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COMPARATIVE EVALUATION OF LTV COMPUTER ROUTINES

Report No. 00.847

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Submitted by

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To

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LIST OF SYMBOLS

h	heat transfer coefficient
$\dot{w}$	flow rate
St	Stanton number
Pr	Prandtl number
Re	Reynolds number
FA	coefficient of radiative
X	Valve bypass fraction
T	Temperature

1.0 SUMMARY AND INTRODUCTION

During the past several years LTV Astronautics has developed many versions of generalized finite difference heat transfer programs for the Crew Systems Division of NASA-MSC. The programs were originally intended for the analysis of space radiators; however, there presently exists a family of routines written by LTV which have provisions for analyzing a variety of problems. Those versions which have found wide application were given LTV computer routine numbers prefixed by LVVM. Reports describing the analytical methods utilized and data preparation requirements were prepared. Seven such routine versions are presently in use for the analysis of various space radiator and other thermal/ fluid flow problems. The routines are quite general in regard to data input with some overlapping of capability.

A brief statement of the overall purpose and use of each routine is provided, followed by a tabulation of the specific options available in each program. Program accuracy, run time, and available data space are also summarized. This document is not a substitute for the individual reports on the computer routines; it is intended to be a guide to more efficient selection and use of LTV computer routines.

2.0 GENERAL ROUTINE DESCRIPTION

A descriptive summary of the seven computer routine versions currently in use is provided in Table 1. The LTV report describing the analytical methods and user's instructions is provided for reference. The routines have a number of options in common because of the versatility created by their inclusion. The following is a list of routine options of significance which all the routines share.

(1) Interruption and Restart - Automatic as well as manual interruption is provided to allow for an intermediate check of the results. Restarting a problem is accomplished by a special procedure detailed in all of the respective user's manuals.

(2) Checkout Printing - This option is provided to assist the routine user in checking the input data and the thermal model. This option should be used cautiously due to the large volume of data output generated under the option. For transient problems, selecting a time for transient equal to the time increment will yield a single iteration checkout printing. A single checkout can be specified as input data for steady state problems.

(3) Steady State Shutdown and Jump Ahead - Each routine contains this important time saving feature. During transient problem solutions, the routines determine whether steady state conditions exist, and if they do, all time dependent variables are inspected to ascertain how far time should be advanced.

(4) Laminar or Turbulent Flow Heat Transfer - All the space radiator computer routines have the capability of handling both laminar and turbulent flow. Laminar flow heat transfer predictions are used until the Reynolds numbers become greater than 2000 at which point turbulent flow heat transfer predictions are used in conjunction with an input friction factor curve.

(5) Laminar or Turbulent Flow Pressure Balance - The pressure balance procedures apply rigorously only for laminar flow. The turbulent flow balances may be achieved in some cases by successive iteration.

(6) Parallel or Simple Banks and Headers Flow - Each routine has the capability of handling a flow system in which all flow paths have identical inlet temperature and pressure (denoted as "Parallel Flow"). When a combination of series and parallel flow paths are to be analyzed the "Banks and Headers" option must be used.

(7) Fluid Freezing - The user may select this option to analyze stagnant or frozen fluid lumps. When the flow rate in a tube drops below some value set by the user, the heat transfer between fluid lump and tube lump is calculated using the fluid thermal conductivity instead of the heat transfer coefficient.

TABLE 1

COMPUTER ROUTINE DESCRIPTION

Routine Number	Description	LTV Report Number
LVVM 15	This is the basic explicit finite difference routine which has been used extensively to analyze the Apollo Block I and Block II ECS radiators.	*Similar to 00.716
LVVM 17	This version was developed to analyze radiant interchange. The routine analyzes diffuse and/or specular reflecting surfaces as well as multiple reflections.	00.655 and 00.656 dated 11 June 1965
LVVM 20	This version was developed to analyze the Apollo fuel cell heat rejection system. The routine analyzes two-phase, two-component flow as well as multiple fluid loops.	00.704 dated 30 Oct. 1965
LVVM 22	This is the only computer routine which uses implicit finite difference techniques. The routine lacks some options of LVVM 15 but requires less computer time than the other routines.	00.809 dated 21 July 1966
LVVM 25	This version was developed to incorporate the latest flow options in a single routine. The routine also has provisions for analysis of heat exchangers and directional surface coatings.	00.823 dated 29 July 1965
LVVM 26	This version was developed to be a general space radiator routine for wide usage. The routine contains the three options shown in Table 2.	00.716 dated 17 Nov. 1965
LVVM 33	Provisions for fluid flow were deleted from this version to maximize data space for structure problems. It was applied to the analysis of the Apollo Block I Command Module structure.	*

*A formal report for this routine was not prepared since it was superceded by later versions

3.0 OPTIONS AVAILABLE IN SPECIFIC PROGRAMS

Table 2 has been prepared to help the user select a routine which contains provisions for analyzing a particular problem. This table presents the various flow options and heat exchanger options as well as several special options available to the user. A brief description of each option is provided in Table 3.

