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Technical Refinements in Design Features of the Airborne Patrol Against North Korean ICBMs

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Summary

This paper provides members of Congress and their staffs with a refined technical assessment of the defense-system concept we call the *Airborne Patrol against DPRK ICBMs*.

We find that the performance characteristics of the anti-ICBM interceptor are central to the successful implementation of the Airborne Patrol, affecting air-operations; patrol management, coverage of launch areas in the DPRK, and system intercept capabilities.

As part of our continued effort to identify optimal achievable designs for the anti-ICBM interceptor, we have collected considerable data on the capabilities and weights of state-of-the-art infrared homing and guidance systems and advanced small solid-propellant rocket motors that would be needed for the anti-ICBM interceptor

We find that it is possible to build an anti-ICBM interceptor that is lighter, smaller, and with a significantly higher burnout speed (5 km/s versus 4 km/s) relative to the interceptor we proposed in our concept paper dated November 27-29, 2017. This faster and lighter interceptor also has a divert speed of 2 km/s which leads to a high homing-intercept rate and a more robust and operationally flexible Airborne Patrol Concept. The extreme importance of having both adequate burnout and divert speeds is discussed in detail in this paper.

We have also been following published discussions about different variants of Airborne Patrol Systems that assume interceptors with divert velocities of 0.5 km/s (rather than 2 km/s) and burnout speeds of roughly 3.5 km/s (rather than 5 km/s). Such interceptors have an evident benefit of being considerably lighter than a 5 km/s anti-ICBM interceptor with a 2 km/s divert speed. However, these anti-ICBM interceptors will not be able to cover significant launch areas in the DPRK and will have low homing-intercept rates. In fact, their intercept capabilities will be low even when target-ICBMs are within their engagement range.

This separate finding is also discussed in this paper.

Introduction

The objective of this paper is to provide members of the Congress and their staffs with updated information about our continuing efforts to refine the defense-system concept we call the *Airborne Patrol against DPRK ICBMs* (see Appendix VI for details).

The House Armed Services Committee has written legislation in response to our earlier efforts to bring this missile defense concept to the attention of the US Government. The legislation directs the Secretary of Defense to "enter into an agreement with a Federally Funded Research and Development Center (FFRDC) to conduct a feasibility study" of this and related system concepts – including "at a minimum" a review of our report dated November 27-29, 2017 (Appendix VI). The language of the legislation is shown in Appendix I at the end of this document.

We have collected considerable additional public-domain data on the state of the art in infrared optical and guidance systems, and on advanced proven solid-propellant rocket-motor technologies. As a result of this new information we have redesigned the anti-ICBM interceptor that was discussed in our earlier briefing to Congress – **yielding an interceptor that is lighter, smaller, and with a significantly higher burnout speed (5 km/s versus 4 km/s).** This interceptor meets the demanding requirement that the *Powered Kill Vehicle* (PKV) have an additional 2 km per second divert velocity for final homing. These considerable improvements in the interceptor result from the use of more advanced rocket motor propulsion systems and lighter optical homing systems than we assumed in our earlier analysis.

The updated performance capabilities of the anti-ICBM interceptor **lead to a more robust and operationally more flexible Airborne Patrol Concept.** The increased speed of the interceptor makes it possible to operate interceptor-carrying drones over much larger ocean areas, while still being able to cover the most difficult launch regions and launch azimuths that North Korea could theoretically use in an ICBM attack against the continental United States.

We have also been following published discussions about different variants of Airborne Patrol Systems that assume interceptors with divert velocities of 0.5 km/s (rather than 2 km/s) and burnout speeds of roughly 3.5 km/s (rather than 5 km/s). Such systems have an evident benefit of considerably lighter anti-ICBM interceptors. **However, anti-ICBM interceptors with these characteristics will have little, if any, intercept capability against North Korean ICBM's in powered flight.**

The reasons are simple. The relatively low divert velocity of 0.5 km/s is not nearly enough to make the final adjustments needed to intercept an ICBM in powered flight where its powered flight profile is not perfectly known in advance. **Our numerous analyses of this problem indicate that a 2 km/s divert in the Kill Vehicle is necessary**. The burnout velocity of 3.5 km/s, results in much more restricted areas of airborne operation, and requires airborne operations over much small areas of ocean that must be closer to potential target ICBMs in powered flight. In particular, our analysis of the potential coverage of anti-ICBM interceptors with 3.5 km/s burnout speeds indicates that there will be significant areas of North Korea that could not be reached if the drones are to patrol no closer than 100 km from North Korea's coast.

We believe that designing a system that must fly over North Korean airspace is highly inadvisable for both military and political reasons. In particular, the drones that are being contemplated for this mission would have significant radar cross-sections due in part due to the exterior carriage of the anti-ICBM interceptors.

We have looked at the use of F-35 stealthy fighter planes as platforms for anti-ICBM interceptors. These aircraft have been occasionally discussed in the press as potential platforms for use against ICBMs in powered flight. F-35's would be capable of carrying two anti-ICBM interceptors within their weapons bay, and would thereby retain the stealth characteristics they have been designed to achieve.

However, F-35's will have a relatively short on-station time (about 2.5 hours per sortie) and at least 10 F-35 sorties per day would be needed to maintain one aircraft on station 24 hours a day. Appendix V, titled *Very Rough Estimates of the Cost of Airborne Patrol Concepts Based on the Predator-B versus the F-35* lays out the arithmetic for the estimated operational costs for maintaining an F-35 on Airborne Patrol for 24 hours a day, 365 days per year, and for ten years. This cost estimate, which includes the cost of fuel, other consumables, replacement parts and depot maintenance ($30,000 per flight hour), is about $3.8 Billion.

A Predator-B Drone costs between $4000 and $5000 per hour and can be on station for roughly 20 hours or more per day. This means that roughly 1.2 predators would be needed to keep one on station for 24 hours per day. The cost per sortie would be about $105,000 leading to a cost estimate of $460 Million for maintaining an F-35 on Airborne Patrol for 24 hours a day, 365 days per year, and for ten years.

The total cost for operating the system for 10 years is then proportional to the number of aircraft that will be needed simultaneously on station. Five aircraft on station simultaneously would be needed to be able to engage a simultaneous launch of five ICBMs.

Aircraft acquisition costs are also significant. If roughly two Predator-B's are acquired so that each could fly every second day, and roughly 20 to 30 F-35's are acquired so that each could fly sorties once every second or third day, the ratio of F 35's to Predator-B's that would have to be purchased to populate a patrol station would be roughly 10 or 15 to 1. The cost of an F-35 relative to a Predator-B is roughly $100 million versus $20 million. This leads to a cost ratio for purchased aircraft of roughly 50 to 75 to1 – or roughly $40 million relative to $2 billion or $3 billion in order to have enough aircraft to populate a single airborne missile defense station in the system (see Appendix V, page 4 for details of the arithmetic).

These alternative technology choices underscore the critical importance of designing from the beginning an adequate and appropriate anti-ICBM interceptor. The total overall system cost savings associated with developing appropriate anti-ICBM interceptors are drastically affected by the final performance of the interceptor. Stated differently, trying to go cheap on an interceptor that is only a small part of the overall system costs will likely result in a system that would work poorly and would entail excessive and avoidable costs.

What's New?

