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HIGH PERFORMANCE BOOST PROPULSION FOR NAVY THEATER MISSILE DEFENSE

W.J. Kearney, Program manager, kearney@post.csd.com, and
E.D. Casillas, Systems analyst, casillas@post.csd.com
Pratt & Whitney, Space Propulsion Operations,
Chemical Systems Division. San Jose, California.

Abstract

Future tactical and defensive missile propulsion systems must provide a high degree of mission versatility and robustness at low cost with minimum development risk. The Navy's Standard Missile has successfully demonstrated an evolutionary philosophy of guidance and propulsion upgrades over its long operational history. Replacing the existing 13.5-in diameter Mk 104 Dual Thrust Rocket Motor (DTRM) with a full 21-in. diameter high performance motor offers increased propulsion capability and weapon system options. An improved performance stage-two motor, consistent with the Mk 72 booster's 21-in. diameter, provides an upgraded missile system with expanded range, greater throw weight and higher velocity increments. Expanded propulsion capability can be achieved with low development risk commensurate with improvements in the Vertical Launch System (VLS) Canister. Pratt & Whitney's Chemical Systems Division, currently manufacturing the Standard Missile 2 Extended Range Block IV (SM2-ER Blk IVA) Mk 72 booster, has established an improved stage-two motor approach. The benefits of this upgraded full caliber motor compatible with the existing Mk 72 booster and VLS interfaces is presented.

Introduction

Recent military experience and U.S. Navy war game results have brought into focus the presence of existing and future threats that require a ship-based, multi-purpose weapon and propulsion system to effectively counteract near future threats.

The SCUD launch experience during the Persian gulf war accelerated the realization that worldwide proliferation of tactical and strategic missiles have multiplied the number of potential aggressors that could use these weapons of mass destruction against American and/or Allied interests abroad. Exoatmospheric hit-to-kill missiles have been singled out as an effective and efficient measure to counteract hostile Tactical Ballistic Missiles (TBM's). A hit-to-kill missile does not require a heavy explosive warhead and associated shrapnel to neutralize its intended target, rather it depends on state of the art seeker/guidance/divert propulsion technology to acquire, track and home-in to destroy its intended target, via kinetic energy, high-up in the atmosphere. As a result, a more compact propulsion system is able to accelerate the lighter payload to higher velocities and thereby increase the altitude and range coverage, intercepts occur higher and farther away from protected areas to eliminate collateral damage. The smaller propulsion volume required also means increased firepower within the envelope allowed by the use of existing ship-based launching platforms. Navy AEGIS cruisers and destroyers, constantly on patrol around the globe, provide a mobile launching platform presence from which to protect against hostile TBM's. Additionally, existing ship-based target tracking radars, battle management command control and communication systems (BMC3) and launch support systems translate into reduced development costs. The existing Mk 41 VLS and compatible lower stage Mk 72 solid motor provide the basis for ship interface and launch, a new 21-in. diameter, high performance, stage-two solid rocket motor provides the propulsion required for improved theater-wide coverage. The stage-two accelerates the kinetic-kill vehicle (KKV), and associated kick stage, to velocities required for expanded area TBM protection.

According to results from a recent U.S. Navy war game[1], larger numbers of forward-deployed precision strike guided weapons could play a critical role in thwarting the advance of enemy formations in the early stages of future conflicts. The use of precision strike weapons would be designed to slow enemy attacks by destroying infrastructure, military assets and hostile forces in the early phase of aggressions, allowing time for

[1] Defense News, Feb. 19-25, 1996.

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heavy U.S. force deployment to bring the conflict to a speedy and efficient conclusion. Forward-deployed Navy cruisers and destroyers, along with their existing weapon launching platforms and support systems, provide excellent means to supply the precision strike weapons to forward-deployed battle stations. The upcoming Arsenal ship also represents a means to supply vertically launched precision strike weapons in large numbers to required battle stations around the globe. The strike missile will be capable of delivering large explosive warheads (for wide area impact), independently targeted brilliant anti-tank, BAT, submunitions (for tanks and other similar targets) and other existing payloads. A new 21-in. diameter, high performance, stage-two solid rocket motor complemented by the existing stage-one Mk 72 solid rocket motor provides fast response capability for deep inland strikes that can deliver any of the aforementioned payloads.

