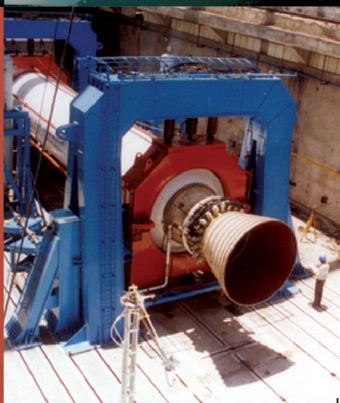
Evolution of Solid Propellant Rockets in India

Rajaram Nagappa



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Rajaram Nagappa
Former Associate Director
Vikram Sarabhai Space Centre
Thiruvananthapuram, India

Defence Research and Development Organisation
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RAJARAM NAGAPPA

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Preface

India has historical record of using rockets as weapons of warfare in the late 18th century. Hyder Ali and later Tipu Sultan maintained a dedicated rocket corps in their army, and in the battle of Pollilur in 1780, Tipu used rockets effectively to rout the British army. After Tipu's defeat by the British in the subsequent Anglo-Mysore war, William Congreve took the captured hardware to England to study the design and modify it. The rockets came to be then onwards known as Congreve rockets; its Tipu and Mysore lineage have been conveniently forgotten. The British established the Cordite Factory at Aruvankadu in Nilgiris, Tamil Nadu in 1904 essentially to make double-base propellant grains for artillery rockets. Modern rocketry in India is just 50 years old and came into being in the early 1960s with the establishment of the Thumba Equatorial Rocket Launching Station, and the associated research and development activities. This initial effort has now grown into a vibrant space programme with the capability to perform end-to-end space missions.

There have been some attempts to write about the historical developments in rocketry and space in India. Narasimha in 1985 wrote about the reemergence of the rocket as a weapon system in the latter half of the 18th century in Mysore. Some aspects of modern day rocketry were described by Dr APJ Abdul Kalam in 1999 in his autobiography, *The Wings of Fire*. A detailed overview of the Country's launch vehicle system development was provided in 2000 by Gopal Raj in his book, *Reach for the Stars–The Evolution of India's Rocket Programme*. Manoranjan Rao and Radhakrishnan have traced the development of rocketry in the Indian Space Research Organisation covering the sounding rockets and launch vehicles in, *A Brief History of Rocketry in ISRO*, which came out in 2012. Manoranjan Rao and Radhakrishnan have devoted a chapter covering the profiles in technology development relating to chemicals and materials. The historical narration relating to missiles is rather sparse. Some aspects of the early days of defence research can be found in *Dare Devil Days* brought out on the occasion of the completion of 25 years of Defence Research and Development Laboratory. A special publication in 2008 similarly described the developments under the Integrated Guided Missile Development Programme. The publication under the title *IGMDP* was published by DRDO to commemorate 25 years of the programme. A similar publication titled, *Glorious Five Decades of HEMRL*, brought out in 2008 to commemorate the Golden Jubilee of the High Energy Materials Research Laboratory traced the history of the laboratory and its major achievements in solid propellants.

Solid propellant rockets have played a key and significant role in the successful evolution of missile and launch vehicle systems in the country. The programmes in both domains went through the phases of experimentation and operationalisation. While new requirement of solid propellant rockets has plateaued out in the space domain, new and diverse requirements continue to be posed for defence systems. Starting from a handful of people in the early 1960s, the solid propellant rocket community in the country can be estimated to be nearly 3000. Starting from one solid propellant plant, the country has more than half a dozen including the ones in the private sector and the Ordnance Factories. Indian industry involvement in the production of input materials, fabrication, and other services is significant.

Literature corresponding to historical narration of such successful systems is sparse. In the field of solid rocket propulsion, the few that are available are technical in nature (HS Mukunda, *Understanding Aerospace Chemical Propulsion*, Interline Publishing, 2004 and Haridwar Singh and Himanshu Shekhar, *Science and Technology of Solid Rocket Propellants*, 2005); and this book is an attempt to provide the background to India's achievements in solid rocketry.

One important fact, which has been emphasised in the text also, is that India has achieved total self-reliance in respect of solid propellant rockets. This happy state of affairs is due to the effort of dedicated and committed persons. Some important stalwarts like WD Patwardhan, MR Kurup, SK Attithan, and K Kishore have passed on leaving indelible marks of their unique contributions. Others are still active and contributing directly or indirectly to the development in this discipline.

I have tried to capture the spirit of self-reliance that pervaded the solid rocket development right from its inception and the high goals it has attained over the years. This is my tribute to one and all who have contributed to this success story.

