FLUINT: General Fluid System Analysis with SINDA '85

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Abstract

THIS synoptic introduces FLUINT (Fluid Integrator), a general fluid system simulation program that works in conjunction with SINDA (Systems Improved Numerical Differencing Analyzer) '85. FLUINT solves networks representing internal fluid systems, while SINDA '85 simultaneously solves traditional conduction/radiation networks. This transportable program provides engineers with the analytic tools needed to simulate single- and two-phase thermal transport loops.

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Background

The SINDA family of thermal analyzers enjoys widespread use due to its simple, flexible approach. Because the use of a standard program throughout government and industry expedites design verification and vehicle integration, there are considerable reasons to extend the capabilities of SINDA to handle advanced systems such as two-phase transport loops. SINDA '85[1] is an evolutionary extension of SINDA and MITAS (Martin Marietta Interactive Thermal Analysis System). The basic approach is the same: thermal systems are modeled as networks of *nodes* and *conductors*. Nodes are points at which energy is conserved; conductors transport energy between nodes. In addition to describing the network to the program, the analyst lists the analytic and output operations to be performed and may include his/her own subroutines to be executed simultaneously.

Program Scope

Because of previous limitations in fluid system modeling with SINDA, most analysts have written their own codes, which are usually specific to the system under consideration. The goal of this program is to provide a common analyzer for a wide variety of systems. In summary, FLUINT is intended to provide the thermal management analyst with the same flexible modeling power for fluid systems that SINDA '85 provides for thermal structures.

The basic building blocks are provided to model almost all internal fluid systems, including valves, pumps, and heat exchangers as well as more complex hardware. Models may be analyzed in either steady-state or transient modes, and many levels of approximation are available. The code is fluid-independent; the user may select from 20 refrigerants (including water, ammonia, and Freons‡) or may describe other working fluids. Fluid systems may be completely single phase or two phase, or may have sections with both regimes. The program can be used to model capillary devices, liquid/vapor separators, flexible containers, stratified vessels, and body forces due to gravity, launch, or orbital maneuvering. In addition, symmetries such as parallel passages can be exploited to reduce the model size.

Concepts and Approach

SINDA '85 master models are composed of thermal and/or fluid *submodels*. The basic building blocks of fluid submodels are *lumps* and *paths*, which are analogous to nodes and conductors, respectively. Energy and mass are conserved at lumps and are transported between lumps by paths. Heat transfer between a duct wall and the fluid within the duct is simulated by representing the fluid with a lump and the inner wall with a node.

There are three types of lumps, analogous to the three types of SINDA nodes. *Tanks* are control volumes that can grow or shrink. *Junctions* have zero volume, reacting instantaneously to changes in mass or energy flows. *Plena* have infinite volume, representing boundary conditions. There are two types of paths. *Tubes* are ducts with nonnegligible inertia, meaning that the flow rate cannot change instantaneously. *Connectors* are paths with negligible inertia. Because of their general governing equation, connectors are used to simulate a wide variety of devices, such as short ducts, valves, fittings, and pumps.

Macrocommands are available to simplify the building of heat exchangers, ducts, and other hardware. Furthermore, the entire input structure has been designed to reduce the amount of required inputs. The user may "walk around" a schematic, inputting elements in any order and resetting default values at any time.

Numerical Methods

The underlying assumptions of one thermodynamic state per lump and one mass flow rate per path result in a system of two equations for each nonplenum lump and one equation for each path. The formulations of these equations vary according to the type of element and its current status, and the numerical solution may be performed in several ways, depending on the status of the network and the type of analysis desired.

Steady states can be found using iterative relaxations of the separated mass and energy equations. Transient solutions are not amenable to such methods because of the tight coupling between mass and energy, especially in two-phase systems. The resulting simultaneous solution requires that 1) the equations be linearized carefully to maximize the changes that can be endured each time step, 2) the number of equations be reduced as much as possible, and 3) a sparse matrix solver be used that exploits the structure of the coefficient matrix. The linearization derived for FLUINT allows arbitrary network construc-

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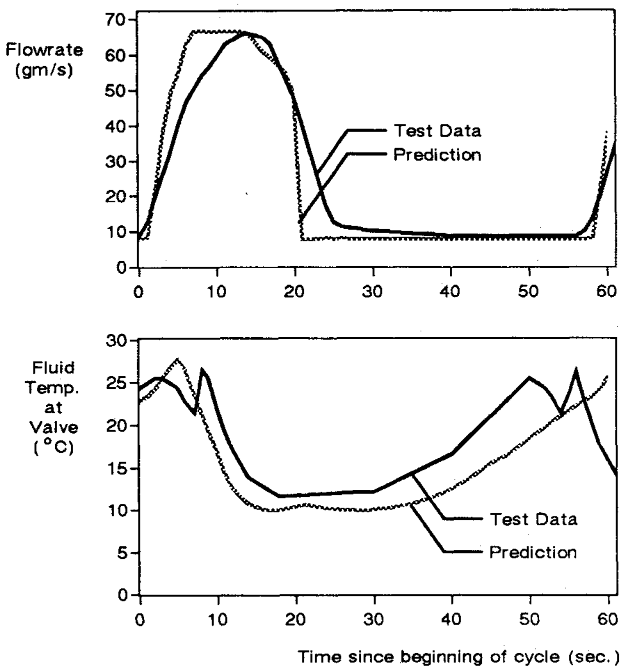

Fig. 1 Test data vs prediction for one valve cycle.

