified by user. User prescribed convergence criterion. Convergence based upon rms or maximum error.

Programming Language: FORTRAN Extended.

Hardware/Operating System: CDC CYBER 175/750, NOS operating system, CDC 6000 series, NOS/BE operating system.

Program Size (Heat Transfer Modules Only):
This program contains approximately 3,000 cards. Pre- and post-processors approximately 3,000 cards each.

Documentation: See Ref. 14

Program Availability: On request from program developer.
Cost: Approximately $200.

ANSYS

Descriptive Program Title: ANSYS

Program Developer: Swanson Analysis Systems, Inc., P.O. Box 65, Johnson Road, Houston, PA 15342.

Date of First Release and Most Recent Update: 1970 and 1981

General Information:
ANSYS is a proprietary finite element program first offered by Swanson Analysis Systems in 1970. ANSYS, Rev. 4, is the most current release. ANSYS is supported by Swanson Analysis Systems, Inc., in Houston, Pennsylvania and by consultants in Los Angeles, California and London, England.

Program Capability and Scope of Analysis:
ANSYS is a general purpose program for steady state and transient heat transfer, as well as structural analyses. Thermal-electrical capabilities and thermal-fluid flow capabilities are also available. Loads include specified temperatures, heat flows, convections and/or internal heat generation. Any thermal solution may be input as a load to a structural analysis. The finite element model is identical; the user need only select structural members from the element library.

User Interface and Modeling Capabilities:

- A powerful preprocessor facilitates complete input data preparation. Model geometry, loads, materials, and analysis options can be described. Many plotting options exist to verify geometry and loads. The preprocessor can be operated in interactive or batch modes.
- Different post-processors aid the user in results evaluation. Isotherms can be plotted, graphs of temperature versus time are available and results can be scanned for user specified temperature and/or heat flow ranges.

Element Library:
A complete library of line, area, shell and solid elements is available. Axisymmetric elements with axisymmetric or nonaxisymmetric loads may be used to perform a three-dimensional analysis with a two-dimensional model. Convection, conduction and radiation element types may be used. Each thermal element has an analogous structural element so that the same model can be used in a structural analysis where the temperature solution is a load.

Solution Methods:

- Transient analysis - Modified Houboldt method.
- Linear equation solver - Wavefront technique, Gaussian elimination on substructures.

Notable Items and Limitations:
Phase change problems can be solved. One of the most powerful features of ANSYS is the ease with which a thermal model can be used in a structural analysis.

Programming Language: ANSI FORTRAN

Hardware/Operating System: CRAY, CDC, IBM, AMDAHL, UNIVAC, Honeywell, PRIME, DEC VAX, Harris.

Program Size: 100,000 lines of code.

Documentation: See Refs. 15 and 16

Program Availability: ANSYS is available at most data centers in the United States and Europe. ANSYS can be leased on an in-house basis. Charges are cents/CP second based on machine speed or fixed cost/month for some in-house leases. Contact the developer for further information.

ASASHEAT

Descriptive Program Title: Linear/Nonlinear Thermal Analyzer of the ASAS Range of Finite Element Programs

Program Developer: Atkins Research and Development, Parkside House, Woodcote Grove, Ashley Road, Epsom, Surrey, England

Date of First Release and Most Recent Update: 1973 and 1981

General Information:

- ASASHEAT is a proprietary code developed and maintained by Atkins Research and Development. Development started in 1972 with the first release in 1973. Nonlinear capabilities were incorporated in 1981 which is also the date of the latest update. The program is supported from the headquarters in Epsom, England, and from Houston, and H. G. Engineering, Ltd., in Ontario.
- The program is modular in design with free format-list directed format input and extensive data checking, model creation and solution modules. Complete saving and restart facilities are incorporated.
- The nonlinear capabilities include: temperature dependent material properties, surface radiation to and from surroundings, temperature dependent free and boundary layer convection, temperature dependent internal/nodal heat generation and thermal flux for both steady state and transient analysis.

User Interface and Modeling Capabilities:
As a result of developments in the field of interactive mesh generation, the ASAS system incorporating ASASHEAT is designed to interface with proprietary pre- and post-processors.

Element Library:
The linear/nonlinear elements include: uniaxial, two-dimensional Cartesian, axisymmetric and three-dimensional isoparametric elements. For coupled thermal-structural analysis, structural elements default automatically to thermal ones.

Solution Methods for Nonlinear Problems:
Nonlinear transient response: Implicit integration; coupled Crank-Nicholson and corrective iterative scheme.
Nonlinear steady state response: Corrective iterative scheme applied to steady state.
Equation solvers for linear problems: Out-of-core, in-core modified frontal solver.

Notable Items and Limitations:
The program is under continual development. Greater flexibility in heat flux output, intersurface radiation, forced convection and phase change effects are being developed and included.

Programming Language: Portable ANSI FORTRAN 66

Hardware/Operating System: UNIVAC 1100 series, SIGMA, PRIME, VAX 11/780, IBM 360 series.

Program Size (Heat Transfer Modules Only):
Core Program: 35,000 statements

Documentation: See Ref. 17

Program Availability: The program is available at several bureaus and computer installations. For further information the developer's Support Manager should be contacted. Absolute versions only are distributed. Program fees are negotiable with developer.

BERSAFE (FLHE)

Descriptive Program Title: FLHE - FLow of Heat by Finite Elements

Program Developer: The overall system was developed by Dr. T. K. Hellen and colleagues, Central Electricity Generating Board, Berkeley Nuclear Laboratories, Berkeley, Gloucestershire GL13 9PB, England. FLHE was developed originally by Mr. K. Fullard and is maintained by Dr. M. A. Keavey at the above address.

Date of First Release and Most Recent Update: 1971. Level 3 released in 1981.

General Information:
BERSAFE is a general purpose finite element system started in 1968. It has been developed for the Central Electricity Generating Board at Berkeley Nuclear Laboratories, and has been available for purchase since 1970. FLHE is the component dealing with thermal analysis within the overall BERSAFE system.

Program Capability and Scope of Analysis:
General purpose program linking the functions of thermal analysis, stress analysis (elasticity, plasticity, creep, large displacements), and linear dynamics. Extensive pre- and post-processor aids are available. A wide range of finite elements exist for two-dimensional and three-dimensional beams, plates and shells.

Solution Methods:
- Transient analysis - Crank-Nicholson scheme.
- Linear equation solver - Wavefront technique.

Notable Items and Limitations:
Storage use is dynamic so the limitations on most variables are imposed by available core - on our system this is very large. Semibandwidth is the only notable limitation (currently 1,000 for stress analysis, but can easily be increased). The stress analysis package uses substructuring techniques and is particularly powerful for

fracture mechanics, as is the nonlinear version. Plasticity, creep and cycling are also well used, often coupled to previous transient temperature analyses.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM (MVS, MVT, DOS), UNIVAC, AMDAHL (MVS), ICL, VAX (MVS), Burroughs, PRIME.

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Size of core is approximately 420 K bytes on IBM. Source statements for FLHE is approximately 10,000. The stress analysis and pre- and post-processor programs are much larger - the whole system being well over 100,000 statements.

Documentation: See Refs. 18 to 20.

Program Availability: The programs are available from the BERSAFE Advisory Group at the above address (Mr. G. Marshall). The price for a five year license for source, including support and maintenance, is from $10,000 for the thermal analysis program including relevant pre- and post-processors.

CAVE I, II, III

Descriptive Program Title: CAVE (Conductive Analysis Via Eigenvalues)
A General Transient Heat Transfer Computer Code Utilizing Eigenvectors and Eigenvalues.

Program Developer: Grumman Aerospace Corporation, Bethpage, New York, under a contract for NASA Langley Research Center, Hampton, Virginia.

Date of First Release and Most Recent Update: November 1977 through October 1979

Brief Summary of the Major Capabilities of the Program:

- The computer code CAVE III (Conduction Analysis Via Eigenvalues for Three-Dimensional Geometries) provides a convenient and economical tool for predicting the transient temperature response of structures. This code is an extension of the work done under contract NAS1-13655 for two-dimensional geometries. CAVE III is written in FORTRAN IV and is operational on both the IBM 370/165 and CDC 6600 computers.
- The method of solution is a hybrid analytical-numerical technique which utilizes eigenvalues (thermal frequencies) and eigenvectors (thermal mode vectors). The method is inherently stable, permitting large time steps even with the best of conductors with the finest of mesh sizes which can provide a factor-of-five reduction in machine time compared to conventional explicit finite difference methods when structures with small time constants are analyzed over long time periods. This code will find utility in analyzing hypersonic missile and aircraft structures which fall naturally into this class.
- The code is a completely general one in that problems involving any geometry, boundary layer conditions and materials can be analyzed. This is made possible by requiring the user to establish the thermal network, e.g., node capacitances, conductances between nodes, etc. Dynamic storage allocation is used to minimize core storage requirements.
- The report is primarily a user's manual for the CAVE III code. Input and output formats are presented and explained. Sample problems are included which illustrate the usage of the code as well as establish the validity and accuracy of the method.

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
The CAVE programs contain approximately 1,600 source statements. The pre-processor network generator and graphics package for CAVE III contains an added 1,400 lines of code.

Documentation: See Refs. 21 to 23.

Program Availability: This program is available from Grumman Aerospace Corporation. For further information contact:

Dr. John G. Roukis
Mail Stop B22/35
Grumman Aerospace Corporation
Bethpage, New York 11714

CONFAC

Descriptive Program Title: Geometric Configuration Factor Program

Program Developer: Grumman Aerospace Corporation, Bethpage, New York 11714

Date of First Release and Most Recent Update: 1964 and 1975

General Information:
This program was originally developed by Grumman to determine geometric configuration factors between surfaces for the LUNAR Module and Orbiting Astronomical Observatory Projects.

