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**Depressed Trajectories:
Unlikely Role for
Soviet SLBMs**

An Intelligence Memorandum

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An Intelligence Memorandum

The authors of this paper are
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**Depressed Trajectories:
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Soviet SLBMs**

Summary

*Information available
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was used in this report.*

We do not believe that currently deployed Soviet SLBM systems can fly reduced-flight-time profiles, usually referred to as depressed trajectories. Furthermore, we see no evidence of Soviet programs to develop SLBMs with this capability. Theoretically, depressed trajectories can reduce flight times substantially below those normally expected. Thus the missiles might reach strategic aircraft and other time-urgent targets without allowing sufficient warning time for aircraft dispersal and for US command, control, and communications systems to respond to the attack in a coordinated fashion.

We believe that the current Soviet SLBM force would require extensive modifications or, more likely, redesign to fly a reduced-flight-time profile. The magnitude of these changes would prohibit their implementation. The missile guidance system, the submarine fire-control system, and the reentry vehicles would all need to be modified or redesigned.

We believe that Soviet emphasis in SLBM design is now and will continue throughout this decade on increasing the survivability and readiness of their systems. To accomplish this, the Soviets are developing long-range, stellar-aided inertially guided SLBMs. The long range allows the Soviets to conduct patrols in or near their home waters, in order to enhance survivability and reduce the time required by the submarine to get on station. The stellar-aided guidance systems enhance system survivability and readiness by making the missile less dependent on external navigation aids. This type of guidance system also helps to provide an acceptable, although modest, missile accuracy for these Soviet systems.

The Soviets undoubtedly recognize the advantage of reaching time-urgent targets quickly. We believe that they might consider reducing flight times by moving a small group of submarines closer to US targets than they are in their current patrol areas. Even in this situation, we believe that their SLBMs would be flown with standard trajectories. Moreover, the flight times would not be comparable to those achievable by using the theoretical reduced-flight-time trajectories.

Depressed Trajectories: Unlikely Role for Soviet SLBMs

Introduction

The possible use of Soviet SLBMs in a reduced-flight-time¹ profile, or so-called depressed trajectory, has received much attention in the United States. This attention is generated by the possible vulnerability of the US bomber force and other time-urgent targets, such as command, control, and communications centers, to a surprise attack by Soviet SLBMs. This would involve using a flight profile whereby the missile flight time is short enough to threaten the escape of strategic aircraft on alert and to prevent US command, control, and communications centers from responding to the attack in a coordinated fashion. We have constructed theoretical and nonstandard flight profiles, which, if flown, could reduce the missile flight time below that normally expected. We also address the compatibility of these trajectories with currently deployed Soviet SLBMs.

Trends in Soviet SLBM Development

The trend in Soviet SLBM development is now and will continue to be throughout this decade on fielding long-range stellar-aided, inertially guided systems. Such designs enhance the readiness and survivability of Soviet SLBM systems.

Through 1968 the Soviets had developed and deployed only single-stage, short-range (up to 2,400 kilometers) SLBMs. The last missile of that series was the SS-N-6, carried by the Y-I-class SSB.

The extremely short range and inflexibility of the SS-N-6 missile and a fire-control system on the Y-I, which we believe has an extremely limited computational capability, undoubtedly were sources of concern for Soviet planners. The short range of the missile necessitated time-consuming transits from Soviet ports to patrol areas within range of US targets. During transit, the submarines carrying the SS-N-6 SLBM were vulnerable to detection by antisubmarine warfare (ASW) forces.

We believe that Soviet attempts to correct the shortcomings of the SS-N-6 led to the design and deployment of long-range stellar-aided, inertially guided SLBMs. The SS-N-8 was deployed on the D-I-class submarines in 1973, and the Mod 1 has a range of 7,800 kilometers (km). The SS-N-18

¹ The term depressed trajectory traditionally has been used to refer to any flight profile specifically used to reduce flight times below those normally expected. Since this is the objective of these profiles, we believe the term reduced-flight-time profile is more appropriate and will be used in this paper.

