

The method has been demonstrated by applying it to a high-dimensional data set representing images, synthesized from images acquired by a spaceborne imaging spectrometer in 18 wavelength bands, that show various attributes of the Marquesas Islands and vicinity (see figure). Details of

individual islands are difficult to discern in any one of the images, but after classification of the image data by the present AIS method, the dominant island groups can be discerned more easily.

This work was done by Terrance Huntsberger of Caltech for NASA's Jet Propulsion

Laboratory. Further information is contained in a TSP (see page 1).

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (818) 393-2827. Refer to NPO-40256.

Computing the Thermodynamic State of a Cryogenic Fluid

A quasi-steady-state thermodynamical model is iterated over time steps.

Lyndon B. Johnson Space Center, Houston, Texas

The Cryogenic Tank Analysis Program (CTAP) predicts the time-varying thermodynamic state of a cryogenic fluid in a tank or a Dewar flask. CTAP is designed to be compatible with EASY5x, which is a commercial software package that can be used to simulate a variety of processes and equipment systems.

The need for CTAP or a similar program arises because there are no closed-form equations for the time-varying thermodynamic state of the cryogenic fluid in a storage-and-supply system. Manual calculations cannot incorporate all the pertinent variables and provide only steady-state solutions of limited accuracy. The heat energy flowing into and out of the system, the inflow and outflow of fluid, the thermal capacitance and elasticity of the storage vessel, and the thermodynamic properties of the cryogenic fluid at each instant of time are needed. In other words, to define the time varying state of the cryogenic fluid, it is necessary to calculate all the pertinent variables and iterate quasi-steady-state solutions at successive instants of time. It is impractical to attempt to do this without the help of a computer program.

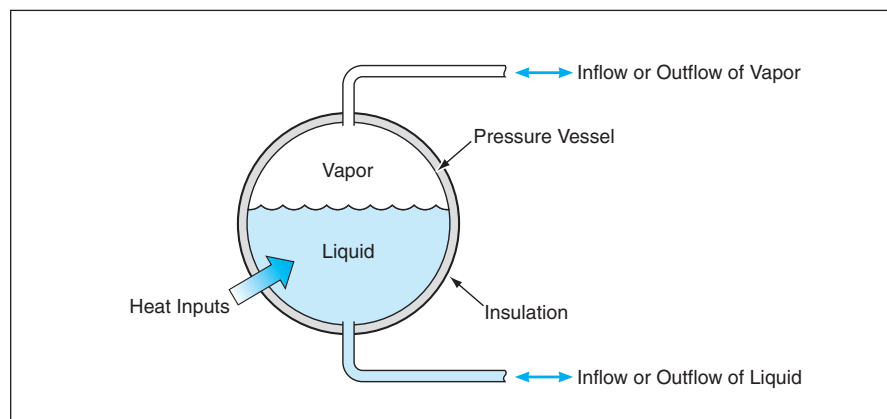
The basic tank system (see figure) modeled in CTAP consists of a pressure

vessel (the tank) that contains the cryogen; the insulation on the tank; the tank supports; and the fill, vent, and outflow tubes. The thermodynamic system is considered to be bounded by the outside surface of the pressure vessel, with provisions for flow of both liquid and gas into or out of the tank. The volume of the tank is treated as a variable to account for contraction and expansion of the pressure vessel with changes in pressure.

The mathematical model implemented in CTAP is a first-order differential equation for the pressure as a function of time. The equation is derived as a quasi-steady-state expression of the first law of thermodynamics for the system regarded as closed and isothermal. The equation includes terms for the parasitic leakage of heat through the insulation, for pressurization energy (supplied by heaters) to be added to the tank fluid, for expulsion of liquid or vapor, for the thermal capacitance of the tank wall, and for stretching of the tank under pressure. CTAP incorporates fluid-property subroutines based on equations of state developed at the National Institute of Standards and Technology. At present, the fluids represented in CTAP are hydrogen and oxygen.

