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A Review Article on Solid Fuel Ducted Ramjet

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Abstract: Advances in ramjet technology over the past century have been remarkable, involving dramatic advances in flight-demonstrated technologies. The path discovery has not been without its distractions, which include world events, Initial motivation began with the will for propelling advanced aircraft, followed by missile technology, and now encouraged by the event of reusable Earth-to-orbit vehicles that employ air breathing engines for at least some of, if not the whole, flight envelope. Solid Fuel Ducted Ramjet is a propulsion technique that is used very frequently in present Air to Air missiles, by modifying the design of duct and mechanism it can available with more powerful output during lifting. The classification and the analytical study of the solid fuel ducted ramjet is given in this literature.

I. INTRODUCTION

The missile was of interest to the Ramjet propulsion systems that use solid fuel. Since l930's, design engineers. The operational ease of the solid fuel jet is of significant importance as it does not include running fuel tanks, fuel pumping equipment or fuel controls. There is only marginally higher cost potential for a highly dependable and efficient ramjet drive system than a solid rocket motor [1]. In the 900-1000 second range, a solid ramjet will produce a particular momentum, usually raising the 200-400 per cent range over a similar size and weight solid rocket motor [2].

The high level of combustion stability observed in different combustion forms and sizes has also been unanticipated for the solid fuel ramjet engine, which developed during ten years of production tests at the Chemical Systems Division. The basic diffusion-controlled combustion method for solid fuel jet results in a distributed release of energy over the combustion cycle. The explanation that no combustion stability issues have arisen in over 2500 fuel test firings in various combustion configurations is believed to be the fundamental reason for this uniform release of energy in the solid fuel jet engine [3].

In the context of all these solid fuel jet attributes, it was important to consider why the solid fuel jet engine for the operating missile has not yet been chosen. The probable explanation why the ramjets with 4 have a specific problem is lack of understanding: solid fuel, which causes that the potential missile developer is worried about his efficient operation of a complete flight envelope and the "off-design" effects. Regrettably, to choose a grain configuration for particular mission requirements, the basic operational simplicity of the solid fuel ramjet requires very complex analysis [4].

The specific problems associated with solid fuel ramjets include:

A. Fuel type range.
B. Flames which restrict the maximum fuel load.
C. Regression of fuel efficiency based on flight speed and altitude.
D. Controlled diffusion combustion process requiring special mixing section.
E. Matching inlet/combustor.

II. CLASSIFICATION OF SOLID FUEL RAMJET

During recent research studies, two types of solid-fuel ramjet engines have developed. These two fundamental forms are represented in Figure 1. The top diagram shows the type of non-bypass combustion unit with special vane mixer mounted behind the solid fuel grain. All inlet air passes through the solid fuel grain in this solid-fuel engine. The schematics below demonstrate the bypass combustion method, which bypasses a fraction of the air into the back portion of the mixing where the fuel-rich combustion gases are combusted from the fuel grain section. Usually, 25% to 80% bypass air ratios are used to fulfil a particular mission range. The air mixer can be used with single or multiple inlets to provide a consistent airflow to a combustor for the two solid fuel ramjet combustor types [5].

