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Developmental Testing of a Candidate Second-Stage Motor for the SS-N-20 SLBM Follow-On (s)

A Technical Intelligence Report

Top Secret

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March 1984

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Developmental Testing of a Candidate Second-Stage Motor for the SS-N-20 SLBM Follow-On (s)

Summary
[redacted]

Preparations for developmental testing of a candidate second-stage motor for the SS-N-20 follow-on SLBM were observed at the Pavlograd Motor Development Complex in September 1983. The motor involved in this test has the same [redacted] diameter as the original SS-N-20 second stage, but [redacted] The development of larger motors for the SS-N-20 follow-on would allow the Soviets to deliver more or heavier reentry vehicles to the SS-N-20's present range, to increase the SS-N-20's present range, or some combination of these possibilities. Special intelligence indicates, and analysis of satellite imagery substantiates, that land-based testing of the new missile will begin in late 1985 and that it may reach initial operating capability in Typhoon-class submarine launchers about 1988. 25X1 25X1 25X1

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Developmental Testing of a Candidate Second-Stage Motor for the SS-N-20 SLBM Follow-On (s)

Introduction

The SS-N-20 SLBM/Typhoon SSBN weapon system consists of the SS-N-20 submarine-launched ballistic missile (SLBM) and its 20 launchers on the Typhoon-class nuclear-powered ballistic missile submarine (SSBN). The MIRVed SS-N-20 has an estimated maximum booster range of about 9,000 kilometers. It is about 15 meters long and has three solid-propellant stages [redacted]. The remaining space, about 4 meters, is occupied by the third stage, postboost vehicle, reentry vehicles, and guidance package. (TS [redacted])

Special intelligence has indicated since early 1980 that the Soviets were planning a follow-on to the SS-N-20 SLBM that would be deployed on the Typhoon-class SSBN. Special intelligence further indicates that land-based testing was to begin in late 1985 and sea-based testing a year later and that the system would reach initial operational capability in 1988. This information also indicates that changes to all three missile stages were being considered. One specific proposal was to increase the length of one of the motors, possibly the second-stage motor, by 0.234 meter. The development of larger motors for the SS-N-20 follow-on would allow the Soviets to deliver more or heavier reentry vehicles to the SS-N-20's present range, to increase the SS-N-20's present range, or some combination of these possibilities. (TS [redacted])

This study analyzes the motor at the test facility as a candidate second-stage motor for the SS-N-20 follow-on SLBM. It also discusses the test preparations being made, the type of test they suggest, and the reasons such a test may be required. (TS [redacted]) 25X1

Discussion

[redacted] test preparations were observed at the test facility of the Pavlograd Motor Development Complex (figure 1). A motor at the facility's static test stand being prepared for testing [redacted] (The nozzle throat dimension could not be accurately measured.) A diffuser (a device used to simulate the environment at altitudes above sea level) consisting of four 5-meter-long segments, with water-coolant lines attached, was in position behind the motor. The assessed thrust capacity for this diffuser is about 1,250 kilonewtons,[1] providing it with the capability to test the maximum thrust expected to be produced by this large second-stage motor (appendix). (S [redacted]) 25X1

The motor observed in September had the same [redacted] diameter as the original SS-N-20 SLBM second-stage motor [redacted] The original motor [redacted] when it was observed being prepared for production-related testing at the Biysk Solid Motor Complex (figure 2). This increase in length and the motor's [redacted] 25X1

[1] A newton is defined as the standard meter-kilogram-second unit of force, equal to the force that produces an acceleration of 1 meter per second per second on a mass of 1 kilogram. (U)

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[redacted]

Special intelligence and imagery have indicated that the Utkin design bureau and its associated test facilities in Pavlograd were involved in developing the SS-N-20 propulsion system. In late 1978, approximately 26 months prior to the first SS-N-20 land-based test, two [redacted] motors were observed at the test facility in Pavlograd. Their lengths suggested they were related to the development of the SS-N-20 first-stage motor. Developmental testing of motors for the SS-N-20 follow-on SLBM at Pavlograd and the timing of these tests are therefore consistent with previously observed practices. The timing of the recent test preparations suggests that this new missile is on a schedule that will lead to flight testing beginning in late 1985 and deployment about 1988 in accordance with the Soviet proposal. (TS [redacted]

