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My Memoirs of Solid Propellant Development at the Air Force Rocket Propulsion Laboratory

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MY MEMOIRS OF SOLID PROPELLANT DEVELOPMENT AT THE AIR FORCE ROCKET PROPULSION LABORATORY

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Abstract

This paper presents the personal memoirs of Mr. Robert Geisler regarding the history of solid propellant development at the Air Force Rocket Propulsion Laboratory (AFRPL) from 1958 to the present. The paper discusses a number of technologies impacting solid propellant development. These technologies include solid propellant ingredients chemistry, solid rocket motor performance measurement, thermo-chemistry, formulation, mechanical properties, aging, surveillance, combustion, exhaust plume phenomenology, hazards and safety, non-destructive inspection, toxicology, and environmental impact. The topics are covered in relation to relevant applications and time periods. The rationale for pursuing specific technologies and the results is highlighted for each decade. The paper discusses key personnel, user needs, and events as they relate to how solid propellant technology evolved at this organization.

Introduction

This paper is based on my recollections and involvement in the Air Force's Solid Propellant Development efforts from my graduation as a Chemical Engineer in 1958 until the present time. Please forgive me if some of the dates and names have become vague but, I will be within engineering accuracy for the most part. I have included the decade before my arrival for completeness. My comments for this period are based on my discussions with the older generation of solid propellant technologists when I arrived and on my reading of older reports. Also note that there is an offset in the timing between when a technology such as a new propellant type is developed and when it is actually applied to a weapon system. I am generally describing the years when the technology was being developed and this, hopefully, tends to precede the fielding of the weapon. This fact, by the way, always required that we engineers in the Air Force labs become crystal ball gazers in trying to "divine" or second-guess what the congress and strategic planners might decide to do and what the world threat picture might be when the technology was ready. For example, imagine trying to predict ballistic missile basing modes five to ten years in advance and then deriving the propellant requirements to satisfy them. I'm sure we can all remember the highest officials in the land struggling with that issue.

I have organized each decade's discussion around what was happening in the World, the Air Force, the Solid Rocket Community, and the Laboratory. I have tried to touch on how the propellant technology interacted with the mission requirements, systems, and the technology base. I have also tried to identify some of the key personnel and the mood of the times. In the summary I have tried to touch on lessons I have learned working in this dynamic and exciting field for over three decades. I would like to emphasize the unpredictability of the payoffs for a given technological pursuit and how they rarely match the original motivation for the work. I believe this highlights the folly of the disconnect between near-term budget justifications and actual long-term payoff for new technology.

I conclude these memoirs with some personal indulgence on what areas of solid propellant development might warrant new emphasis for the future.

The First 726 Years

Any good historical perspective should place the segment under discussion in the context of the more

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global history. Therefore, I will start by briefly summarizing the history of solid propellants for the first 726 years just prior to my arrival on the scene . As you will recall the Chinese first used the "arrows of flaming fire" to repulse assaults in the battle of Kai-fung-fu in 1232 AD. These were ordinary arrows to which were tied small packages of incendiary powder, a solid propellant. By 1379 and 147 years of R&D later they had hit on the idea of powering the arrow with crude powder rockets and succeeded in setting a defending tower afire in the battle for the Isle of Chiozza. We can also observe the swing from defense to offense between these two battles. By 1814 the first solid rockets made their way to the United States and made a lasting impression in Washington DC., having been used by the British ships in the attack of Fort McHenry. This incident also marked an early plume phenomenology reference in the Star Spangled Banner's renowned "rockets red glare" lyric.