~~Normal~~

was deployed on the D-III in 1978, and the Mod 2 has a range of 7,950 km. (We are excluding from consideration the SS-N-17, which is deployed only on the single 12-tube Y-II-class SSBN.) In January 1980 the Soviets began flight-testing yet another long-range SLBM. This missile, which we designate the SS-N-20, is not yet operational; its maximum booster range is about 8,000 to 9,000 km.

The SS-N-18 is the most recent Soviet SLBM to reach operational status.

An apparent Soviet goal in designing the SS-N-18 was to increase its survivability and readiness by making it less dependent on external navigation aids. Survivability is increased because the use of navigation aids to update the submarine navigation system will be less frequent. Such updating often requires near-surface submarine operations. System readiness in the SS-N-18 is improved by eliminating the requirement to take a final position fix after the launch command is given. The older SLBMs, SS-N-6 and SS-N-8, may well require such a fix because of the low-quality Soviet submarine navigation systems.

The current trend in Soviet SLBM development is to field long-range systems that can operate covertly and at a high state of readiness for long periods of time. The very long range of the SS-N-8 and SS-N-18 SLBMs allows the Soviets to patrol in areas close to their home ports while remaining in range of targets in the United States. The location of these patrol areas would make it very difficult for Western ASW forces to engage and destroy Soviet SSBNs during times of hostility. Moreover, the location of these patrol areas close to the Soviet homeland makes it easier for them to protect their patrolling SSBNs. (The Soviets have committed a significant portion of their general purpose forces to this role.) We believe that the Soviet desire to patrol in areas closer to their own ports was, at least in part, the motivation for developing their large long-range SLBMs.

We believe the Soviets will follow their well-established trend of fielding large long-range SLBMs for the remainder of this decade. There is no evidence to indicate that they will do otherwise. If the Soviets decide to develop an SLBM system specifically for reduced-flight-time profiles or to modify an existing system for this role, they would have to conduct flight

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tests to verify the missile's performance. We believe that the Soviets would have little chance of concealing either the tests of a modified missile or the more extensive tests that would be required for a new missile. We have high confidence that we would detect, and recognize the intent of, such tests if the Soviets were to conduct them.

Theoretical Trajectory Considerations

Large ballistic missiles in general fly a minimum-energy, gravity-turn trajectory. The theoretical technique that appears to be most effective in reducing flight time is referred to as angle-of-attack steering (designated α -steering).

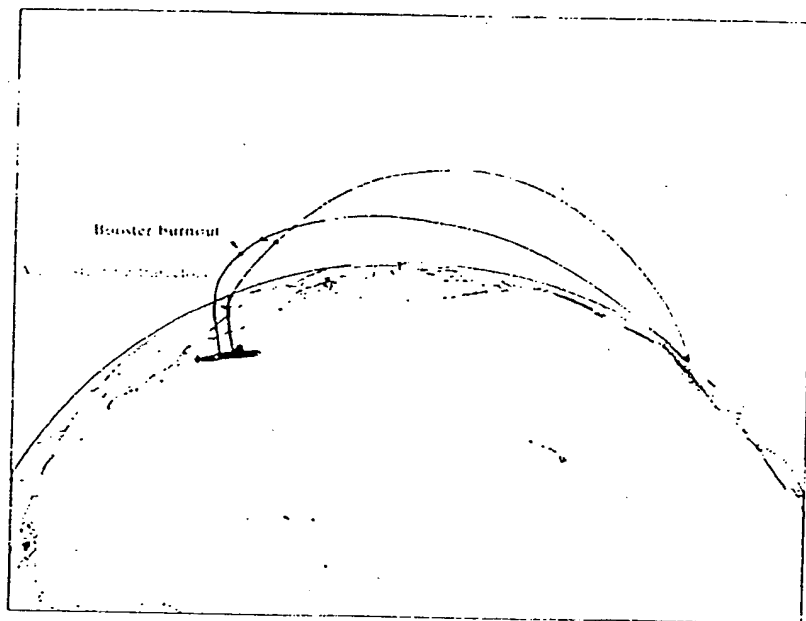
Ballistic missiles generally follow a flight profile that provides a maximum range for a fixed amount of energy and does not produce excessive aerodynamic and heating loads on the missile. In such a flight profile, the missile pitches over in the direction of the target shortly after launch and maintains the direction of the velocity it has gained parallel with the missile's longitudinal axis during transit of the earth's atmosphere.