Construction to support simulated altitude testing of large motors at Pavlograd began in July 1980, probably as part of an effort observed at other Soviet solid-propellant facilities to improve the effectiveness of their static test programs. An assembly and control building, rail lines (required for the movement of diffuser segments), and a water reservoir (required for

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storing water to cool the diffuser segments) were constructed near the test stand. In August and September 1981, compatibility tests of the diffuser were conducted using four of five diffuser segments, each 5 meters long and 3 meters in diameter.[2] [redacted] 25X1 [redacted] the facility appeared to be preparing to use t 25X1 diffuser in a static test for the first time, although an environmental cover at the thrust block precluded observation of the motor. (S [redacted] 25X1 25X1

In the September 1983 preparations, however, the environmental cover had been removed and the motor was in the test stand with the water-cooled diffuser behind it. Diffusers are used in various configurations to simulate the environment at altitudes above sea level for static testing of motors. Testing a motor in a simulated-altitude environment provides data that otherwise would be available only through flight testing. Altitude environments, in relation to missile stages, differ from a sea-level environment in two primary effects: lower ambient pressure and reduced heat transfer. These changes affect motor ignition, chamber pressure, nozzle design, insulation, thrust termination, and structural integrity. (S [redacted] 25X1 25X1

In the September test preparations, we could not determine if the diffuser would have been attached to the motor nozzle prior to testing. If it were not, the Soviets could have measured motor thrust and burn rate in the simulated-altitude environment that w 25X1 be created after the motor was ignited and began to exhaust through the diffuser. The Soviets then could have extrapolated their measurements to reflect the same parameters at a given altitude. The effectiveness of the thrust vector control systems in altitude environments could also have been tested. (S [redacted] 25X1 25X1

Alternatively, the diffuser could have been attached to the motor nozzle and evacuated of air prior to 25X1 test to simulate ignition at high altitude. Solid-pro 25X1 lant motors are ignited by filling the propellant cavity with hot gas produced by an igniter. More gas is required to ignite a motor at higher altitudes than at sea level because of the lower ambient pressures at

[2] The fifth segment appears to be a spare, probably to replace the segment closest to the nozzle during a static firing because it probably will receive the most ablative force from the motor's exhaust. (S [redacted] 25X1

higher altitudes. If the original second-stage igniter (or a minor modification of it) were being used on the second-stage motor for the SS-N-20 follow-on, an altitude-simulation test would be required to assure that enough gas would be produced to ignite the additional [redacted] of propellant. (TS [redacted]) 25X1 25X1

Another purpose for an attached nozzle test at Pavlograd could have been to test specially configured nozzles for use at higher altitudes. Gases escaping the nozzle of a burning motor expand more rapidly at high altitude than at sea level. Upper stage nozzles, therefore, are configured with a higher area ratio to obtain the greater efficiency in performance available at altitude.[3] Simulating the altitude at which the motor is expected to operate allows these specially configured nozzles to be tested on the ground prior to their use on flight test missiles. Improving nozzle design is an option the US has pursued for several years, resulting in specially configured nozzles being used on the third stage of the Peacekeeper (MX) missile. The test activity observed at Pavlograd may be an indication that the Soviets are also attempting to improve their nozzles. (S [redacted]) 25X1 25X1

[3] The nozzle area ratio is equal to the area of the nozzle exit divided by the area of the nozzle's throat: A_e/A_t. (U)

Appendix

Calculating the Thrust Capacity of the Diffuser

The measured thrust of a motor (T_m) is the sum of the momentum thrust and the pressure thrust:

$$T_m = \dot{m}\, V_e + (P_e - P_a)\, A_e$$

where $\dot{m}$ is the propellent mass flow, V_e is the velocity of the exiting gases, P_e is the pressure at the nozzle's exit plane, P_a is the ambient pressure, and A_e is the area of the nozzle's exit (figure 3).[1,2] Assuming the diffuser is connected to the nozzle and is evacuated of air, P_a in the formula decreases and will be represented by P_a'.[3] The steam thrust at the diffuser exit (T_{se}) is the pressure thrust in the diffuser factored by the ratio of specific heats (Y) relative to the Mach number (M):