World War II gave rise to a number of unguided solid rocket powered ordnance items including the 2.75" Folding Fin Air Rocket (FFAR) in 1944, the Bazooka shoulder fired anti-tank weapon developed and fielded during WW II (first conceived by Goddard, circa 1917) and similar relatively small weapons. All of these solid propellants were spin-offs of smokeless powder, contained an extruded two-component propellant based on nitrocellulose and nitroglycerine. When the United States Air Force was founded in 1947 these developments represented the state of the art of solid propellants available for weapon system application. An important technological factor was evolving at the same time during the war which was to emerge as a major influence on solid propellant development in the next decade and that was the development of the new science of polymer chemistry. This innovation was sparked by massive efforts during the war years to make synthetic rubber from petroleum products since the natural rubber supply from Malaysia was cut off. This inspired the rise of the petrochemical industry and the general introduction of synthetic plastics, rubbers, and fibers which dominate modern solid rocket designs.

From JATO's to Sputnik (1947-1956)

The World Situation: The Korean Conflict was the principal war of the period. The Air Force was assessing the wealth of captured German technology including the V-2 and other armament and derivative thereof. The growing tensions of the Cold War and the growing nuclear arsenal led to an interest in long range bombers and air defense. Missiles were just evolving as pilotless aircraft in the form of the Navajo, Snark, etc.

System Requirements: Solid rockets and propellants were being looked upon primarily in the role of boosters for aircraft and missiles as well as for gas generators for starting jet engines. The quest in this decade was for an inexpensive Jet-Assist Take-Off (JATO) rocket motor to help heavily laden bombers such as the B-47 takeoff with heavy payloads in hot weather from short runways. The first homing missile, the Sidewinder, had emerged from the Korean War as an important weapon for air-to-air warfare, and it was intended to replace the cannon and machine gun.

Solid Propellant Trends: The new polymers resulting from the synthetic rubber effort during World War II were beginning to find their way into solid propellants. The propulsion group at the Guggenheim Aeronautical Laboratories, California Institute of Technology (GALCIT) made the first castable, curable, case bondable composite solid propellant based on a polysulfide polymer provided by a small business which was to become the Thiokol Corporation in later years. In this decade the Air Force had a major emphasis on the mass production of JATO's for the bomber force. Two JATO units evolved, one was the 15 KS 1000 from Aerojet using a polyester/polystyrene binder with potassium perchlorate. The second was an extruded double base motor designated the 14 NS 1000. The designations gave the burn-time, followed by a two-letter propellant designator which was followed by the thrust in pounds of force. The major Air Force propellant development effort of the era focused on a low cost composition based on asphalt and ammonium nitrate. Asphalt was first used in a JATO motor by Jack Parsons, one of Dr. von Karman's fellow founders of Aerojet as early as 1942. This propellant was favored by Mr. Weldon Worth, Technical Director of the Air Force Propulsion Lab at Wright Patterson AFB. It was dropped after several years of development at AF Plant 66 because of technical difficulties meeting the -65 °F to +165 °F operating requirement and the fact that the use of JATO's on bombers was waning.

The Science: Since the motors were small and computational capability was limited to slide rules, log tables, and mechanical four-function calculators, there was very little sophistication in analysis and most engineering was of the "cut-and-try" variety. This served the needs reasonably well since the rocket applications were not of a high performance nature and the units were relatively small and inexpensive to make. It is interesting to reflect that instrumentation was very crude with oscillographs and oscilloscopes being the principal propellant performance data acquisition equipment. There was no shifting equilibrium Isp calculational program and few of the high temperature thermodynamic functions existed that would be needed for such calculations anyway. There was also no computer available to handle the complex number of species in a solid propellant exhaust. Performance estimates were highly empirical and comparative in nature. Endless discussions ensued as to the effect of such items as motor size and oscillograph paper stretch on measured values of Isp. None of the propellants in operational systems yet used aluminum powder in any quantity and the hardware couldn't have handled it. Nozzle throats were generally machined from steel and there was no ability to vector the thrust. Propellant mixers were generally of the horizontal Baker-Perkins variety with submerged bearings modified from bread mixers. These bearings had the unnerving habit of igniting the mixer upon start-up due to residual material from the previous mix.