Bangaluru — Rajaram Nagappa

Acknowledgements

November 2013 will mark the 46th year of the flight of the first indigenously developed rocket RH-75, which was launched from Thumba. In the four and a half decades following this flight, the solid propellant rocket technology has seen tremendous development and crossed important milestones. I felt it was essential to capture some of the historical development and management issues and write them down. The Directorate of Extramural Research and Intellectual Property Rights (ER&IPR), DRDO whom I approached for funding, agreed with the objectives and scope of my proposal and gave me the go ahead. My immense thanks to Dr S Sankaran, the then Director, ER&IPR, and his colleagues in the Directorate for providing the funding, arranging periodic reviews as well as for putting up with the slight delay in the task completion.

In the preparation of this document, I have drawn support and information from former colleagues in ISRO and DRDO scientists – serving and retired – belonging to the solid rocket community. It is only due to their active collaboration that I have been able to complete the task and I offer my sincere and heartfelt thanks to all of them. I wish to particularly mention Shri RN Agarwal, former Director, ASL; Shri Avinash Chander, CC R&D, Strategic Systems; Shri Bikash Bhattacharya, Director HEMRL; Shri PVG Brahmanandam, Scientist, ASL; Shri AK Chakraborti, Director DRDL; Dr Seema Kakade, Scientist, HEMRL; Dr Shrikant Pande, Scientist HEMRL; Shri Pappa Rao, Scientist, ASL; Dr KRK Rao, former Director, HEMRL; Dr VG Sekaran, Director, ASL; and Shri PN Tengli, General Manager, SFC.

Dr A Subhananda Rao, former Director, HEMRL and currently CC R&D has been ever helpful. Discussions with him and the mid-project review taken by him provided very useful inputs in the preparation of this document. I am very thankful to him for hosting me at HEMRL during September–November 2011, which provided me an opportunity to concentrate on preparing the manuscript and to interact with a number of scientists. I am also thankful to Dr Manoj Gupta and his colleagues at SRP who went out of the way to make me feel at home during these two months at HEMRL. The stay at HEMRL provided me an opportunity to interact with Dr Gupta and other scientists. I am thankful to him for this and also for providing me with all the office and library resources and facilitating my visit to sister laboratories.

My own former colleagues in ISRO have been a source of great help. Some have contributed to the write-up, some have dug deep into their memories and provided me inputs, and others have been helpful in reading and critiquing the write-up. I am deeply indebted to them and particularly to PJ Abraham, AV Hanumantha Rao, K Harinath, Pramod Kale, VN Krishnamurthy, GK Levin, PD Mujumdar, SK Radhamohan, S Ramesh, KS Sastri, V Srinivasan, T Sriram, and K Vishvanathan. I would also like to thank Smt C Sarojini, who helped in transcribing some parts of the manuscript. Shri MC Uttam started his career in solid propellants at RPP, continued with it at SPROB, and has settled down at Pune. He was generous enough to share his long years of experience. I am extremely thankful to him for not only providing inputs on propellant development at ISRO, but also providing me material on the propellant development at DRDO.

Shri T Rajagopal in the SMP Office has been of great help in a variety of ways. He has been as much help to me today as he was when I was in service. It is difficult to put value to the type of friendship and support people like Rajagopal provide – I am deeply indebted to him.

Academic interaction has stood the solid rocket community in good stead. As examples, I have provided glimpse of some interactions. Prof HS Mukunda, former Director, CGPL, IISc; Prof SR Chakravarthy, Aerospace Engineering, IIT-M; and Prof BTN Sridhar, Aerospace Engineering, Anna University readily agreed to my request and provided inputs on the research relating to solid propellants undertaken in their institutions. I am thankful to them for their contribution, which I have included in the text with very minor editing.

Industry in India has played a positive role in the development of capability and building of capacity in solid rocket systems. Some industrial contributions are highlighted in the document based on inputs provided by the Company Executives. I am thankful to Shri VM Parthasarathy of Walchandnagar Industries Ltd, Shri AM Palanisamy of Aerospace Materials Ltd, Shri Peter Valeth of Valeth High Tech Composites, and Shri AN Gupta of Premier Explosives Ltd for sparing the time not only for discussion but also for arranging visits to their facilities.

Shri SK Jindal , Director, DESIDOC and his dedicated colleagues have gone out of the way to make this publication happen. Ms Anitha Sarvanan is a perfectionist and has ensured the quality of the figures by getting many of them redrawn and asking me to provide better quality pictures. Her scrutiny and editing of the text as well as getting the document reviewed has helped me to correct and sharpen the text. She and her colleagues in DESIDOC deserve. I am happy to record their contribution in bringing the book to final shape.