The new 21-in. diameter stage-two motor provides the propulsion needed to allow a single propulsion system to support dual payloads and thereby confront the threats posed by hostile TBM's and early military conflict aggression. These mission capabilities complement the Navy's already existing multi-purpose SM2-ER Blk IV capabilities, as shown on Figure 1, to result in a most formidable forward-deployed weapons platform.

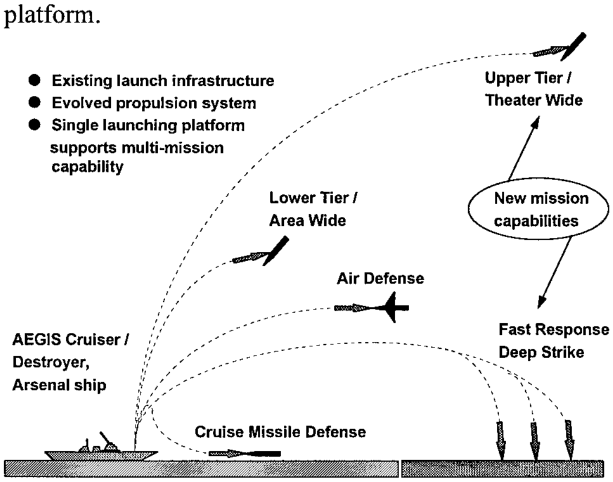

Figure 1. Multi-purpose Propulsion Supports Multi-mission Capability

The new 21-in. diameter stage-two motor represents the next natural evolution of Standard Missile, it will interface on the aft end with the existing Mk 72 solid rocket motor and on the forward end with a variety of payloads which can include a kick stage, kinetic-kill vehicle, large warhead, anti-personnel/material bomblets, BAT submunition delivery system, and other existing ordnance payloads. The evolved missile round, as shown on figure 2, is designed to satisfy multi-mission flight performance requirements and fit within the existing ship-based VLS.

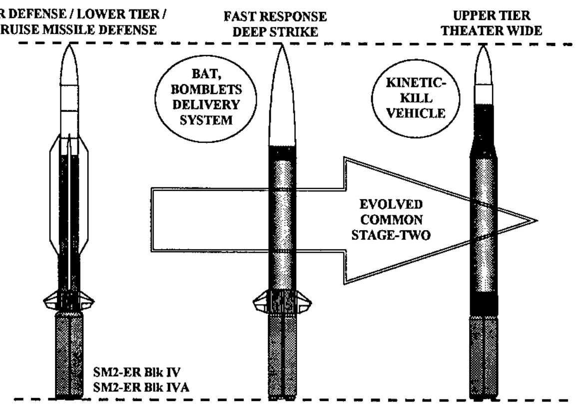

Figure 2. Natural Standard Missile Evolution

Systems Requirements

Envelope

The new evolved stage-two propulsion system design is driven by a desire to maximize flight performance while satisfying the existing VLS length and diameter envelope constraints. As such the motor is sized to take full benefit of the available envelope to maximize propellant loading and impulse. The VLS canister allows a maximum motor diameter of 21-in. and a maximum missile total length of 262 in. The stage-two motor length is dictated by length distribution among all the major missile components included in the theater-wide and strike applications. These include the Mk 72 booster motor, the stage-two steering control section, the stage-two motor, and the remaining forward components (autopilot, warhead, guidance and payload sections). Various parametric studies have been conducted where the overall available length (forward of Mk 72 booster) is distributed differently among the forward missile components and the second stage. These studies examined the resulting stage-two motor length with a thrust vector control (TVC) and with a movable wing steering control section, and included theater-wide and strike missile forebodies. Results from these studies have placed the stage-two motor length at somewhere between the 65 to 115 in. range, which is indicative of the wide range of missile configurations that are potentially possible. Hence, the optimum stage-two length that will satisfy both missile configurations, strike and theater-wide, will require further evaluation.

