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Chapter 10

Fundamental Scientific Questions in the Early Period of Rocket Propulsion Development[1]

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This memoir may be regarded as a sequel to the series of memoirs presented at previous Congresses of the IAF/IAA by Frank J. Malina, the American pioneer in rocketry who died during the past year. It is dedicated to his memory. The author had the good fortune to be his professional collaborator in rocketry during the early critical phase in the United States, as well as his personal friend. The author was also a close collaborator in this program and a friend of Theodore von Kármán, a founder of the International Academy of Astronautics and its first President, who led this early American research effort. Both Malina and von Kármán had important roles in shaping American rocketry and space exploration; and indeed, their roles acquired world significance as the years went by.

To those of us who were participants in the search for solutions to the many problems that arose in those years and who are therefore sensitive through experience to the various alternatives, it is immediately evident that today's rocket propulsion technology flows, in major ways, directly from the results of the work of the team that those two men formed and led. We have only to take a quick look at the types of liquid propellant rocket engines in use today—the injectors, the chamber configurations, the nozzle designs, the cooling techniques, etc.; and in the types of castable, composite solid propellant engines—the grain configurations, the igniters, etc.; to appreciate immediately the clear line from those early years.

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[1] Presented at the Sixteenth History Symposium of the International Academy of Astronautics, Paris, France, 1982.

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In this paper, I will present some of the critical issues that arose in the very earliest stage of liquid propellant rocket engine development. Much of the wisdom that governed the final technical choices was due to von Kármán and Malina; the author was their associate and the performer of the investigations in the particular problems described here. In recounting this early history of the search for technological solutions, it is hoped that useful principles will become evident to the reader on how scientific minds approach and solve difficult engineering questions.

This history goes back to the 1940-1942 period at the California Institute of Technology, when the principal question facing Theodore von Kármán and his little group of post-docs was simply this: Is high performance rocket flight feasible, or are there fundamental thermodynamic, physical, and/or chemical kinetic barriers that stand in the way? More specifically:

1. Do chemical rocket propellants, even the most energetic combinations known to chemists, possess enough energy to permit, say, escape from the Earth? Is there a simple equation that might serve to reassure us, that the long-range objective is indeed possible, granted that some formidable engineering problems would have to be solved? No rocket had yet achieved significant flight performance.
2. Can the combustion reaction be carried out with high efficiency in a volume small enough to be acceptable in a weight-limited rocket vehicle, when the only practical, high-efficiency combustion chambers known to engineers at the time were a thousand-fold and more greater than anything that could fly? Were there fundamental chemical kinetics limitations that would prevent us from reaching the goal of a high performance rocket that could pull away from the Earth's gravitational field? Were the practical combustion engineers justified in their skepticism?
3. Can a long-duration rocket motor based on liquid propellants be regeneratively cooled so as to permit steady-state operation without burnout, and especially, would this be possible for the high temperature, efficient combustion that would be needed in order to make space flight a reality? If one believes that rocket motors are similar to conventional power plants, with their typical 25 percent to 50 percent heat rejection to the coolant, the whole idea of a regeneratively cooled rocket motor would be impossible. Was there a practical way around this seemingly difficult obstacle? No one had yet found one. Was there a fundamental reason?
4. Is stable combustion possible? True, instability had never posed an insurmountable barrier to man's development of novel systems; a means to stabilize any kind of novel system had always been found in the past. Still, the question had to be raised at the outset: would a basic source of instability be encountered that might not be solvable in a straightforward manner?
5. Can one find a practical self-pumping system that could generate the required propellant injection pressures on a sustained basis that would be light enough to fly in a high-performance rocket vehicle? Engine-driven pumping systems depend on air for combustion power, and a self-contained air supply would be far too heavy to carry along, as in the torpedoes of the time. Pressure-feed systems are also too heavy. No other practical systems were known at the time. Would this problem turn out to be the "Achilles' Heel" of the escape-from-the-Earth problem?

The Caltech group, led by the thinking of von Kármán, posed these basic questions early in the beginning of the rocket program. In fact, assailed by doubts on all these points, the attitude of von Kármán was to go slowly, at first, not to promise too much, to keep a "low profile" about the project, to hold spending at a very low level, to hold back on hiring so-called permanent staff, and generally to refrain from making a firm commitment. We must remember, in the year 1940, despite the previous 20-odd years of work by Robert H. Goddard the American rocket pioneer, everything that was known, either by practical test or theoretically, pointed toward negative answers to the above five questions. Could the work of Goddard have been misleading? Why, after two decades of work, had high performance rocket flight eluded him? Were the above problems indeed so fundamental as to make rocket flight improbable, or worse, impossible? If the barriers could be shown to be fundamental on theoretical grounds, then there would be no point in making all these efforts, and no point in taking the sponsor's funds, tiny though they were (less than $20,000 per year). The years 1940-1941 were the critical ones for von Kármán and Malina, while these questions were being analyzed and a decision made to go forward or not.

One by one, the above-listed questions were resolved, all of them in the affirmative, and the decision was reached by von Kármán that high performance rocketry would indeed be possible. It would now be the task of clever engineers to work out the practical solutions. How these problems were resolved, at first theoretically and then by confirming experiments, is explained elsewhere in scientific and engineering terms.

Although these questions were faced also by the German rocket engineers during the decade prior to 1942, none of their accomplishments were known in the United States until nearly the end of World War II (late 1943, to be exact). Our purpose in briefly discussing this early history of Caltech rocket work was to set forth the fundamental questions identified, the questions that had to be resolved in order to make high performance rocket flight possible, and to set forth the scientific logic of the attack on these questions as it was pursued by the von Kármán-Malina team.