My wife Malathi in her own quiet fashion has been a great motivator. She has put up with my odd hours of work on the manuscript without complaining and has kept me company when I have preferred to work out of Bangaluru. She has been a useful sounding board for ideas and has provided insightful comments. I owe a lot to her in the completion of this task.

Rajaram Nagappa

List of Acronyms

ABM	apogee boost motor
ACP	advance casting powder
ADE	Aeronautical Development Establishment
ADN	ammonium dinitramide
AMPL	Aerospace Materials Private Ltd
AP	ammonium perchlorate
APEP	ammonium perchlorate experiment plant
ARCAS	Atlantic Research Corp
ARCO	American Richfield Co
ARDB	Aeronautics Research and Development Board
ARDE	Armament Research and Development Establishment
ASL	Advanced Systems Laboratory
ASLV	Augmented Satellite Launch Vehicle
ASP	Alloy Steel Plant
ATM	anti-tank missile
BAMO	bis azide methyl oxetane
BARC	Bhabha Atomic Research Centre
BEM	ballistic evaluation motor
BHEL	Bharath Heavy Electricals Ltd
$BKNO_3$	boron-potassium nitrate
BSF	Border Security Force
CECRI	Central Electrochemical Research Institute
CFA	Cordite Factory Aruvankadu
CFD	computational fluid dynamics
CFRP	carbon fibre reinforced plastics
CGD	Control and Guidance Division
CNES	Centre National d'etude Spatiales
CTPB	carboxy terminated polybutadiene
CWS	central workshop
DAE	Department of Atomic Energy
DFVLR	Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt
DMRL	Defence Metallurgical Research Laboratory
DoS	Department of Space

DOVAP	doppler velocity and position
DRDL	Defence Research and Development Laboratory
DRDO	Defence Research and Development Organisation
DTA-TGA	Differential thermal analysis–thermogravimetric analysis
EDB	extruded double-base
EPDM	ethylene propylene diene monomer
ERDL	Explosives Research and Development Laboratory
ESR	electro-slag refined
FEM	fluid energy mill
FRPD	Fibre Reinforced Plastics Division
GAP	glycidyl azide polymer
GFRP	glass fibre reinforced plastics
GoCo	Government owned–contractor operated
GSLV	Geo-synchronous Launch Vehicle
GTO	geostationary transfer orbit
HEMRL	High Energy Materials Research Laboratory
HNF	hydrazinium nitroformate
HPM	high performance motor
HTPB	hydroxy terminated polybutadiene
IAF	Indian Air Force
ICBM	inter continental ballistic missile
IGMDP	Integrated Guided Missile Development Programme
IGY	International Geophysical Year
ILSS	inter laminar shear stress
INCOSPAR	Indian National Committee for Space Research
INDAL	Indian Aluminum Company
IPP	ISRO polyol propellant
ISAS	Institute of Space and Astronautical Science
ISRO	Indian Space Research Organisation
ITE	integral throat and entrance
IUS	inertial upper stage
JATP	Joint Advanced Technology Programme
JPL	Jet Propulsion Laboratory
L&T	Larsen & Toubro Ltd
LiF	lithium floride
LVDT	linear variable differential transformers
MAPO	methyl aziridinyl phosphine oxide
MEOP	maximum expected operating pressure
MIDHANI	Mishra Dhatu Nigam
MIT	Madras Institute of Technology
MSIP	Maraging Steel Indigenisation Programme

NAL	National Aerospace Laboratory
NASA	National Aeronautics and Space Administration
NC	nitrocellulose
NDE	non-destructive evaluation
NDT	Non-destructive testing
NG	nitroglycerine
NIMMO	nitromethyl methy oxetane
NOCIL	National Organic Chemical Industries Ltd
OFI	Ordnance Factory, Itarsi
PBAA	polybutadiene acrylic acid
PBAN	polybutadiene acrylic acid acrylonitrile
PED	Propellant Engineering Division
PEL	Premier Explosives Ltd
PFC	Propellant Fuel Complex
PGN	polyglycidyl nitrate
PPG2000	polypropylene glycol
PRL	Physical Research Laboratory
PSLV	Polar Satellite Launch Vehicle
PSND	Propulsion Engineering Division
PTA	pilot-less target aircraft
PU	polyurethane
PVC	poly-vinyl chloride
R&ML	Rockets and Missiles Laboratory
RAP	Resins and Allied Products
RATO	rocket-assisted take off
RFF	Rocket Fabrication Facility
RPE	Royal Propulsion Establishment
RPP	Rocket Propellant Plant
RSRM	reusable solid rocket motor
RTH	Rocket Test House
SA to RM	Scientific Advisor to Raksha Mantri
SCP	slurry casting powder
SEM	Scanning electron microscope
SEP	Société Europée ne de Propulsion
SFC	Solid Fuel Complex
SITVC	secondary injection thrust vector control
SLV	satellite launch vehicle
SNPE	Société Nationale Poudres et Explosifs
SPAN	SPROB Augmentation Project
SPROB	Solid Propellant Space Booster Plant
SPSB	Solid Propellant Strand Burner

