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A Rocket Engine Design Expert System

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ABSTRACT

The overall structure and capabilities of an expert system designed to evaluate rocket engine performance are described. The expert system incorporates a JANNAF standard reference computer code to determine rocket engine performance and a state-of-the-art finite elements computer code to calculate the interactions between propellant injection, energy release in the combustion chamber, and regenerative cooling heat transfer. Rule-of-thumb heuristics have been incorporated for the hydrogen-oxygen coaxial injector design, including a minimum gap size constraint on the total number of injector elements. One-dimensional equilibrium chemistry was employed in the energy release analysis of the combustion chamber. A three-dimensional conduction/one-dimensional advection analysis is used to predict heat transfer and coolant channel wall temperature distributions, in addition to coolant temperature and pressure drop. Inputting values to describe the geometry and state properties of the entire system is done directly from the computer keyboard. Graphical display of all output results from the computer códe analyses is facilitated by menu selection of up to five dependent variables per plot.

INTRODUCTION

The process of designing a rocket engine involves many complex domains of technical expertise (figure 1). Each discipline has a unique set of computer codes, a unique set of past experimental experience, and a specific set of constraints which guide the component design process. Overall engine size and performance parameters are determined by an analyst who is concerned with the overall mission and vehicle. The injector is often selected using existing experience based on past performance. Regenerative cooling channels and the thrust chamber design are also chosen for good historical performance reasons. Other areas of engine design include performance analysis of the expanding gases, design of a high performing expansion nozzle, predicting the atomization process of the chosen injector, and evaluating the combustion and injection processes for the possibility of combustion instability.

Designing a rocket engine also requires the solution of many multidisciplinary issues. Accurate design of rocket engine components assumes that an open channel of communication exists between the resident experts in each of the knowledge domains, and relies upon an iterative process to arrive at a solution. The injector designer needs to know the engine parameters and the propellant injection temperatures to design the elements. To do his job, the chamber designer requires the propellant injection temperatures and chamber geometry data to calculate the heat transfer to the regenerative cooling channels. The amount of energy injected into the chamber, transferred through the chamber wall to the coolant, and then reintroduced into the chamber is determined by successively using improved estimates as calculated by the computer codes.

The computer codes in use by the designer of each component have always been complex to run and to understand due to the necessity of modeling the physical phenomena as closely as possible. The task of running single-point designs, which are commonly derived by slightly varying previously run cases, is far easier than developing input datasets for a design from scratch. Even after the computer program accepts the input data, the user must be careful in interpreting the results.

As a result of the various necessary areas of expertise, the required interaction between these areas, and the complexity of each area's computational tools, some less-than-rigorous approaches to rocket engine design have been established in each discipline. Hard-earned experiences have been condensed to simplified "rules-of-thumb," the lack of open channels of communication between disciplines has resulted in "open-loop" approaches to engine design, and computer codes which make a compromise between technical thoroughness and ease-of-use and understanding are relied upon to a great extent.

To provide a rigorous solution to the problem of rocket engine design, the obstacles mentioned above need to be eliminated. All disciplines must be represented, if not in a completely thorough fashion, then by their "rules-of-thumb" which can be relied upon to provide engineering approximations to specific questions. Complex codes must give the engineer more than hard-to-read tables of output. They must have a user-interface which makes the codes easy to use, allows for the sharing of input data between more than one code, and provides the user easy-to-understand output information. The computer codes need to interact with each other, allowing for iteration towards a solution and design optimization. Finally, the codes need to be collected in a framework which allows for future growth of capability, upgrades of current functions, and inclusion of new computational modules.

To meet all of these goal will require many years of programmer's time and larger, faster computers, in addition to the continued evolution of the technical design codes. A method of providing the interface between user and computer program, and between more than one computer program, can be done through the use of an expert system shell. The Rocket Engine Design Expert System (REDES) prototype is an initial attempt to achieve the goals for better rocket engine design through these means. As well as encouraging and insuring proper utilization of the rocket engine evaluation codes, the first stage of the expert system design was to implement a method of collecting data from the user, sharing inputs and outputs between computer codes, and displaying the results. The expert system being designed is currently addressing the problems encountered in trying to keep track of the large amounts of data required to run the available evaluation codes. As the number of evaluation codes which are contained in the expert system grows, the amount of data required to run them will increase, also. The capabilities of REDES can be expanded to handle these new inputs in manageable steps and be used as a design tool at each stage of development.