The important new developments in the updated technology assessment are as follows:

1. Open literature information on the weight and characteristics of infrared homing optical systems that could be used in the homing section of the proposed anti-ICBM interceptor indicates that the infrared homing and guidance section of the Powered Kill Vehicle launched by the interceptor could be roughly 7 or 8 kg or less. Our original design for the anti-ICBM interceptor assumed an infrared homing and guidance package that weighed 25 kg. Our new estimate of the properties of our baseline interceptor assume that the weight of the optical and guidance components of the Powered Kill Vehicle is roughly 13 kg.
2. The 5 kilograms is added to include the weight of thermal batteries and other elements that are not part of the rocket motor and optical system.
3. These new assumptions about the weight of the "front-end" of the kill vehicle lead to an overall weight prediction for a Powered Kill Vehicle with a 2 km/s divert velocity of roughly 43 kg. The entire interceptor, assuming an adequate propulsion system to achieve a 5 km/s burnout speed for the Powered Kill Vehicle will have an overall weight of roughly 1100 pounds (490 kg). A full engineering assessment that will have to be done by the appropriate FFRDC will eventually provide a much more accurate estimate of the overall weight and dimensions of the anti-ICBM interceptor. However, a full engineering analysis is unlikely to produce an interceptor that is either drastically lighter or heavier based on the current revised estimates.
4. In this document we also provide information about the performance of alternative Airborne Patrol Concepts that propose using interceptors with a 3.5 km/s burnout speed and a Kill Vehicle with a divert velocity of 0.5 km/s for final homing.

   These systems superficially appear attractive because the light interceptor allows the carrying of more interceptors on each patrolling aircraft. However, the low interceptor burnout velocity (3.5 km/s) is insufficient for covering important potential ICBM launch areas in North Korea without entering North Korean airspace. In addition, the very low kill-vehicle *divert* velocity (0.5 km/s) leads to a high miss-rate against ICBMs in powered flight even when the interceptors can reach their targets.

Compensation for these limitations will require very high levels of redundant interceptor launches, which will then result in significantly lower intercept rates relative to a faster interceptor that has an adequately high single-shot kill rate. The short engagement ranges of the 3.5 km/s interceptor will also greatly limit the over-ocean operating areas for drones and complicate air operations considerably.

The Revised Baseline Interceptor

In this section we describe the physical characteristics of the anti-ICBM interceptor. This interceptor has a burnout speed of 5 km/s, a Powered Kill Vehicle divert velocity of 2.1 km/sec, a weight of roughly 490 kg (1100 lbs) and a length of roughly 3.75 meters.

As already noted, we assume that the optical homing and guidance section of the Powered Kill Vehicle weighs about 13 kg (we do not rule out a lower weight). In this case, only a single rocket motor is needed to quite efficiently provide both the required divert velocity of 2 km/s, and a high acceleration for the final seconds of the intercept process.

We estimate that the Powered Kill Vehicle could be fitted with a single stage small solid-propellant rocket motor similar to the STAR 12GV, produced by Orbital ATK. This motor was originally developed to propel the Terrier Exoatmospheric Light Projectile (LEAP) in early missile defense experiments during the early 1990s.

The STAR 12GV motor has a very high fuel fraction, an extremely lightweight thrust vector control system (movable nozzle) and a quite high propellant exhaust velocity (often expressed in terms of a quantity known as the specific impulse, which in this case is around 282 seconds, or 282s×9.8m/s = 2.79km/s).

The variant of this rocket motor that would be used for the Powered Kill Vehicle would be somewhat smaller (about 30 kg versus 42 kg) and would be modified to produce about half the thrust for twice the time relative the original motor.

Since the weight of the Powered Kill Vehicle drops as propellant is burned, the initial acceleration would be about 4G's rising to nearly 9G's by burnout at 35 seconds after ignition. The use of a single rocket motor solves the problem of getting an initial modest acceleration to more than 2 km/s that ends with a high acceleration for final maneuver to hit the target.

It is important to understand that more detailed engineering analyses could produce a better optimized design for the Powered Kill Vehicle. However, the current estimates of the engineering parameters of the Kill Vehicle should be similar to that produced by a detailed engineering design.

Stated differently, the available technology supports a conclusion that there is no technology needed for the kill vehicle that has not been demonstrated in other applications.

The main propulsion section of the anti-ICBM interceptor is somewhat lighter and smaller than the original interceptor design concept.

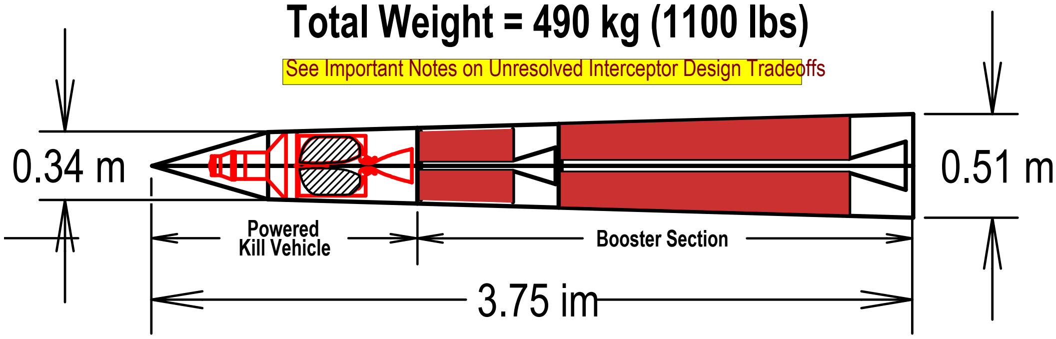
The characteristics of the two rocket stages in the "Booster" section are estimated by assuming that rocket motors designed specifically for this anti-ICBM interceptor have a similar level of performance relative to small solid-propellant rocket motors that have already been flown in other applications.

Examples of motors that exhibit the required levels of high fuel fractions, thrust vector controlled nozzles, high exhaust velocities, and extremely lightweight motor casings are the ASAS 13-30V and the STAR 37FMV. As will be the case with the rocket motor needed for the Powered Kill Vehicle, the actual rocket motors in the propulsion section will need to be designed so as to achieve similar performance to the ASAS 13-30V and STAR 37FMV motors, with modifications to achieve appropriate thrust levels and burn times.

Figure 1 below shows the estimated performance characteristics of the different stages of the Baseline Interceptor. Again, as already noted, a final interceptor derived from a detailed engineering assessment should be expected to be somewhat but not radically different from what is proposed herein.