In contrast to a minimum-energy, gravity-turn trajectory, a trajectory generated by α -steering uses a steeper ascent for the missile while it passes through the atmosphere. When above the atmosphere, the missile pitches down, developing a large angle between the velocity vector and the longitudinal missile axis; that is, the missile develops a large negative angle of attack. Thus, the missile thrust is used to change rapidly the direction of the velocity as well as its magnitude (see figure 1).

For a given range, α -steering produces a shorter flight time with correspondingly smaller aerodynamic and heating stresses than any other technique for reducing flight times substantially below those of a minimum-energy trajectory. However, for SLBM systems where the launch location and ranges to assigned targets are constantly changing as the submarine moves through its patrol region, trajectories using α -steering require flexible missile guidance systems and a submarine fire-control computer with substantial computational capability. The pitch history, engine burn time, and reentry angle of missiles flying trajectories generated by α -steering are all dependent on and vary with range to target. The Soviets basically operate their SLBMs essentially with fixed-pitch programs and generally constant reentry angle for all ranges.

A comparison of flight time versus range for missiles flying α -steering and nominal trajectory profiles and having the total impulse of the SS-N-6 Mods 2 and 3 and the SS-N-8 Mod 1 are shown in figures 2 and 3. The top branch of each curve represents the nominal (demonstrated) time-of-flight profile, and the lower branch represents flight times that could be achieved

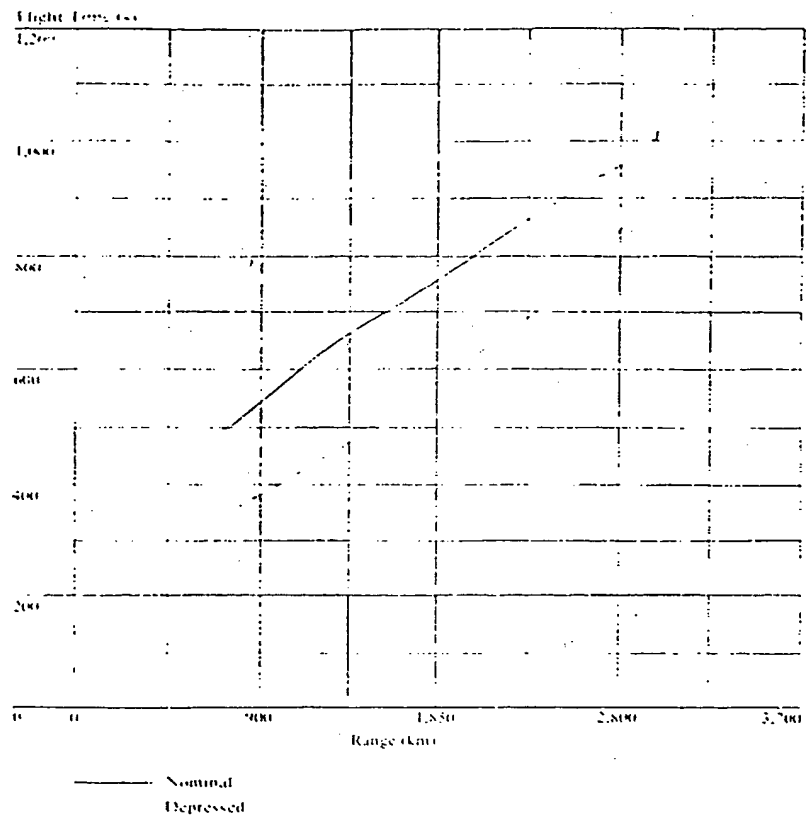
Figure 1
Comparison of Gravity-Turn and Alpha-Steering
Trajectories



using α -steering. The actual missile propulsion characteristics C_D and angle-of-attack limitations were used in generating these curves. The ability or inability of the missile's guidance and control system to support the α -steering flight profile was not considered (this is discussed in a later section of this paper). For planning purposes, the lower branches of these curves are practical lower bounds for the time of flight to the indicated ranges.