EXPERT SYSTEM OVERVIEW

The approach taken was to construct the expert system within a shell in a modular fashion. Each part of the expert system was initially designed with a low level of complexity with the intention of increasing the complexity (and functionality) in an incremental fashion. For example, the initial analysis of the thrust chamber energy release is one dimensional equilibrium (ODE) chemistry, but the ultimate development of this portion of the program would include state-of-the-art finite-rate reaction models. This module accepted inputs from the simplified injector design module and provides outputs that are required as input to the three-dimensional regenerative cooling channel module. Once the computational loop is functioning properly for these simplified modules, the complexity of any one of the modules can be increased without greatly interrupting the flow of information between them. Upgrading the one-dimensional chemical reactions to include kinetic effects can be done later and only slightly affects the data flow between modules. Similarly, the complexity of existing modules can be increased or new modules can be added without having to make major changes to the fundamental structure of the expert system. Proceeding from the simple scheme to the more complicated can be done after other capabilities become operational and the interaction between parts is successfully demonstrated. In a similar manner, the functional complexity of the injector element design, injector face design, regenerative cooling channel evaluation, and the analysis of other parts of the engine, can all be initially integrated and tested at a low level of complexity.

The first "closed-loop" computation consisted of the injector design-energy release-regen cooling computational iteration. Specific computer programs which were included in the expert system include the Three Dimensional Kinetics (TDK) code[1], and the Rocket Thermal Evaluation (RTE) code[2]. Initial implementation of the TDK code only uses the ODE chemical reaction program contained in TDK as a subprogram.

The expert system can accept input data describing a rocket engine, determine the required number and size of coaxial elements for that engine, determine the energy release of the combusting propellants based on one dimensional equilibrium calculations, and calculate the heat transfer to a coolant flowing through the regenerative cooling channels of the engineusing a three-dimensional conduction code.

The structure of the data which define thrust chambers, nozzles, and other components of a rocket engine was determined by input data requirements of the included computer codes. The information which is collected for each component is only that which is required for the computer programs which are currently available. Therefore, if pertinent data for component #1 is A, B, C, and D, but code XYZ only needs A, B, and C, the input of D may not be provided for at the current time. In most cases, if the data is not needed, it is not asked for. Possible values for injector and propellant types were limited to facilitate the expert system development. Injector design is limited to coaxial tube injectors and the only allowable types of fuel and oxidizer are diatomic hydrogen and diatomic oxygen.

The form of the user interface was created to provide ease of use and understanding (figure 2). It consists of an "Engine Control" table (or *panel*) of parameters, divided into groups (called *subpanels*, such as thrust chamber, injector, for example), and each group has entries (also called *slots*) in the table where values can be input as well as table entries where calculated output values are displayed. If a value is entered into an input slot which is connected to a computation, the output value affected by the input slot will be updated immediately. Some calculated values can be computed in many different ways. For example, the thrust chamber diameter can be computed from either the injector face area or the contraction ratio and the area of the throat. Only one method of calculation has been currently implemented in the expert system. The flexibility of being able to calculate all possible quantities given a limited set of inputs is currently being sacrificed to avoid infinite self-referencing calculations.

An input-output relationship exists between the user, the subpanels, and the computer codes as shown in figure 3. The user provides inputs to the subpanels which compute output values in other subpanels or provide input values for the computer codes. Interaction with the program is through a menu selection or, in the case of numerical values, by directly typing them in from the keyboard. The method of accessing data, creating datasets, executing a FORTRAN program, and extracting the desired output data was implemented in REDES. When a

FORTRAN computer program is to be run, computer programs (called *methods*), written in the computer language LISP, perform the functions of collecting the necessary data, create a well-formed input dataset for the FORTRAN code, run the code, and finally, look through the output for necessary information and then store that information in the expert system format. This process is initiated by pushing a button (called a *method actuator*).

Computer codes ultimately provide the necessary data for conveying the computed information back to the user (figure 3) in the form of graphs. Display of the program results in graphical form was developed and extended to provide plots with multiple dependent variables. Figure 4 displays the panel on which the graphs are constructed. Method actuators are used to plot nozzle contours or X-Y plots. Nozzle contours are specified in the nozzle subpanel located on the Engine Control panel. Abscissa parameters and up to five ordinate parameters are specified on the graphic panel via pop-up menu selection. The plotted parameters can be from the same computer run or from two (or more) different runs. This allows comparative plots showing similar parameters from different engines or engine conditions.