Baseline Interceptor

Total Weight = 490 kg (1100 lbs)



5 km/sec Burnout Speed
8 kg IR and 5 kg Guidance Payload
Powered Kill Vehicle with 2 km/sec Divert
25 Seconds Acceleration to 5 km/sec

Total Weight of Interceptor	1073.79 lbs (486.98 kg)
Payload Weight	94.81 lbs (43.00 kg)
Speed at Burnout	5.00 km/s
First Stage Propellant Weight	648.44 lbs
First Stage Structural Weight	114.43 lbs
First Stage Structure Factor	0.15
First Stage Motor Specific Impulse	275 sec
First Stage Burnout Speed	2.50 km/s
First Stage Peak Acceleration	28 G
Second Stage Propellant Weight	183.69 lbs
Second Stage Structural Weight	32.42 lbs
Second Stage Structure Factor	0.15 lbs
Second Stage Motor Specific Impulse	285 sec
Second Stage Burnout Speed	2.50 km/s
Second Stage Peak Acceleration	26 G
Thrust Level of First Stage	14185.50 lbs
Thrust Burn Time of First Stage	12.57 seconds
Thrust Level of Second Stage	4243.16 lbs
Thrust Burn Time of Second Stage	12.34 seconds

Powered Kill Vehicle Details;

Total Weight	43.00 kg
Divert Velocity	2.09 km/sec
Weight of Motor	30.00 kg
Motor Fuel Fraction	0.75
Motor Specific Impulse	282 sec
Weight of IR System	8.00 kg
Weight of Batteries-etc.	5.00 kg
35 Second Burn;	
Initial Acceleration	4.2G
Final Acceleration	8.8 G

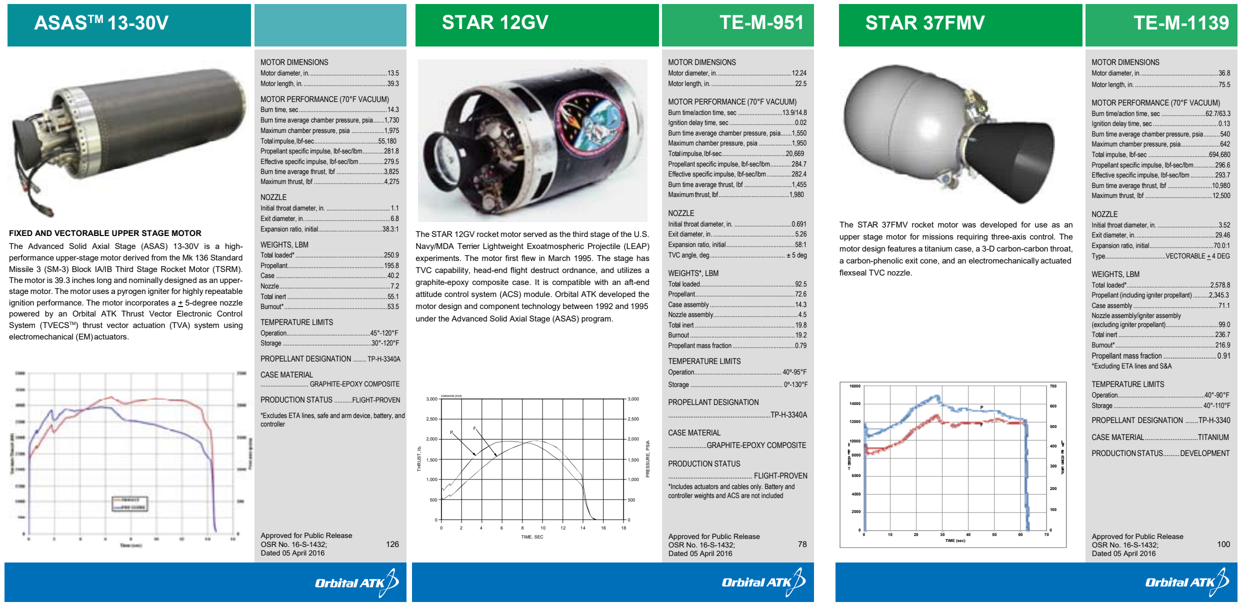
Note on Unresolved Interceptor Design Tradeoffs:

During the last 20 years there have been very significant technology advances in the ability to produce small rocket motors with very high fuel fractions (on the order of 90% of total rocket motor weight) with thrust vector control systems that are compact and light. There have also been advances in the production of lightweight nozzles and high exhaust velocity propellants. These advances raise the possibility of a single stage to accelerate the Powered Kill Vehicle to 5 km/s. We cannot resolve this question without direct access to the current state-of-the-art in advanced solid-rocket motor systems. Thus we propose herein a conservative two-stage propulsion system to boost the powered Kill vehicle to 5 km/s.

Figure 1

Figure 2 below shows the specifications of the rocket motors that have been used by us to estimate what we believe are close to the state-of-the-art capabilities in small solid-propellant rocket motors. In our estimates we have been careful to slightly underestimate performance parameters to leave room for factors that we have not considered like excess materials associated with the structure of the overall interceptor.

For those readers who are interested in the technical details of these rocket motors, we reproduce these data sheets in an easier to read format in Appendix II titled *Examples of State-Of-The-Art Rocket Motor Technologies*.



See appendix for enlarged images of these descriptions of the technical characteristics of modern solid-propellant rocket motors

Figure 2

Interceptor Coverage of Launch Areas in the DPRK

As already noted, the ability of the Airborne Patrol to intercept ICBMs in powered flight is intimately connected to two properties of the interceptors carried by drones on station. The first property is the range at which the interceptor can hit and destroy an ICBM in powered flight. The second critical property is the divert velocity and acceleration capability of the interceptor, which must be substantial in order to adjust for changes in the "Predicted Intercept Point" or PIP. The PIP changes in part because the prediction of the target-rocket powered flight path during the early phases of flight contain uncertainties from noise in the tracking data. However, even if the tracking data was perfect (noise-free), the rocket could deviate from its expected azimuth or loft angle as it continues its later powered flight. In addition, the acceleration rate of the rocket will not be precisely known because the rocket's payload is not known in advance by the defense.

The failure to take into account these basic facts of the real combat environment resulted in the Missile Defense Agency vastly overstating the capabilities of the Aegis-based European Phased Adaptive Approach prior to the president's decision on September 17, 2009 to proceed with deployments. This serious error was manifested as the "*Early Intercept*" concept which claimed that it was possible to launch EPAA interceptors before rocket-targets had finished powered flight. The concept was based on the incorrect assumption that once the rocket's location and velocity was known during its initial powered flight, that the remainder of its powered flight could then be completely predicted. This incorrect assumption then led to an additional incorrect conclusion that the intercept point *after* rocket burnout could be precisely predicted making it possible to launch interceptors towards accurately determined intercept points.

The net result of this error was that the Missile Defense Agency was overstating the capability of the EPAA to the president. It is possible that this overstatement of the abilities of the EPAA encouraged the White House to approve the September 17, 2009 commitment to build a system that was inadequate for the job.

Concerns about a repeat of this kind of error in part motivate the current discussion about the technical requirements on Airborne Patrol interceptors. Interceptors that do not have adequate burnout and divert velocity will be essentially unable to produce a workable Airborne Patrol system.

Missile Defense Agency briefing slides claiming that the *early intercept* concept could be used to considerably expand the capabilities of the EPAA system are included in Appendix IV at the end of this document.