Principia to Fracture Mechanics (1957-1966)

The World and Local AF Situation: On the 4th of October in 1957 the Soviets launched Sputnik-1, the first man made earth orbiting satellite. This caused extreme anxiety throughout the world and particularly within the US. Air Force where it was recognized that the same boosters represented an intercontinental nuclear delivery capability. The "Missile Gap" was upon us and this is where I entered the scene in June of 1958. The Air Force was on a hiring binge for new engineers to help rush to get even with the Soviets in the rocket and missile game. I came on board at Wright Patterson Air Force Base (WPAFB), Dayton, Ohio and a couple of weeks later a Mr. Tom Davidson was reassigned from the jet engine fuels and oils lab to be my section chief in the solid propellant section who's symbol was WCLPRXB at the Propulsion laboratory. It might be noted that the importance of your position is inversely proportional to the number of letters in your organizational symbol with the highest level having only two letters. Other new hires at the time included Clark Hawk, Wil Andrepont, Curt Selph, and Bob Wiswell. We joined other young engineers who had a year or two more experience such as Jim Edwards, Gene Haberman, and Don Hart. The week I started many of the engineers were on the West Coast at the AF Western Development Division evaluating proposals for a new Inter Continental Ballistic Missile (ICBM) named Minuteman which was being developed under a group headed by an Air Force Colonel named Bernard Shriever who later became General Shriever, the Air force Chief of Staff and the Chairman of the Joint Chiefs of Staff.

System Requirements: Suddenly there was an all-out effort to develop a solid propelled ICBM named Minuteman by the AF and a similar project for a Submarine Launched Ballistic Missile (SLBM) in the Navy called Polaris. Activities were also well under way to develop a host of Air Launched motors for the Falcon and other missiles. This decade also saw the development of the large solid segmented booster prototypes in the 100" and 156" size and the large 260" monolithic solid booster. This technology eventually enabled the Titan-III/IV family of workhorse space boosters as well as the shuttle SRM's. These were very exciting and challenging projects for solid propellants and motor technology which was just emerging form the JATO class of motor with 100 lb. of propellant and very low mass fraction hardware. In addition, the use of computers was just becoming possible for design and thermochemical problems.

Solid Propellant Trends: In the late 1950's and early 1960's, the rubber-based; castable, curable, and case bondable composite propellants were just emerging from development. The high performance requirements for ICBM's called for the use of the energetic oxidizer known as ammonium perchlorate (AP) and large amounts of aluminum fuel. The real challenge for all of the solid rocket components at that time was to demonstrate them at motor diameters of four and five feet and for a duration of 60 sec. for the ICBM applications. A most difficult problem driven by the need for high propellant performance was that of developing thrust vectorable nozzles that could survive 5,000 °F - 7,000 °F temperatures for this burn time. The group was filled with elation when nozzles survived 20 or 30 seconds and as the months passed the nozzles began to approach survival times on the order of the motor's designed burn time.

The Science: The propellant community struggled for the first time with all of the now classic problems and constraints of scale-up, pot life, solids loading, ballistic and mechanical property tailoring, performance prediction, NDT, age life, and hazards evaluation and classification. This was all new and a tall order of issues to take on simultaneously. The cornerstone scientific propellant effort of the decade was the ARPA Project Principia. This was a $20,000,000 per year (in then year dollars) effort from 1958 to 1964 to enlist the US. chemical industry in making a great leap forward in rocket propellant chemical energetics. The goal was to discover solid propellant combinations capable of delivering 280 sec. of Isp at optimum sea level expansion ratio and a chamber pressure of 1,000 psi. The goal was never achieved but, virtually every imaginable chemical and scheme that might be investigated over the next twenty years was carefully examined and in most cases found to be intractable for the application. The most promising candidates were the NF_2 or difluramino polymers and plasticizers, Metal Hydrides, Beryllium fuel, and numerous perchlorate salts of hydrazine, hydroxyl amine, nitronium and the like. Hydrazine nitroformate was also a contender for a while. All of these compounds proved to be too unstable and reactive or toxic for practical use in the final analysis. Farther out compounds such as the OF_2,, ONF_2+, Ozonides, excited state compounds, free radicals, etc. proved to be blind alleys.. There was a flurry of activity to make compounds high in nitrogen content with the idea of making BN as a principal exhaust product. This failed due to incomplete combustion problems and the discovery of intermediate BNH compounds that prevented the reactions from going to completion in the exhaust.