TABLE 2

COMPUTER ROUTINE OPTIONS

Option	LVVM15	LVVM17	LVVM20	LVVM22	LVVM25	LVVM26	LVVM33
FLOW OPTIONS:							None
Valves, General Package			x		x		
Valve, Imaginary Bypass	x	x		x		x	
Valve, Real Bypass				x			
Valve, Proportioning	x	x		x			
Off Axis Flow Path				x	x		
3-D Flow Path Network				x	x		
Closed Loop			x		x		
HEAT EXCHANGER (HX) OPTIONS:				None			None
Regenerator Only	x	x					
HX with $h = f(\dot{w})$			x		x	x	
HX with $St(Pr)^{2/3} = f\ (Re)$			x		x		
HX with h = Calculated			x		x		
GRADIENT SOLUTION	x		x			x	
DIRECTIONAL COATING					x		
RADIANT INTERCHANGE		x(1)					(2)
CONDENSATION AND TWO-PHASE FLOW			x				
KNOWN HEAT LOAD	x	x	x			x	

(1) Specular and/or diffuse
(2) FA's input

TABLE 3

DESCRIPTION OF ROUTINE OPTIONS

Option	Description	Typical Page	Reference Report No.
Valve, Imaginary Bypass	Flow bypasses the system through a valve which has zero pressure loss and no thermal connections.	46	00.704
Valve, Real Bypass	Pressure losses in valve and bypass line are calculated. Bypass tube has heat transfer capabilities.	46	00.704
Valve, Polynomial Bypass	Fraction bypassed is determined by 4th order polynomial (X versus temperature).	46	00.704
Valve, Proportioning	Flow is proportioned between two branches according to outlet temperatures.	50	00.704
Valves, Shut-Off	On/off valve closes when $T_{sensor} < T1$ and opens when $T_{sensor} > T2$. Off/On valves opens when $T_{sensor} < T1$ and closes when $T_{sensor} > T2$. Switching valve switches all flow entering valve to one of two branches according as T_{sensor} is greater than or less than T1 or T2.	50	00.704
Valves, General Package	The general valve package contains: Real, Imaginary, and Polynomial bypass valves; the Proportioning valve and the Shut-off valves.	46	00.704
Off-Axis Flow Path	An extension of the simple banks and headers option, this option analyzes a system involving a flow tube in parallel with two tube banks in series.	27	00.823
3-D Flow Path Network	Analyzes flow networks which cannot be drawn in a plane without intersecting.	27	00.823
Regenerator Options	Inserts a counter flow regenerator into the system with inlet and outlet of system exchanging heat. The cold side of the regenerator has a bypass valve which operates identically to the imaginary bypass.	43	00.716

TABLE 3 (Cont'd)

DESCRIPTION OF ROUTINE OPTIONS

Option	Description	Typical Page	Reference Report No.
H/X	Inserts a heat exchanger according to data input. No limit to the number or arrangement of lumps is made. The heat transfer coefficient may be specified separately on each side, according to three calculation options; 1) the coefficient will be calculated as if it were an ordinary lump, 2) the coefficient will be a tabular function of flow rate, or 3) the Reynolds number will be used to determine the $StPr^{2/3}$ in a form commonly specified in heat exchanger literature.	39	00.823
Gradient Solution	An analytical steady state solution to the radiating fin problem is achieved and stored in data. The data is interpolated in a straight-line fashion to provide fin base gradients. A nodal subdivision of the tube network provides the base upon which the fin solutions are applied in the problem.	12	00.716
Directional Coatings	A second heating mode is assumed for optional use. This heating mode is such that the absorption from the source is directionally dependent.	43	00.823
Radiant Interchange	(1) Diffuse multi-reflection of two wavelength sources, one of which is external and the other infrared, provisions for specular reflection, solves for the absorbed energy at each surface. Input required is only areas, view factors, and exchange factors. (2) Radiant interchange is possible with inputs of FA's between participants.	223	00.655
Condensation and Two-Phase Flow	Condensation heat transfer in ducts and heat exchangers in the presence of a non-condensible gas is assumed. Pressure drop by Martinelli correlation is calculated for annular flow.	35	00.704
Known Heat Load	This option provides an automatic interative procedure to achieve the inlet temperature required to reject a steady load and achieve a given outlet condition.	37	00.716