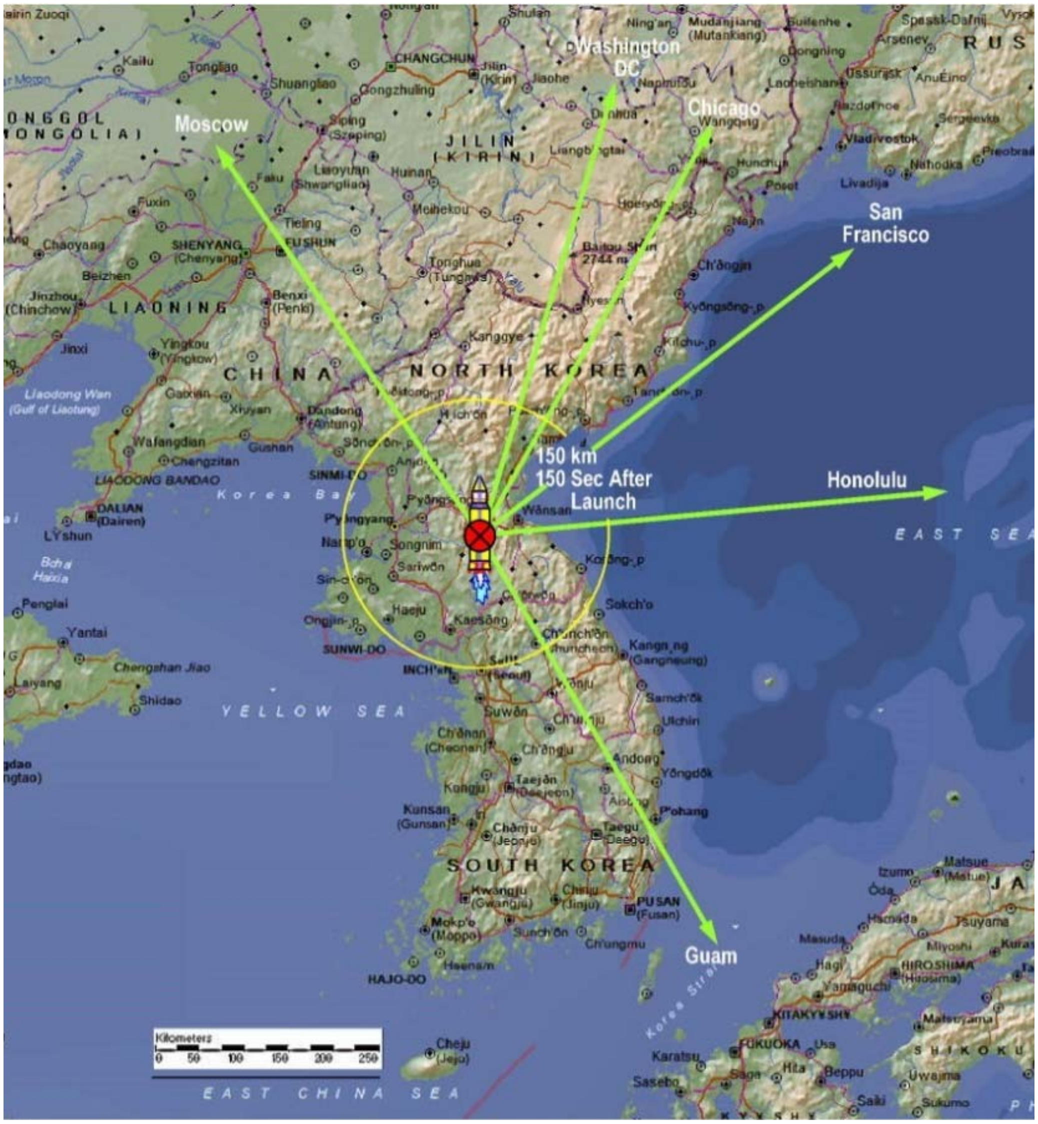


Figure 3

Figure 3 above shows the azimuths to various US targets that would have to be flown by DPRK long-range ballistic missiles at the beginning of an attack. Attacks against the East Coast of the United States would fly roughly north northeast, on a great circle route that would take the nuclear payload close to the North Pole on its trajectory toward East Coast targets like Washington DC, New York, and Boston.

As shown in Figures 4 through 8 below, launches towards the East Coast of the United States from mobile ICBMs intentionally operated in the northwest corner of North Korea cannot be engaged by Airborne Patrol interceptors with burnout speeds of 3.5 km/s. As already noted, if these interceptors have divert velocities of 0.5 km/s, even if they are within range of an ICBM in powered flight, they will have an extremely high miss rate. We estimate that the miss rate would be roughly 50%. ** Where is this estimate?**

Figures 4 through 8 show that the ocean operating areas for Airborne patrol aircraft carrying 3.5 km/s interceptors would be very restricted.

In the next section, we explain, for those readers who are sufficiently interested, how to determine the engagement range for 5 and 3.5 km/s interceptors.

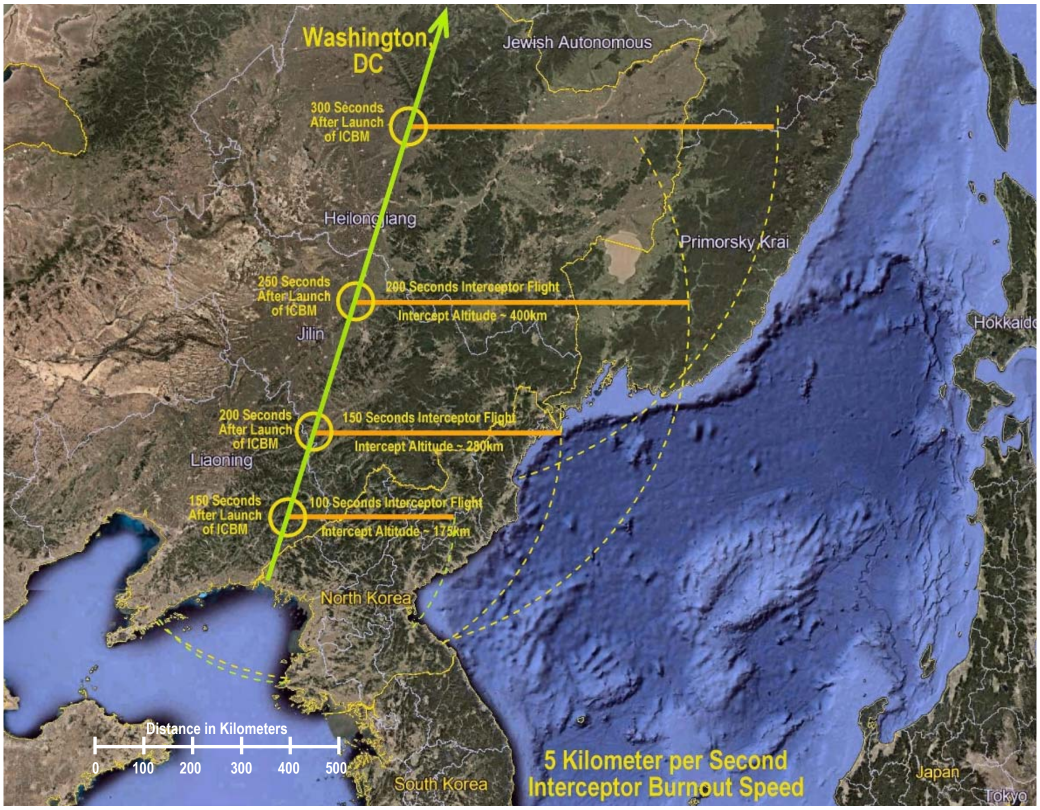


Figure 4

The map above shows the range contours within which Airborne Patrol 5 km/s interceptors could engage a DPRK ICBM launched towards the East Coast of the United States – in this case, Washington DC. This is the most demanding trajectory that the Airborne Patrol must be able to engage as the launch point is in the extreme northwest of the DPRK and the trajectory azimuth is North Northeast. Figures 7 and 8 show that this area would be beyond the reach of 3.5 km/s Airborne Patrol interceptors.

