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Technical Comments

Comment on "Evaluation of the Munich Method for Calculating Rocket Engine Performance"

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THE purpose of these comments is to add some information in connection with Dr. Frank Zeleznik's recently published article,[1] which evaluates Dr. Straub's "Munich Method"[2] for calculating theoretical rocket performance. In his book, Dr. Straub extols the virtues of his own method, while simultaneously harshly criticizing the NASA Lewis code.[3] Dr. Zeleznik not only refutes Dr. Straub's claims of superiority, but shows in explicit detail a number of errors in the Munich Method's working equations, momentum conservation, and entropy of the combustion state. Nothing needs to be added to this careful analysis of the subject. However, I believe that there may be some interest in some pertinent events that took place at a small meeting held in November 1991, at the University of Alabama, Huntsville. In attendance at this meeting were Dr. Zeleznik, Dr. Straub, Mr. Klaus Gross, and I, in addition to about 8 or 10 other individuals. Mr. Gross is a NASA rocket design engineer stationed at the NASA Marshall Space Flight Center. One of the tools that he uses as an aid in his design work is the NASA Lewis Chemical Equilibrium and Rocket Performance Program.[3,4] Understandably, when Mr. Gross read Dr. Straub's book impugning the theoretical basis and results of the NASA Lewis code, he was rightfully concerned. He therefore arranged for the aforementioned meeting in order to resolve conflicting theory, methods, and results of the NASA Lewis and Munich codes.

I will limit my comments on the discussions that took place at the Huntsville meeting to only one topic: the issue of accuracy of calculated results obtained from the Munich Method and the NASA Lewis code. On pages 190–211 of his book,[2] Dr. Straub presents tables of theoretically calculated rocket performance parameters for six different hydrogen-oxygen rocket engines. For the purpose of comparison with the Munich Method results, I ran the identical cases with the NASA Lewis code. Table 1 presents a comparison of the two sets of calculations for several rocket performance parameters: vacuum specific impulse I_{vac}, mass flow rate $\dot{m}$, and momentum $P + \rho u^2$. These results were presented at the Huntsville meeting. Of these three parameters, vacuum specific impulse compares the closest, differing for all six cases by only 0.6–1.1%. However, momentum differs by 1–13%, and mass flow rate by 2–30%. Obviously, both sets of calculations cannot be correct. As large as some of these differences are, they would have been even larger had Dr. Straub actually used his own recommended method for calculating combustion entropy. As Dr. Zeleznik has pointed out, by using the NASA Lewis method for calculating combustion entropy rather than his own incorrect method, Dr. Straub obtained results that, "while still incorrect, are not totally ridiculous."[1]

At some point in the meeting, to my great surprise, we were informed that Dr. Straub had already revised his program which he is now calling "Munich Method II." That morning, Mr. Gross was able to run one of the test cases with the revised code, but there wasn't time to review the results. I offered to prepare a chart comparing the results of the Munich I and II and NASA Lewis codes.

The results of that comparison are most revealing (Table 2). I will compare only two parameters to illustrate the results: I_{vac} and $\dot{m}$. The calculations are for the Space Shuttle Main Engine (SSME), and the specific impulse value is for an area ratio of 77.5. The results are for the NASA Lewis code (my calculations), the Munich I method (Straub,[2] p. 202), and the Munich II method (results presented at the Huntsville meeting).

The Munich I results for I_{vac} are not too far off—higher than the Lewis value by 0.8%. However, the corrected Munich II value of 466.2 is much closer, differing from the Lewis value by only 1 unit in the fourth figure (0.02%). The Munich I value for $\dot{m}$ differs considerably from the Lewis value—by 6%. The corrected Munich II value is much more nearly accurate, differing from the Lewis value by only 0.2%.

At the Huntsville meeting, I inquired from Dr. Straub how he could possibly justify his harsh criticisms of the NASA Lewis code. His reply was that the criticisms were intended for an earlier version of the code which contained a rocket model with an infinite area combustion chamber rather than a finite area chamber which is included as an optional model in the present code. However, his explanation is unsatisfactory for the following reason. In a NASA report[4] it was shown that, for expansion to the same area ratio, the theoretically calculated specific impulse is essentially the same (within 0.05%) for both rocket models. Therefore, for the purpose of comparing the theoretical performance of various rocket propellants, either model is satisfactory. It appears that Straub's criticisms were based on his mistaken conclusion that the large differences between his and NASA Lewis calculated results were due to his superior thermodynamic theory, rocket model, and mathematical techniques rather than due to gross errors on his part.

Now that Dr. Straub has corrected some (all?) of the errors in Munich I, where does this leave the matter? In addition to a number of misstatements concerning the NASA Lewis code, Dr. Straub's book[2] contains a number of tables with incorrect data together with explanations on how to improve performance of actual rocket motors based on these erroneous theoretical results (pp. 190–211). As a minimum, I believe it would be appropriate for Dr. Straub to write an acknowledgment that his analysis and computed results, as well as his criticisms of the NASA Lewis code, contain errors and that this acknowledgment be published in some appropriate journal such as this one. I believe such an action would be helpful in putting an end to this unusual affair.