SUMMARY

Designing a rocket engine requires the expertise of many disciplines which exist in both the analytical and empirical domains. Computer codes presently attack a portion of the entire problem at best, usually at the expense of user-friendliness or generality.

A prototype of a rocket engine design expert system has been designed using an expert system shell to encourage and insure the proper use of a wide range of codes. The development of the expert system is incremental starting with simple physical models and systems and progressing toward completely detailed systems using transient, three-dimensional state-of-the-art models. Energy release in the combustion chamber is presently modeled using ODE and the temperature distribution of the chamber wall is calculated with RTE. Currently, the injector design is limited to coaxial tube injectors using diatomic oxygen as the oxidizer and diatomic hydrogen as the fuel.

The expert system uses panels and subpanels to control input and output. Values which describe the different pieces of the entire rocket engine are directly input from the keyboard. Calculating or nondimensionalizing nozzle coordinates and imposing a minimum coaxial gap size to determine the number of injector elements can be performed at the touch of a button. Output values are displayed graphically in user-specified plots with up to five dependent variables per plot.

The ultimate goal of being able to optimize an engine design considering all of the contributing, complex factors using a closed loop process is becoming a reality with the development of the Rocket Engine Design Expert System.

REFERENCES

1. Nickerson, G.R., Coats, D.E., and Dang, L.D., "Two Dimensional Kinetic Reference Computer Program, (TDK)" NASA CR-178628, 1985.
2. Naraghi, M.H.N., "RTE-A Computer Code For Three Dimensional Rocket Thermal Evaluation" NAG3-759, 1988.