$$T_{se} = P_d\, A_d\, (1 + YM^2)$$

where P_d is the pressure in the diffuser and A_d is the area of the diffuser and M is the Mach number (figure 4). Finally, the steam thrust at the diffuser inlet (T_{si}) of a vacuum test cell is the sum of the velocity thrust ($\dot{m}\, V_e$) and the pressure thrusts relative to the nozzle and to the test chamber:

$$T_{si} = \dot{m}\, V_e + P_e\, A_e + P_a'\, (A_d - A_e)$$

where P_a' is the ambient pressure at the diffuser inlet if connected to the nozzle. (U)

[1] For more information on the origination and use of these formulas, see *Rocket Propulsion Fundamentals,* L. K. Isaacson, July 1981. (U)

[2] In measured thrust, the effect of the gravitational constant (G_c) from Newton's second law of motion, $F = M_a/G_c$, is negligible. The formula for the calculation of measured thrust thus becomes $F = M_a$. (U)

[3] If the diffuser is not connected to the nozzle, P_a' would more closely approximate P_a, thereby reducing the capacity of the diffuser. (U)

Figure 3

Calculation for Thrust of a Rocket Motor

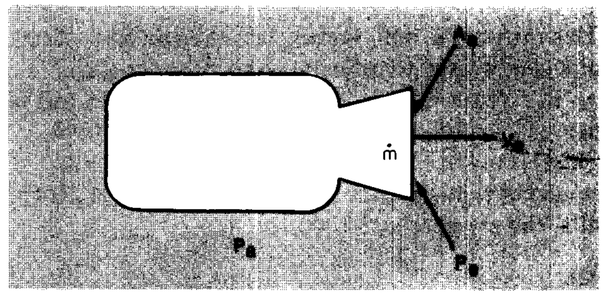
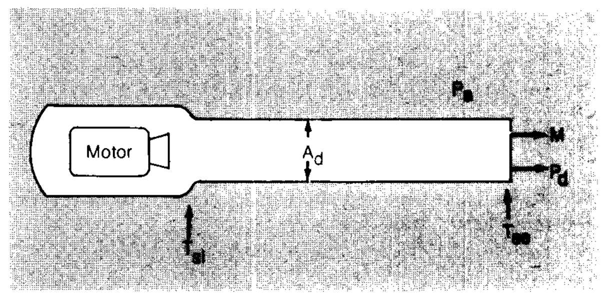


Figure 4

Motor in a Test Cell/Diffuser



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Summarizing, we have:

$$T_m = \dot{m}\, V_e + (P_e - P_a')\, A_e$$
$$T_{se} = P_d\, A_d\, (1 + YM^2)$$
$$T_{si} = \dot{m}\, V_e + P_e\, A_e + P_a'\, (A_d - A_e).$$

Rearranging for T_{si} produces:

$$T_{si} = \dot{m}\, V_e + (P_e - P_a')\, A_e + A_d\, P_a'$$

and the formula for motor thrust becomes $T_m = T_{si} - A_d P_a'$. For purposes of this estimation, friction effects on the steam thrust can be neglected, resulting in T_{si} being roughly equal to T_{se}. Substituting produces:

$$T_m = P_d A_d (1 + YM^2) - A_d P_a'$$

This quantity is only slightly less than diffuser thrust and can be used to estimate the diffuser capacity ($T_m \approx T_d$). Y can range from 1.16 to 1.34, so 1.25 will be used; P_d for solid motors is usually about 1 atmosphere, or 101.33 kilopascals[4] (kPa); and P_a' is assumed to be no greater than 0.1 atmosphere or 10.133 kPa, the pressure at 50,000 feet. (U)

Using M = 1, a nominal value for diffuser operations, and the 3-meter diameter diffuser (estimated 2.7-meter inner diameter):

$$T_d = (101.33)\,\pi\,(1.25)^2\,(1 + (1.25)\,(1)^2) - \pi\,(1.35)^2\; 10.133$$

T_d = 1,247 kilonewtons (S NF REL UK CAN WN)

[4] A pascal is defined as a unit of pressure or stress; 1 pascal equals 1 newton per square meter. (U)

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