SRMU	solid rocket motor upgrade
SSPO	sun-synchronous polar orbit
SSTC	Space Science and Technology Centre
STEX	Static Test and Evaluation Complex
STRD	Structural Engineering Division
SWDT	Special Weapons Development Team
TDI	toluene di-isocyanate
TERLS	Thumba Equatorial Rocket Launching Station
TMP	trimethylol propane
TSLA	titanium substrate lead dioxide anodes
VSSC	Vikram Sarabhai Space Centre
WIL	Walchandnagar Industries Ltd
WIMCO	Western India Match Company

Introduction

The Cordite Factory Aruvankadu (CFA), in Nilgiris district of Tamil Nadu has been producing double-base propellants for artillery rockets for more than 100 years now. Modern rocket technology as we know it, had its beginning in the 1960s, went through the development phase in the decades of 1970, 1980, and 1990, and has been operationalised since then. The Indian Space Research Organisation (ISRO) and the Defence Research and Development Organisation (DRDO) are the two entities involved in the development of rocket technology and realisation of rocket systems. The propulsion system powers the rocket or missile to meet its functional requirement and hence is one of the principal subsystems. Chemical rocket propulsion systems use either solid propellants or liquid propellants, and of these, the solid propellant rockets are the preferred choice for boosting space launch vehicles and for most missile applications.

Rocket development in the civilian sphere had its roots in the study of the ionosphere and for gathering monsoon related data over the equatorial region. Sounding rocket flights were taken up from the Thumba Equatorial Rocket Launching Station (TERLS) (now part of the ISRO) in 1963, and technology acquisition from abroad as well as technology development was taken up shortly thereafter. Dr Vikram A Sarabhai, the founding father of the Indian Space Programme laid great stress on self-reliance and demanded that rocket development activity should develop on our own steam beyond the initial technology acquisition for sounding rockets. In hindsight, this dictum was remarkable as at that time it was possible to negotiate and procure advanced technology like that of the Delta Launch Vehicle without significant difficulty. The young band of engineers recruited by Dr Sarabhai went about the technology development tasks with enthusiasm, and over the years reached high levels of proficiency and expertise. Managerially, ISRO enjoyed one great advantage of being able to set the product specifications realistically in relation to the development needs and requirements as it foresaw. Quite often these specifications were conservative and did not represent the top of the line achievements in the West. In case of technology issues cropping up during the development, performance compromises could be conditionally accepted and were never reasons for outright rejection. To be fair, most technology developments in general either met or exceeded the target specifications.

Missile research and development took birth in the early 1950s with the formation of the Defence Science Organisation (predecessor to the present DRDO) under the leadership of Dr DS Kothari, who was the first Scientific Adviser to the Defence Minister. From its inception, the organisation was closely linked to the three services.

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About the Book

Historical narration of technological achievements is more an exception than the rule in India. The narration in respect of rocket development in the country generally follows this trend with a few notable exceptions covering the developments in the Indian Space Programme. The development of defence rockets has hardly been touched upon. Propulsion forms a major subsystem of the space launch vehicles and missiles, and today, India boasts of a significant capability and capacity in this discipline. The solid propellant rocket technology in India is essentially home-grown and has found wide application and adaptation in sounding rockets, launch vehicles, and ballistic missiles. While the requirements of solid propellant rockets for the space programme have reached a maturation phase, the requirements of solid propellant rockets for missile applications are diverse in their characteristics, and performance needs continue on a demand and development trajectory.

This book highlights the development of solid propellant rockets and the main solid rocket subsystems used in the space programme and ballistic missiles with emphasis on the indigenous nature of development.

About the Author

Rajaram Nagappa is Visiting Professor at the National Institute of Advanced Studies, Bangaluru. He holds a Bachelor's degree in Science from Guwahati University and a Diploma of the Madras Institute of Technology in Aeronautical Engineering. His active years were spent at the Vikram Sarabhai Space Centre, Thiruvananthapuram where he was responsible for the design, development and realisation of solid propellant motor systems for rockets and satellite launch vehicles of the Indian Space Research Organisation. He retired as the Associate Director of Vikram Sarabhai Space Centre and then served as Pandalai Memorial ARDB Chair Professor at the Madras Institute of Technology, Anna University, Chennai. He also spent a semester at Technion, Haifa, Israel as Lady Davis Visiting Fellow in the Faculty of Aerospace Engineering.

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