The most resounding success and impact of the program was the development of the JANNAF Thermochemical Tables and related Isp computer programs to permit the accurate determination of theoretical propellant performance. To this day, these tables are found in the engineering labs of every university and major industrial lab in the world and are widely used on problems of energy conversion in all fields. This is a prime example of a military R&D effort that has impacted all other fields in important and practical ways leading to generate and use energy of all forms. The principal investigator who produced these tables through first class and arduous work over a large number of years was a Dr. D. Stull of Dow Chemical. The program was largely conceived and managed for many years by Curt Selph and Jim Edwards of the AFRPL.

The Science Decade (1967-1976)

The World and Local AF Situation: The missile race with the USSR was going full tilt and we were progressing from the first two generations of Minuteman silo-based missiles with single warheads to the Minuteman III with Multiple Independently-targeted Re-entry Vehicles (MIRV's). In Support of the Triad concept, we were also working on missiles to facilitate bomber penetration such as the Short-Range Attack Missile (SRAM).

This was perhaps the most productive decade in the propellant group with such names as Dr. Frank Kelley, Jim Edwards, Dr. Frank Roberto, Maj. Chuck Payne, Bob Biggers, Norm Vanderhyde, Dr. Jim Trout, Dr. Bob Corley, Charlie Beckman, Jim Koury, and many more excellent people.

System Requirements: The monumental logistics task of maintaining , predicting age-out, and initiating an orderly replacement rationale for a force of 1,000 3-stage silo-based solid propellant missiles was beginning to tax our knowledge and our technological base in the areas of non-destructive testing, failure criteria, stress analysis, chemical aging mechanisms, reliability, statistics, and fracture mechanics. We were also dealing with even larger space boosters such as the Titan-III which also stretched the limits of our knowledge since traditional empirical solutions were becoming too expensive at this scale. Pulse motors such as the SRAM for the bomber force were also demanding new advances in internal insulation, igniter design and high burning rate/high pressure operation.

Solid Propellant Trends: Composite propellants were evolving from binders and processing technology involving polyether polyurethanes, polybutadiene acrylic acid acrylonitrile, and similar hydrocarbon polymers to more capable ones allowing higher solids loadings. These earlier polymers limited solids loadings to 84-87% by weight. The advent of Carboxy Terminated Polybutadiene (CTPB) polymers and related AP bonding agents allowed solids loadings to rise to 88%. This decade also saw the initiation of the development of Hydroxy Terminated Polybutadiene (HTPB) binders which permitted 88-90% solids loadings with reasonable stress-strain values. The higher solids loadings meant that oxidation ratios could be increased which would allow higher aluminum fuel loadings to be burned efficiently. This last factor placed a premium on searching for new nozzle technologies that could withstand the higher temperature and oxidation level of the exhaust. This caused the evolution from tungsten to pyrolytic graphite washers and ultimately to 3-D carbon-carbon billets for rocket nozzle throats.

It is interesting to note again at this juncture what an important impact the commercial petrochemical industry of the United States has had on the evolution of solid propellants. HTPB came to the solid propellant labs as a result of it having been developed by ARCO as a commercial mastic used in places such as bathrooms for caulking, etc. Because of this application, it originally sold for about $.50 per pound and was available in massive quantities. Had the same chemical been produced just for the solid rocket industry it would have probably cost $10-$20 per pound and been less readily available. I am sure this was the case in many countries outside of the U.S.