Weight

Some of the missile configurations examined have resulted in a missile total weight that, when added to the existing VLS canister weight (about 3200 lb.) exceed the existing VLS loaded canister weight limit (6500 lb.). The higher missile weights are due to combined larger stage-two and forebody throw weight. Several canister design contingencies are being examined that include modifications to the existing canister as well as a completely new light-weight composite canister design. The objective is to satisfy the VLS loaded canister weight limit, without sacrificing achievable expanded mission capability that has been determined to be critical for the near future. The final canister design avenue that will be pursued will depend on ongoing mission requirements analyses and ensuing missile requirements definition, including both strike and theater-wide missile applications.

Steering

The stage-two steering control system design requirements are driven by the type of mission application. The strike mission flight profile can be characterized by an atmospheric flight path where aerodynamic lift is used to provide mission range and time flexibility. It would include a maximum flight altitude ceiling of 100000 ft. and stage-two motor coast flight phases, prior to ignition and after burnout, that steer the payload to a pre-determined location prior to submunition dispensing. As such, a movable wing steering control system would be required for the strike mission. The theater-wide mission, on the other hand, intends to perform an exoatmospheric intercept that generally results in a relatively steep flight profile during the boost phase. This causes the stage-two to burnout at high altitudes (well above 100000 ft), where a movable wing steering control system does not seem practical. Moreover, the stage-two motor would only be required to provide steering control during its burn, the spent motor is jettisoned following burnout, such that the KKV onboard ACS and divert propulsion assume steering control. Consequently, a TVC steering system appears more practical for the theater-wide mission. The new 21-in. diameter stage-two motor may then include design features, in the case and propellant grain, to allow compatibility with a blast tube/nozzle assembly to enable movable wing steering, or with a movable nozzle to enable TVC control.

Propulsion

The required propulsion thrust characteristics are also a function of the specific flight profiles required to maximize performance for the strike and theater-wide missions. Studies accomplished to date, for both types of missions, indicate that a simple all-boost thrust characteristic results in maximum flight performance. Other thrust characteristics such as a boost-sustain profile manage aerodynamic drag losses to extend missile range. However, this effect is only noteworthy when the flight takes place in low to moderate altitudes. Both strike and theater-wide missions exhibit flight profiles where the higher altitude nullifies the range improvement effect. Moreover, performance is actually penalized due to a less efficient motor design resulting from the boost-sustain feature. Additionally, the strike mission requires fast response to deep inland targets and, therefore, there is a desire to minimize flight time as function of range, as shown on figure 3.

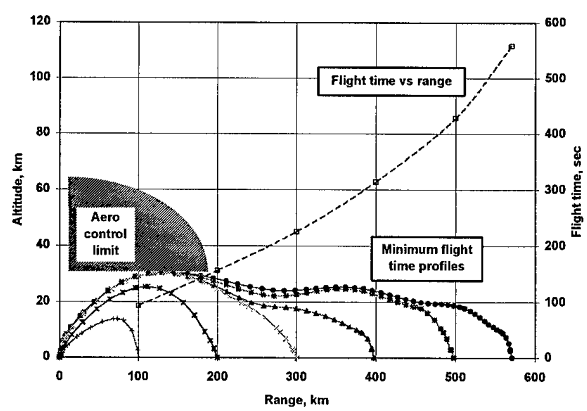

Figure 3. Strike Missile Flight Time vs Range

Both boost-sustain and dual-pulse motor propulsion characteristics result in undesirable longer flight times in addition to increased motor complexity and cost. Therefore the new 21-in. stage-two motor should include a simple all-boost thrust characteristic.