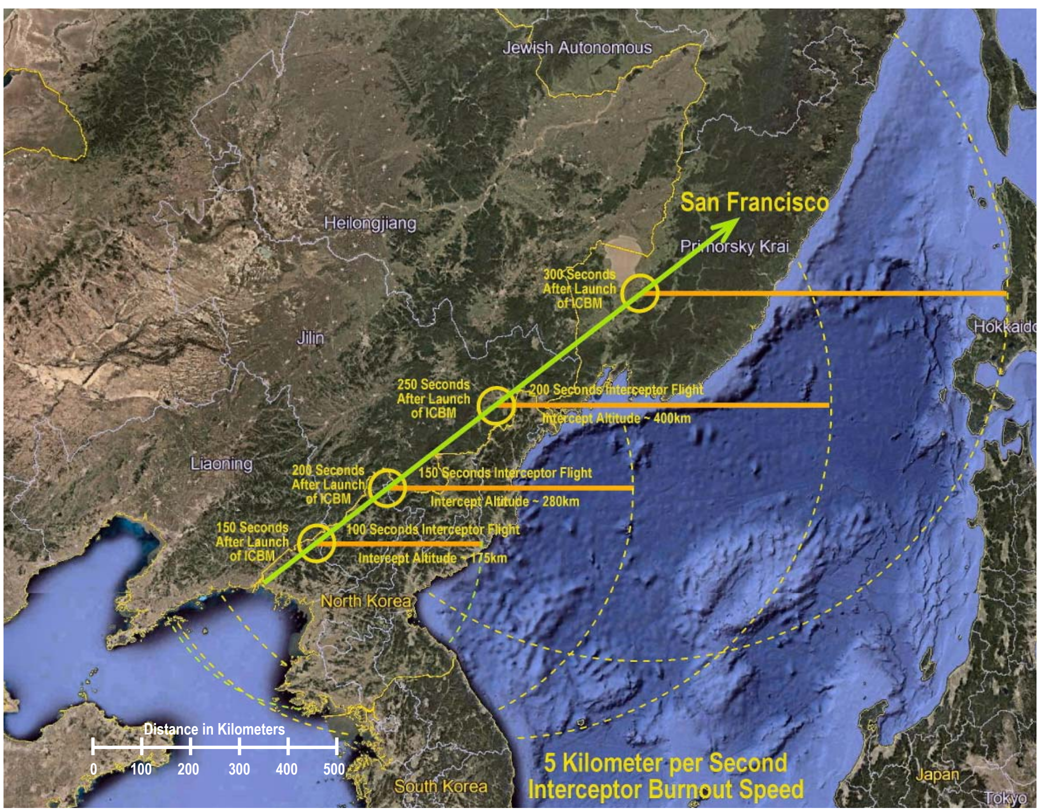


Figure 5

This map shows the range contours within which Airborne Patrol 5 km/s interceptors could engage a DPRK ICBM launched towards the West Coast of the United States – in this case, San Francisco. This is not the most demanding trajectory that the Airborne Patrol must be able to engage as the trajectory azimuth is Northeast, resulting in a flight path that is much closer to the Sea of Japan. Note the very large areas in the Sea of Japan from which Airborne Patrol interceptors could be used to destroy the ICBM while it is still in powered flight.

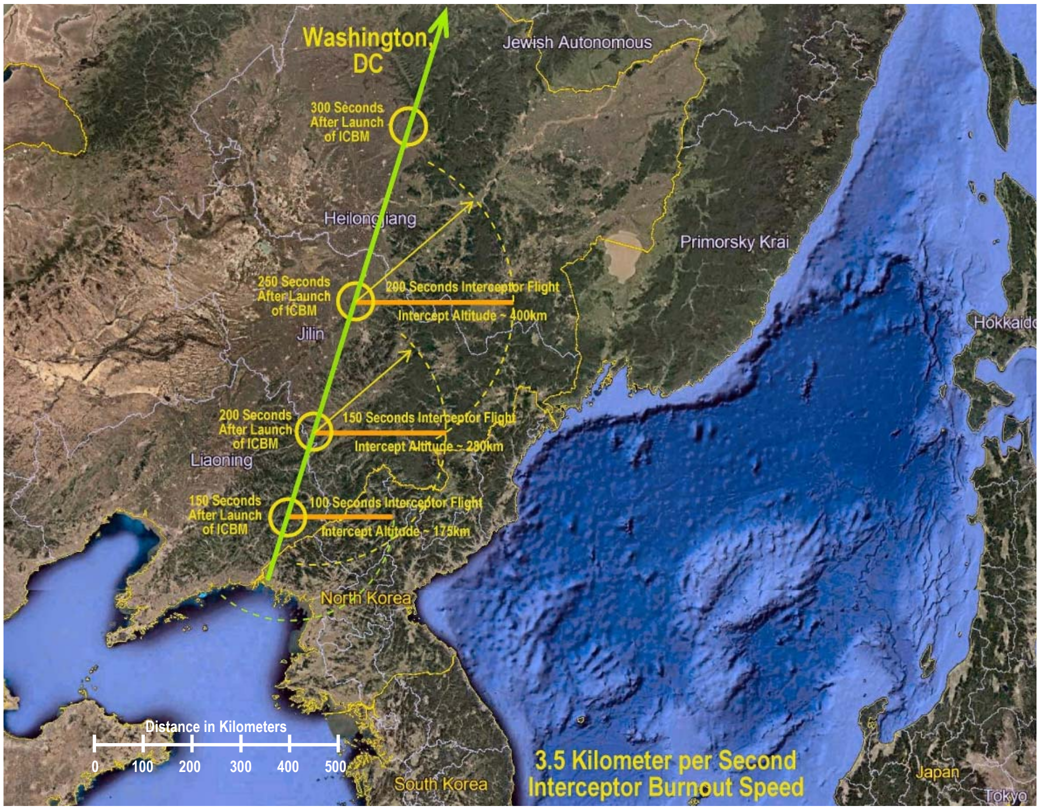


Figure 6

The map above shows the range contours within which Airborne Patrol 3.5 km/s interceptors could engage a DPRK ICBM launched towards the East Coast of the United States – in this case, Washington DC. This demanding launch point and trajectory would be beyond the reach of airborne patrol interceptors with speeds of 3.5 km/s. In fact, as shown in the Figure 7 there is a significant area in the northwest of the DPRK where mobile DPRK ICBMs could be launched towards the East Coast of the United States.