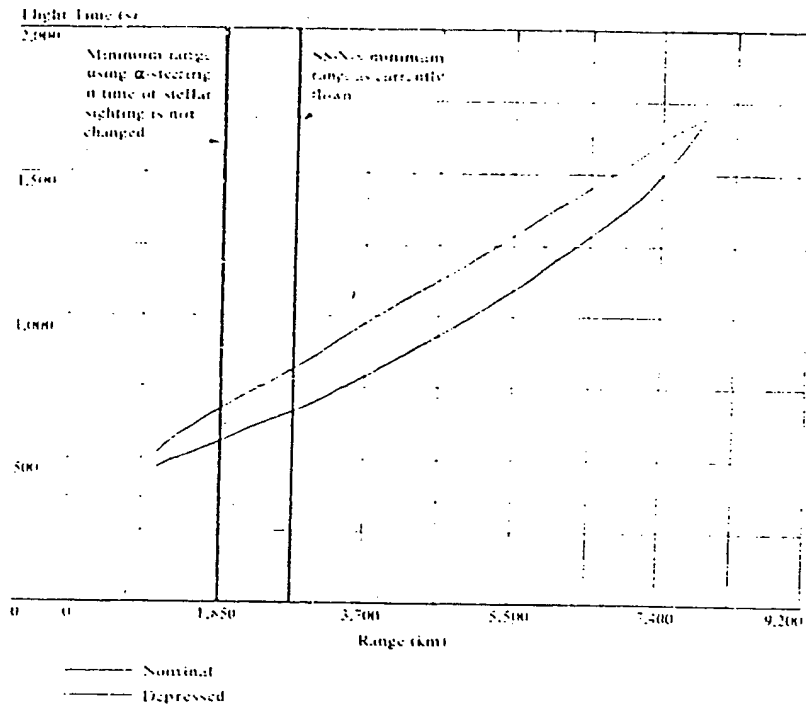
The curves shown in figure 3 for the SS-N-8 are also representative (although not exact) of flight times for the SS-N-18 because their boosters are very similar. The greater throw weight of the SS-N-18 Mods 1 and 3,

Figure 2
Nominal and Theoretical Depressed Trajectory
Flight Times for the SS-N-6 Mod 2/3 SLBM



however, reduces the maximum booster range to about 6,700 km. The Mod 2 has a substantially lighter throw weight than Mods 1 and 3. Thus, the booster range for the Mod 2 is very close to that of the SS-N-8 Mod 1 shown in figure 3

Figure 3
 Nominal and Theoretical Depressed Trajectory
 Flight Times for the SS-N-8 SLBM



Capability of Soviet SLBMs To Fly Reduced-Flight-Time Profiles

Of all the flights ~~that we have observed to date~~ the Soviets have not flown an SLBM to any range in a deliberate attempt to minimize the flight time.

The three Soviet SLBM weapons systems currently deployed against the continental United States are the SS-N-6, SS-N-8, and the SS-N-18. We do not believe that any of these deployed SLBM systems are viable candidates for use in a reduced-flight-time trajectory without extensive system modifications. We believe that the modifications would make their implementation unreasonable.

SS-N-6

We do not expect the SS-N-6 to be used in a manner different from that used since it was deployed in 1968. The SS-N-6 generally follows flight profiles that are close to minimum-energy trajectories. For the Mods 2 and 3, however, the trajectories are lofted slightly compared to minimum-energy trajectories, and slightly longer flight times are actually realized.

The SS-N-6 is the oldest of the modern deployed Soviet SLBMs. It is deployed in three variants on the Y-I-class SSBN.

We know all three variants use the same pitch program during missile boost. The program is optimized for the maximum range of the Mod 1. The missile uses an analog flight computer, and we believe the pitch program is irretrievably stored in the computer before it is installed in the missile. Consequently, any Soviet attempt to implement a different pitch program for the SS-N-6, such as α -steering, would require installing a new computer and modifying the missile's guidance and control system. Such changes are substantial, and we believe they are too extensive to be implemented on this aged system.