Program Capability and Scope of Analysis:
The program determines geometric configuration factors between convex planar polygons. Thermal radiative behavior is in accordance with Lambert's Law.

User Interface and Modeling Capabilities:
Versions have been developed for up to two hundred surface geometries. Graphics pre-processor packages will provide model generation and model verification capability.

Solution Method:
CONFAC uses the method of contour integration and includes the effects of intervening surfaces in the results. Surfaces are divided into subareas based on a user selected mesh size.

Notable Items and Limitations:
This program is limited to planar convex polygons that are described by a maximum of ten vertices. Intersecting surfaces (other than a common edge) cannot be treated without subdivision to eliminate the intersection.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 370 (OS/VS)

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
This program contains approximately 1,250 source statements.

Documentation: Informal users guide documentation is available.

Program Availability: For further information contact:

Dr. John G. Roukis
Grumman Aerospace Corporation
Mail Stop B22/35
Bethpage, New York 11714

FLUX2

Descriptive Program Title: Grumman Orbital Heat Flux Program

Program Developer: Grumman Aerospace Corporation, Bethpage, New York 11714

Date of First Release and Most Recent Update: 1965 and 1980

General Information:
This program was developed by Grumman to evaluate the orbital environments of the Orbiting Astronomical Observatory and the Lunar Module. Its verification was based on extensive correlation with flight test data from these programs.

Program Capability and Scope of Analysis:
This program calculates solar, planetary albedo and planetary emission fluxes for up to one hundred surfaces of any orbiting vehicle. Blockage of the environment by intervening surfaces can be accomplished by tabular input. Six different vehicle orientation modes are available.

Solution Methods:
Computation of albedo and IR fluxes can be accomplished with options of either numerical integration or an approximate technique for determining the form factors between the planet and the vehicle.

Notable Items and Limitations:
Blockage effects for albedo and IR fluxes are only available if the numerical integration option is selected.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 370 (OS/VS)

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
This program contains 770 source statements.

Documentation: Informal users guide documentation is available.

Program Availability: For further information contact:

Dr. John G. Roukis
Grumman Aerospace Corporation
Mail Stop B22/35
Bethpage, New York 11714

HEATING5

Descriptive Program Title: Finite Difference Heat Conduction Program

Program Developer: W. D. Turner, D. C. Elrod, I. I. Siman-Tov, Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee 37830

Date of First Release and Most Recent Update: March 1977 and July 1979

General Information:
HEATING5 was written over a period of years by personnel at Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee, and was funded by various departments of the Department of Defense and the U.S. Nuclear Regulatory Commission.

Program Capability and Scope of Analysis:
HEATING5 is a general purpose heat conduction code designed to solve steady-state and/or transient heat conduction problems in one-, two- or three-dimensional Cartesian or cylindrical coordinates or one-dimensional spherical coordinates.

User Interface and Modeling Capabilities:
The user defines the problem by a series of regions having common characteristics. HEATING5 generates the nodal configuration from this information. Parameters may be defined by built-in functions or by user-supplied functions.

Solution Methods:
Steady-state problems are solved by SOR with Aitken's extrapolation. Transient problems may be solved by either implicit schemes ranging from Crank-Nicholson to fully implicit or by forward difference technique or Levy's extrapolation procedure.

Notable Items and Limitations:
Variable-dimensioned with respect to maximum number of nodes.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 360, IBM 370, IBM 3033, CDC 6600, CDC 7600.

Documentation: See Ref. 24

Program Availability:

Radiation Shielding Information Center
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

or:

National Energy Software Center
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

HEATING6

Descriptive Program Title: Finite Difference Heat Conduction Program

Program Developer: W. D. Turner, D. C. Elrod, G. E. Giles, Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee 37830

Date of First Release and Most Recent Update: October 1981

General Information:
HEATING6, an extensive revision of HEATING5, was written by personnel at Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee, and was primarily funded by the Transportation Branch, Nuclear Materials Safety and Safeguards, U.S. Nuclear Regulatory Commission.

Program Capability and Scope of Analysis:
HEATING6 is a general purpose heat conduction code designed to solve steady-state and/or transient heat conduction problems in one-, two-, or three-dimensional Cartesian or cylindrical coordinates or one-dimensional spherical coordinates.

User Interface and Modeling Capabilities:
The user defines the problem by a series of regions having common characteristics. HEATING6 generates the nodal configuration from this information. Parameters may be defined by built-in functions or by user-supplied functions.

Solution Methods:
Steady state problems are solved by direct solution techniques or by SOR with Aitken's extrapolation. Transient problems may be solved by either implicit schemes ranging from Crank-Nicholson to fully implicit or by forward difference technique or Levy's extrapolation procedure.

Notable Items and Limitations:
All arrays whose length is a function of the input parameters are variable-dimensioned. Extensive error checking facilities are incorporated into the code.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 360, IBM 370, IBM 3033

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Core Program 15,000

Documentation: See Ref. 25

Program Availability:
Radiation Shielding Information Center
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

HEATRAN

Descriptive Program Title: A Two-Dimensional Finite Element Program for HEAT TRANsfer Analysis

Program Developer: Dr. W. D. Collier, United Kingdom Atomic Energy Authority (UKAEA), Risley Nuclear Power Development Establishment, Warrington, Cheshire WA3 6AT, England.

Date of First Release and Most Recent Update: 1969 and 1979

General Information:
HEATRAN was developed to meet the need of users in the UKAEA. The intention was to provide a simple but concise and natural means of inputting the data and to provide a wide range of boundary conditions. It runs about 4,000 jobs a year for UKAEA and other companies associated with the nuclear industry, but work is being phased over gradually to TAU.

Program Capability:
HEATRAN deals with conduction in materials of varying composition with material data varying with position, time or temperature. Radiation may be specified between arbitrary surfaces. Boundary conditions include natural and forced convection, convection to a fluid whose temperature is to be found, radiation to ambient, fixed temperatures, fixed flux. Calculations are performed in one- and two-dimensional (slab and axisymmetric) for steady state and transient situations.

User Interface and Modeling Capabilities:
There is a simple and natural system for inputting nodes and connections. Various shorthands are provided. Mesh and result plots are provided and a tabular output of temperatures is available. Temperatures may be saved for transfer to a stress analysis program.

Element Library: Linear triangular elements only.

Solution Methods:

- A sparse equation solver using a variant of Gauss elimination is used. Many solutions stay in core using work space provided by the program at run time. Data is moved out of core automatically in an efficient systematic manner if in-core storage is insufficient.
- Nonlinear cases use a Newton-Raphson iterative scheme.
- Transients use a fully implicit method (backward difference) with time steps adjusted automatically for accuracy.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 370, IBM 3033 (OS/VS); ICL 2900 (VME/B)

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
9,500 lines

Documentation: See Ref. 26

Program Availability: Available for use under contract on the Risley, Harwell and Winfrith computers of the UKAEA.

Source (1976 vintage) available from:
Nuclear Energy Agency - Computer Program Library
Gif-sur-Yvette
Paris, France

MARC

Descriptive Program Title: General Purpose Finite Element Code

Program Developer: MARC Analysis Research Corporation, 260 Sheridan Avenue, Suite 200, Palo Alto, California 94306.

Date of First Release and Most Recent Update: 1970; Version J.2 - September 1981

General Information:
MARC is a proprietary code supported by MARC Analysis Research Corporation with offices in Palo Alto, California, Tokyo, Japan, and The Hague, Holland. The current state-of-the-art of finite element technology is adapted and incorporated into the program. New releases of the program are generated at the rate of about one per year.

Program Capability and Scope of Analysis:
MARC is designed for the linear and nonlinear analysis of structures in the transient heat transfer, static and dynamic regimes. Anisotropic heat conduction, and latent heat effects are included. The heat transfer model uses element types of which a structural analog exists, making a decoupled thermo-mechanical analysis using the identical mesh possible. All properties may be thermally dependent. Numerous user interfaces for specification of user selected parameters make the program extremely flexible. Properties may be specified as a function of other state variables through user subroutines.

User Interface and Modeling Capabilities:
An interactive pre- and post-processor, MENTAT, assists in the two- and three-dimensional mesh generation and other data preparation areas. Post-processing includes displaced geometries and contours of element quantities. MENTAT interfaces to MARC, NASTRAN and other FEM programs. MARC also contains complete pre- and post-processing capabilities.

Solution Methods:
Backward difference (modified Crank-Nicholson).

Notable Items and Limitations:
Most of the different options can be used simultaneously to cover an extremely wide range of nonlinear applications: tying degrees of freedom, joining shell and solid elements, fine and coarse mesh, user supplied constraints, friction and gap element.

Programming Language: FORTRAN IV

Hardware/Operating System: CDC 6600, 7600, CYBER 175, 176, AMDAHL, IBM, UNIVAC, CRAY, HITAC, ACOS, FUJITSU, MAGNUSON, PRIME, VAX.

Program Size (Heat Transfer Modules Only):
40,000 core programs, 20,000 pre-processors; 20,000 post-processors.

Documentation:

MARC User Information Manual, Version J.2
- Volume A - User Information Manual
- Volume B - MARC Element Library
- Volume C - Program Input Manual
- Volume D - User Subroutine and System Description
- Volume E - Demonstration Problems
- Volume F - Structural Analysis with MARC Course Notes
- Volume G - MARC Background Papers

Published by MARC Analysis Research Corporation

For background material see Refs. 27 to 29.

Program Availability: MARC is available internationally at the following data centers: CDC Cybernet, McAuto, Information Systems Design, Boeing Computer Services, Westinghouse, and Babcock and Wilcox. The program is available from MARC Analysis Research Corporation on a lease basis in either a binary or a binary and source form.