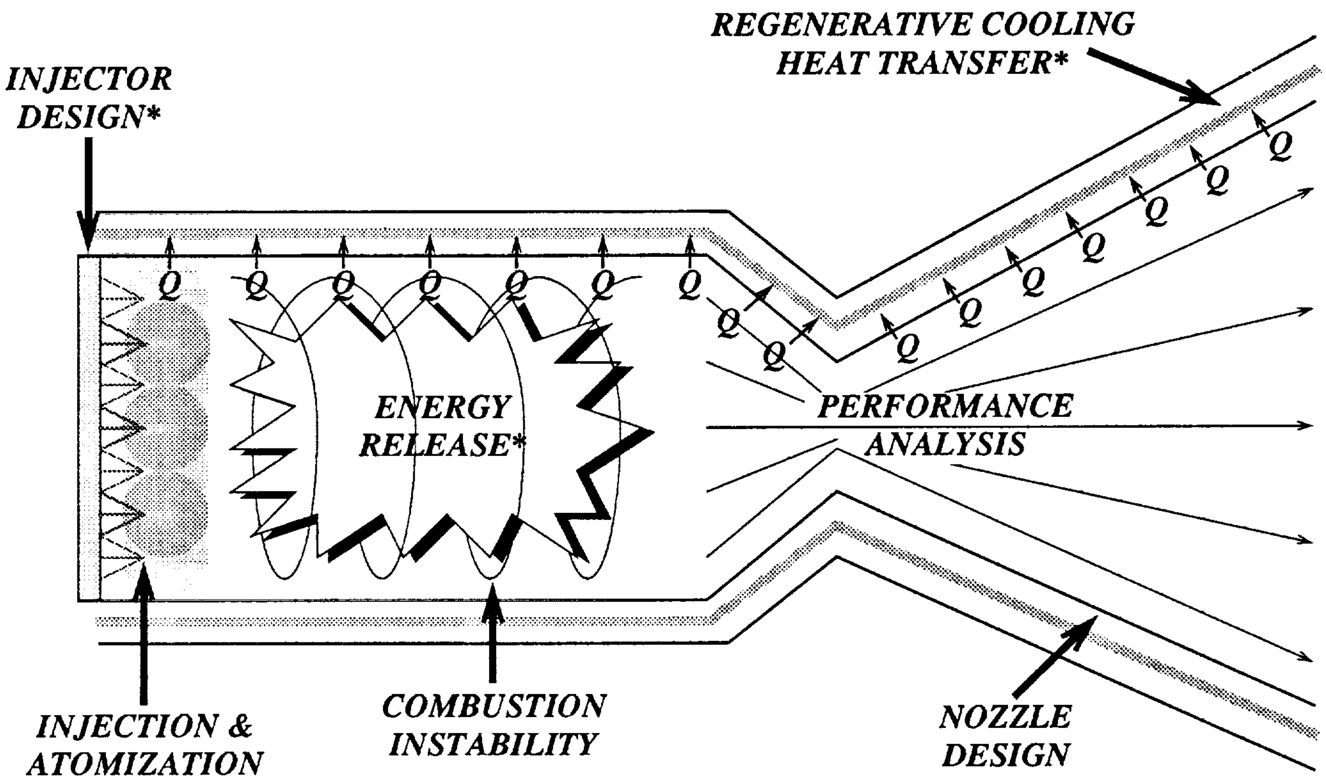

Figure 1. There are numerous technical disciplines which are involved in the design of a liquid rocket engine. Those which appear with an asterisk (*) are currently included in the Rocket Engine Design Expert System Prototype.

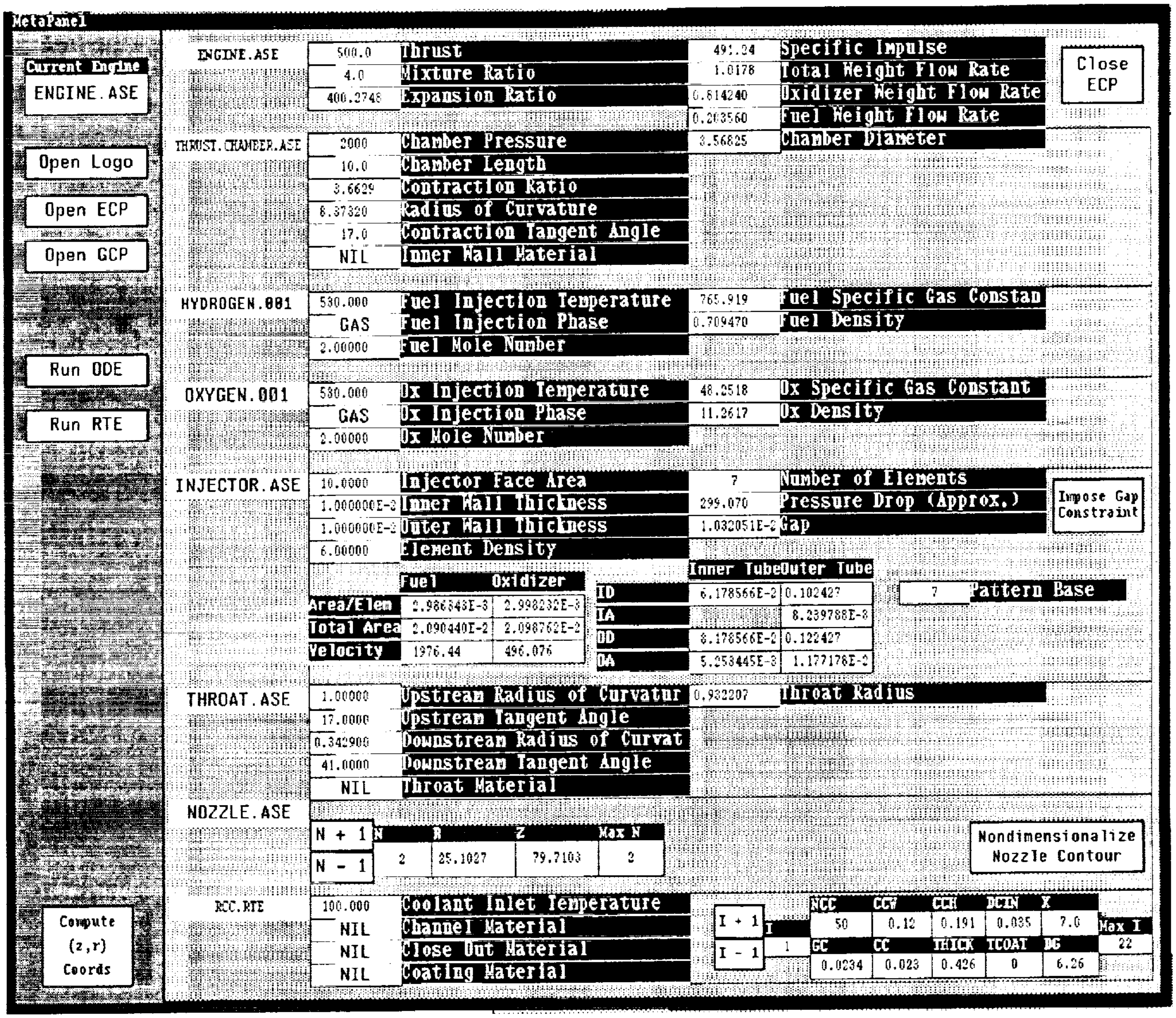

Figure 2. On-screen display of the Engine Control Panel. Visible portion of metapanel is dark gray column on the left and individual subpanels are to the right of each subpanel identifier display.