We believe that one of the reasons for the simplistic implementation of the pitch program on the SS-N-6 is to ease the targeting burden on the Y-I fire-control system. The SS-N-6 Mods 2 and 3 have a higher specific impulse than the Mod 1 but were developed with the same pitch programs. The Mod 2 has a slightly less efficient, more lofted trajectory than the Mod 1. The Soviets apparently were reluctant to develop different pitch programs even for different variants. Even if the Soviets were to install a completely new computer on the SS-N-6, they undoubtedly would have to make changes in the fire-control system of the submarine.

SS-N-8

The SS-N-8 frequently has demonstrated flight times slightly less than those obtained in minimum-energy trajectories.

]

The SS-N-8 was designed from the outset as a long-range system and incorporates a stellar sensor as an integral part of the guidance system. The stellar sensor provides the missile guidance system with information [required to remove errors in the missile's flight azimuth.] We believe that the minimum design and operational range of the SS-N-8, using the current guidance algorithm, is approximately 2,800 km with a flight time of about 13 minutes. In contrast to the trajectory obtained using α -steering, the SS-N-8 uses the same basic pitch program for all ranges, and the

reentry angle is held fairly constant [

] Even if it were possible to use a-steering to shorten the range and flight time, and a stellar sighting was still required [

] the minimum range would still be approximately 1,850 km. The flight time would still be in excess of nine minutes.

For the SS-N-8 to achieve flight times substantially under 10 minutes, the stellar sighting would have to be either dispensed with or performed earlier in powered flight. Simply deleting the stellar sighting, however, would degrade system performance to an unacceptable level because of the large azimuth alignment errors at the time of missile launch. Moreover, [] we believe that extensive modifications would be required to change the time of the stellar sighting or to implement an a-steering program technique.

We believe the salvo time for the 12-tube D-I-class submarine is four to five minutes; for the 16-tube D-II, the time is six to seven minutes. While this is a respectable salvo rate, the total salvo time is incompatible with launching a full complement of missiles against time-urgent targets for all the missiles to be effective. Thus, the submarine's fire-control system must be improved to allow a more rapid launch sequence, or the number of SSBNs allocated to a given attack must be increased. In the latter case, each SSBN would launch a partial load of missiles to the most time-urgent targets. However, the Soviets realize that increasing the number of SSBNs would dramatically increase the probability of detection by US acoustic sensors. The result would be that mobile time-urgent targets, such as aircraft, could be dispersed.

SS-N-18

Three variants of the SS-N-18 are deployed. Mods 1 and 3 are equipped with MIRVs, and the Mod 2 carries a postboost vehicle with a single reentry vehicle. The booster is, in effect, an upgraded SS-N-8, but the stellar-inertial guidance system used on the SS-N-18 is much more sophisticated than that of the SS-N-8. [

] The information obtained is used to correct errors in the missile's flight azimuth and to correct errors in the launch location calculated by the submarine's navigation system.

[]

]the performance of the SS-N-18, as currently configured, in achieving reduced flight times would not be significantly different from that of the SS-N-16.

]We believe the minimum range of the SS-N-18 using current pitch programs yielding trajectories close to minimum energy is about 2,700 to 3,000 km with a flight time of 13 to 15 minutes. Shorter ranges are possible but would require a more leaved trajectory.

For flight times substantially under 13 minutes to be achieved, the stellar sightings would have to be either eliminated or modified. Given the care and concern that the Soviets have exercised in the development of the stellar sensor, we do not believe that either of these alternatives would be attractive to the Soviets.

We do not yet know if the salvo time of the D-III-class submarine will be as long as that of the D-I and D-II. To date we have observed only dual launches of SS-N-18s at intervals of approximately 15 seconds.

The apparent Soviet goal in the SS-N-18 design was to field an SLBM system that was, to the extent possible, independent of external navigation aids. Generally, the SS-N-18 does not require a submarine navigation fix shortly before launch, and is superior to any previous Soviet SLBM system in both readiness and survivability.