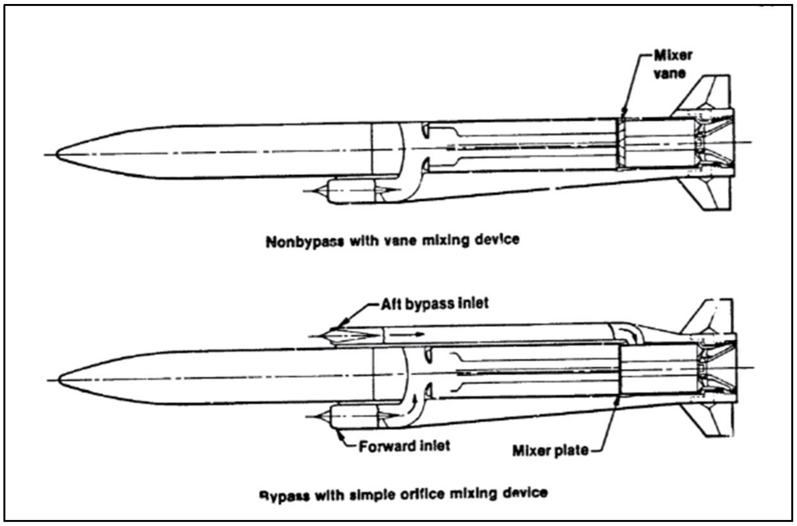

Figure 1 SFRJ Combustor Configurations

As Figure 2, additional station positions were added to the regular Ramjet stations because of the unique operating features of the solid fuel ramjet. The special designations for solid fuel ramjets comprise:

1) 2a -entrance to inlet air manifold
2) 2b - entrance to air flow injector

These special designations are used to evaluate the performance of combustion and pressure losses of solid ramjet fuel engines.

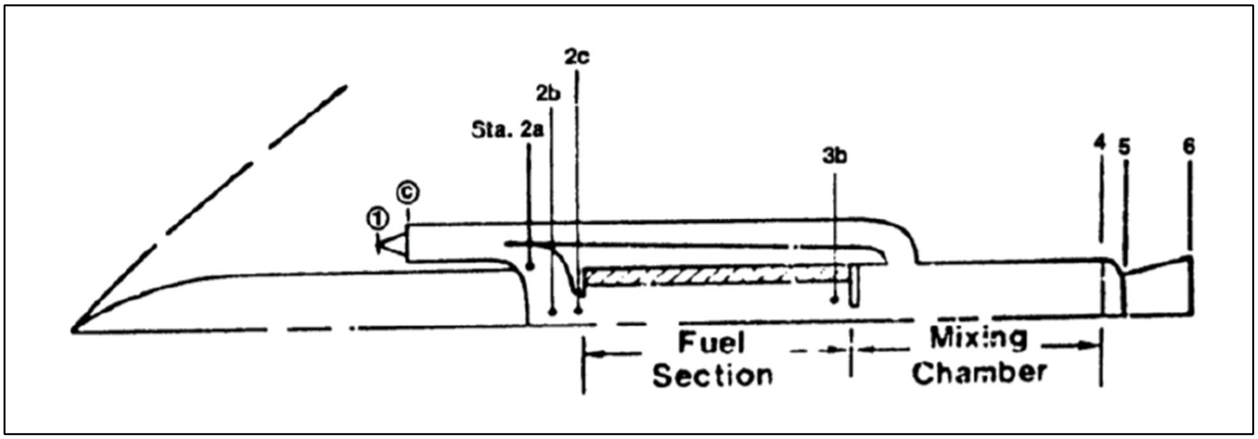

Figure 2 Solid Fuel Ramjet Combustor Phenomena

To date, there is a wide range of solid fuel binder materials. The best heat release fuel binder can be chosen depending on the mission requirements. A blend of PB and polystyrene, which provides a high gravimetric heat release, high mechanical properties, good regression characteristics, and high combustion efficiency over a wide range of conditions are among the most successful solid fuels produced to date. The gravimetric heat release and heat release volumetric in solid fuels using metal additives can be increased. Both gravimetric and volumetric heat releases have the greatest potential for the boron family of metal additives. The attractive additives for solid fuels are titanium, boron and boron carbide. With the solid fuel jet casting of metal fuel, the dynamic problem of storing, pumping and injection of liquid slurry fuels is removed directly in the combustion gases. However, it poses an enormous design challenge to achieve a high combustion efficiency with boron fuels [6].

III. SOLID FUEL REGRESSION RATE

The fuel flow rate of the solid fuel jet engine depends on the surface area of the grain, the regressive fuel formulation rate, and the light velocity and the missile altitude. The temperature of the fuel grain rises ultimately to a point where the fuel is vaporized. The heavy, spray fuel then spread in the border layer to create an airstream fuel oxygen mixture. A flame is formed and stable state combustion is released within the boundary layer [7].