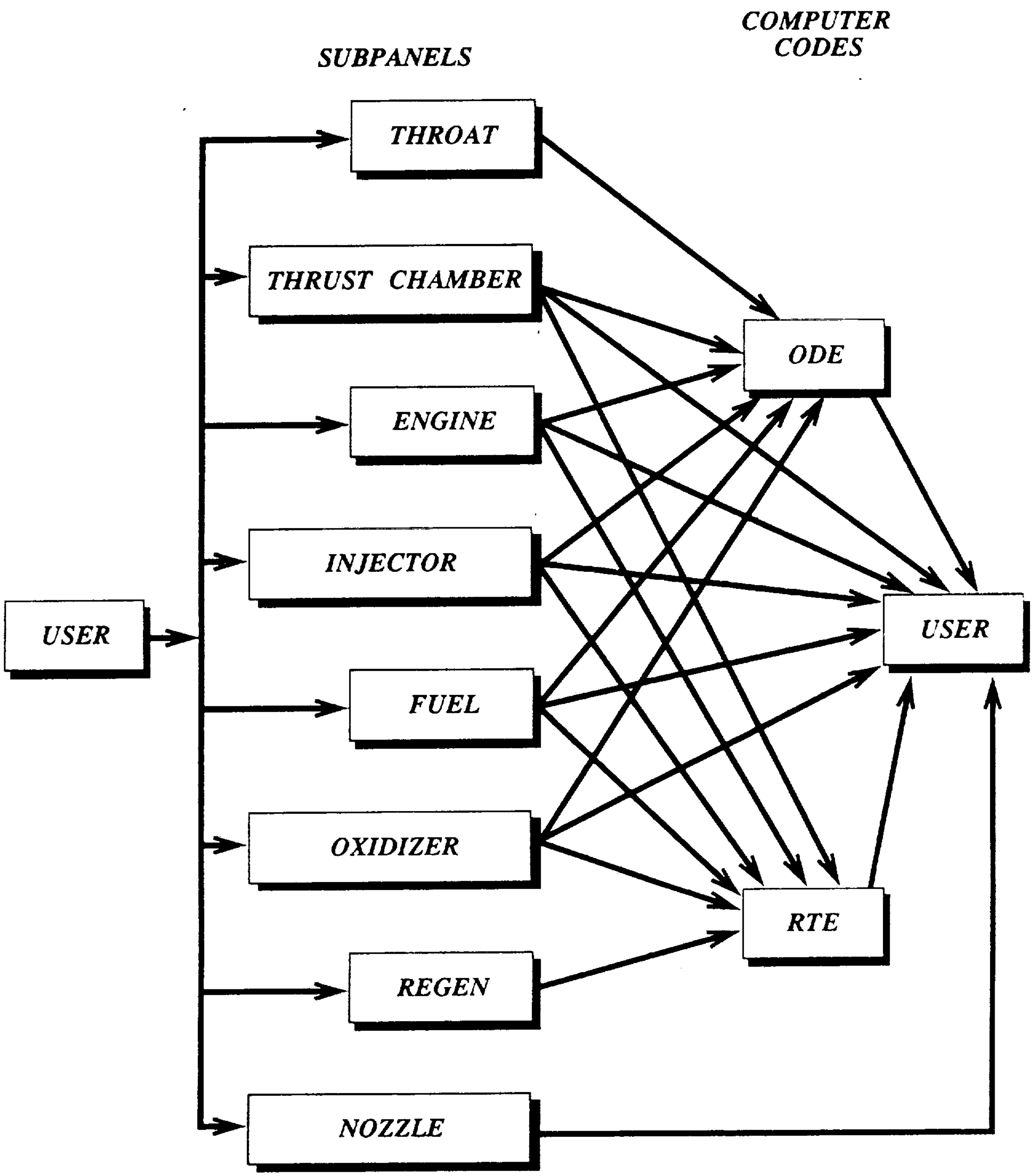

Figure 3. An input-output relationship exists between the user, the subpanels, and the computer codes. Subpanels and computer codes both provide output back to the user.