CTAP is set up as a large subroutine to be called from within EASY5x. CTAP requires 28 input variables and returns 12 values for use in execution of EASY5x. The input variables define the fluid (oxygen or hydrogen), the initial state of the fluid, the tank and its parameters, the thermal environment, and the fluid scenario (defined next). The user can select any one of the following 12 options or fluid scenarios:

1. Program calculates rates of boil-off or expulsion for a supercritical fluid at constant pressure.
2. Program calculates rate of expulsion of liquid at constant pressure.
3. Program calculates rate of expulsion of vapor at constant pressure.
4. Program calculates the rate of increase of pressure under a condition of tank lockup.
5. Program calculates the rates of inflow of heat required for a given mass flow rate of supercritical fluid at constant pressure.
6. Program calculates the rates of inflow of heat required for a given mass flow rate of liquid at constant pressure.
7. Program calculates the rates of inflow of heat required for a given mass flow rate of vapor at constant pressure.
8. Program simulates tank blowdown — the expulsion of initially supercritical fluid from the tank. This calculation includes effects of stretching of the tank under pressure.
9. Program calculates variable-pressure expulsion of liquid under heater and mass-flow conditions specified by the user.
10. Program calculates variable-pressure expulsion of vapor under heater and mass-flow conditions specified by the user.
11. Program calculates heat loss through thermodynamic vent system.
12. Program calculates pressure rise in the tank from helium pressurant.



A Cryogenic Fluid and Tank, taken together as a time-varying system, are modeled in CTAP by a quasi-steady-state differential equation based on the first law of thermodynamics.

For steady-state solutions, CTAP returns single values (temperatures, heat flows, and/or mass flows) that describe the state of the cryogenic system. For transient solutions, CTAP returns rates of change of pressure and density, so that EASY5x can update the pressure and density accordingly at

each time step, then pass new values of pressure, density, and any other parameters (e.g., external temperature) that might change with time back to CTAP.

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Refer to MSC-22862.

Safety and Mission Assurance Performance Metric

Relevant data are presented in formats that help managers make decisions.

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The safety and mission assurance (S&MA) performance metric is a method that provides a process through which the managers of a large, complex program can readily understand and assess the accepted risk, the problems, and the associated reliability of the program. Conceived for original use in helping to assure the safety and success of the International Space Station (ISS) program, the S&MA performance metric also can be applied to other large and complex programs and projects. The S&MA-performance-metric data products comprise one or more tables (possibly also one or more graphs) that succinctly display all of the information relevant (and no information that is irrelevant) to management decisions that must be made to assure the safety and success of a program or project, thereby facilitating such decisions.

S&MA organizations within NASA have traditionally provided data products that target specific stages of the life cycles of projects and are generally independent of each other. Such data products have included (1) critical-items lists (CILs) generated through failure-modes-and-effects analyses (FMEAs); (2) noncompliance reports (NCRs) — more specifically, reports of noncompliance with safety requirements as revealed through safety-oriented analyses

and reviews; and (3) problem reporting and corrective action (PRACA) documents, which are used in tracking and classifying hardware failures that occur during testing, assembly, and operations. Notwithstanding the value of these data products, it is difficult to assess the effects on the overall program or project from the contents of such a data product considered by itself. Prior to the conception of the S&MA performance metric, there was no process for integrating the individual S&MA data products into a data product that could enhance the decisions of program managers.

The S&MA-performance-metric process is one of gathering information generated according to the various S&MA disciplines (for example, data products like those described above). The gathered information is differentiated into four categories:

- **Accepted Risk** — This category includes information from CILs and NCRs. The critical items and noncompliances can be classified against specific affected subsystems of the ISS or other system that is the focus of the program or project.
- **Anomalies** — For the purpose of S&MA, anomalies are defined as hardware or software failures, or adverse discrete events that have occurred during development and operation of the system.

Anomalies include the subject matter of PRACA reports and of the corresponding reports for software, denoted S/W PRs. The PRACAs and S/W PRs can also be classified against specific subsystems.

- **Capability Reliability** — This category is particularly relevant to the ISS because the ISS is being assembled in stages over a period of several years, and its configuration and required capabilities for each stage are different. A predicted-reliability analysis is performed for each capability, and consequently for each stage. This analysis is based on the planned times between assembly flights, the predicted failure rates of the components, the system architecture, the profile of operations for each stage, and data pertaining to failures observed in flight.
- **Subsystem/Capability Dependencies** — The final piece of the ISS S&MA metric is the dependency of subsystem and stage capabilities. One relies on the ISS subsystems to realize the capabilities required at each stage. This dependency of capabilities upon subsystems provides an integrated system perspective that helps in the correlation of capability performance with anomalies and accepted risk across subsystems.

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