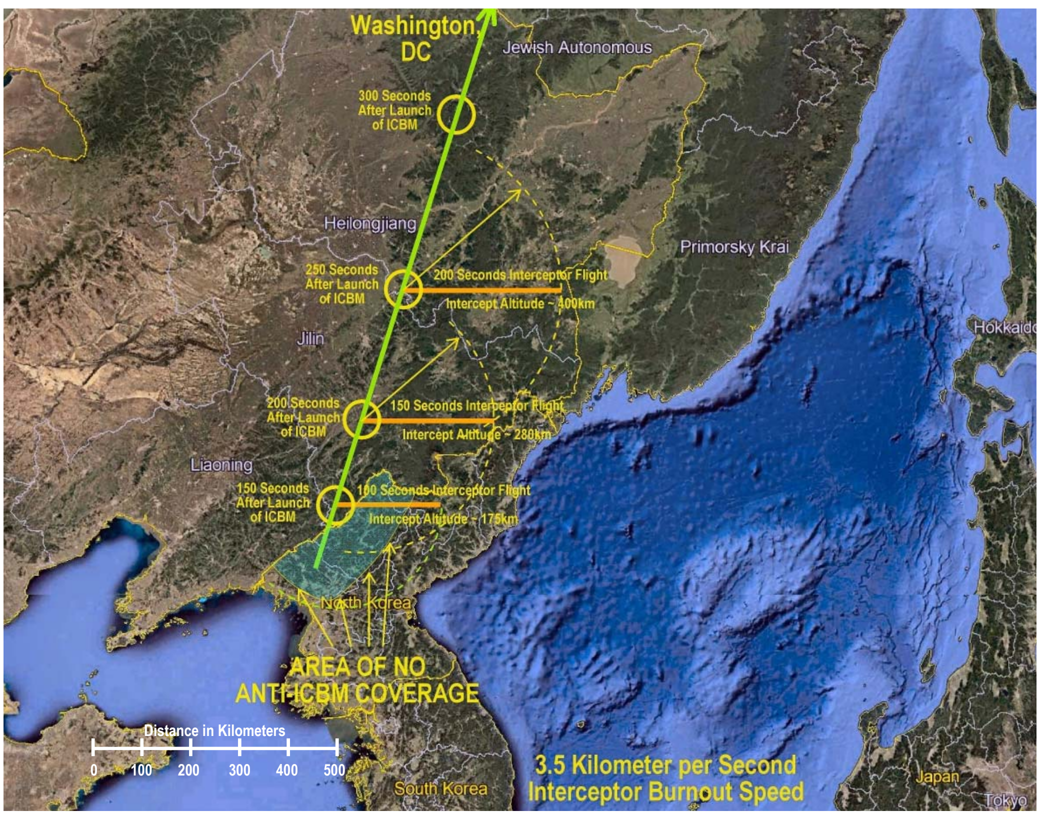


Figure 7

The area within which 3.5 km/s interceptors could NOT engage mobile DPRK ICBM launches towards the East Coast of the United States is shown in the map above. This is a significant operational area relative to the entire area of the DPRK. This particular map underscores the need for Airborne Patrol interceptors with adequately high burnout speeds.

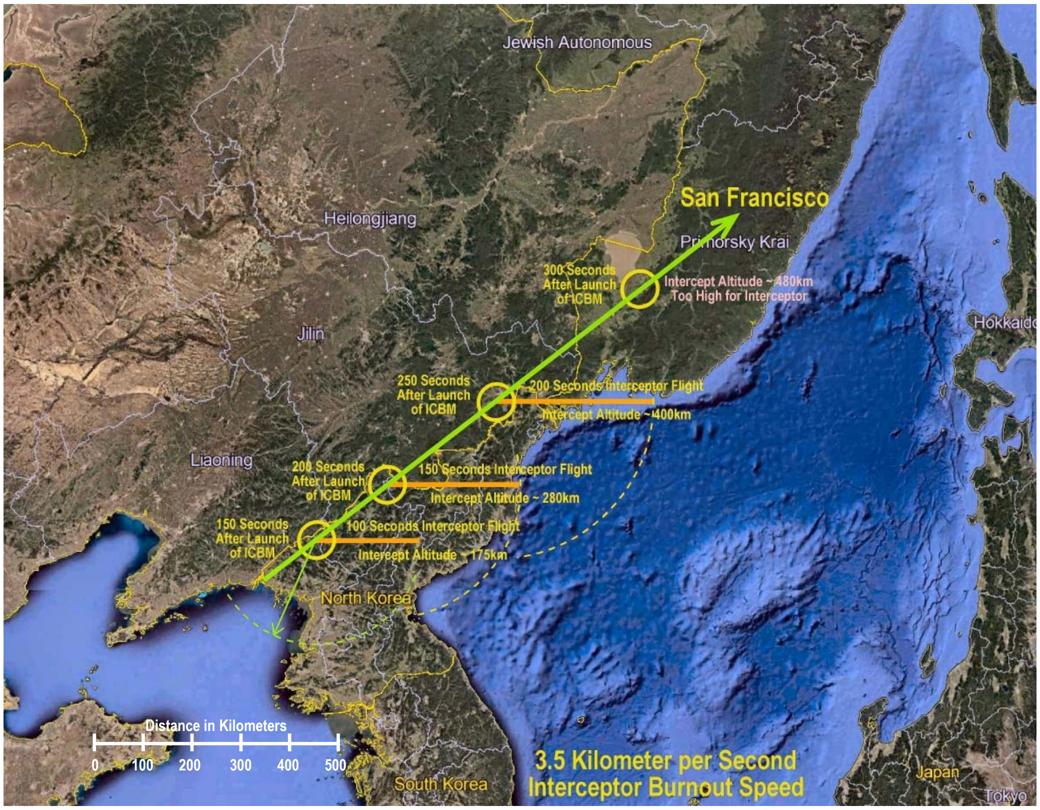


Figure 8

Mobile DPRK ICBMs on trajectories towards the West Coast of the United States are within the engagement range of 3.5 km/s Airborne Patrol interceptors. Note however that the operating areas over the Sea of Japan are quite restricted, unlike the vast operating area shown in Figure 5 for a 5 km/s Airborne patrol interceptor engaging the same ICBM on the same trajectory. The limited engagement range of 3.5 km/s not only results in a more restricted over-ocean operating area, but it also results in the possibility of fewer Airborne Patrol interceptors simultaneously being able to engage the target. This could have implications for scenarios where an attack consists of multiple launches of ICBMs.

Why Are There Such Dramatic Differences in the Engagement Range Capabilities of 5 Km/s Versus 3.5 Km/s Airborne Patrol Interceptors?

Because the issue of interceptor burnout and divert speeds is so important, we are including this section to describe the key factors that determine the engagement range of interceptors. As noted earlier, inadequate technical input to decision-makers on this matter may have already resulted in decisions about missile defense systems that have been far less than optimal.

Figures 9 and 10 below show the flight profiles of the Hwasong-15 DPRK mobile ICBM and Airborne Patrol interceptors that have burnout speeds of 5 and 3.5 km/s.

The graph on the left side of Figure 9 shows the powered and early free flight trajectories from an estimated model of the Hwasong-15 ICBM. The general characteristics of this powered flight trajectory are well represented by this model.

The graph on the right side of Figure 9 shows the locations at 10 second intervals of the baseline 5 km/s interceptor.

The baseline interceptor takes 25 seconds to accelerate to 5 km/s. In the early phases of flight, it is subject to aerodynamic drag and the exhaust velocity of its rocket motors is somewhat reduced by the pressure of atmospheric gases. In actual engagement trajectories, the Powered Kill Vehicle would ignite its rocket motor about 30-35 seconds prior to the final expected intercept. The velocity of the Powered Kill Vehicle could be used to either increase its overall speed towards the target-ICBM or divert its trajectory to match unpredictable accelerations of the target-ICBM. These accelerations of the Powered Kill Vehicle are not included in these calculations.

The graph on the right side of Figure 10 shows the range of similar trajectories for an alternative interceptor that is assumed to be no different from the 5 km/s interceptor except that it accelerates to 3.5 km/s in 25 seconds.

Note that the trajectory lines for the 3.5 km/s interceptor bend down substantially relative to those of the 5 km/s interceptor. This is because the action of the downward pull of gravity during the slower forward motion of the interceptor significantly alters the shape of the trajectory. This effect of gravity results in trajectories at longer ranges that cannot reach the target-ICBM during its last seconds of powered flight.

It is useful to examine a single intercept scenario in order to understand the interplay of different factors that control the range at which intercepts can occur.

If we assume that an intercept is to occur 250 seconds after the launch of the ICBM, an inspection of the graph on the left side of Figure 9 shows that the intercept will have to occur at an altitude of 370 km. Since the interceptor is not launched for 50 seconds after the ICBM is launched, it only has 200 seconds of flight to achieve the intercept point at an altitude of 370 km.