Performance

Since required values for the stage-two motor length and strike missile throw weight have not been determined, a flight time vs range performance parametric study was conducted to examine the flight time sensitivity to stage-two motor length and throw weight (actual values are proprietary to third parties and are omitted throughout this publication), the results are as shown on figure 4.

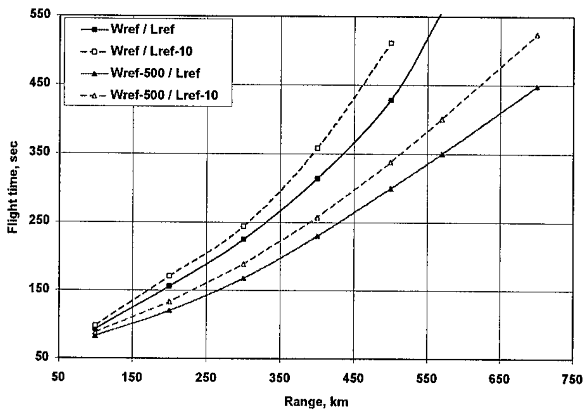

Figure 4. Flight Time Sensitivity

The results show that flight time sensitivity is higher with increased flight range, the flight time penalty, due to reduced stage-two motor length and/or increased throw weight, is significantly more apparent when a longer range mission is required. For short range profiles there is only a small apparent flight time impact with motor length or throw weight. As the required range is increased, the flight time sensitivity also increases markedly. A lighter throw weight (Wref-500 lb) results in shorter flight times and expanded maximum range capability, however, it can also result in significantly reduced submunitions cargo capability. Reduced submunitions cargo translates into an increased number of missile launches required to engage a given regional conflict. Consequently, it may be advantageous to design the strike missile with a heavy throw weight capability.

Theater-wide mission flight performance has been characterized, by government and industry, with a simple performance indicator as the vertical flight path missile burnout velocity (Vbo). Missile Vbo is maximized with a 21-in. diameter stage-two motor but will also be a function of the KKV weight and upper kick stage motor performance. While a definite Vbo value has not been defined as a requirement, various estimates ranging from 3.5 to 5.5 km/sec have been calculated to provide various degrees of theater-wide coverage protection. The new 21-in. diameter stage-two motor with TVC can easily increase the missile Vbo by more than 1.0 km/sec as compared to the existing 13.5-in. diameter motor (i.e., Mk 104). Its inclusion will result in missile Vbo performance closer to the upper end of the Vbo range estimated, this in turn, generates a greatly expanded missile TBM intercept range capability. Increased missile range capability allows a single AEGIS/Arsenal ship to provide significantly expanded theater area coverage. Expanded coverage will result in a reduced number of AEGIS/Arsenal ships required to provide cover to a given regional conflict, this in turn, minimizes the overall number of military assets at risk and ultimately mission cost as well.

Motor Requirements

Table 1 summarizes some of the new 21-in. diameter stage-two motor design requirements.

Design Parameter	Value
Operational temperature range, deg F	45 to 95
Storage temperature range, deg F	-20 to 130
Case length, in	TBD
Case OD, in	21
Control steering section length, in	TBD
TVC angle, deg	4 to 8
Motor Impulse, lb-sec	TBD
Thrust profile	All-boost
Propellant type	Class 1.3

Table 1. Stage-two Motor Requirements

Additional motor design provisions, aimed at maximizing flight performance while ensuring that the motor design is compatible with loads and environments typical of ship-based storage and operation, consist of state-of-the-art (SOTA) solid rocket motor component technologies as will be described in the next subsection.