Tactical hydrocarbon propellants for missiles such as SRAM required high burning rates via the use of fine and ultra fine ammonium perchlorate and ferrocene derivatives for burning rate catalysis. Studies were required on the effects of plasticizer and rate catalyst migration and their effects on bondline integrity and service life. We also became acutely aware of such issues as irregular burning at the sides and center of end burners as well as the effect of pressures of around 2,000 psi on pressure exponent and nozzle integrity.

In this same decade, the more energetic and detonable double base or nitrate ester propellants were also being improved, particularly for upper stage ICBM and SLBM applications. The evolution was from Composite Modified Double Base (CMDB) casting powders with 40-50 % solids loadings and lower nitroglycerine levels to castable and curable compositions with solids loadings of around 70% and high concentrations of HMX, aluminum and nitroglycerine. These later propellants were initially called Cross-Linked Double Base (XLDB) and later evolved to the more generic family of Nitrate Ester Poly-Ether (NEPE) propellants.

An early XLDB propellant underwent a DDT type of failure on 5 May 1974 in a Navy Trident-I C-4 development motor. This put a premium on understanding and formulating for hazards reduction with respect to Deflagration to Detonation Transition (DDT) and to Shock to Detonation Transition (SDT) phenomena. I spent the next 10 years as the sole Air Force member of the Navy-DOE team engaged in a massive recovery program to fully understand the detonation hazards and develop systems having a low probability of detonating. This put an interesting burden on one individual to carry the lessons learned from the Navy Trident to the Air Force MX program and I sometimes found myself lecturing the management in the Pentagon on the subject. This collaboration between shock-hydrodynamicists from the weapons community and propulsion engineers was a key enabling step for the future generations of high performance ICBM's which were to follow.

Attempts to dramatically and easily increase the Isp of all solid rockets by 15 seconds by substituting beryllium for aluminum metal fuel culminated in 1968 with the detonation of the BE-14 prototype motor containing about 15,000 lb. of berylliumized double base propellant on Eniwetok Atoll. Explosively safe and usable berylliumized motors based on hydrocarbon binders and ammonium perchlorate oxidizer had been demonstrated in numerous 4,000 lb motor firings. They were slightly less efficient than aluminized propellants, more expensive, and attacked nozzles more severely. The major problem which caused the technology to be shelved was the unacceptable toxicity level of the exhaust and the related problems that toxicity would cause in manufacturing, storage, transportation, and test of missiles using these propellants.

<u>The Science:</u> The above systems environment made it obvious that the application of solid propulsion technology to AF requirements was out-pacing our understanding of the science and engineering issues. Consequently, this became the "Golden Decade" of AFRPL funded programs which have served as our tech base to this day in most of the fundamental solid propellant sciences. As solid rocket motors became larger, more expensive, and more complex we learned that design and development problems could no longer be solved solely by "brute force " and "cut-and-try" methods. This led to the establishment of the emerging propulsion sciences of combustion, performance prediction, mechanical behavior, plume phenomenology, and motor hazard evaluation. All of these areas intimately involved the solid propellant and gained their start in the propellant group for the most part. It was now becoming necessary to become quite an inter disciplinarian to cover all of the aspects of solid propellantry. In retrospect, we were in the process of becoming some of the world's first "Composites Engineers" and "Materials Scientists". We also quickly discovered that Chemical Engineers were the most relevant inter disciplinarians available for this type of work.

The "Illities" Decade (1977-1986)

<u>The World and Local AF Situation:</u> The emphasis on ballistic missiles continued with an emphasis on potential basing modes involving mobility and compactness of the missiles. As the Southeast Asian conflict wound down, there was an emphasis on improving tactical weapons based on the lessons learned . This tended toward smarter and more stealthy weapons.

System Requirements: As rocket-related weapon systems grew in size, complexity, and numbers, the emphasis on science increased impacting their affordability and operability. This became known as the "illities" decade. We wanted higher performing and more reliable systems at a lower cost.