The graph on the right side of Figure 9 shows the ranges achieved by the interceptor after 200 seconds of flight. Since the interceptor hits the target at 370 km, the intersection of the range contour at the altitude line for 370 km shows the range at which the intercept can occur. In this case the range is about 685 km.

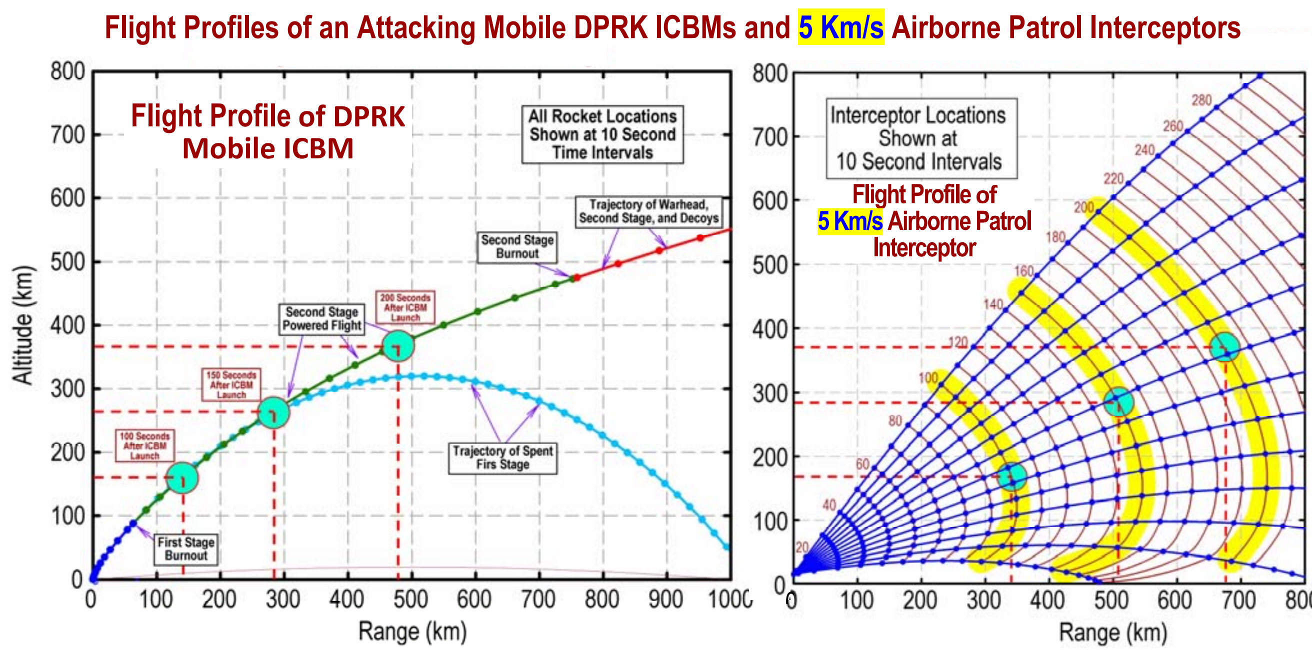


Figure 9

The two graphs above show the locations of a postulated DPRK mobile target-ICBM and the anti--ICBM interceptor that would be launched by the Airborne Patrol. The graph on the right shows the range of locations of the 5 km/s interceptor as a function of time. The discussion in the text describes a scenario where a target-ICBM is to be intercepted 250 seconds after its launch, and 200 seconds after the delayed launch of the interceptor. For this particular scenario the ground-distance to the intercept point is about 690 km.

In the case of the 3.5 km/s interceptor (Figure 10), the effects of gravity and the slower forward motion of the interceptor substantially decrease the forward distance of the interceptor by the time it reaches 200 seconds of flight. In this case, if the interceptor is to occur after 200 seconds of interceptor flight time (250 seconds after target-ICBM launch), then the range of the interceptor is roughly 320 km – less than half the distance achieved in the same time by the 5 km/s interceptor.

As already noted, two of the main reasons for this dramatic differential in range have to do with the slower forward motion of the interceptor in the gravitational field. However, the fact that the interceptor must take 25 seconds to accelerate to a burnout speed of either 5 or 3.5 km/s is an additional factor that results in the striking range differential between 3.5 and 5 km/s interceptors.

For this reason, it is essential that an adequately high speed interceptor be used for the Airborne Patrol in order to achieve adequately large over-ocean operating areas and full coverage of launch areas in North Korea

Flight Profiles of an Attacking Mobile DPRK ICBMs and 3.5 Km/s Airborne Patrol Interceptors

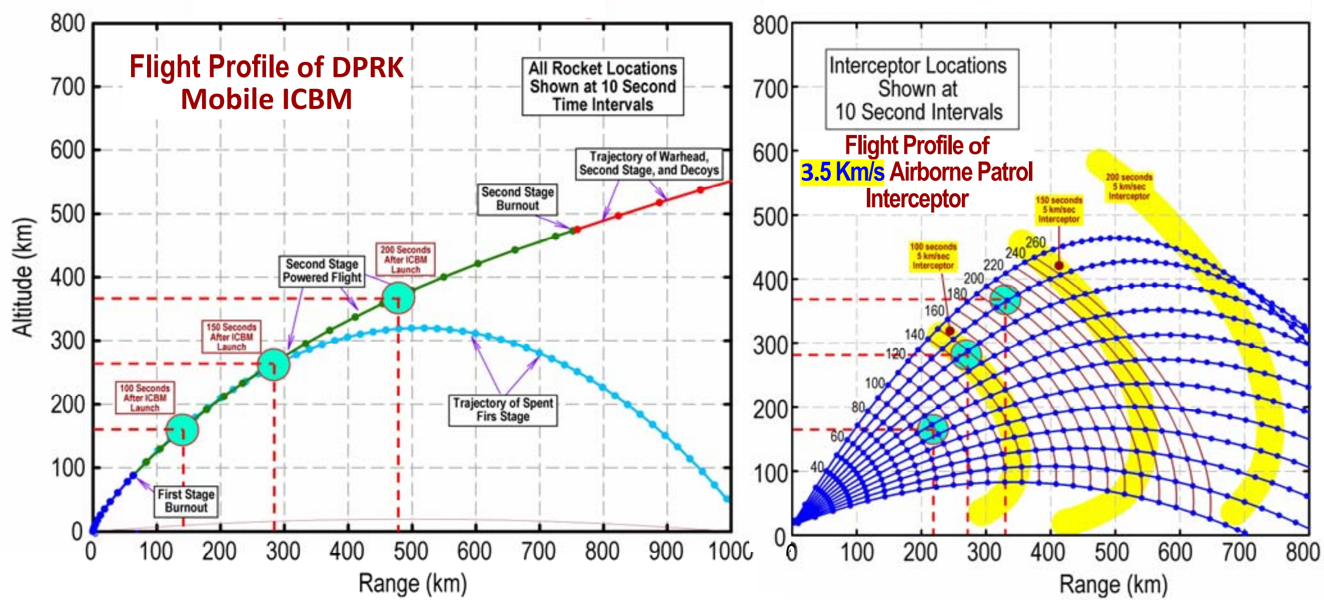


Figure 10

The two graphs above are similar to those shown in Figure 9, except that the graph on the right shows the locations of a 3.5 km/s interceptor as a function of time. The discussion in the text describes a scenario where a target-ICBM is to be intercepted 250 seconds after its launch, and 200 seconds after the delayed launch of the interceptor. For this particular scenario the ground-distance to the intercept point is about 320 km, less than half the range achieved by the 5 km/s interceptor discussed in Figure 9.