MITAS II

Descriptive Program Title: Martin Marietta Interactive Thermal Analysis System, Version 2.0 (MITAS II), Lumped Parameter Finite Difference Thermal Analysis Program

Program Developer: R. E. Kannady, Jr., R. J. Connor, C. E. Shirley, Martin Marietta Corporation, P.O. Box 179, Denver, Colorado 80201

Date of First Release and Most Recent Update: 1969 and 1981

General Information:

MITAS II is a computer code developed and maintained by Martin Marietta Corporation, Aerospace Division. Development started in 1969 and was an offshot from the CINDA-3G code developed by Chrysler-Aerospace for NASA.

Program Capability and Scope of Analysis:

MITAS II is a general purpose program system that provides a solution to a lumped parameter representation of the diffusion equation. The boundary conditions can be conduction, convection, radiation or some user-defined heat flow function. There is a large library of subroutines and functions that the user can employ in setting up boundary functions or determining values during the course of problem solution.

User Interface and Modeling Capabilities:

- The problem is defined in terms of nodes which represent the lumped mass of the system. The specific heat of these nodes can be allowed to change as a function of temperature or some user-defined function. Nodes with a very small thermal mass can be considered to have a zero mass. Boundary nodes' temperatures are specified by the user and can be altered during the course of the solution.
- Heat flow paths (conductors) can be linear for conduction and convection, non-linear for radiation heat transfer or defined by the user to simulate some process. Conductors can be generated by using short hand input statements and can be constants, temperature varying or varied by some user definition.
- During the solution process the user has access to the temperature solution vector and the matrix of conductors. The contents can be tested and altered if the user desires.

Solution Methods:
The program provides for a steady state temperature solution and transient solutions. The transient solutions available are explicit (forward differencing) and implicit (backward differencing and forward-backward differencing).

Notable Items and Limitations:
Due to a word packing technique and code which adjusts to the size of the problem, MITAS II has very few practical limitations as to the size of the problem to be solved. The structure of MITAS II allows the user to code in logic which will be executed prior to and after the temperature solution is obtained. This feature allows the user to describe conditions or printouts as he desires.

Programming Language: CDC FORTRAN 2.4

Hardware/Operating System: CDC 6000 series, CDC CYBER series/Operating systems NOS, NOS/BE1, SCOPE3

Program Size: Preprocessor = 50,000 statements
Library = 100,000 statements

Documentation: See Ref. 30

Program Availability: MITAS II is available through the Cyber Service network executing on a CYBER 750 computer. For further information as to this service, contact Martin Marietta Corporation, Data Systems, 104 Inverness Circle East, Suite 310, Englewood, Colorado 80112, Alan R. Cheuvront or John W. Davis (303) 740-3012.

The MITAS II source code is available through Martin Marietta Denver Aerospace, P.O. Box 179, Denver, Colorado 80201; Roy E. Kannady, Jr., (303) 977-3075.

MSC/NASTRAN

Descriptive Program Title: The MacNeal-Schwendler Corporation, "NASA STRuctural ANalysis"

Program Developer: The MacNeal-Schwendler Corporation, 7442 North Figueroa Street, Los Angeles, California 90041.

Date of First Release and Most Recent Update:
The initial release of the NASA funded program NASTRAN occurred in 1969 (NASTRAN is a registered trademark of NASA). The MacNeal-Schwendler Corporation has marketed and serviced an advanced version of that code since 1972. MSC releases a new, updated version of MSC/NASTRAN twice yearly. The latest version was released in March 1981.

General Information:
MSC/NASTRAN is a large-scale, general purpose computer program which solves a wide variety of engineering problems by the finite element method. The program is an advanced, proprietary version of the NASA-funded structural analysis program NASTRAN. MSC/NASTRAN is marketed and serviced from MSC's offices in the United States, Europe and Japan, and is available at most major public data processing centers. Customer hotline service is available to users in need of assistance. The engineering community is also aided by a wide variety of MSC/NASTRAN instructional courses.

Program Capability:

• The program's capabilities include static and dynamic structural analysis, both geometric and material nonlinear static analyses, thermal analysis, acoustics, aeroelasticity, electromagnetism and other types of field problems. Many substructuring options are also available with the above capabilities.

• MSC/NASTRAN's thermal analysis capabilities include linear steady state, nonlinear steady state, and transient heat transfer. As outlined in the tables, these basic capabilities are available in scalar, one, two and three dimensions with various material properties and various boundary, loading and initial conditions. These basic capabilities can be further enhanced through many options available to the analyst. Some options not included in the tables are, for example:

• The analyst may input his own elemental matrices, thereby defining his own elements (these matrices may be symmetric or unsymmetric);

• He may input transfer functions for use with active thermal mechanisms such as heat pipes and thermostatic controls;

• He may use matrix order reduction methods such as Guyan reduction;

• He may use the thermal analysis capabilities to solve analogous electrostatic problems.

User Interface and Modeling Capabilities:

MSC/NASTRAN contains many special features to support and enhance its "user-friendliness" and modeling capabilities. These features include:

• Pre- and Post-Processors:

MSC/NASTRAN's internal pre-processor MSGMESH automatically generates finite element models from analyst supplied descriptions of one, two and three dimensional regions. Since MSGMESH is an integral part of MSC/NASTRAN, finite element model generation and solution may be accomplished in a single execution. Post-processing may be performed by either of two post-processors. MSGVIEW enables the user to graphically display undeformed structural models in both batch and interactive modes. MSC's newest post-processor, MSC/GRASP (scheduled for release later this year) provides extensive interactive post-processing capabilities including: many model viewing and manipulation functions, deformed and modal plots, element stress contours, output scanning, x-y plots and keyframe animation.

• Data Checking and Error Analysis:

Special aids help to detect errors in such input data as geometry, element connections, elastic properties, mass properties, constraints, loads and temperatures. These aids include editing of input card formats, verification that all required cards are present, and verification that data for specified elements are geometrically compatible. In addition, formatted tables present summaries of grid point geometry, coordinate systems, constrained degrees of freedom, and element connections. This information can be assessed prior to initiating the problem's matrix operations.

• Matrix Operations:

• Automatic Resequencing - The user can request automatic internal resequencing of grid points in order to minimize the time for equation solution. The sequencing processor also provides time estimates for the generation and decomposition of the stiffness matrix.

• Automatic Singularity Suppression - At user option, singular or nearly singular degrees of freedom will be suppressed. Output data are supplied which indicate the degrees of freedom which have been removed.

• Sparse Matrix Routines - All of MSC/NASTRAN's matrix routines have been designed for the efficient solution of very large problems. Detailed patterns of nonzero terms are recognized and processed in condensed form. Efficient automatic spill logic is provided for matrices which are too large to be kept in high speed memory. The availability of several methods of matrix multiplication provides optimum efficiency for wide ranges of matrix size and density.

- External Post-Processing:

The program contains a number of methods by which the analyst may output intermediate or final results (on punched cards or FORTRAN readable files) for easy input to external post-processing.

Solution Methods:

- MSC/NASTRAN's solution methods are directed toward large-order complex structural models. The linear static solution methods provide for multiple loading conditions and boundary conditions in a single run. Superelement/substructure and modal methods are also available to reduce the size of the final solution matrices for thermal as well as structural analysis.
- Heat transfer solutions are performed by straightforward matrix methods similar to the structural analysis methods. For the nonlinear statics solution, a modified Newton/Raphson iteration is performed, starting from a user-selected initial estimate of temperatures. Conduction, convection, and surface coefficients may be functions of temperature.
- Both linear and nonlinear transient solutions are performed using a user-specified parameter for controlling the time steps and forward-backward difference ratio. The default provides an implicit integration with an optimum balance between stability and drift errors.

Notable Items and Limitations:

- Large Problem Capabilities:

MSC/NASTRAN employs many features that make possible the solution of large problems in an accurate and efficient manner. These features include: multilevel superelement substructuring, cyclic symmetry substructuring, and matrix reduction methods.

- Problem Oriented Language:

MSC/NASTRAN's DMAP (Direct Matrix Abstraction Program) allows the user to specify his own series of matrix operations in order to perform a specific type of problem solution that is not contained in a solution sequence supplied with the program.

Programming Language: FORTRAN IV, with isolated machine dependent assembly language routines.

Hardware/Operating System: MSC/NASTRAN is available at most major public data centers and is currently operational on more than 200 computers, including the IBM 360/370 series, the AMDAHL series, the ITEL AS, the Fujitsu M series, the CDC 7600, and the CDC CYBER series, the UNIVAC 1100 series, Digital's VAX 11/700 series and the CRAY-1.

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
The delivered system contains approximately 430,000 source statements.

Documentation: The following manuals are available from MSC:

NASTRAN Theoretical Manual
MSC/NASTRAN User's Manual (2 volumes)
MSC/NASTRAN Programmer's Manual (3 volumes)
MSC/NASTRAN Application Manual (2 volumes)
MSC/NASTRAN Demonstration Problem Manual
MSC/NASTRAN Aeroelastic Supplement
MSGMESH Analyst's Guide
MSC/NASTRAN Handbook for Linear Static Analysis
MSC/NASTRAN Primer, Statics and Normal Modes Analysis
MSC/NASTRAN Handbook for Superelement Analysis

(See Refs. 31 to 34).

In addition, NASTRAN user's conferences have been sponsored by MSC and NASA. Many papers have been published in these proceedings.

A manual describing MSC/NASTRAN's thermal capabilities, with how-to descriptions and many example problems is in preparation.