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The basic model of the rate of regression for solid fuels is shown in Figure 3. The "solid fuel grain" is heated by means of a convective and radiative heat transfer from the diffusion flame. The vaporized fuel diffuses from the grain surface to the boundary layer. The convective heat transfer portion depends on the air mass flow through the fuel grain port, the air temperature and the air pressure. Thus, at low altitudes where the air mass flow is high, a broad convective heat trans is heated. The main contributors to the radiative heat flux are carbon radiation, vapour and carbon monoxide from combustion products [8].

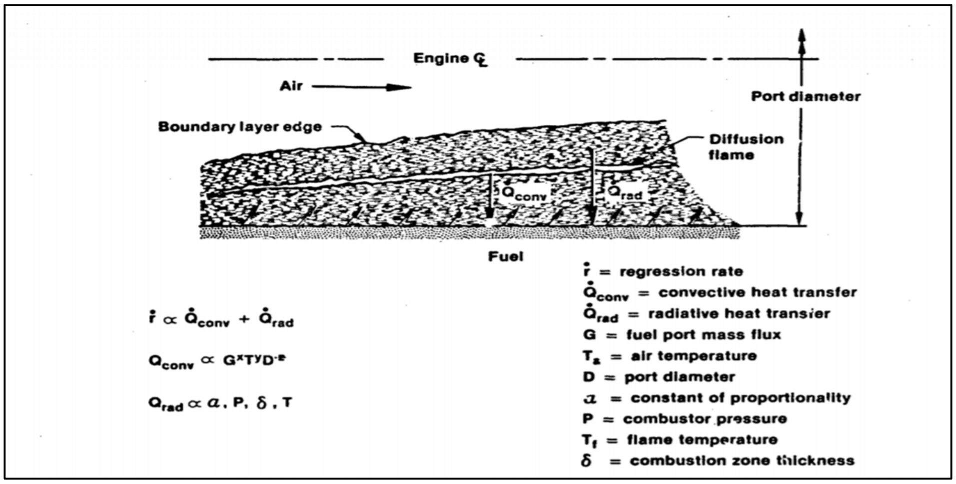

Figure 3 Regression Rate Model for SFRJ Fuel

An approximate expression for the convective heat transfer function is shown in figure 3 where:

$$Q_{convective} = G^{x} T_{a}^{y} D^{-z} \quad (1)$$

The strong dependence of convective heat flux to the fuel port mast flux (G) is the major contributor to the self-throttling characteristic of the solid fuel ramjet.

IV. SOLID FUEL RAMJET COMBUSTION EFFICIENCY

The rearward stage of the solid fuel jet engine creates a recirculation zone that constitutes the core area of flame resistance. Figure 6 demonstrates this field of flammable stabilization. For combustion in a solid fuel ramjet engine a critical step-height, h, is needed. The required phase height value is dependent on the flow and temperature of the inlet air mass. A minimum phase height for sustained combustion is required for each particular solid fuel formulation. In the end, it restricts maximum fuel grain loading and hence the range in a solid fuel jet engine. The minimum stage height restriction. It is therefore highly desirable to reduce the step height required.

