Book Review

Thermofluiddynamics of Optimized Rocket Propulsions by Dieter Straub, Birkhauser Boston Inc., 1989, 270 pp, $95.00

The main subject area of this book, namely the computer analysis of rocket combustion gases in a flowing stream, concerns a very specialized branch of rocket propulsion. The book describes a particular set of refinements to the analysis and the computer program (originally undertaken by the NASA Lewis Laboratory about 20 years ago) for determining the gas composition, average gas properties, gas temperature profile, and performance of rocket propulsion systems once the chamber pressure (at the injector end of a liquid propellant thrust chamber), chamber/nozzle geometry and size, and fuel/oxidizer composition are known.

The principal contribution of this book is a new approach, called the Munich method, which is claimed to be superior to the NASA method. Any attempt to improve the algorithms and better simulate the actual phenomena is laudable. Straub has helped with our understanding of the models and pointed out some areas of improvement. For example, it includes a complex approach to determine the pressure loss due to the acceleration of combustion gases in a chamber with low values of exit to throat area; an ability to include the heat loss to the regenerative coolant (it neglects heat loss to precombustion chambers or radiation losses), making it easier to expand the model in some ways; and a somewhat more elegant method of analysis of the thermochemical processes. Although the Munich method attempts to include an optimization subroutine, the criteria for optimization may not be the proper ones.

While such improvements are useful, they are not new. The early rocket designers (1930-1950) included simple corrections for heat transfer and chamber pressure drops (which had been done by just reducing the effective chamber pressure by the pressure drop calculated from flow in pipes); they were mathematically crude compared to the analyses in this book, but they were effective and may still be useful.

This type of rocket gas analysis today is understood and practiced by perhaps 20 people worldwide. There is a larger number of experts who use these and similar computer programs in companies, universities, and government laboratories, but they usually do not attempt to improve the algorithms.

The author limits his examples and his analysis to the very simple set of simultaneous chemical reactions occurring with the combustion of liquid oxygen and liquid hydrogen, because that seemed to have been the interest of his sponsor. He does not mention other liquid propellants or solid propellants, where the chemical reactions, alternate geometries, two phase flow, or the equations of state become more complex.

It is well known that the resulting distribution of reaction species, pressures, and temperatures in the chamber/nozzle flow paths are influenced by a number of physical phenomena. For example, the author states (p. 16) that effects of regenerative cooling, turbulence, mixing beyond the injector section, combustion chamber oscillations, nonequilibrium reactions, and shock wave reflections are usually neglected in this analysis; later in the book, he attempts to correct for a couple of these. He also implies that the thermochemical properties of the gas species are not well known under some of the rocket operating conditions. He does not mention some of the other key phenomena that can also cause errors but are also usually neglected, namely the viscous friction and heating in the boundary layers (which can be quite thick in large nozzles), the design of the injector (which can have a big effect on the combustion efficiency), the two-dimensional nature of the gas flow, the changes in thrust caused by ambient air flow, the nozzle contour, or the wall surface roughness and reflectivity. The point this reviewer wishes to make is that some of these phenomena can have an equal or larger effect on the results of this analysis than the changes from the NASA to the new Munich method of analysis treated in this book.

The tables in the book give comparisons between actual test data (some of which may be incorrect, such as the I_{sp} of the SSME) and calculated results from both the NASA method and the Munich method. One finds that the differences are small, usually within 1% and in a few cases up to 3%. Since several of the phenomena that have been neglected in the analysis can have an equal or greater effect on the results, one has to wonder if the additional sophistication of the analysis or the resulting complex computer program are worth the effort. The book is devoted to a relatively minor improvement in the calculated performance results. Even though there are approximations and known flaws in relatively simple codes like the NASA code, the results are usually satisfactory to rocket designers, particularly in the comparison of one propellant combination to another or one mixture ratio to another.

The book is difficult to read or digest, and the explanations for the basic phenomena are sometimes not very lucid. Some statements made about the Navier-Stokes equations are questionable. A rationale of why the free enthalpy must be minimized or a definition of chemical equilibrium would have been helpful. There are a number of symbols used in the text that could not be found in the list of relevant symbols.

A number of organizations have developed their own refinements of this kind of thermofluiddynamic analysis for their own in-house use to fit their needs and rocket products. For example, some solid-propellant makers have included a two-phase flow capability, and another company has included diffusion effects that cause a nonuniform two-dimensional distribution of gas species in the exhaust of rockets that burn propellants with hydrogen.

This book is not recommended for the majority of rocket propulsion students or engineers actively working on rocket engines; they have no need or interest to become knowledgeable in this specialized area. The book is strictly for experts in thermofluiddynamics. Even for them, it will probably require several weeks of intensive study before he or she can truly comprehend the book, review the quoted references and the computer approach. Such a study can be useful to those who wish to improve the algorithms further or include additional phenomena in the mathematical simulation; but it will help them only if the phenomena they wish to simulate are those that were selected by the author.

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