Program Availability:
An executable version of the program is available under lease agreement from MSC through any one of our regional sales offices in the United States, Europe and Japan. Prices vary with computer type, therefore, interested persons should contact one of the sales offices listed below:

The MacNeal-Schwendler Corporation
7442 North Figueroa Street
Los Angeles, CA 90041 U.S.A.
Tel. (213) 254-3456
TWX: (910) 321-2492 MACN SCHW LSA

MSC Southwest Regional Office
P.O. Box 1606
Grapevine, TX 76051 U.S.A.
Tel. (817) 481-4812

MSC Midwest Regional Office
5745 Oxford Drive
New Berlin, WI 53151 U.S.A.
Tel. (414) 542-5747

MSC Eastern Regional Office
P.O. Box 504
Oakdale, NY 11769 U.S.A.
Tel. (516) 589-8316

MacNeal-Schwendler GmbH
8000 Munchen 80
Prinzregentenstrasse 78
West Germany
Tel. (089) 47 02 068
Telex: (41) 523784 MSG D

MacNeal-Schwendler Representative Office
Kyodo Building (Kodenma-cho)
16-8 Kodenma-cho, Nihonbashi
Chuo-ku, Tokyo 103
Japan
Tel. (03) 661-0133
Telex: (781) J23363 MSGWATA

NNTB

Descriptive Program Title: Nodal Network Thermal Balance Program

Program Developer: J. T. Skladany, NASA-Goddard Space Flight Center, Code 732, Beltsville, Maryland 20771

Date of First Release: 1967

General Information:
Performs thermal analysis of lumped parameter networks consisting of both radiation and conduction. Nodal performs a thermal analysis of a spacecraft during all stages from launch to orbital dynamic steady state. The program is designed to solve integro-differential equations taken from a thermal network composed of radiatively and conductively coupled modes. A finite difference form of the equation is used but they are solved using a matrix inversion technique known as Gauss elimination. Nodal is designed to handle both steady state and transient problems.

User Interface and Modeling Capabilities:
The program contains no automatic modeling capabilities.

Solution Methods:
A finite difference form of the thermal equations is used but is solved implicitly by the Gauss elimination method.

Notable Items and Limitations:
The program was written to handle thermal analysis of spacecraft. Hence, great emphasis was placed on radiation between nodes including temperature varying radiation. The program can handle up to 300 nodes.

Programming Language: FORTRAN IV

Hardware/Operating System: OS-360, VAX 11/780

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Total program includes 2,000 statements.

Documentation: See Ref. 35

Program Availability:

Computer Library
Goddard Space Flight Center
Beltsville, Maryland 20771

Computer Software Management
and Information Center (COSMIC)
Computing and Information Services
Suite 112, Barrow Hall
The University of Georgia
Athens, Georgia 30602

NTEMP

See TEMP

PAFEC

Descriptive Program Title: Program for Automatic Finite Element Calculations

Program Developer: PAFEC, Ltd., Strelley Hall, Strelley, Nottingham NG8 6PE, England.

Date of First Release and Most Recent Update: 1970 and November 1981

General Information:
PAFEC is an independent company which grew from a research group active in finite element methods during the 1960's. First copies of the system were sold while members of the group were still working at the University of Nottingham, but, subsequently, the extent of commercial involvement became too great and PAFEC, Ltd. was formed. Since then, PAFEC has continued to increase its share of the finite element market and the system is now supported in the United States, Europe, Australia and South Africa.

Program Capability and Scope of Analysis:

• Many advanced facilities are available with PAFEC in the fields of statics and dynamics as well as heat transfer. The basic system includes linear and nonlinear elastic stress analysis, large displacements, modes and frequencies and dynamic response, creep and plasticity.

• Problems may be solved involving steady state and transient heat transfer with conduction and convection. Nodal temperatures and heat flux are user definable with time as are all material and boundary layer properties. Temperature dependent properties are available in both isotropic and anisotropic elements. Stress analyses can be performed directly from the temperatures calculated in a thermal analysis or in combinations with thermal and static loads applied from another data file. PAFEC's development of the Boundary Integral Method for heat transfer is currently under test and is expected to be released in the very near future.

User Interface and Modeling Capabilities:
PAFEC's greatest selling feature is its extreme versatility and ease of use. Data preparation is the simplest yet devised for any major finite element system. PAFEC employs free format input with engineering key words and modular layout. The use of system defaults, abbreviated headings, constant properties and data generation reduces to a minimum the amount of user effort required for data preparation. Data may also be prepared interactively using the APES (nongraphics) package or the PAFEC Interactive Graphics System (PIGS). PIGS allows the user to generate many elements and shapes automatically and then replicate these shapes to form other parts of the structure. Nodes and elements may be added and removed with ease. Post-processing options allow temperature contours and many graph options including temperature, stress and displacement. Sophisticated hard copy plots of all of the above options are available without PIGS.

Element Library:
PAFEC has over eighty element types including four two-dimensional and two three-dimensional temperature distribution elements for isotropic applications and duplicates of these for anisotropic calculations. In addition to these there are four two- and three-dimensional boundary layer elements.

Solution Methods:
Three system solution methods are available: front solution, blocked front solution, and partitioned banded solution. Each has some advantages. Steady state temperature problems are solved directly while incremental methods are used for nonlinear steady state. Transient analyses use a modified Crank-Nicholson technique.

Additional Information:
There is no limitation on problem size other than those imposed by machine capacity. PAFEC always supplies source code.

Programming Language: A subset of ANSI FORTRAN.

Hardware/Operating System:
PAFEC is currently running on the following computers: DEC (10, 20 and VAX), IBM, UNIVAC, CRAY, Burroughs, GEC, SEL, PRIME, CDC, Perkin-Elmer, Honeywell, ICL (1900 and 2900), Sigma and Itel.

Documentation: See Refs. 36 to 38

Program Availability:

PAFEC Engineering Consultants, Inc.
5401 Kingston Pike
Knoxville, TN 37919
Tel. (615) 584-2117

PAFEC, Ltd.
Strelley Hall, Strelley
Nottingham NG8 6PE
England
Tel. 0602-292291

PAFEC, Ltd.
3 Marsh Street
Bristol BS1 1SS
England
Tel. 0272-213914

Matrix Computing Services Pty, Ltd.
64 Randhill Building
106 Jan Smuts Avenue
Randburg 2194
South Africa
Tel. (011) 481084-5

Megadata, Pty, Ltd.
24 Falcon Street
Crows Nest
New South Wales 2065
Australia
Tel. 438-1233

Value Engineering (WA), Pty, Ltd.
32 Kings Park Road
West Perth
Western Australia 6005
Tel. 322-2211

Cost: The current (1981) prices of the FORTRAN source and installation are: PAFEC - $41,900; Interactive Graphics - $9,600; Substructures - $7,200. Six-month trial installations are currently $7,500.

SAHARA

Descriptive Program Title: General Purpose Conduction, Convection and Radiation Heat Transfer Code Used at Sandia Laboratories, Livermore, California.

Program Developer: V. K. Gabrielson, Organization 8331, Sandia National Laboratories, Livermore, California 94550.

Date of First Release and Most Recent Update: 1972 and 1981

General Information:
The SAHARA set of codes contains a very general finite difference pre-processor and several interactive post-processor codes. The SAHARA codes have developed over the past fifteen years for adaptations to Sandia Laboratories' special needs and computer hardware. The work is funded by the United States government.

Program Capability:
SAHARA is a general purpose conduction, convection and radiation heat transfer code applicable to nonlinear steady-state and transient analysis. Model sizes can be easily extended to capacity of each computer. A variety of boundary and initial conditions are available with special emphasis on radiation heat transport. Boundary and fluid elements may be defined within the model.

User Interface and Modeling Capabilities:
SAHARA uses the HEATMESH pre-processor for developing the finite difference mesh of two-dimensional axisymmetric solids with some capability for three-dimensional modeling.

Solution Methods:
Successive overrelaxation iteration used for most transient problems. An adaptive conjugate gradient method used for steady-state problems.

Notable Items:
- Input for both HEATMESH and SAHARA use mnemonic keywords for all data sets.
- Several interactive post-processors are available providing time history and mesh plots.

Programming Language: CRAY-CFT and CDC-FTN FORTRAN

Hardware/Operating System: CRAY-COS and CDC-NOS-BE systems

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:

Pre-processors:	2,000 statements
SAHARA:	4,500 statements
Post-processors:	2,000 statements

Documentation: See Refs. 39 and 40

Program Availability: For CRAY or CDC versions - contact author. Little or no experience on machines other than CRAY and CDC.

SAMCEF (THERNL)

Descriptive Program Title: Systeme d'Analyse des Milieux Continus par Elements Finis (Thermique Non Lineaire)

Program Developer: L.T.A.S., Aerospace Laboratory, University of Liege, Rue Ernest Solvay 21, B-4000 Liege, Belgium

Date of First Release and Most Recent Update: Both 1981

General Information:
SAMCEF is a university code. The package was first developed as a research tool in the structural mechanics area. Progressively, further developments were financed by industries and since 1970 a general purpose code is operational. It is being used in an industrial as well as research environment. The LTAS Group provides the users with the service they require for using the program, which is available for various computers. The price includes the source code, installation, documentation and training. A yearly contribution allows the users to obtain updated versions.

Program Capability and Scope of Analysis:
THERNL is a member of SAMCEF Systems dedicated to linear and nonlinear, steady-state and transient heat transfer analysis. The finite element library covers one-dimensional, two-dimensional, and three-dimensional geometries including shells and transition-to-volume elements. Boundary elements for forced convection and radiation are included. Specialized elements for forced convection in ducts are available. Thermal conductivity of the material can be anisotropic and all thermal characteristics are temperature dependent. Step-by-step analysis is allowed: data preparation - element generation, steady-state and transient responses and restarts.

User Interface and Scope of Analysis:
THERNL allows to use the general pre- and post-processors of SAMCEF, including graphic displays of the data and results.

Solution Methods:
The nonlinear algebraic systems are solved via a secant method performed block-by-block.