Solid Propellant Trends: A major emphasis was placed on tactical air-launched exhaust visibility. It was determined that during the Air War in Vietnam. We had lost a number of kills because enemy aircraft were taking evasive action based on visual cues from the smoke in the rocket exhaust as it was launched to intercept him. Our aircraft were also more vulnerable to attack from air and ground when observable plumes from our missiles cued our location. This led to an emphasis on "Reduced Smoke" propellants having no aluminum or particulates in the exhaust. These were typically based on HTPB and AP alone. The less visible "Minimum Smoke" propellants having no particulates or hydrochloric acid condensate were of even greater interest despite the fact they were more prone to detonation and combustion instability and were more expensive. Space booster propellants with reduced hydrochloric acid for environmental reasons were also being sought. These propellants could not, however, be less safe, more expensive, or less reliable. This has proven to be a nearly impossible combination of properties to achieve within the confines of traditional ways of formulating propellants and building motors .

The Science: This was the period where we made one last valiant attack on increasing motor performance. We had long recognized that there are inherent barriers to the upper performance of solid propellants dictated by the nature of the elements available on the Periodic Table and the thermochemistry of the chemical bond. The Isp is essentially determined by the square-root of the propellant chamber temperature divided by the molecular weight of the exhaust and the pressure ratio between the chamber and the exhaust. Furthermore, rocket motor and missile performance are governed by the Isp times the propellant density to some power which is large for lower stages and lower for upper stages. The delivered Isp is also severely reduced by the presence of condensable in the exhaust such as those resulting from metal oxides.

In reality, all of this boils down to the fact that we need metals to provide the great enthalpy we require and there are only about four metals that give good performance and they are Beryllium, Aluminum, Magnesium, Boron. The metals have the other desirable feature that they are the densest constituent of the propellant. They have the disadvantage of producing high molecular weight condensable exhaust products. An excellent thermodynamic solution and compromise would be to introduce hydrogen in the form of the metal hydrides of the above metals. Unfortunately they have all been found to be extremely expensive and chemically unstable.

Since we can't get the molecular weight down with hydrogen, we had to resort to raising the exhaust temperature by using high solids loadings of very energetic oxidizers such as nitroglycerine and nitramines like HMX. This, of course, resulted in severe attack on the nozzle hardware and insulation and a general increase in explosive sensitivity and yield of the propellants. It appeared that the azido compounds such as Glycidal Azido Polymer (GAP) might be an exception to the above constraints, and we embarked on a long-term development effort on that compound after long discussions between Dr. Frank Roberto and myself. We recognized full well that development of a new polymer takes about 17 years and dedication and persistence which are rare in the government and propulsion industry. But, we saw no alternative and took our best shot.

The final approach to increasing propellant performance is to look for ways to eliminate two-phase-flow losses related to condensables and to increase the chamber to exit plane pressure ratio. The latter approach was elegantly applied to the Peacekeeper missile by the use of very high chamber pressures and Extendible Exit Cones. The reduction in two-phase-flow loss still eludes us although the integrated stage design of Aerojet is an excellent attempt at the solution of both problems.

Clean Air to "Demil" (1987-1996)

The World and Local AF Situation: With the downfall of Communism the end of the Cold War, and the rise in public emphasis on environmental and safety issues, our propulsion priorities changed. We became aware of the need for clean and safe "Demilitarization" of weapons including dismantling and destroying them. We also became sensitized to public interest in the safe operation of nuclear weapons in peacetime and the safe launch of space vehicles with an emphasis on cleanliness of exhaust and minimization of loss of life and property on the ground in the case of a launch failure or abort.

Unfortunately, the situation at the AF laboratory level has worsened with respect to budgets and trained personnel in the rocket propulsion area while the need to work smarter has increased. Massive retirements of the "Sputnik Babies" such as myself have seriously eroded the experience base and the lack of resources and emphasis on mission importance has made it virtually impossible to attract young energetic people with the special "Rocket Scientist" qualities that have kept us in the lead with respect to our adversaries during the Cold War. The laboratory infrastructure has aged severely and has begun to fall into disarray. The disruption and moving of major in-house capabilities is also causing the remaining talent to depart for greener pastures as the capability they have built with such personal care and sacrifice over periods of many years falls into new and less capable hands. It would appear that we are heading for a decade of "Dark Ages" with respect to solid rocketry within the Air Force.