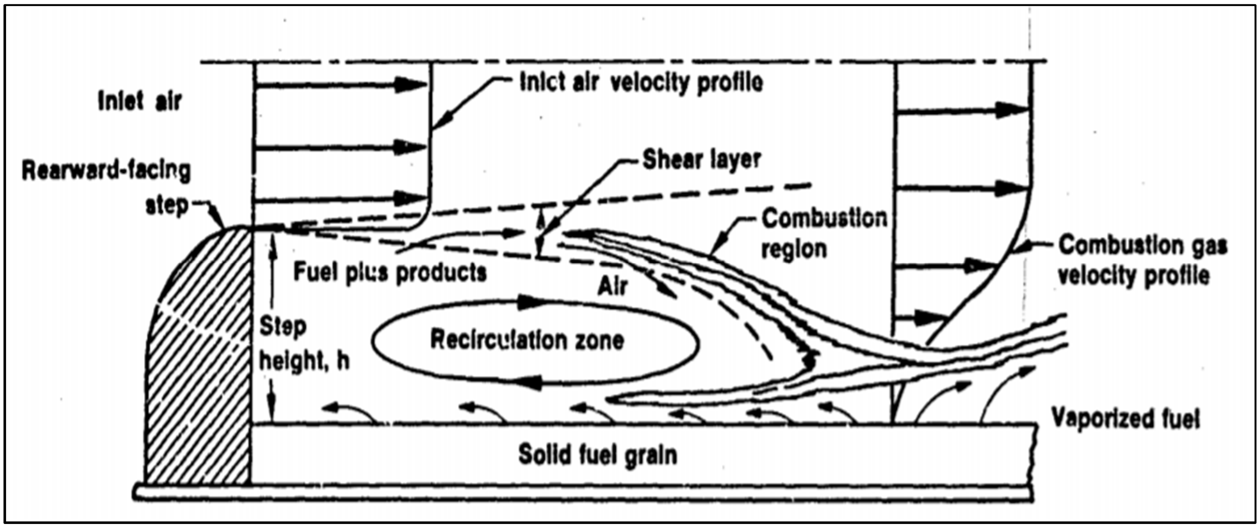

Figure 4 Schematic representation of SFPJ combustion

CSD studies have shown that the degree to which fuel and air mix in the SFRJ are determined by combustion. The mixing rate is regulated by a turbulent diffusion in the combustion boundary layer along the grain and a normal separation of the fuel and the air occurs [9]. Based on turbulent boundary layer theory, mixing calligraphies within the fuel port showed that only about 50% of the fuel mixed and consumed on the exit chamber.

The calculations demonstrated the significance of the additional grain mixing and are generally compatible with the combustion efficiency found in low-L / D mixer motors [10].

Analysis has shown that the mixer L / D, e equivalence ratio and port-to-injector area ratio are the parameters governing combustion efficiency. Equivalence is important because it specifies the relative thickness of the fuel-rich layer that must be mixed, and the port-to-injector area ratio tests the injector turbulence level that affects the whole combustor mix. Combustion efficiency correlations were effective with respect to these three parameters. Early efforts to test the combustion efficiency of SFRJ at low pressure have shown that efficiency reduction could be anticipated under 25 psi. This result was based on seven pressures tests ranging from 7.5 to 16.4 psi. More recently, CSD performed 13 experiments at pressures between 7.6 and 35 psi. The burning efficiency did not degrade to 12 psi. At pressures below 12 psi, some of the individual test points indicate a lower combustion efficiency [11].

The combustion performance of the solid fuel ramjet engine has been associated for both circular and spoke form grains, varying from 2.5-in.-diameter to 10-in.-diameter. Designated burn factor (BF) compares combustion efficiency with the equivalence ratio (C), L / D of the engine, and the fuel port-to-air (A3 / Ai) ratio of the fuel injector. The strong agreement has been achieved between the combustion efficiency predicted by the burner factor (BF) and a large number of combustion test fires and configurations. Combustor designs and mixing aids, therefore, aim to increase the combustion efficiency of the solid fuel ramjet. In non-bypass combustors, the use of special vane mixers at the rear end of the solid fuel grain is efficient in the overall efficiency of the F engine. In the bypass combustor, the radial injection of bypass air in the secondary combustor facilitates better mixing and thus improves the efficiency of combustion [12].

V. LITERATURE REVIEW

The basic feature of the extended-range ramjet projectile is that the high-effect ramjet engine is used to support the flight. The engine used in the projectile consists of an inlet, a gas generator, a secondary firebox, and a nozzle. The purpose of the inlet of the ramjet engine is to switch the kinetic energy to potential energy and increase the gas stream pressure using the velocity in front of it and provide the airflow required by the engine [11]. The working state of the ramjet supported projectile inlet is determined by the fly condition, the firebox operating state, and also the inlet geometry model. The results show that the inlet diffuser design adopts the equal pressure grade theorem, the flow field aberrance exponent is the least and the maximum pressure recovery coefficient is the total pressure recovery coefficient [12].