Solid Rocket Motor Technology

Motor Elements

Figure 5 shows motor design elements which are typical of a tactical motor application and provide a configuration representation for the new 21-in. stage-two motor. Key design requirements for the stage-two solid rocket motor include compliance with the VLS launch canister radial restraint group along with sufficient provisions for interstage clearance and attachments for the Mk 72 booster. In addition, the design will be compatible with environmental shipboard requirements including near miss shock, vibration, launch and storage temperature/humidity limits. Subsystem component designs will include an insulated composite case, ignition and safe-and-arm, propellant and grain configuration, nozzle/blast tube assembly, electrical cable raceway/strakes, thermal protection system and interface design features.

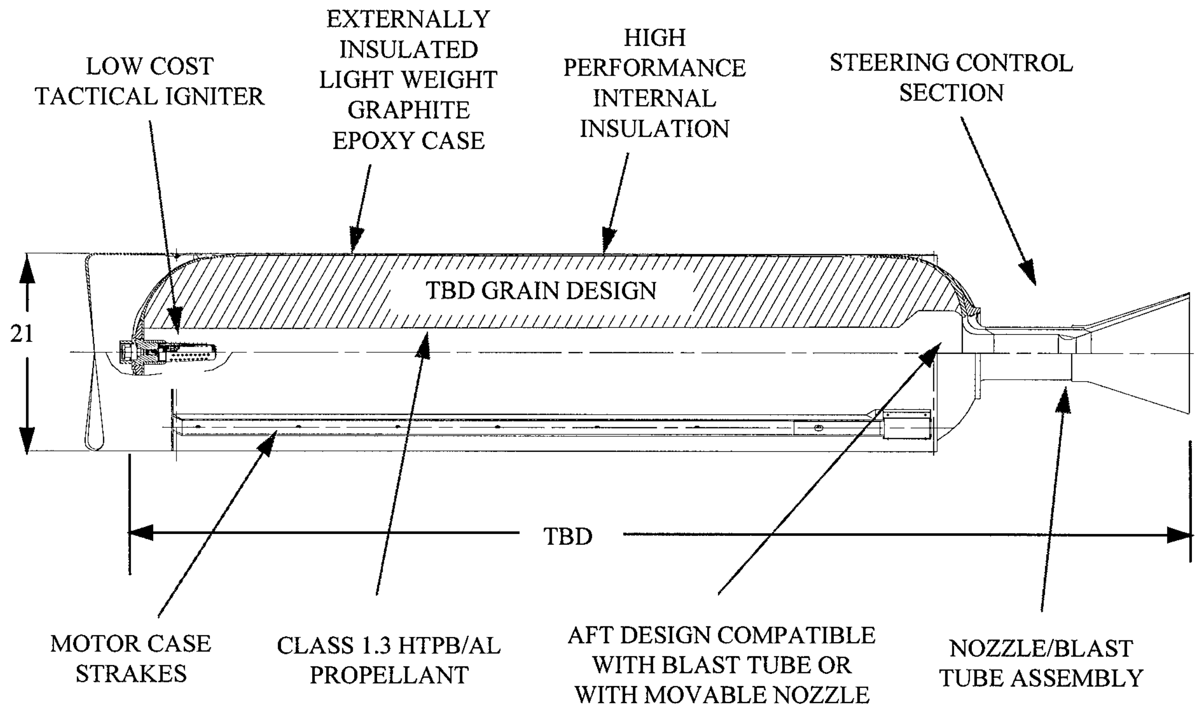

Figure 5. Representative Stage-two Motor Configuration

These components will be based on a portfolio of proven SOTA solid rocket motor technologies, which will be integrated into a low cost and reliable solution.

Proven / Demonstrated technology

Pratt & Whitney's CSD, building on its Navy solid rocket motor heritage, with the Tomahawk Mk 111 booster, Trident II stage-three (D5) and the SM2-ER Blk IV Mk 72 booster has the technology, experienced personnel, analytical tools, motor processing facilities and systems in place to offer a mature and improved new 21-in. diameter stage-two motor.

