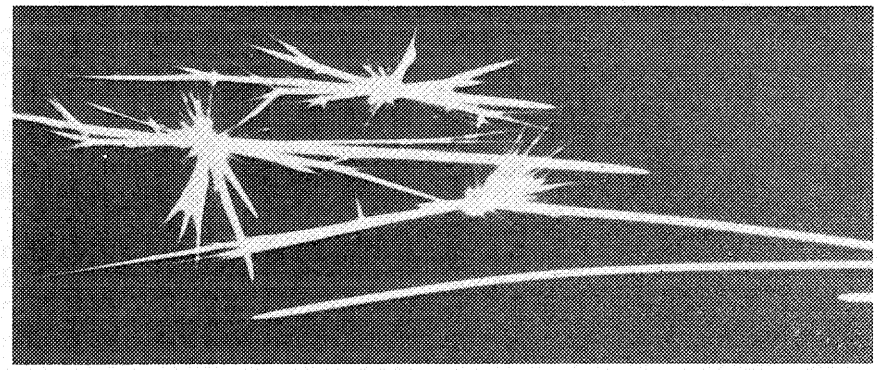
STATE OF THE ART — 1962



Propellants and Combustion

BY STANFORD S. PENNER
INSTITUTE FOR DEFENSE ANALYSIS, WASHINGTON, D.C.
CHAIRMAN, ARS PROPELLANTS AND COMBUSTION COMMITTEE

During the last year, several significant publications dealing with propellants and combustion were published. The most voluminous and extensive effort is represented by the proceedings of the *Eighth International Combustion Symposium*, which was devoted to papers dealing with combustion research on rocket engines, ions in flames, and other basic topics such as laminar flame theory, detonations, etc. The American Rocket Society contributed Vol. 6 of the series on *Progress in Astronautics and Rocketry*, which deals with detonations, two-phase flow in nozzles, and combustion in liquid-fuel rockets. Since the writer served as chairman of the Papers Subcommittee of the Combustion Symposium and as one of the editors of the ARS publication, he is clearly in no position to offer objective comments on these two productions. However, at the risk of overstepping the bounds of propriety, he will nevertheless assert that careful study of the papers published in these proceedings, as well as examination of original articles contributed to *Combustion and Flame* and the rather surprisingly small number of papers published in the *ARS Journal*, will justify the conclusions that follow.

1. Significant progress has been made in our understanding of the essential features of the steady combustion processes in a (one-dimensional) liquid-fuel rocket engine.

2. The burning mechanism and decomposition rate of ammonium perchlorate are now well understood, except for some details concerning the low-pressure deflagration limit, that is, the limiting pressure below which the propellant ceases to burn.

3. The problem of two-phase nozzle flow is well described insofar as the gross features of the physical processes are concerned.

4. Shock and detonation phenomena continue to be of fundamental interest and importance. Progress is being made in clarifying the microscopic processes not only in gas mixtures but also in the condensed phases. There is growing evidence that the structure of the detonation waves may not be steady (on the microscopic scale) although the wave front is essentially flat.

5. The microscopic descriptions of composite propellant burning mechanism and of resonance burning in solid rockets require further elucidation. Nevertheless, in spite of significant experimental and theoretical developments, we regard it as unlikely that a useful prediction can ultimately be made of burning rates on the basis of chemical composition and of stability behavior on the basis of chemical composition and geometric considerations.

6. No real progress has been achieved in connecting liquid-rocket instabilities with microscopic processes. But, a useful phenomenological methodology has been developed for correlating observational results.

7. The important problem of supersonic burning is receiving the attention which it deserves and preliminary results have encouraged some people to the point where they are willing to state that the design of the combustion chamber will not be a major stumbling block to the development of hypersonic ramjets. If this optimism is justified remains to be seen.

8. Hybrid rockets promise to become the next significant target for research on combustion processes motivated by propulsion development.

9. The combustion processes of metals have been studied and some interesting suggestions have been made concerning combustion mechanisms.

10. Much remains to be learned about the nature of the elementary processes responsible for the production of ions and electrons in flames.

Some general observations with regard to advances in propellant technology can also be made. Today, N_2O_4 with a mixture of UDMH and hydrazine is an operational propellant system. Liquid hydrogen-liquid oxygen engines are currently under extensive development. Composite solid propellants using high-weight fractions of aluminum particles are finding daily use. It has now become generally accepted that large perform-

(*Reprinted from* Astronautics, *November, 1962*)

ance increases in either storable liquid or solids or even liquid hydrogen-liquid oxygen can be obtained only through addition of the light metallic elements. Research in solid propellants thus takes the direction of either removing partially the heterogeneous oxidizer by modification of the binder to contain oxidizer elements so that larger mass fractions of metals may be added or complete removal of the oxidizer and reverting to hybrid technology. Similarly, metal addition in liquids can be obtained by suspension in gels. Thus the search for thixotropic gelling agents for liquid propellants that will permit suspension of reasonable quantities takes on some significance.

The theoretical advantages of fluorine-liquid hydrogen with respect to performance and of fluorine-hydrazine for extended early space missions permits fluorine to keep its place in the propellant spectrum. In the opinion of some, the disadvantages of fluorine may overshadow the apparent gains and the efforts associated with this propellant are much smaller than those with other oxidizers.

Four major symposia dealing with propellants and combustion were held during 1962. These were the AGARD Colloquium on "High-Temperature Phenomena" in Braunschweig, Germany, during April; the Ninth International Combustion Symposium at Cornell Univ. during August; an ARS-sponsored specialist meeting on "Ions in Flames and Rocket Exhausts" at Palm Springs, Calif., during October; and a group of tutorial papers at the ARS Annual Meeting in Los Angeles during November. This heavy schedule of combustion symposia attests to the vigor of effort in this field as well as to the fact that combustion researchers burn up a great deal of energy and time in attending meetings. The detailed technical summary of the accomplishments of the 1962 symposia will be left to the next Annual Review. However, the preliminary conclusion of one indefatigable combustionist who attended nearly all four of the meetings is that the previously itemized conclusions remain invariant, that real progress is almost undetectably slow, and that serious consideration should be given to the definition of crucial studies by the stalwarts working on propellants and combustion.

Acknowledgment

The author is indebted to Dr. I. Glassman for contributing the discussion on propellant technology.