As described in this paper, the windowed, two-dimensional solid fuel ramjet combustor allowed the surface and gas-phase processes to be visualized during combustion. High-speed photography of the combustion of strongly metalized, boron-containing fuels shows processes and mechanisms associated with the combustion process that can have a major effect on engine operation and performance [13]. In the form of segments and parts, the material was regularly released from the condensed fuel surface into the gas stream. In general, there was no ignition of metal particles on the surface. Due to surface roughness or waviness, the impingement of gas-containing oxygen on the surface can lead to surface heating and chemical reactions glowing. The site of surface activity is these hot surface areas [14].

The key difference between this missile and conventional air-to-air missiles is the propulsion technology of the air-breathing ramjet, which helps propel the missile at high supersonic speeds for long-range target engagement. These are to be used in future missile versions that are planned to expand the range to 150 km, including an advanced version of the ASTRA, Beyond Visual Range [15].

In terms of increasing survival and elimination probability, the importance of propulsion technology in improving the efficiency of missile systems has been demonstrated. Standoff range, missile velocity, missile size, target flexibility, and maneuver capabilities are particular areas where the propulsion system has been shown to have a major effect on missile performance capabilities. It is among these classifications. It has been shown that the use of air augmentation would significantly increase the missile capabilities during the sustained process at flight. The advanced solid fuel ramjet concept demonstrates the full gains of the systems considered, with its minimal oxidizer and self-throttling capability [16].

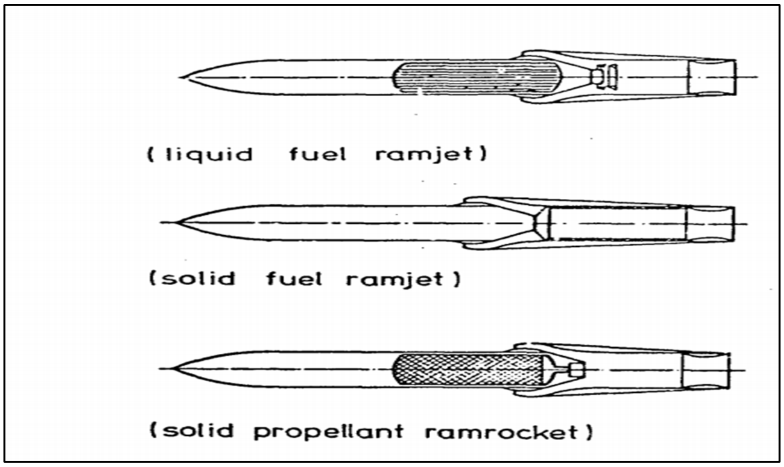

Figure 5 different types of ramjet

Although showing less performance benefit than the solid fuel ramjet, the air augmented ducted rocket provides possible near-term solutions to the expanded standoff range and intercept speeds required against future threats. The benefits of fuels with high volumetric heating values such as boron have been demonstrated by an assessment of the use of advanced fuels in propulsion systems. In the advanced air-breathing propulsion cycles, boron fuel integrations have provided significant mission benefits such as increased range, higher intercept speeds, reduced vehicle sizes, and time to aim [17].

For a conventional air-launched missile system, Figure 4 provides a comparison of the possible propulsion system developments discussed in Figure 1 on the missile standoff range capabilities. The use of a two-phase boost/sustain rocket motor almost doubles the capabilities of the pure boost system's flood range. As in the ducted rocket concept,