Notable Items and Limitations:
- Explicit mesh deformation for modeling steep gradients and implicit mesh deformation for phase change problems are included for one-dimensional situations.
- User supplied elements are easily introduced. The front width is limited to one thousand degrees of freedom.

Programming Language: Subset of FORTRAN IV

Hardware/Operating System: IBM (OS, DOS, VS, CMS) - UNIVAC (double precision), CDC (6400, 6600, 7600), DEC 2040, VAX, SIEMENS.

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processing:
40,000 source statements

Documentation: See Refs. 41 to 45

Program Availability and Cost: Contact developer. Cost negotiable depending on source availability, maintenance, assistance, etc. Special rate for universities.

SESAM-69
NV615

Descriptive Program Title: Analysis of Heat Conduction in Three-Dimensional Solids, Stationary and Transient

Program Developer: A. S. Computas, Data Division of Det Norske Veritas, Veritasveien 1, P.O. Box 310, 1322 Høvik, Norway.

Date of First Release and Most Recent Update: 1976 and 1981

General Information:
The general heat conduction program NV615 is part of SESAM-69 (see Ref. 46) which is a proprietary code developed and maintained by A. S. Computas which is a subsidiary and the Data Division of the Norwegian classification society Det Norske Veritas. Development of NV615 started in 1974 and was released for external use in 1976. The program is supported from the headquarters in Oslo, Norway, and from four European branch offices (London, Paris, Rotterdam and Hamburg).

Program Capability and Scope of Analysis:
NV615 is a general purpose batch program for calculation of stationary- and transient temperature distributions in three-dimensional solids. Both linear and nonlinear heat conduction problems may be analyzed. Isotropic material properties are assumed, but the properties may be temperature dependent. NV615 is based on the finite element method. The multilevel superelement technique (see Ref. 47) may be used.

Considerable advantages are obtained with this technique both for linear and nonlinear problems. The program has complete saving and restart facilities.

- Boundary Conditions/Thermal Loads:
  1) Prescribed zero or nonzero temperature
  2) Given heat flow
  3) Given heat flux
  4) Given ambient temperature (convective heat transfer)

Given heat flux, heat flow and ambient temperature may be time-dependent in transient analyses.

- The convective heat transfer coefficients used in connection with ambient temperatures may be temperature and/or time-dependent. In stationary analyses the heat transfer coefficients are, of course, limited to temperature dependency. The initial temperature of the structure may be at zero temperature or a nonzero value varying throughout the region.

User Interface and Modeling Capabilities:
NV615 utilizes a highly efficient data generator (see Ref. 46) both for the geometric modeling and specification of thermal loads, boundary conditions, etc. The input is fixed format batch input specifications. The input data generator has extensive checking and visualization facilities (plots).

- Element Library:
  1) Isoparametric hexahedral solid element, eight nodes
  2) Isoparametric hexahedral solid element, twenty nodes

In connection with eight node basic elements, diagonal or consistent capacitance matrix may be requested. Twenty node basic elements always require the use of consistent capacitance matrix.

- A separate post-processor (NV340) (see Ref. 48) performs print and plot of temperatures in the form of tables, isoplots, etc.

Solution Methods:

- In the case of stationary heat conduction the system equation is solved by Choleski factorization accompanied by forward and backward substitution (see Ref. 49).
- For the solution of transient heat conduction problems the time integration is carried out by means of the trapezoidal formula, i.e., a step-by-step time integration (see Ref. 49).

Notable Items and Limitations:

- Adding some supplementary input data, the output (i.e., nodal temperatures) may be used as input for a corresponding thermoelastic static stress analysis using the same finite element mesh. The communication is via magnetic tape (see Refs. 50, 51).
- Due to extensive use of superelements, NV615 gives very few limitations with respect to problem size (total number of elements, nodes, etc.). In direct analysis, i.e., not using the superelement technique, the limits are: 1,000 nodes, 175 elements, 400 boundary condition nodes.
- When the superelement technique is employed the above limitations relate to each first level superelement. For higher levels the following limitations have to be observed: 5,000 nodes, 100 elements (superelements), 10 levels.

Programming Language: Simplified ANSI 1966 FORTRAN

Hardware/Operating System: UNIVAC 1100 Series/Exec 8

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Core program abt. 80,000; post-processor abt. 30,000.

Documentation: See Refs. 46 to 52

Program Availability:

- The program is available at several European service Bureaus and computer installations. For further information the developer should be contacted. Normally absolute versions only are distributed. However, program sales will also include source code. Program fee to be negotiated with the developer.
- Contact A. S. Computas, Section for Technical Software Series, P.O. Box 310, 1322 Høvik, Norway.

SINDA

Descriptive Program Title: Systems Improved Numerical Differencing Analyzer

Program Developer: Chrysler Corporation, Space Division, New Orleans, Louisiana; TRW Systems, Redondo Beach, California; TRW Systems, Houston, Texas; LTV Aerospace Corporation, Dallas, Texas; Lockheed, Houston, Texas.

Date of First Release and Most Recent Update: 1967 and 1975

General Information:

- SINDA has been in use at NASA and throughout industry since 1967. Several modifications have been made to the original code to adapt it to various computers. Pre- and post-processor codes have been adapted to run with SINDA.
- The SINDA system consists of two main pieces: (1) the preprocessor and (2) the library. The SINDA preprocessor is a program which accepts problems written in the SINDA language and converts them to the FORTRAN language. The preprocessor also accepts 'program-like' logic statements and subroutine calls (requesting some particular routine from the library) as data, which permits the user to tailor the program to suit his particular problem. The SINDA library consists of many pre-written FORTRAN subroutines which perform a large variety of commonly needed actions and which reduce the programming effort which might have been required to solve a given problem. These routines are fully compatible with the FORTRAN routines produced by the preprocessor. It should be recognized that the use of a preprocessor provides a system with a large capability and considerable flexibility, but because of the numerous options that are generally offered, user instructions are more difficult than other thermal analyzer-type programs which have less flexibility.

Program Capability and Scope of Analysis:

- SINDA, the Systems Improved Numerical Differencing Analyzer, is a software system which possesses capabilities which make it well suited for solving lumped parameter representation of physical problems governed by diffusion-type equations, such as Fourier, Poissons, or Laplace equations. The system was originally designed as a general thermal analyzer accepting resistor-capacitor (R-C) network representations of thermal systems, although, with due attention to units and thermally oriented peculiarities, SINDA will accept R-C networks representing other types of systems (e.g., electrical networks).
- As a thermal analyzer, SINDA can handle such interrelated complex phenomena as sublimation, diffuse radiation within enclosures, transport delay effects, sensitivity analysis, and thermal network error correction methods. The thermal analysis is performed on thermal analog modes presented in network format. The network represents a one-to-one correspondence with both the physical and mathematical models. SINDA has been used in the analysis of networks containing about 2,000 nodes without

requiring unreasonable amounts of computer time. The thermal network can be coupled to an iterative solution of a lumped parameter fluid network. Nonlinear material properties and boundary conditions may be calculated simultaneously as a function of one or more independent variables.

- The general fluid flow solution capabilities include extensive valve characterization and ability to match pump curves and system pressure-flow characteristics. The valves have been formulated so that either cooling or heating situations may be controlled with any of the valve types. Pump options included are pressure rise as a tabulated function of system flow rate and pressure rise as a polynomial function of flow rate. Special subroutines are included in the SINDA library to facilitate the thermal analysis of systems containing counter flow heat exchangers, parallel flow heat exchangers, cross flow heat exchangers, condensing heat exchangers, and any heat exchanger with an input effectiveness. The Flow-Hybrid method is incorporated for calculating fluid temperatures, with improved calculation accuracy obtained by using fluid enthalpy rather than specific heat for the convective term of the fluid temperature equation. To facilitate the speedy analysis of a general flow problem, provisions have been made for the user to divide the flow system network into sub-network elements.

User Interface and Modeling Capabilities:
Software using DISPLA produces temperature history plots through the use of a post-processor in batch or demand mode.

Solution Methods:
The use of SINDA is based on a lumped parameter representation of a physical system. Thus, SINDA solves numerically a set of ordinary (in general nonlinear) differential equations that represent the transient behavior of a lumped parameter system or a set of nonlinear algebraic equations representing steady state conditions. The numerical techniques used by SINDA are based on finite difference algorithms as opposed to finite element methods. For user decision flexibility, SINDA provides a number of implicit and explicit numerical solution methods for both steady-state and transient solutions.

Notable Items and Limitations:
The generality of the SINDA code is largely accomplished by being able to program the driver code for each particular problem. This flexibility often requires more tedious input to somewhat standard types of problems.

Programming Language: FORTRAN

Hardware/Operating System: CDC 7600, UNIVAC 1100, VAX, IBM, CRAY

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
There are approximately 30,000 cards for the SINDA pre-processor and library.

Documentation: See Refs. 53 to 55

Program Availability: Computer Software Management
and Information Center (COSMIC)
Computing and Information Services
Suite 112, Barrow Hall
The University of Georgia
Athens, Georgia 30602

SPAR

Descriptive Program Title: SPAR Thermal Analysis Processors - SSTA, TRTA, TRTB and TRTG

SSTA - Steady State Thermal Analyzer
TRTA - Transient Thermal Analyzer, Explicit Method
TRTB - Transient Thermal Analyzer, Implicit (Galerkin) Method
TRTG - Transient Thermal Analyzer, Implicit (Gear) Method

Program Developer: Engineering Information Systems, Inc., 5120 West Campbell Avenue, Suite 240, San Jose, California 95130.

Date of First Release and Most Recent Update: Level 12 - 1977; Level 20 - 1981

General Information:
The SPAR thermal analyzer is a system of finite element processors that perform steady-state and transient thermal analyses. The processors communicate with each other through a random-access data base. As each processor is executed, all pertinent source data is automatically extracted from the data base, and computed results are stored in the data base. Each processor may be executed in interactive or batch mode.