The motor will employ a Class 1.3 Hydroxyl-terminated Polybutadiene (HTPB) Aluminized propellant system configured in a center-perforated grain configuration. The grain design will be tailored for manufacturing and operational robustness, efficient pressure neutrality, all-boost propulsion and high propellant volumetric loading. The propellant formulation will be from a family of well characterized CSD tactical motor propellants which exhibit excellent physical properties and combustion stability characteristics. Additionally, the propellant burn rate will be tailored to minimize the radial size required for the blast tube and nozzle assembly, which in turn, translates into greater steering section packaging volume and increased motor performance due to higher nozzle expansion ratio

The composite case design will be based on experience derived from strategic and tactical missile development programs as well as CSD's wide family of space motors. The design will be driven by flight structural and thermal loads, shipboard loads and operating pressure requirements. The lightweight graphite composite motor case may incorporate integrally wound forward and aft skirt attachments designed for maximum skirt axial load bearing requirements. The case fiber winding pattern will be tailored to provide the required stiffness characteristics, to ensure missile structural integrity and controllability at any time during its flight mission.

During September 1995 under Navy funding for a low cost booster propellant development and demonstration program, CSD fabricated and test fired a near 21-in. diameter motor (19.24-in. motor diameter and approximately 55-in. long). The case design included high strength graphite epoxy materials and was pressure proofed to 2230 psi.. The actual test firing and pressure test data are shown on figures 6 and 7 respectively.

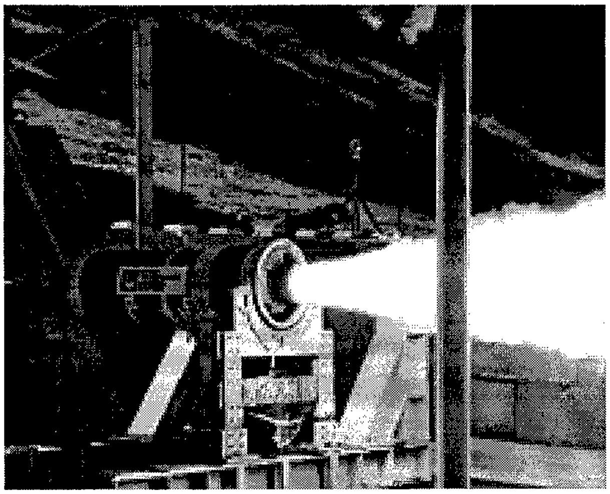

Figure 6. Navy Low Cost Motor Static Firing

The static firing was a complete success as all technical goals were achieved. The low cost propellant exhibited low end-of-mix viscosity, excellent combustion of Aluminum particles, negligible slag formation, and excellent mechanical properties over a wide temperature range (i.e, -55 to 150 deg F.).

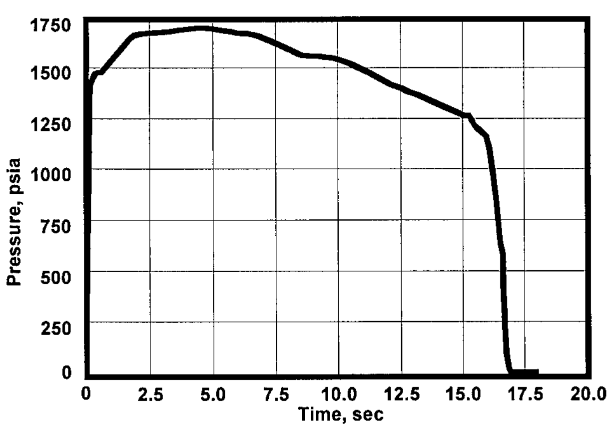

Figure 7. Static Firing Pressure Time History

The test motor included design elements which are representative of the technologies that may be required for the new 21-in. stage-two motor. The nozzle design consisted of a 4D carbon-carbon nozzle throat insert with a tape-wrapped carbon-cloth phenolic exit cone. The internal thermal protection was provided by Kevlar-filled Ethylene-Propylene Diene Monomer (EPDM), which features low density and high ablation resistance. This insulation system is well characterized and exhibits flight proven compatibility with the prospective propellant and liner system. Examination of post-test motor hardware showed excellent all-around internal motor conditions