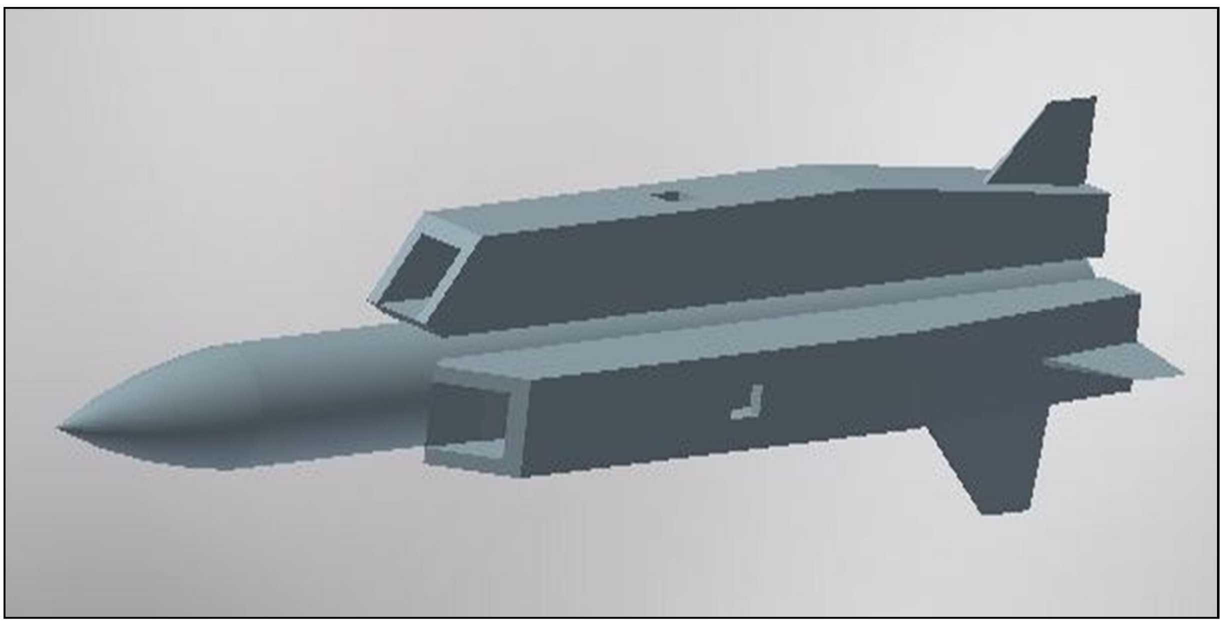
Figure 6 Ramjet rocket model

the addition of air augmentation for the sustain phase more than doubles the flyout range capabilities over the two-phase rocket again. The principle of hydrocarbon solid fuel ramjet, which does not hold internal oxidizers for continuous flow, entirely depending on free stream airflow for combustion, shows almost two more for an increase in range [18].

The key difference between this missile and the conventional air-to-air missiles is the air-to-air propulsion technology [19]. It helps propel the missile at high supersonic speeds to attract long-range targets. Unlike the standard rocket engine, SFDR can throttle its engine during various phases of flight, particularly when approaching its target, it can throttle up and be able to maneuver and operate [20].