4.0 ACCURACY

Each routine (exclusive of LVVM 22) which uses the explicit technique will produce identical results on the same basic problem. The implicit techniques used in LVVM 22 produce answers different from the explicit during transients. This difference is discussed thoroughly in Report No. 00.809 for several problems.

The chief source of error in any of the routines is attributable to the fact that finite differences are employed. The implicit method solves the finite difference equations by an iterative approximation which is controlled by the user to be as close as desired to the precise solution. This error may be kept to a significantly smaller value than the finite difference errors which are incurred. Studies of the finite difference errors which are generated may be broken into the following categories.

(1) Truncation error is that error generated by replacing the differential equation by a difference equation.

(2) Discretization error is that error arising near boundary nodes of the network.

Both of these errors are somewhat reducible at the expense of computation time and data storage. For mathematical error analyses, the methods in order of increasing error are mid-difference implicit, explicit, and backward-difference implicit. However, the differences are generally not large between the methods such that each is basically accurate.

Another source of error occurs in almost every actual analysis due to the complexity of most systems. The analyst is required to break irregular shapes into nodes, simulate composite nodes, and analyze fluid flow. None of these are accounted for in the highly idealized error analyses performed mathematically. Therefore any error estimation is usually qualitative or semi-emperical in nature. Basically the above source of error can be eliminated only by the cleverness and experience of the user.

5.0 RUN TIME

The computation time required for analysis of a problem depends most strongly on the number of nodes and the number of iterations required. It also is dependent on the ratio of the number of fluid to tube and structure lumps, on the number of tubes in the system, and on the number of curves used. The estimation of run time is best made after some experience; however, an approximate relation for an IBM 7094 has been generated to assist the user. The method proposed for estimating the run time of the routines is outlined below and should be expected to predict run time within about ± 50 percent.

For All Routines:

Flow Balance:

Time per increment = 10^{-6} (number of tube)^3 minutes

Pressure Drop Calculation:

Time per increment = .000205 minutes per fluid lump

For the Implicit Temperature Determination:

Time per increment = .00018 minutes per lump

For the Explicit Temperature Determination:

Time per increment = .00007 minutes per lump

Use of the two-phase flow option adds 30 percent to the pressure drop calculation time and 40 percent to the temperature determination time. The radiant interchange option will seldom cause over a one-minute increase in total problem run time. Owing to the complexity of interconnection between the various options and the basic routine, no attempt has been made to separate the effect of the various options on run time.

6.0 DATA SPACE

The data space is limited by the computer core storage (IBM 7090 and 7094 have 32,768 locations; Univac 1107 and 1108 have 65,536 locations) and the storage requirements of the routine under a particular monitor system. The limitations on data space are slightly different for each routine due to the different options. Also data space use rate per lump varies according to the routine. The data space requirements and an estimate of the maximum problem size for each routine are based on the use of a Fortran II monitor system and the Univac 1108 Fortran IV monitor system for LVVM 20, LVVM 22, and LVVM 25. Each routine user's manual contains a section with the necessary equations to accurately calculate the data space based on the user's particular problem. A summary of the data space capability is tabulated in Table 4. Included in the tabulation is an approximate maximum number of nodes which may be used. The values presented are a guide for the user, the actual value depending on the options used, on the ratio of fluid lumps to fin lumps, and on the number of conduction (and radiation) paths.

TABLE 4

DATA SPACE AND PROBLEM SIZE REQUIREMENTS

Computer Routine	Data Space/Approximate Number of Nodes	
	Fortran II	1108 Fortran IV
LVVM 15	17600/1200	--
LVVM 17	18120/1300*	--
LVVM 20	12400/700	32000/1800
LVVM 22	17000/600	37000/1300
LVVM 25	17000/1200	37000/2600
LVVM 26 (Public)	17600/1200	--
LVVM 33	21000/1500	37000/2600

*Maximum number of radiation participants is 65