[]

SS-NX-20

The Soviets are now flight-testing a new long-range (8,000 to 9,000 km), solid propellant, three-stage SLBM, which we designate the SS-NX-20. [] like its predecessors the SS-N-8 and SS-N-18, this missile also uses stellar-inertial guidance. []

[] Unlike the SS-N-8 and SS-N-18, the SS-NX-20 boost motors cannot be shut down at some arbitrary time (thrust terminate); they must operate until the propellant is depleted. Therefore, if the missile is flown to less than maximum range, the excess energy must be dissipated []

[] the SS-NX-20 dissipates its excess energy by flying very lofted trajectories compared to minimum-energy trajectories. The lofted trajectories markedly increase the time of flight. Given the apparent design and operation of the SS-NX-20, a capability to fly a reduced-flight-time trajectory was not even contemplated.

Reentry Environment for Reduced-Flight- Time Profiles

An additional consideration in executing reduced-flight-time profiles is the ability of the reentry vehicle (RV) to survive and protect the warhead during the very shallow, high-velocity reentries. We are certain that not every RV deployed by the Soviets could survive such reentries and allow the warhead to function properly. We estimate that none of the currently deployed Soviet SLBM RVs can be used in such reentries.

We believe that (at least until recent years) Soviet RVs were designed so that the temperature rise in the RV during reentry would not be more than 5 degrees Celsius. We simulated the reentry environment that the SS-N-18 Mod 2 RV would experience during a reduced-flight-time trajectory to see if this criterion would be satisfied.

We assumed that the Mod 2 RV heat shield consists of two layers of silica phenolic insulation with the appropriate bonding material and thickness. The thickness chosen was such that the temperature rise inside the RV structure during reentry of a demonstrated maximum range trajectory would be about 1 degree which is consistent with what we believe to be Soviet design philosophy for this RV. While we do not know why the Soviets limit the temperature rise in the RV shell to such precise tolerances, it nevertheless appears to be a genuine part of their design considerations.

Analysis of reentry angles representative of reduced-flight-time trajectories shows that temperature rises inside the RV structure would be about 57 degrees at a 5-degree reentry angle and 29 degrees at a 10 degree reentry angle. Based on these results, we do not believe that the design of the Mod 2 RV would permit the RV to withstand the reentry of a reduced-flight-time trajectory and still allow the warhead and associated electronics to function properly with a high degree of confidence.

A modification, such as adding thermal insulation inside the RV shell, undoubtedly could be made to provide the necessary protection during reentry in reduced-flight-time trajectories. We do not believe, however, that the Mod 2 RV was designed from the outset to be used in a reduced-flight-time trajectory reentry.

Inasmuch as the Soviet long-range Mod 2 RV does not appear to be designed for shallow, high-velocity reentries, we believe it highly unlikely that RVs for the shorter range systems such as the SS-N-6 and SS-N-18 Mods 1 and 3 would have been designed with this capability. We believe that the reentry system would present another source of problems that the Soviets would have to consider before using their SLBMs in an unconventional manner, such as reduced-flight-time trajectories.

**Risks of Implementing
an Attack Using
Reduced-Flight-Time
Profile**

We believe that the Soviets perceive their greatest risk in implementing an attack using a reduced-flight-time profile to be the positioning of large numbers of SSBNs within suitable range of the targets without detection. If detected, not only would the Soviet SSBNs be vulnerable to attack, but detection would provide time for the dispersal of alert strategic aircraft. Thus, the very purpose for an attack using reduced-flight-times against this class of time-urgent targets would fail.

The Soviets undoubtedly have evaluated the concept of flying reduced-flight-time profiles against time-urgent targets. We do not believe, however, that current Soviet philosophy for using their SSBN force includes such a role, and indeed, we do not believe that the Soviets have that capability. While we believe the Soviets would strike strategic aircraft bases and command, control, and communications facilities rapidly in a nuclear conflict, we do not believe they are equipping their SLBM force with the capability to attack these targets using trajectories other than conventional ones. In attacking these targets, we believe the Soviets might move a few SSBNs closer to the United States and fly standard trajectories. The flight time will be reduced by simply flying a shorter range to target.