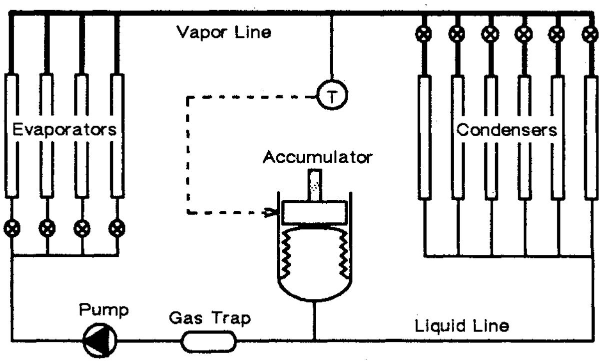

Fig. 2 Two-phase loop with accumulator.

tion and is based on a first-order implicit integration scheme to allow large, stable time steps. In order to guarantee accuracy with a minimum of computation, maximum allowable time steps are calculated continually.

Simulation Examples

Single-Phase Valve Stability

A temperature-sensitive control valve was installed in a simple liquid water loop consisting of an electrically heated pipe, a centrifugal pump, and an ice bath. This system was observed to oscillate continually with a period of about 1 min. A simple model was built using 17 lumps and 21 nodes. Test data and predictions for one cycle of the oscillation are plotted in Fig. 1. The comparison is excellent considering that the vendor data for the pump and valve had known errors approaching 15%. FLUINT was used to help choose acceptable valves before testing and to determine the criteria for valve stability.

Two-Phase Accumulator Transient

A two-phase Freon 11 transport loop was built using electrically heated evaporators and shell-and-tube condensers with

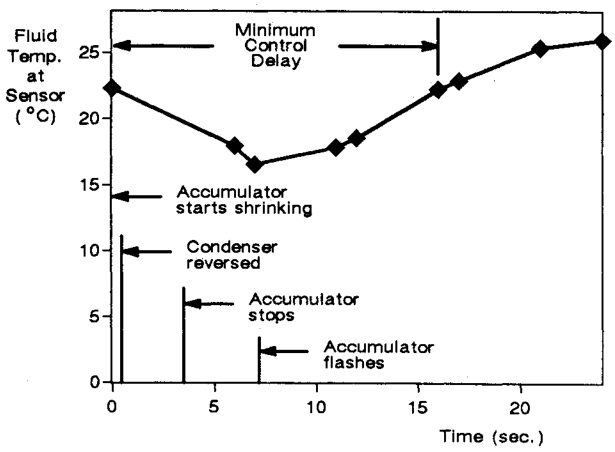

Fig. 3 Test data and events for accumulator step.

circulation provided by a positive displacement pump (Fig. 2). The system pressure was regulated using a space-compatible accumulator whose volume was changed stepwise in response to the temperature sensed at the evaporator outlet.[2] During testing, it was noticed that compressing the accumulator caused a transient *decrease* in the vapor temperature before a gradual rise to a higher level than before. Stability of the control system hinged upon allowing a sufficient response delay before making subsequent accumulator adjustments. A very simple FLUINT model (11 lumps and 7 nodes) revealed the cause: the positive displacement pump forced a flow reversal in the condenser, where existing subcooled liquid and transiently cooled backflow quenched the high-quality fluid near the sensor (Fig. 3). Further decreases in pressure were prevented by brief boiling in the accumulator, at which time the system began to re-establish normal circulation and the temperature began to rise. Once the system response was understood, general criteria for control system stability could be established.

Conclusions

FLUINT provides a set of system-independent tools for performing steady-state and transient thermal-hydraulic analyses. Like SINDA '85, FLUINT is designed to be dynamically tailored to project-specific needs with concurrently executed logic. Many of the algorithms developed throughout industry to analyze specific thermal transport systems can be retained as user-provided logic. SINDA '85/FLUINT could then be used as a common ground for analysts in diverse organizations.

Availability

The first general release is expected after November 1987, and will be available through COSMIC, NASA's central software distributor. SINDA '85/FLUINT is written in standard Fortran 77 and has been hosted on several mini- and mainframe computers.

Acknowledgments

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[2]Cullimore, B. A. and Epper, R. C., "Thermostatic Control of Two-Phase Spacecraft Thermal Management Systems," AIAA Paper 86-1246, June 1986.