Program Capability and Scope of Analysis:

- The steady-state processor SSTA performs linear and nonlinear analyses. The user may exercise complete control over the solution process through a variety of commands. The processor may be restarted, as required, from any initial temperature state.
- The transient processors TRTA, TRTB and TRTG perform linear and nonlinear transient analyses. Each processor may be started from any point in time using any stored temperature vector.
- The thermal element repertoire consists of a complete set of conduction, forced convection, fluid-surface convective-exchange, mass-transport, and radiation-exchange elements.
- All properties may be functions of temperature, pressure and time. Properties may be isotropic or anisotropic.
- Thermal loading may be of any combination of the following excitation types:
  - Time-dependent volumetric heat generation
  - Temperature-dependent volumetric heat generation
  - Time-dependent surface heat fluxes
  - Time-dependent convective-exchange temperatures
  - Fluid-surface convective-exchange
  - Time-dependent prescribed nodal temperatures
  - Radiation-exchange.

User Interface and Modeling Considerations:
The SPAR thermal analysis processors utilize data generated by the SPAR or EAL processors TAB (geometry), ELD (element connectivities), AUS (tables of properties and thermal excitation), and SEQ (minimization of the system K matrix rms bandwidth). Source data and results may be scanned and displayed using processor DCU.

Solution Methods:
Processors SSTA, TRTB and TRTG use a skyline method to solve systems of equations. A modified Newton method is used to perform nonlinear analyses. Processor TRTA uses an explicit method to compute solutions.

Notable Items and Limitations:

• An experimental element capability is provided for those users who wish to insert their own element formulation into any of the processors.

• An automated verification package is used to assure proper functioning of the thermal analysis processors each time new capabilities are added to the system or the system is installed on a new host machine.

Programming Language: FORTRAN V

Hardware/Operating System: UNIVAC 1100, CDC CYBER 175 - NOS BE1.3

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Approximately 18,000 statements (thermal analysis processors only).

Documentation: See Ref. 56

Program Availability: Contact: James C. Robinson
Loads and Aeroelasticity Division
Mail Stop 243
NASA Langley Research Center
Hampton, Virginia 23665

Engineering Information Systems, Inc.
5120 West Campbell Avenue, Suite 240
San Jose, California 95130

SSPTA

Descriptive Program Title: The Simplified Shuttle Payload Thermal Analyzer

Program Developer: Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts 02140

Date of First Release and Most Recent Update: First release - November 1977. Second release - September 1979. Current update in process.

General Information:
SSPTA was developed by Arthur D. Little, Inc., under contract to NASA Goddard Space Flight Center, to simplify the computational procedures involved in defining the thermal design of shuttle payloads. It comprises a number of subroutines which have been in use for ten to fifteen years. The input to the program has been designed to simplify its use through the use of engineering terminology and stored Job Control Language (JCL) procedures. The program has the capability to easily store and keep a record of data for use with subsequent runs.

Program Capability and Scope of Analysis:
Transient or steady-state thermal analysis, in general, with shuttle payloads as a specific example. Programs can generate and automatically store view areas, orbital fluxes, thermal models, etc., so that in subsequent runs only new data has to be inputted or generated. The data file management system has the capability to handle up to fifty stored data sets with automatic backup. The program was designed primarily for transient, orbital, thermal design analysis of shuttle payloads.

User Interface and Modeling Capabilities:
A user language has been defined, based on simple thermal engineering terms, to input data and to define files for the storage of data. Geometric modeling of a cargo bay full of payloads is enhanced by an internally stored model of the shuttle cargo bay. Geometric models of individual payloads can also be stored in the program file storage system and placed within the geometric model of the cargo bay using coordinate transformations. Radiative view areas and orbital fluxes (with shadowing and multiple diffuse reflections) are then computed by the program using the unified geometric models.

Solution Methods:
Contour integration is used to compute black body view areas. The thermal analyzer uses the Newton-Raphson iterative procedure on each nonlinear energy balance equation and the modified Gauss-Seidel procedure for solving the set of energy balance equations.

Notable Items and Limitations:
SSPTA greatly simplifies the engineer-computer interface associated with developing a thermal design for a shuttle payload. This is done by a system of user oriented input data formats and data storage schemes. In order to keep the program as simple as possible, the analytical capabilities do not automatically handle variable properties.

Programming Language: FORTRAN

Hardware/Operating System: IBM System/370 Model 4341, VM370 System Product Release 1, TI ASC, VAX 11, VMS

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Core Program: 5,000 statements

Documentation: See Refs. 57 and 58

Program Availability:

Computer Software Management
and Information Center (COSMIC)
Computing and Information Services
Suite 112, Barrow Hall
The University of Georgia
Athens, Georgia 30602

Dr. David W. Almgren
Arthur D. Little, Inc.
Room 20-531
Acorn Park
Cambridge, Massachusetts 02140

TACO

Descriptive Program Title: A Finite Element Heat Transfer Code

Program Developer: W. E. Mason, Applied Mechanics Department, Sandia National Laboratories, Livermore, California 94550

Date of First Release and Most Recent Update: 1979 and 1980

General Information:
TACO is a two-dimensional implicit finite element code for heat transfer analysis. It can perform both linear and nonlinear analyses and can be used to solve either transient or steady state problems. Either plane or axisymmetric geometries can be analyzed.

Program Capability and Scope of Analysis:

- TACO has the capability to handle time or temperature dependent material properties and materials may be either isotropic or orthotropic. A variety of time and temperature dependent loadings and boundary conditions are available including temperature, flux, convection and radiation boundary conditions and internal heat generation.
- Additionally, TACO has some specialized features such as internal surface conditions (e.g., contact resistance), bulk nodes, enclosure radiation with view factor calculations, and chemical reactive kinetics. A user subprogram feature allows for any type of functional representation of any independent variable. A bandwidth and profile minimization option is also available in the code.

User Interface and Modeling Capabilities:

- TACO has some limited capability for generation of nodal, element and boundary data. However, it relies on separate mesh generation codes for complex models.
- Graphical representation of results in the form of time histories, isoplots, and profile plots are provided by a companion post-processor named POSTACO.
- Temperature states calculated by TACO are written to a file which can be read by mechanical codes for uncoupled thermal stress calculations.

Solution Methods:

- Time integration: Generalized trapezoidal method (Ref. 59) varying from forward explicit to backward implicit.
- Nonlinear solution scheme: Modified direct iteration and BFGS method.
- Equation solver for linearized equations: Compact out-of-core skyline.

Programming Language: ANSI FORTRAN

Hardware/Operating System: CDC 6600/NOS BE, CDC 7600/LTSS, CRAY 1-S/COS and CTSS

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Core Program - 10,000; Post-Processor - 2,000

Documentation: See Refs. 59 to 61

Program Availability: Presently available from the developer at no cost.

TAC2D

Descriptive Program Title: Thermal Analysis Code - Two-Dimensional

Program Developer: General Atomic Company, P.O. Box 81608, San Diego, California 92138

Date of First Release and Most Recent Update: 1969 and 1976

General Information:
TAC2D is a code for calculating steady state and transient temperatures in two-dimensional problems by the finite difference method.

Program Capability:
Linear and nonlinear problems may be treated with TAC2D. Internal and external flowing coolants may be used, and there may be internal and external thermal radiation. Thermal expansion of materials may also be accounted for.

User Interface and Modeling Capabilities:
The configuration to be analyzed is described in the rectangular, cylindrical or circular (polar) coordinate system. The input of thermal properties is by FORTRAN statement functions. This permits flexibility as many of the calculation variables (time, local temperature, local position, etc.) are available for use in these functions. There is a wide selection of optional output.

Solution Methods:
Alternating direction implicit method for two-dimensional problems (Peaceman-Rachford).

Notable Items and Limitations:
The grid lines must be orthogonal, and the entire problem must be bounded by four grid lines in one of the coordinate systems. All radiation is one-dimensional. There is no provision for phase change.

Programming Language: FORTRAN V

Hardware/Operating System: UNIVAC 1110/Exec 8

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
65,000 word storage; 120,000 statements total

Documentation: See Refs. 62 to 64

Program Availability: Contact developer. Cost is negotiable.

TAC3D

Descriptive Program Title: Thermal Analysis Code - Three-Dimensional

Program Developer: General Atomic Company, P.O. Box 81608, San Diego, California 92138

Date of First Release and Most Recent Update: 1969

General Information:
TAC3D is a code for calculating steady state and transient temperatures in three-dimensional problems by the finite difference method.

Program Capability:
Linear and nonlinear problems may be treated with TAC3D. Internal and external flowing coolants may be used, and there may be internal and external thermal radiation.

User Interface and Modeling Capabilities:
The configuration to be analyzed is described in the rectangular or cylindrical coordinate system. The input of thermal properties is by FORTRAN statement functions. This permits flexibility as many of the calculation variables (time, local temperature, local position, etc.) are available for use in these functions. There is a wide selection of optional output.

Solution Methods:
Alternating direction implicit method for three-dimensional problems (Douglas).

Notable Items and Limitations:
The grid planes must be orthogonal, and the entire problem must be bounded by six grid planes in one of the coordinate systems. All radiation is one-dimensional. There is no provision for phase change or thermal expansion of materials.

Programming Language: FORTRAN V

Hardware/Operating System: UNIVAC 1110/Exec 8

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
65,000 word storage; 150,000 statements total

Documentation: See Refs. 65 and 66

Program Availability: Contact developer. Cost is negotiable.