System Requirements: A new class of space launch vehicles for a larger array of payload sizes was required. These vehicles were to be highly reliable, low in environmental impact, and cost effective in various mission model extremes. Nuclear weapons are to be safer during peacetime operation and capable of a variety of basing modes. Tactical weapons are to be smarter and more stealthy. Theater ballistic missile defense with kinetic kill vehicles has become an entirely new application area for rocket propulsion.

Solid Propellant Trends: Demands for more sophisticated designs with more advanced composite materials increase. The technological base needs modernizing just like the national infrastructure of highways, bridges, etc. if we are to remain viable. Clean and safe propellant development is a key area and as usual with "Mother Nature", both features are often difficult to obtain in concert. Controllability for smart motors and interceptors is a major consideration for the smaller motors. The trend in propellants is away from ingredient combinations creating hydrogen chloride in the exhaust because of its disagreeable effects on humans, leafy plants, and possible effects on the earth's ozone layer. Substitutes are being evaluated which maintain performance and detonation insensitivity. The issue of acceptable detonation sensitivity is becoming one of the most important issues in the propellant formulation community.

The Science: When money is scarce the wise technology investor replaces expensive prototyping and testing with science. This investment attitude will undoubtedly permeate this decade for this reason and the need of the more sophisticated weapon designs. Combustion understanding will lead to more motor controllability and "Higher IQ" motor designs. It will also aid in the reduction of exhaust environmental impact. Plume phenomenology sciences will lead to stealthier missiles and an improved ability to kill enemy missiles as we emphasize the importance of interceptors and the defensive role. Space boosters will emphasize safety, environmental acceptability and also failure detection and related reliability improvement strategies from the propulsion system . New materials and methods of manufacture will lead to booster performance and reliability improvement. The time seems ripe for a bold move away from traditional design procedures including the introduction of combined liquid-solid technology in new and beneficial ways.

Future Trends for Solid Rocket Propulsion

Performance Improvement: In closing the loop on my observations earlier in this paper on performance barriers, I would like to offer some suggestions on how to approach them. First, the single most important approach toward significant increases in performance and flexibility is to learn how to design and manufacture grains differently than we do today. In the case of the hydride problem, we must create a fuel-rich grain that has enough porosity to "breathe" and let the small percentage of hydrogen out that is liberated with age. This may provide a way to use aluminum or lithium aluminum hydride, two of the most energetic non-toxic hydrides available for consideration.

The two-phase-flow losses which can be as high as 30 sec. in modern high performance motors can only be solved by limiting the size of particulate passing through the throat to a diameter of less that 1 micron. One way to do this is to generate metal and oxidizer rich gases in isolated regions of the same or different motor chambers and then let them react in the gas phase as gas-gas reactions. Physical chemistry informs us that such reactions produce the very smallest particulate in the most kinetically favorable way.

Exhausts of this type have the added advantage of being usable with isentropic spikes, force deflection, and other forms of altitude compensating nozzles which can effectively increase the pressure ratio of the rocket.

High IQ Propulsion: I agree with Dr. Bill Stephens of Army MICOM that the future battlefield weapon will require a "High IQ" propulsion system representing extreme flexibility in energy management. I disagree with Bill's assertion that solid rockets can't be developed with that capability. The solid Kinetic Kill Vehicle (KKV) propulsion systems presently being developed for the Strategic Defense Initiative Organization (SDIO) are good examples of what solids can do. I am also optimistic that new combinations of liquids, solids, and gels which are not true hybrids may hold great promise.