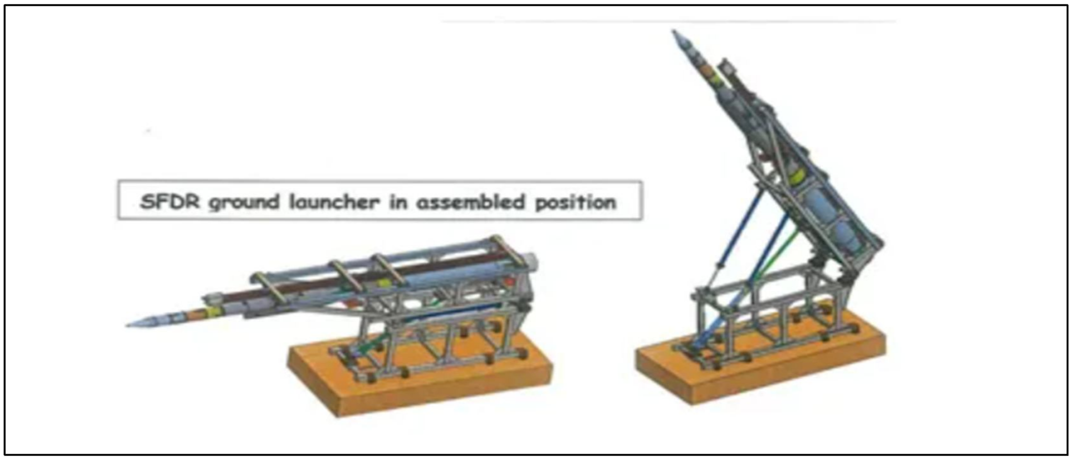

Figure 7 SOLID FLUID DUCTED RAMJET

In this article, the ramjet is set as the research goal. In the current research, the thermodynamic efficiency analysis of the ramjet in broad working conditions was carried out based on the Bryton cycle. The pressure ratio and the temperature ratio have a decisive impact on the output of the ramjet and the production of the entropy in the isobaric combustion phase of the combustor is the main part of the total entropy in the entire process. As the inlet pressure ratio of the ramjet increases, the variance of the individual thrust is not linear but decreases after an increase in the phase. The inflow conditions, the angle of the oblique shock wave, and the usual shock wave have a significant effect on its variable pattern [21]. The air-fuel ratio (f) is finally determined to be one of the key factors influencing the efficiency output of the ramjet. With the continuous rise in the air-fuel ratio (f), there is a growing trend in the basic thrust of the ramjet. In the earlier stage, the specific impulse (Isp) increases and then decreases slightly under the low flight Mach number, but with the increased freestream Mach number, the specific impulse (Isp) increases with the increase in the air-fuel ratio [22].
The flight envelope with diminutive dynamic pressure will satisfy requirements for the low flight Mach number. However, for high Mach number flight, for optimal efficiency, it is better to choose high dynamic pressure [23]. The corresponding best air-fuel ratio (f) is 0.038 when the specific thrust requirement is 600 N, and the nozzle throat area (A5) is 0.8. With the flight Mach number and flight height being 3.5 and 12 km respectively, this is the best configuration characteristics and fuel injection scheme of this ramjet under the working condition [24].
For two factors, accurate modeling of the performance of a TDR propulsion system is mandatory. First of all, the performance, namely the thrust, is highly dependent on the missile's flight conditions, such as altitude, Mach number, or attack angle [25]. Therefore, either by ground or free flight, it is not possible to cover the entire flight domain. As a consequence, only through a simulation tool can a performance prediction be given. The second explanation is the possibility of active thrust control because the design of the control algorithm is necessary for a thorough understanding of the processes inside the TDR [26].
The principle concept is to test these components independently, to set up a model concept based on the gathered data, to translate this concept into computer code, and to merge the single subsystems into a complete model [27]. After the correct implementation is verified the model can be validated based on the further test. The objective of the validation is the confirmation of both the correct modeling concept and the model-specific parameters [28]. During the validation process, it has to be shown that the dispersive parameters of the model are within the defined probability distribution. Besides, it can be checked whether the results of further tests are within a corridor given by Monte Carlo runs based on these distributions. Such a validation process is shown in this paper via a free flight trial and a CPT test [29].
Ramjet combustion engine experiments using boron-based gel fuel were designed and performed to check the configuration of the ramjet and to investigate the effect of combustion chamber length and boron particle content on the efficiency of combustion [28].The conclusions drawn are presented as follows When the mass fraction of boron particles in gel fuel exceeds 40 percent, the ramjet combustor can function stably and the temperature-based combustion efficiency is around 80 percent. With the increase in boron particle content, the efficiency of combustion decreases. Gel fuels with a boron content of 30 % and 40% have a combustion efficiency of 90% and 80 %, respectively. In the high-boron content experiment, more deposits were found in the nozzle. The efficiency of combustion is sensitive to the combustor's duration. Subject to the conditions of experimentation, the combustion efficiency manifested a decline by approximately 9% when the length of the combustor decreased by 150 mm [29].

VI. CONCLUSION

The technical simplicity of the solid fuel ramjet combined with high performance makes this type of engine very attractive for many potential tactical tasks. Conversely, the difficulty of the study of fuel regression behavior, combustion efficiency and inlet combustion matching caused vehicle designers to be concerned about the capacity of the solid fuel ramjet to function effectively under all the off-design conditions needed by the tactical missile propulsion system. Over the last 15 years, a broad engineering database has been developed for the solid fuel ramjet, which offers answers to all the special design problems of the solid fuel ramjet. This technology base contains 2,500 ground-testing shots as well as several hundred successful flight tests. This large technology base offers verified solutions to the unique design problems of the solid fuel ramjet.

