

Foreword

This book is a translation, with some slight adaptations, of *Technologie des propergols solides*, published in French in 1989. 743 606

There are few books on solid propellants and their use in rocket propulsion, and few of these present a comprehensive review of the field.

There are many reasons for this. For the most part, applications of this technology, with the exception of fireworks displays, have been limited to the fields of advanced armament and space activities. Therefore, most of it has been protected by industrial or military security classifications. It was thus necessary to wait for the moment when a significant quantity of data would be disclosed through open literature or patents.

These restrictions on the free flow of information led to different designs and methods in different countries. In France, for instance, there has been intensive use of trimmed axisymmetric grain designs with high loading fractions which have not been developed in any other countries, and for which the design and production methods were protected by a "secret" classification for a long time. In the USSR a very specific composite propellant formulation has been used in a family of missiles, with a binder that uses a derivative of a terpenic resin found only in the Ural forests of the USSR.

The technology of propellants is, like other technology, subject to the influence of fashionable trends. In France today, for example, Finocyl grain designs are currently popular. The main reason for this is probably that Finocyl geometries are very adaptable to various flow rate or thrust requirements. There are, however, cases where a simple star-shaped design would have satisfied the main requirements, and also offered some better secondary characteristics.

While the original objective was to present, to the extent possible, a universal body of knowledge, factors such as restricted information flow, specific industrial developments in various countries and fashionable trends have sometimes made this difficult. Readers may therefore find a French flavor to some of the chapters.

As already stated, we tried to cover all aspects of the field, and consequently this is a long book. We had to be as concise as possible on each subject; therefore we often refer the reader to what we feel is essential material for additional information. One original intention was that each chapter should be readable independent of the others, implying a great amount of redun-

dancy. Because of space limitations we discovered that this could not be done. Therefore, some chapters refer to other chapters. This practice was, however, kept to a minimum, and we used a traditional approach: each chapter uses concepts already developed in previous chapters.

After a first chapter reviewing the fundamentals of rocket propulsion, the second chapter develops all the descriptive aspects. The second chapter is recommended to anyone who is interested only in reading about one of the more specialized subjects found in later chapters. The subsequent chapters present the specific design methods and the theoretical physics underlying them. These are chapters where, after the fundamental mechanisms involved in the working of propulsion systems are presented, the rules of the art and specialized engineering methods are then deduced.

The last part of the book deals with the industrial production of the most important motor component: the propellant, and the inert materials, such as thermal insulations and bonding materials.

Some subjects of common interest to different chapters are covered in only one of them. Hence, processes used to manufacture composite propellants, used for composite double-base propellants (Chapter 11), are covered in Chapter 10. Non-destructive testing techniques used for every type of grain are also found in Chapter 10. Some mechanisms for the transition from deflagration to detonation are described in Chapter 11. The decomposition of nitrate esters and critical dimensions for cracking by internal pressure are discussed only in Chapter 9; vulnerability issues are discussed in Chapter 8, etc.

All authors who contributed to this work belong to the same company: Société Nationale des Poudres et Explosifs — SNPE. The reason for this is quite simple. SNPE originated from a famous official French governmental organization: the "Service des Poudres". For several centuries this organization held the monopoly in France for the production of "explosive substances" (substances that can deflagrate or detonate). During the 19th century and the first part of the 20th century it was one of the great French chemical groups where fundamental research in the field of physical chemistry was most advanced. SNPE has kept the mandate, for reasons of national interest, to develop all types of products for propulsion applications and for all basic research programs in this area, differing from most other countries, where companies often specialized in only one family of products.

Daniel Quentin had the original idea for this project, and stimulated the first drafts. The requirements of his professional activities took him very far away from France, making it impossible for him to participate directly in later drafts. Even though there is now little left from the voluminous first drafts, these had the great merit of resulting in internal documents on each subject that are proving to be extremely valuable for our company.

I was assisted, for the French version of this book, by a very conscientious editorial committee that included Claude Grosmaire, Roland Lucas and

Bernard Zeller, later replaced — again because of the press of other professional duties — by Rene Couturier.

The French edition of this book was published by Masson, Paris, at the beginning of 1989 with the usual high standards of this publisher. It found quickly a significant audience (relatively speaking!) but its diffusion would nowadays stay essentially limited to French-speaking countries.

The publication of an English version was considered at an early stage. Pergamon Press, with its dynamic policy, agreed to publish it despite the limited audience of this specialized subject. We asked Mrs Anne Baron, Daniel Quentin's assistant, to make a first draft of translation. This draft was then reviewed by the authors with the help of their knowledge of the vocabulary of their technical field. Then we asked some English-speaking colleagues, knowledgeable in the field, to check our translation. We wish to express all our gratitude to Miss Carol Jones (Chapter 13), Professor Beddini (4) and to Tom Boggs (9), John Consaga (11), Ron Derr (3), Geoffrey Evans (9), Ray Feist (2), Joseph Hildreth (1), Frank Roberto (8, 10, 14), Bert Sobers (12), Frank Tsé (6) and Andy Victor (5).