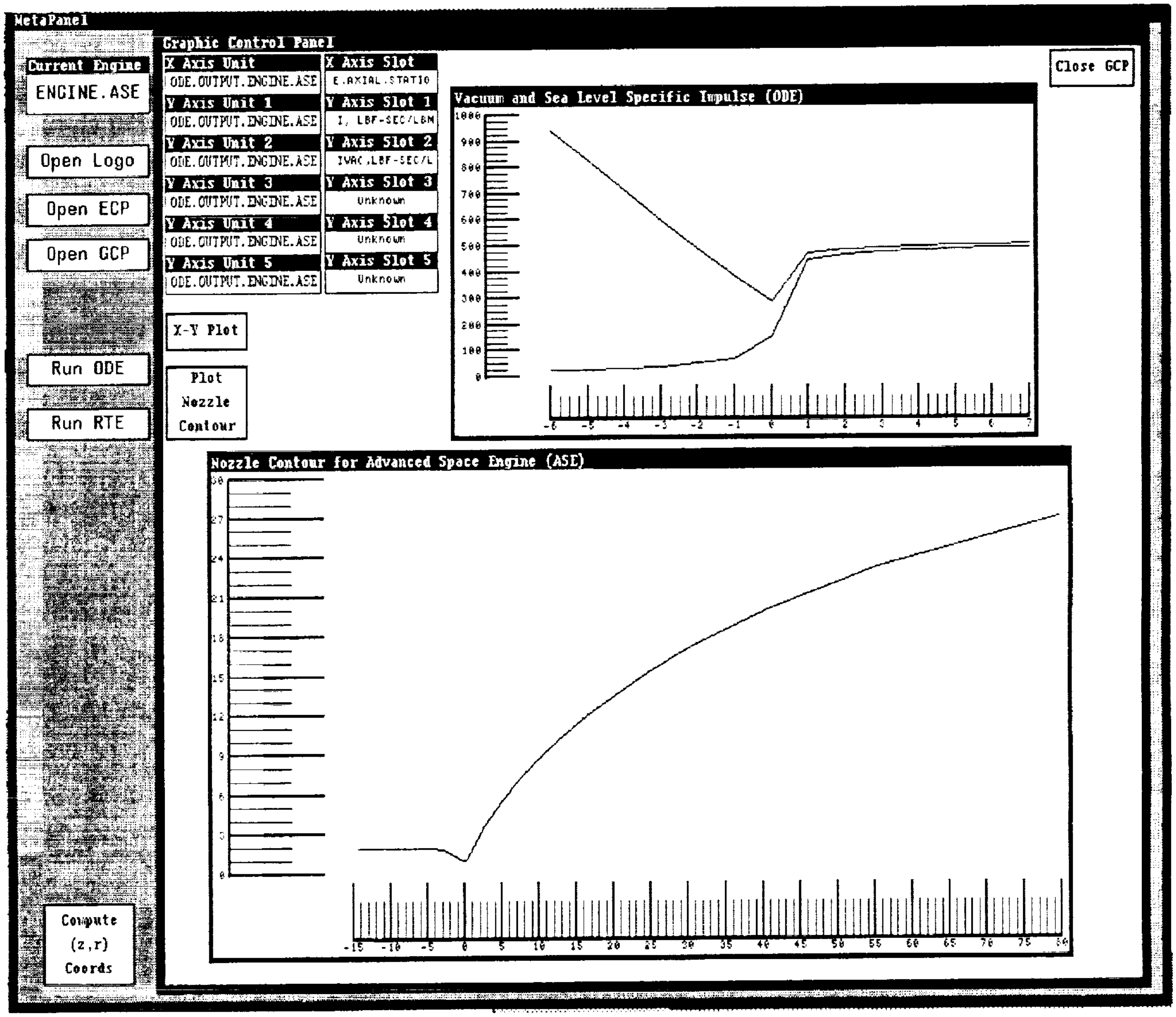

Figure 4. On-screen display of the entire Graphic Control Panel showing nozzle contour of Current Engine (ENGINE.ASE) and a specific impulse plot from an ODE evaluation of the Advanced Space Engine.

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