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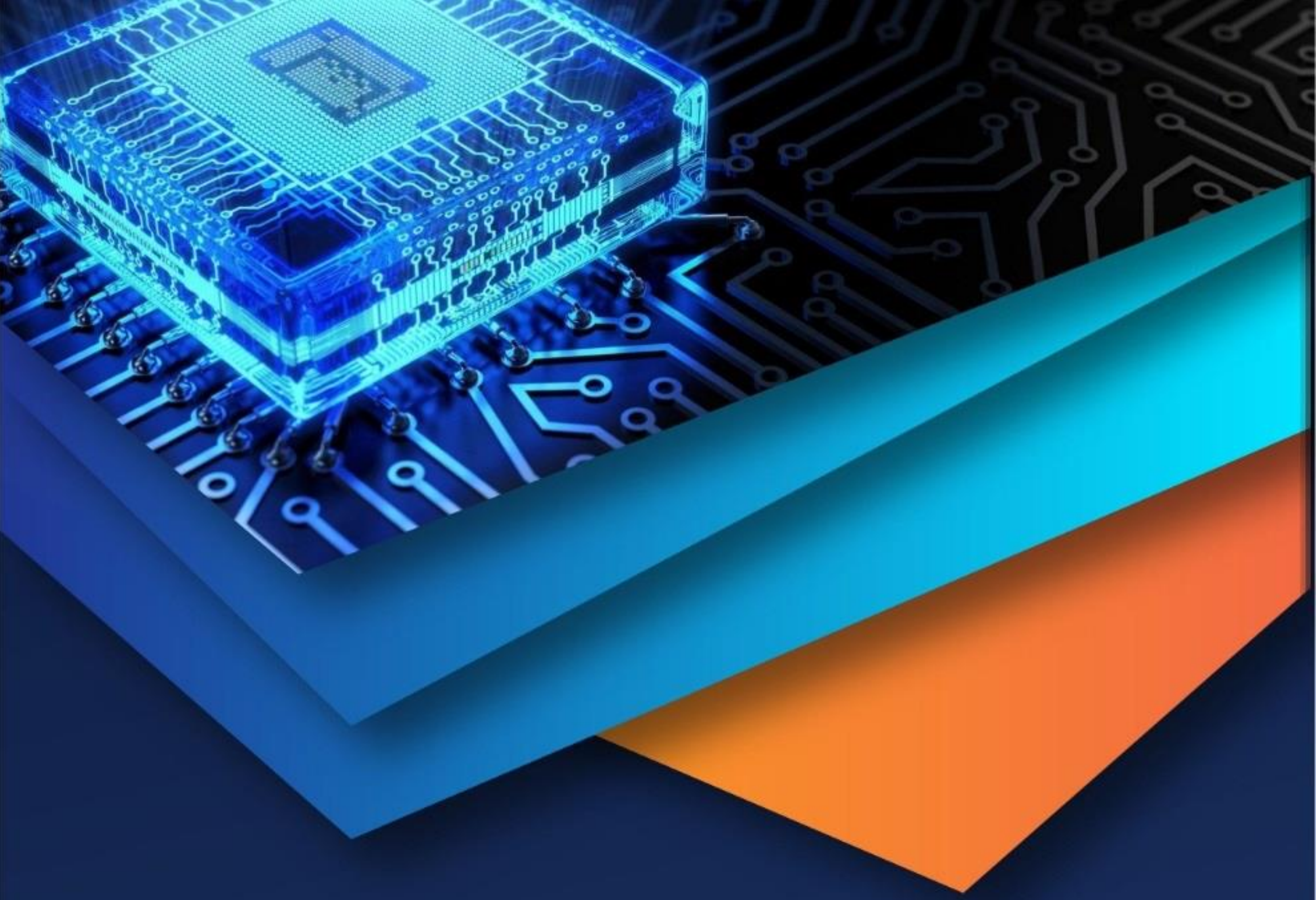

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