Some of the problems we encountered during the translation were due to the fact that some concepts that are represented by one word in one language needed a long sentence for their translation — and this to my surprise is true both ways (for instance "autoseorage" for "burning area to port area ratio" or "indice structural" for "ratio of inert mass to propellant mass for a given motor", etc.). Another difficulty was that terminology has sometimes still to be standardized even if some progress is being made in this area (for example in low visible signature propellants, hazards classification, etc.). This is particularly true for propellant formulations. We have developed in French a specific terminology to name propellants according to their main components, which is compact, efficient and (of course!) Cartesian. It was used for the French version but there is no English equivalent so we had to decide, for the English vocabulary, somewhat arbitrarily. Some traces of the French names may be found in some chapters. In case of possible ambiguities we have made a special presentation, in an addendum, of the decisions we have taken to name propellants in English, and the rules of French terminology.

Since the French edition was published, at the beginning of 1989, there has not been much important evolution in solid propulsion technology, so the changes made are quite limited.

Some developments on program management were suppressed in Chapter 8 because they were very specific to the French organization. A small addition was made in Chapter 12 on integral boosters that were briefly mentioned in the French edition, and in Chapter 7 on XDT (delayed detonation through shock). Some developments related to clean propellants for future space boosters and continuous-mixing processes of composite

propellant, which may become important in the near future were added to Chapter 14. Some "fresh" references were added to some chapters.

On behalf of myself and my co-authors I would like to record our gratitude to our colleagues at SNPE, whose names do not always appear, for their generous cooperation in the preparation of this book. We would also like to thank all those who have provided illustrations.

Finally I would like to thank my wife Cathy for her patience and understanding during the summers of 1987 and 1988 (French version) and 1989 (English version) while I was assuming my editorial duty, and to thank my supervisor, Pierre Dumas, who encouraged me with this work, even when business was brisk, also all our French, British and American colleagues and friends who helped us in this task.

ALAIN DAVENAS

Note on International Nomenclature for Solid Propellant Compositions

TERMINOLOGY for propellants has still to be standardized. Many equivalent names for the same propellant can be found in the literature (or in this book); besides that the French have developed a specific terminology for composite and high-energy propellants which is described in Chapter 2, Section 3.2.1. This is probably due to the fact that authors sometimes refer to the chemical composition, sometimes to the production process and sometimes to some functional characteristics such as smoke or mechanical properties (e.g. elastomeric modified double-base).

Homogeneous propellants are also called (surprisingly) double-base propellants (based on nitrocellulose and a nitric ester). The two main types are extruded double-base or EDB (in French SD for "sans dissolvant", meaning without solvent) and cast double-base or CDB (in French Epictète!). When energetic solids are introduced into this propellant it becomes a CMDDB, for composite modified double-base. This name is used only for cast propellants even if some EDBs can contain oxidizers or energetic solids. Elastomeric modified cast double-base or EMCDB propellants have been developed. They are cast double-base propellants in which an elastomeric binder has been added to the double-base. They can involve the addition of energetic solids. In French, since it is a composite propellant, the rules for nomenclature apply: these propellants are nitragols (generic term). If they contain AP they will become nitralites. If they contain HMX they will be nitramites, etc. These propellants will be minimum smoke propellants if their formula contains only or mostly C, H, O, N.

In English composite propellants are generally named according to their binder, e.g. HTPB or polyurethane propellants, etc., which of course leaves ambiguity except for the fact that most industrial composite propellants use AP for oxidizer, and this is generally implied. The presence of a solid fuel is less clear, since more and more "reduced smoke" propellants, i.e. without metallic fuel, are used in practical applications. In French the names will vary according to the main ingredients of the composition. For instance a composite propellant based on polybutadiene, AP, Al will be a butalane. Without Al it will be a butalite, etc.

So-called high-energy propellants are generally composite propellants with an energetic binder. The most typical use a nitroglycerine plasticized binder and are called XLDB for crosslinked double-base even if there is almost no nitrocellulose in the binder. In French they are nitragols (nitra for the binder). Minimum smoke XLDB based on HMX, for instance, are nitramites.

The terms "minimum smoke" and "reduced smoke" are themselves not sufficient to differentiate propellants clearly. A working group of AGARD is now trying to define more clearly the level of smoke, in order to be able to compare different propellants made in different countries or organizations. The idea is to characterize the level of primary and the level of secondary smoke of any propellant. In order to be independent of the method and hardware used to measure optical transmission, the classification will be made by reference to two given defined propellants, and the level of smoke will be considered as higher than or lower than ...