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Table 1 Comparison of NASA Lewis and Munich Method theoretical rocket performance parameters

Rocket engine				Theoretical performance parameters					
	Operating conditions			I_{vac}, m/s		$\dot{m}$, kg/s		Momentum, bar	
Type	Chamber pressure, bar	Oxidant-to-fuel weight ratio	Area ratio	NASA	Munich	NASA	Munich	NASA	Munich
J-2	53.1	5.552	27.5	445.3	451.5	232.6	303.0	53.1	60.5
J-2S	85.9	5.85	39.8	452.7	458.4	266.9	288.3	85.9	89.4
SSME	207.9	6.00	77.5	466.2	469.9	468.8	497.0	207.9	213.2
ASE	140.0	6.00	400.0	485.9	489.1	19.0	19.4	140.0	142.2
HM7-B	35.9	5.30	82.9	467.2	470.2	13.2	13.8	35.9	36.8
HM60/1	103.6	5.70	45.0	457.1	461.0	234.1	253.1	103.6	107.5

Table 2 NASA Lewis and Munich I and II performance parameters

	NASA	Munich I	Munich II
I_{vac}, m/s	466.1	469.9	466.2
$\dot{m}$, kg/s	468.8	497.0	470.0

References

[1]Zeleznik, F. J., "Evaluation of the Munich Method for Modeling Rocket Engine Performance," *Journal of Propulsion and Power*, Vol. 9, No. 2, 1993, pp. 191–196.

[2]Straub, D., *Thermofluiddynamics of Optimized Rocket Propulsions: Extended Lewis Code Fundamentals*, Birkhauser Verlag, Basel, Switzerland, 1989.

[3]Gordon, S., and McBride, B. J., "Computer Program for the Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks, and Chapman-Jouguet Detonations," NASA SP-273, 1971, Interim Revision, March 1976.

[4]Gordon, S., and McBride, B. J., "Finite Area Combustor Theoretical Rocket Performance," NASA TM-100785, April 1988.

Comment on "Evaluation of the Munich Method for Modeling Rocket Engine Performance"

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THE review of a book[1] addressed mainly to experts, which covers six pages and appears 4 yr after the book's publication is a spectacular event and demands comment. This comment consists of six narrow parts and intends to reduce the article's polemics to a fair, rational level.

1) In order to make space vehicles reusable, some extreme requirements must be met for the propulsion system. For the design of the Space Shuttle Main Engine (SSME) in particular, the LH-LOX combustion with gas temperatures above 3000 K is the sore spot.

The risks involved have already been recognized in working with SATURN V-engines. Therefore, some members of the NASA-Marshall Space Flight Center (MSFC), Huntsville, Alabama, recommended a fundamental reconsideration of the "Rocket Performance Theory" whose computation code in the version NASA SP-273 (March 1976) is in worldwide use today.

In an in-house study Lockheed (1969) tried to secure a realistic assessment of the gas temperatures which are experimentally not determinable in the nozzle throat. The results, documented in a technical brief not yet officially available, were unanticipated. In the representative test case of the J-2 engine, the agreement between theory and experiment allowed experts to conclude that the real effects were only insignificantly different from Lockheed's modification of the Lewis Code. Furthermore, the new theory explicitly includes the finite area combustion processes along the combustion chamber, thus predicting considerably lower and more manageable gas temperatures in the nozzle throat cross section. For the J-2 engine, Lockheed's "Constraint Entropy Maximization Concept" forecasts a combustion exit temperature which ranged about 700 K (!) lower than that indicated by the Lewis Code. This sensational result was—surprisingly enough—confirmed 12 yr later by Continuum Inc., Huntsville, Alabama, a contract with NASA.

In order to find a conclusive answer, NASA organized a first workshop at the end of February 1985, attended by delegates of the MSFC and Continuum Inc. as well as by U.S. experts from various universities, and S. Gordon as one of the two authors of the NASA report SP-273. I then accompanied Prof. Straub, the only European expert who was invited by the MSFC.

In a final communiqué unanimously passed by all the experts, the "Constraint Entropy Maximization Concept" was rejected as unfounded. It was recommended that the Gibbs-Falk thermodynamics should be investigated and, if found suitable, be used as the theoretical basis for an "Extended Lewis Code." The participants trusted, of course, that intellectual integrity and scientific honesty require proven theorems referring to the theory as a whole, or to concrete application to be deduced from a relevant hierarchy of general axioms. S. Gordon himself, who shared the committee's resolution, mentioned no results at all of any updated Lewis Code version with rocket performance calculations for finite area combustion chambers. Nor did he even try to impose ex cathedra any method of his own for the calculation of complex chemical equilibria in one-dimensional gas dynamic modeling processes. Dr. Zeleznik was invited, but he could not attend due to unapproved travel at Lewis Research Center.

2) Prof. Straub's "rocket book"[2] is a response to the experts' resolution of February 1985. It was not financed by NASA but by the German Federal Ministry for Research and Technology; for that reason, the book contains passages concerning fundamentals of thermofluiddynamics that the sponsor insisted be included.

The essence of the book concerns the following problem: a gaseous combustion mixture flows under high pressure and high temperature first through a finite area combustion chamber and then through a Laval nozzle where it is accelerated up to supersonic velocity. The NASA report SP-273[3] gives

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