True Composite Engineering: I was very much impressed by a discussion I had some years ago with the manager of the Aerospatiale composites facility in Bordeaux France. He emphasized that composites as a material require that we abandon our "Metal Materials Mindset" to master and optimize their use. He said a new type of engineer must be developed who can meld disciplines of chemistry, materials, structural mechanics, NDT, and processing to a degree not before witnessed. He also noted that the automated processing and manufacturing , NDT, and Failure Criteria must be developed in parallel for each new composite material at each scale of its development.

Pondering these concepts, it has become clear to me that solid rocket propellants and motor cases and the engineers who perfected them actually represent the present bulk of the state-of -the -art of composites in this country. If we can review and harness the methodologies we have single-handedly developed over the past 30 years we should be able to help the newly emerging composite applications areas such as those for aircraft, ground vehicles, and ships to advance more rapidly.

The advances I see to be made in solid rocketry and propellants here is to marry our ability to computer control machinery on the shop floor with an automated lay-up procedure for propellant, insulation, and case as one monolithic structure. The ballistic, thermal, and structural properties will be varied spatially as the motor is laid up and NDT will be performed and recorded simultaneously. Such technologies as energy beam , radiation , and thermoplastic cure are critical to this new approach.

Belt and Suspenders Reliability: I believe that future solid rockets and propellants can best meet the requirements for reliability and safety by combining multiple solutions to failure prevention critical motor areas such as bondlines. We must search for ways to provide idiot proof design and manufacturing techniques to solve these problems. These may have to be radically new ways of doing the job. We will also need sensors and devices built into the structure which provide us with information on the margins in the unit before and during its operation so that we may avert failure before it strikes.

Systems Engineering the Components: More effective components such as propellant and hardware items can only be identified on a systems level. For example, some of the most cost effective propellants for ballistic missiles have been the most expensive ones since they resulted in a smaller missile force to do the job and thereby saved billions of dollars by spending a few more millions of dollars on the component level. It is often quite true that increased component investments produce high leverage on systems savings.

The Solid Rocket Propulsion Community

I would be remiss if I failed to point out what a model of government and industry cooperation the solid rocket propulsion community has been over the past three decades. There has also been a maximum of coordination and fellowship between the government agencies involved. This could well serve as a model for redesigning the government today. Let us examine how and why this has happened. First, this field is one where there was initially no commercial sector or market, and it had to be solely funded by the government who was the sole customer. The old arsenal concept went out with the Second World War and, by the time of Sputnik and ICBM's, we were in dire need of the involvement of the private sector and industrial community.

The AFRPL worked hard to protect industrial proprietary ideas and fill in the gaps in the technology which were technically important but unprofitable to industry with government in-house efforts. In other words, we became a helpful adjunct and clearing-house for industry ideas and not a threat. We often provided expensive facilities and test articles that industry couldn't afford on an individual basis and which also gave the government a comparative basis upon which to judge technologies. For example, the

AFRPL became the "Bureau of Standards" for propellant and nozzle performance with the BATES, Super BATES, CHAR, and HIPPO motors. We also provided a "High-Hazard" altitude facility for initial testing of developmental motors. The classic SOPHY and PYRO hazards experiments also served as a central clearinghouse for studying important phenomena that was not a profit center for industry and could best be undertaken in a government Lab. Laboratory work on NDT, composites, propellants, combustion, and mechanical behavior also tended to guide the industry in standards and procedures needed to provide technology to fill the gaps in the science of rocketry.

The Unique Contributions of the AFRPL

In its three-plus decades of service, the AFRPL was the source and focal point for the solid rocket propellant technology in the United States Air Force and the propulsion community at-large. The lab produced over 5,000 proud rocket scientists and technicians. It was the only facility in the country who's exploratory development program spanned the spectrum of propulsion system applications including Tactical Rockets, Ballistic Missiles, Space Propulsion, and related multiple application technologies such as materials , structures, combustion, plume phenomenology, and hazards. It has provided unique and valuable in-house capabilities and facilities which have greatly altered the course of events of rocket propulsion. It has made the Air Force an intelligent buyer and user of rocket technology upon which the security of the nation has relied.