The new 21-in. diameter stage-two motor will include a nozzle/blast tube design configuration, consistent with the strike missile requirements, with a design approach based on CSD's wide range experience designing and testing nozzle/blast tube configurations. These include motors with maximum operating pressures of up to 4,000 psi. and port-to-throat area contraction ratios from 1.3 to 2.0. A variety of nozzle throat insert and blast tube liner materials, as well as propellant formulations (Aluminized and otherwise) are built into this experience data base. The data base also includes a series of rapid response demonstration test firings (conducted in 1995) at ambient temperature and -65 deg F. with operating pressures up to 2400 psi. where evaluation of nozzle/blast tubes with alternate shell manufacturing techniques and low-cost ablative materials and processes was conducted.

The nozzle/blast tube configuration design will be sized to accommodate adequate radial and longitudinal clearance for the movable wing steering control section equipment, and provide proper backside temperature control.

CSD's use of well characterized and readily processed tape-wrapped carbon-cloth phenolic liners/insulators and 4D carbon-carbon providing uniform and reproducible erosion characteristics is widely proven on Mk 111, Mk 72, Trident II stage-three and Orbus 1.

The theater-wide stage-two motor version may be equipped with a movable nozzle configuration to allow missile steering via TVC at high altitudes. Figure 8 shows a typical movable nozzle design and its associated electro-mechanical thrust vector actuation (EM-TVA) mechanism. The movable nozzle design will be based on a flight proven flexseal configuration for which CSD has extensive experience in design/analysis, testing and production; including Trident II stage-three, SICBM stages one and three, and Orbus 1 motors.

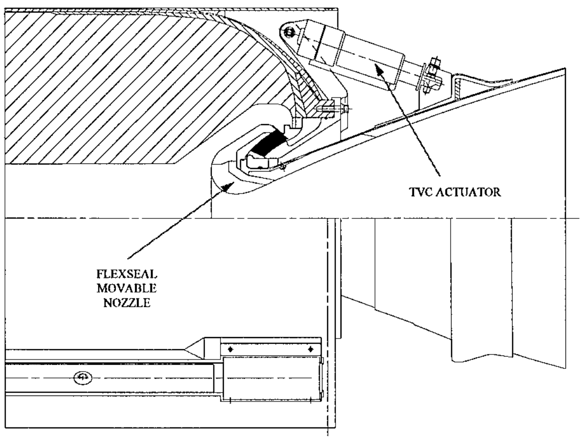

Figure 8. Movable Nozzle Configuration and TVA

The flexseal movable nozzle configuration approach will result in lower actuation load requirements to allow for efficient EM-TVA system packaging. The flexseal movable nozzle can also be readily integrated with an existing CSD flight proven, low cost, high reliability actuator package and controller. The 4 hp. output, brushless DC motor, bearing driven ball screw is digitally controlled by a hybrid powered controller with internal thermal batteries.

Summary

The next natural evolution for the Standard Missile is to implement a new 21-in. diameter, high performance, stage-two motor. The new stage-two motor will enable Standard Missile to significantly increase the types of missions it is able to engage, including Navy theater-wide and fast response deep strike. Engaging both of these missions is crucial for near future military conflicts.

CSD believes in the need for the new 21-in. diameter stage-two motor and has the propulsion know-how and resources necessary, as demonstrated by several successful development, production and technology Navy propulsion programs, to provide a high performance and low cost propulsion solution. Previous and on-going efforts are focused on enhancing a technical foundation upon entry into a development phase.

The evolved full caliber 21-in. diameter stage-two motor will be compatible with the existing Mk 72 booster and VLS interfaces. It will incorporate minimum changes to proven SOTA technologies, support the Standard Missile evolutionary approach, and offer the lowest risk path and lowest cost to meeting performance and infrastructure requirements.