TANG

Descriptive Program Title: Thermal Analyzer Network Generator

Program Developer: Grumman Aerospace Corporation, Bethpage, New York 11714

Date of First Release and Most Recent Update: December 1976

General Information:
The Thermal Analyzer Network Generator software has been developed to automate the creation of finite difference thermal models. The program is a proprietary code belonging to Grumman Aerospace Corporation.

Program Capability and Scope of Analysis:
The program is capable of generating two- and three-dimensional thermal models of general geometries.

User Interface and Modeling Capabilities:
The program makes use of the interactive capabilities of the IBM operating system and user graphics hardware (digitizers and CRT displays) to expedite data display and verification.

Solution Methods:
The code employs standard conduction coupling formulation and surface area evaluation for convection and radiation coupling determination.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 370 (OS/VS)

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
The pre-processor code contains 384 source statements and performs digitizing and input data graphics functions. The core program for model generation contains 573 lines of code. Post-processor plotting - 173 lines of code.

Documentation: See Ref. 67

Program Availability: For further information contact:
Dr. John G. Roukis
Grumman Aerospace Corporation
Mail Stop B22/35
Bethpage, New York 11714

TAU

Descriptive Program Title: Thermal Analysis of Uncle

Program Developer: J. A. Enderby, United Kingdom Atomic Energy Authority (UKAEA), Risley Nuclear Power Development Establishment, Warrington, Cheshire WA3 6AT, England.

Date of First Release and Most Recent Update: 1975 and 1981

General Information:
TAU is the heat transfer module of a general finite element system UNCLE which provides all the facilities needed by a general purpose finite element program. It is used extensively within the UKAEA and by a number of companies associated with the nuclear industry.

Program Capability:
TAU deals with conduction in materials of varying composition with material data optionally a function of temperature, time, or space and with internal heat generation. Radiation is allowed between all surfaces with a direct line of sight. Surface conditions include natural and forced convection, fixed flux, radiation to ambient, convection to an internal fluid whose temperature is to be found, and fixed temperatures. Calculations are performed for two-dimensional (slab and axisymmetric) and three-dimensional models in steady state and transient modes.

User Interface and Modeling Capabilities:
A unique element-cell-array-structure hierarchy gives an extremely concise and powerful yet natural way of inputting finite element models. The difficult task of providing radiation between surfaces, calculating viewfactors, and allowing for "shadows" can be accomplished with minimal effort on the part of the user. Mesh plots (including hidden line plots of three-dimensional structures) are provided. On-line interaction with the output routines allows selection of type of plot, size, viewpoint at run time.

Printed and plotted presentations of results are available (contour and line plots of temperature against position) and dump files may be used for restart purposes, for providing additional output, and for transfer of temperatures to the associated stressing program.

Element Library:
Two- and three-dimensional isoparametric elements are provided including triangles, quadrilaterals, tetrahedra, bricks and prisms with and without mid-side nodes. Boundary conditions are attached using compatible surface elements whose dimensionality is one less than that of the whole problem.

Solution Methods:
A sparse equation solver using a variant of Gauss elimination is provided. Many solutions stay in core using work space provided by the program at run time. Data is moved out of core automatically in an efficient systematic manner if in-core storage is insufficient. Nonlinear cases use a Newtonian iteration, or a modified Newton method in which the matrix of equations is set up and eliminated only once.

Transients use a backward difference (implicit) technique with time steps adjusted automatically for accuracy.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 370, 3033 (OS/VS), ICL 2900 (VME/B)

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
UNCLE (input and solution - 18,000 statements; UNCLE (output) - 8,500 statements; TAU - 4,300 statements; LISTIN - 3,300 statements.

Documentation: See Refs. 68 to 70

Program Availability: Available for use under contract on the Risley and Harwell computers of the UKAEA. Expected to be available in the United Kingdom and the United States on bureau by early 1982.

TEMP and NTEMP

Descriptive Program Title: TEMP - Temperature Analyzer; NTEMP - New Temperature Analyzer

Program Developer: Dr. A. F. Emery, Department of Mechanical Engineering, University of Washington, Seattle, Washington 98195

Date of First Release and Most Recent Update: TEMP - 1970 and 1981; NTEMP - 1980

General Information:
- TEMP handles temperature dependent, time dependent properties and boundary conditions. Dynamic core allocation.
- NTEMP - Same as TEMP with the following additions:
  - Algebraic formula input for time and temperature dependent variables.
  - Direct solution on modification and resolution using R. Young's method - choice determined on basis of execution times.
  - Convergence based upon dT/dt or dF/dt using rms or mat. value.

Scope of Analysis:
Two-dimensional and axisymmetric. Radiation and convection. Nonlinear problems. Used for input to SAAS.

User Interface and Modeling Capabilities:
Batch processing. Interactive graphic input of mesh. Separate mesh generator or internal generation of simple meshes.

Solution Methods:
Direct solution of equations combined with iteration for nonlinear problems. Young's method used to reduce solution time for nonlinear problems. User prescribed convergence criterion. Convergence based upon rms or maximum error.

Notable Items and Limitations:
NTEMP has the following two mesh generators:

- Batch processor based on solution of Laplace's equation. Arbitrary mesh capability.
- Interactive generator. Triangles or quadrilaterals. Library of different surfaces. Spheres, cylinders, cones, etc.

The post-processor has the following facilities:

- Contour plotter
- Three-dimensional perspective hidden line plotter
- Determined mesh plotter
- Temperature-time plots
- Heat flux - time plots

Programming Language: FORTRAN Extended

Hardware/Operating System: CDC 6000 series/NOS BE; CDC CYBER 175/750/NOS

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
1,500 cards. Pre- and post-processors - 3,000 cards each.

Documentation: See Refs. 71 and 72

Program Availability: Contact developer. Cost: $250

TEPSA

Descriptive Program Title: Thermal Elasto-Plastic Stress Analysis

Program Developer: T. R. Hsu, Department of Mechanical Engineering, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2

Date of First Release and Most Recent Update: September 1973 and November 1980

General Information:
TEPSA is a proprietary finite element computer code developed and maintained by Professor Tai-Ran Hsu. The code was initially developed to predict the thermo-mechanical behavior of reactor core components especially the fuel elements. However, it can be used equally well for other structures which comply, either three-dimensional axisymmetric or two-dimensional plane geometries. This code can

be used to handle thermal only, mechanical only, or coupled thermomechanical problems.

Program Capability:
The thermal analysis part of the TEPSA code is fully capable of handling both steady state and transient heat conduction of solids involving temperature-dependent material properties. Nonlinear convective and radiative boundary conditions can be applied, as well as heat generating elements. The analysis applies to the instantaneous geometry of the solid in the transient cases. Phase changes of the structure can also be handled. Extensive experimental verification of the code predictions has been made and a comprehensive user's manual is available.

Solution Methods:
Incremental process was used in the code for the nonlinear loads, material properties and geometries involved in the solution. Both two-level implicit and three-level explicit time difference schemes have been used. The "averaging enthalpy" algorithm was used for the evaluation of latent heat involved in the phase change process.

Programming Language: FORTRAN IV

Hardware/Operating System: AMDAHL, IBM

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Preprocessor: approximately 100 statements.
Core program: approximately 1,684 statements.

Documentation: See Refs. 73 and 74

Program Availability: Contact developer. Cost is negotiable.

THAC-SIP-3D

Descriptive Program Title: A Three-Dimensional, Transient Heat Analysis Code Using the Strongly Implicit Procedure

Program Developer: W. D. Turner, Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee 37830

Date of First Release and Most Recent Update: September 1978

General Information:
THAC-SIP-3D was written at Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee, and was funded through the Office of Waste Isolation as part of the National Waste Thermal Storage Program.

Program Capability and Scope of Analysis:
THAC-SIP-3D is a transient analysis code designed to calculate temperature distributions for problems that can be modeled in the three-dimensional Cartesian coordinate system.

User Interface and Modeling Capabilities:
The user defines the problem by a series of regions having common characteristics. THAC-SIP-3D generates the nodal configuration from this information. Parameters

may be defined by built-in functions or by user-supplied functions.

Solution Methods:
Uses Stone's strongly implicit procedure for three-dimensional, transient problems.

Notable Items and Limitations:
Variable-dimensioned with respect to maximum number of nodes.

Programming Language: FORTRAN IV

Hardware/Operating System: IBM 360, IBM 370, IBM 3033

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:
Core program - 5000

Documentation: See Ref. 75

Program Availability:
Radiation Shielding Information Center
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

THTD

Descriptive Program Title: Transient Heat Transfer Program Version D

Program Developer: General Electric Company, AEBG, Cincinnati, Ohio

General Information:
THTD is a proprietary code developed and maintained by the General Electric Company. Development started in 1956 with the first version released for use in 1957. Since then the program has undergone numerous changes and updates with continuing ongoing work to expand program and pre- and post-processor capabilities.

Program Capability and Scope of Analysis:
THTD is a general heat transfer code based on a finite difference implicit formulation of the partial differential equation for heat conduction. It computes transient and steady-state temperatures for three-dimensional geometries with a large variety of optional boundary, interface and internal conditions including:

- Internal heat generation, volumetric, time dependent
- Surface flux, time dependent
- Contact coefficient, constant
- Node to node or node to boundary radiation
- Convective boundaries with and without fluid flow, natural and forced convection, time and temperature dependent
- Temperature dependent physical properties
- Phase change (melting)

User Interface and Modeling Capabilities:
- THTD includes options for output data generation for direct interfacing with finite element stress programs through appropriate file manipulation.
- Extensive pre- and post-processor plotting capabilities for input and output

data analyses and documentation including isotherm plots, geometry plots and time and space dependent temperature plots are part of the THTD system.

- Input to the program is greatly simplified by the use of pre-processors in the preparation of geometry and boundary condition input data and a conversational input generation program. Geometry input data processing is accomplished by use of digitized nodal coordinate data generated by use of digitizer or mesh generator programs.

Solution Methods:
The solution method used is based on the Gauss-Seidel procedure with solution obtained by iterative solution of simultaneous algebraic equations for node temperatures derived from finite difference analysis. Convergence is recognized by user specified successive sets of maximum temperature changes (tolerance) permitted between iteration sweeps. The fully implicit formulation of the finite difference solution precludes any stability limitations on time increments and permits a direct steady state solution.

Notable Items and Limitations:

- THTD is a strongly user-oriented program with extensive data checks and edited output features and capabilities to accumulate solution results on binary tapes for problem restart, stress program interface and for graphical display.
- Although the program includes node to node and node to boundary radiation among its boundary condition options, it is generally not recommended for use in node to node radiation dominant problems.
- The program is currently limited to 2047 nodal elements, but can be readily expanded to 6,999 nodes.

Programming Language: Basic program language is FORTRAN IV. However, several service type subroutines are encoded in the GMAP assembly language for the Honeywell 6000 computers.

Hardware/Operating System: THTD is operational on the Honeywell 6000 computers at several locations within the General Electric Company. Earlier versions of the program are operational on the CDC 6400 at Battelle Memorial Institute and the UNIVAC computer at the NASA Manned Spacecraft Center, Houston, Texas.

Program Size (Heat Transfer Modules Only) - Number of Source Statements of Core Program, Pre- and Post-Processors:

- Core Program: 45K, additional memory required for loading of input data and depends on the number of nodes and tables used in the input.
- Source Statements: 22,000

Documentation: See Refs. 76 to 83

Program Availability: Inquiries should be addressed to:
W. K. Koffel
General Electric Company AEBG
Mail Drop K70
Neumann Way
Cincinnati, Ohio 45215

Descriptive Program Title: A Computer Program for Transient and Steady State Temperature Distributions in Multidimensional Systems

Program Developer: Arthur L. Edwards, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94550

Date of First Release and Most Recent Update: 1967 and 1974

General Information:
TRUMP is a computer program in the public domain available from the Argonne Code Center, Argonne, Illinois. TRUMP is currently in use at Lawrence Livermore National Laboratory, and at a number of other locations in the United States, Canada and several other countries.

Program Capability and Scope of Analysis:

- TRUMP is a general purpose program for solving linear or nonlinear, steady-state or transient potential flow problems, including heat flow in temperature fields, Darcy flow in pressure fields, and fluxes in electrical and magnetic fields. In addition, TRUMP solves two additional equations representing, in thermal problems, heat production by decomposition of two reactants having rate constants with a general Arrhenius temperature dependence.
- Geometrical configurations may consist of complex three-dimensional structures of many materials which are described by specifying the dimensions or volumes of volume elements, and the dimensions or areas of their connections or surfaces.
- Material properties (e.g., thermal conductivity, specific heat) may be tabulated functions of the field variable (e.g., temperature) or time. Initial conditions may be specified for each volume element. Sources (e.g., heat) may be specified for each volume element, and may be tabulated functions of the field variable (i.e., temperature) or time, or may be given an exponential time dependence. Boundary conditions may be specified for each surface and each volume element, and may consist of a time-dependent field variable (e.g., temperature) or flux (e.g., heat), or a combination of a time-dependent external field variable and an interface conductance which may also be a tabulated function of time or the surface field variable (e.g., temperature). In thermal problems both convective and radiative transport may be represented at boundaries and between volume elements, and the surface conductance may be made proportional to a specified power of the difference between surface and external temperature.
- On thermal problems, a mass flow field may be specified, which may be either time or temperature dependent, constrained only by the requirement that all mass flow connections are between volume elements of the same material, and that inflow equals outflow for each volume element. In problems of Darcy flow in a pressure field, this field may be used to model the effects of gravity.
- Special elements may be specified that measure linear combinations (sums, averages, differences) of the field variable (e.g., temperature), or its rate of change. Any property that may be a tabulated function of the field variable (e.g., temperature) in one volume element may be made to depend on the field variable in another volume element, including the special elements specified for measurement purposes. In thermal-reactive problems, these properties include specific heat, thermal conductivity, heat of reaction, collision frequency, activation energy, heat generation rate, mass flow rate, and surface convection coefficient. This capability allows the solution of problems involving remote or automatic control.

• The solution method and accuracy may be determined by the program or specified by the user. Save-restart capability is provided by the program.

User Interface and Modeling Capability:
TRUMP geometric input can be produced directly by the user or by a pre-processor such as FED (Dale Schauer, LLNL). At LLNL the user may interact to determine the progress of the calculation, change output intervals, interrupt and restart, or end the problem. The user controls output intervals and quantity from minimum (e.g., temperature and global heat balance values) to maximum (e.g., detailed heat balance data for each volume element and connection, phase concentrations, chemical reactant concentrations, flow totals and rates, etc.). Plots include snapshots, time histories and contour plots, produced either directly or by a post-processor.

Physical Property Library:
A collection of critically evaluated thermal properties of over 1,000 materials in the required input format for TRUMP is available (see UCRL-50589) as part of the TRUMP package at Argonne Code Center.

Solution Methods:
TRUMP uses a combination of explicit and implicit methods to solve the algebraic set of difference equations for each time increment, or the user can choose a particular method, such as explicit, or two forms of implicit (backwards time-step or Crank-Nicholson) methods. In the combination explicit-implicit method, the zones done implicitly are determined by the program, but others may be added by the user. The particular mix varies as the problem proceeds, to optimize the use of computer time for the accuracy specified. The implicit method uses a one-point iterative scheme, with an extrapolated first estimate and local and global convergence criteria.

Notable Items and Limitations:
TRUMP is a very general and powerful solver of the general nonlinear parabolic partial differential equation describing flow in various kinds of potential fields in complex geometries. Geometry is specified independently of any global coordinate system, which limits the types of plots which can be made. Coordinate data is easily added when a geometric pre-processor is used. The number of volume elements and their interconnections and boundary connectors is limited by the memory size of the computer.

Programming Language: LRLTRAN at Lawrence Livermore National Laboratory, and various versions of FORTRAN at other locations.

Hardware/Operating System: CDC 7600, 6000 and 3000 series, IBM 360, UNIVAC 1100 series and GE 200

Program Size (Heat Transfer Modules Only):
Pre-processors - 5,000 statements, variable
Core Program - 5,000 statements
Post-processors - variable.

Documentation: See Refs. 84 to 86

Program Availability: National Energy Software Center
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

WECAN

Descriptive Program Title: Westinghouse Electric Computer Analysis

Program Developer: Analytical Mechanics, Westinghouse Research and Development Center, Pittsburgh, Pennsylvania 15235

Date of First Release and Most Recent Update: 1973 and 1981

General Information:
WECAN is a proprietary code. It was and is developed jointly by Westinghouse Research and Development and other Westinghouse user divisions to be efficient, capable and easy to use. WECAN and its close relatives WAPPP (WECAN Pre- and Post-Processors) and FIGURES II (Finite Element Interactive Graphics User Routines) were designed to provide a complementary system of computer programs for structural analysis. Maintenance is funded by a surcharge. New developments are funded by user organizations desiring new development and the surcharge.

Program Capability:
WECAN is a general purpose static, dynamic transient linear buckling, and heat transfer and analogous field problems. Isotropic, orthotropic, and anisotropic materials are permitted. Material properties are defined as a fifth order polynomial of temperature. Substructures are linear but can be combined with nonlinear elements in the solution phase. Multilevel substructures are permitted. Substructures may be rotated, reflected or scaled. WECAN may be restarted at preselected time steps.

User Interface and Modeling Capabilities:
WAPPP is a collection of batch pre- and post-processors for WECAN. The pre-processors generate meshes and loads, check isoparametric element shapes, reduce wave fronts, prepare input for general matrix input and for composite materials. The post-processors edit heat transfer results, edit mode shapes and frequencies, combine results, plot contours, deformed shapes, transients and general xy curves, process seismic data, calculate J-integrals and calculate Fourier coefficients.

FIGURES II is a collection of interactive pre-processors that prepare input for WECAN. It can interactively plot what is being generated.

Solution Methods for Nonlinear Problems:

- WECAN solves transient heat transfer problems using the Crank-Nicholson-Galerkin integration scheme with $\alpha = 2/3$ or 1 or else uses a quadratic integration scheme.
- WECAN uses the wave front equation solver with as much in core as possible.

Notable Items and Limitations:
WECAN's heat transfer capabilities offer a wide range of applications. By analogy it has been used to solve electromagnetic field problems, fluid-structure interaction, torsion of prismatic bars, incompressible inviscid fluid flow, corrosion, seepage, acoustics, and electrical conductance problems. Interactive post-processing of results is under development. Users may specify any element conductivity or specific heat matrix through the general matrix input element. Basic workshops and advanced training sessions are offered periodically to train inexperienced and experienced WECAN users. An annual user's colloquium is held each Fall where users present papers in competition for prizes.

Programming Language: WECAN and WAPPP are over 99 percent FORTRAN IV, and less than 1 percent COMPASS. FIGURES - 100 percent FORTRAN IV

Hardware/Operating System: WECAN and WAPPP - CDC 7600 (SCOPE); FIGURES II - PRIME 750 (PRIMOS)

Program Size (Heat Transfer Related): WECAN 35,000; WAPPP 20,000; FIGURES II 100,000.

Documentation: See Refs. 87 to 89

Program Availability: Program can be used on Westinghouse PSCC Engineering Computer System or CDC Cybernet System for a surcharge on each run of WECAN, WAPPP or FIGURES II. The object tapes are available with terms negotiable. For further information please contact William Kunkel, Advance Systems Technology, Westinghouse Electric Corporation, 777 Penn Center Boulevard, Pittsburgh, Pennsylvania 15235 (412) 824-9100.

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