Observations and Conclusions

We have presented herein an updated estimate of the characteristics of the Airborne Patrol anti-ICBM interceptor which is a critical component of the Airborne Patrol Concept presented in the briefing to the Congress dated November 27-29, 2017.

We show that the inclusion of accurate technical data on the weights and performance characteristics of the infrared homing and guidance section of the interceptor, along with realistic parameters for small solid-propellant rocket motors that have been built and applied to other applications, should result in an interceptor weighing roughly 1100 pounds with a 5 km/s burnout speed and 2 kilometers per second divert velocity in its Powered Kill Vehicle.

Since the interceptor is the most critical and demanding component-system needed for an effective Airborne Patrol system, these results indicate a considerably more capable system then originally conceived in the earlier briefing.

We have also underscored the danger of taking "shortcuts" in the development of the interceptor. It is a key component that essentially facilitates all other aspects of the Airborne Patrol. As such, the interceptor must have an adequate burnout speed and divert velocity if there is to be an effective Airborne Patrol system.

It is likely that such a system could be built if a national decision were made to go forward. Past experience, however, shows that unless the critical needs of the system under development are considered carefully, it is entirely possible to invest in a system that has little or no capability.

The remainder of this paper contains appendices for interested readers.

Appendix I shows the language of the legislation from the House Armed Services Committee directing that the Secretary of Defense enter into a contract with an appropriate Federally Funded Research and Development Center to do a detailed assessment of this and other system concepts.

Appendix II contains information about the performance of small solid-propellant rocket motors that could be modified for use in building the proposed baseline interceptor.

Appendix III contains information about the weights of different components associated with infrared homing and guidance systems that could be adapted for use in the baseline interceptor.

Appendix IV contains slides showing the claims of the Missile Defense Agency for a concept called "Early Intercept." The false assumption that this concept was workable led to serious performance overestimates for the Aegis-based European Phased Adaptive Approach (EPAA) system. It cannot be ruled out that these ideas created optimism about the potential capabilities of the EPAA that could have influenced the presidential decision to move forward with this system concept.

Appendix V contains very simple cost estimates for Airborne Patrol systems based on the Predator-B and F-35 airborne platforms. It shows that an Airborne Patrol system based on the use of F-35 aircraft would certainly be at least 10 or more times more expensive than a system based on the use of the Predator-B. In addition, the only advantage and F-35-based system would have is the ability to take advantage of the aircraft stealth to enter North Korean airspace to shoot down target-ICBMs. However, as long as an adequate interceptor is built for the Airborne Patrol Concept, this capability offers no advantage in meeting the requirements of this particular defense-system, but does result in a great increase in cost.

APPENDIX I

Language from 2019 Defense Authorization

Contents

This appendix contains the text of the House Armed Services Committee legislation ordering the Secretary of Defense to enter a contract with an appropriate Federally Funded Research and Development Center to study airborne and other boost phase missile-defense concepts.

SEC. 16 .[Log 675171 BOOST PHASE BALLISTIC MISSILE DEFENSE.

(a) DEVELOPMENT AND STUDY.—Section 1685 of the National Defense Authorization Act for Fiscal Year 2018 (Public Law 115-91; 10 TJ.S.C. 2431 note) is amended hv adding at the end the following new subsections:

"(d) DEVELOPMENT.—

"(1) REQUIREMENT.—Beginning fiscal year 2019, the Director of the Missile Defense Agency shall carry out a program to develop boost phase intercept capabilities that—

"(A) are cost effective;

"(B) are air-launched, ship-based, or both; and

"(C) include kinetic interceptors.

"(2) PARTNERSHIPS.—In developing kinetic boost phase intercept capabilities under paragraph (1), the Director may enter into partnerships with the Ministry of National Defense of the Republic of Korea or the Ministry of Defense of Japan, or both. "(e) INDEPENDENT STUDY.—

"(1) REQUIREMENT.—The Secretary of Defense shall seek to enter into an agreement with a federally funded research and development center to conduct a feasibility study on providing an initial or demonstrated boost phase capability using unmanned aerial vehicles and kinetic interceptors by December 31, 2021. Such study shall include, at a minimum, a review of the study published by the Science, Technology, and National Security Working Group of the Massachusetts Institute of Technology in 2017 titled 'Airborne Patrol to Destroy DPRK ICBMs in Powered Flight'.

"(2) SUBMISSION.—Not later than July 31, 2019, the Secretary shall submit to the congressional defense committees the studv conducted under paragraph (1).".

(b) DIRECTED ENERGY DEVELOPMENT.—Subsection (b) of such section is amended—

(1) by striking "The Secretary of Defense" and inserting the following:

"(1) lx GENERAL.—The Secretary of Defense"; and

(2) by adding at the end the following new paragraph:

"(2) ROLE OF DIRECTOR.—

"(A) TRANSFER OF RESPONSIBILITY.—Be-

APPENDIX II

Examples of State-of-the-Art Small Solid-Propellant Rocket Motor Technologies.

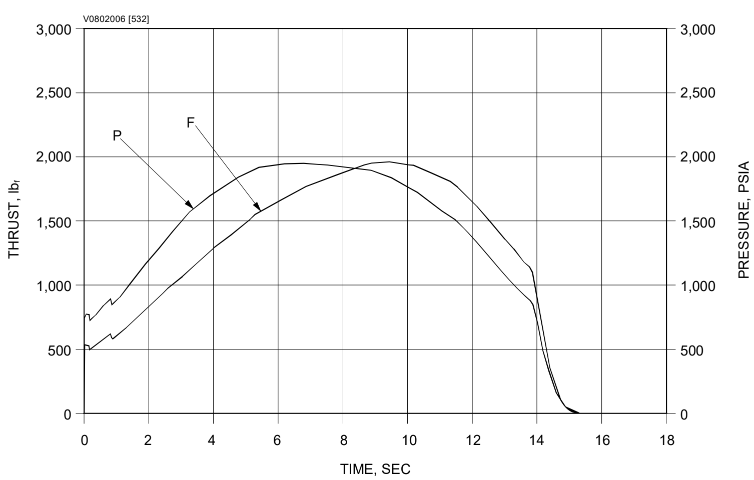
Contents

This appendix contains information about the achievable fuel loadings, exhaust velocities, thrust profiles, and vector control systems of small solid rocket motors that have been used for a variety of reasons. We assume that the same level of technology would be adapted for the baseline interceptor. We have intentionally assumed somewhat lower performance parameters for the baseline interceptor because we do not have full knowledge of weight of components that do not include the motors themselves and the homing package.

STAR 12GV

TE-M-951

The STAR 12GV rocket motor served as the third stage of the U.S. Navy/MDA Terrier Lightweight Exoatmospheric Projectile (LEAP) experiments. The motor first flew in March 1995. The stage has TVC capability, head-end flight destruct ordnance, and utilizes a graphite-epoxy composite case. It is compatible with an aft-end attitude control system (ACS) module. Orbital ATK developed the motor design and component technology between 1992 and 1995 under the Advanced Solid Axial Stage (ASAS) program.



MOTOR DIMENSIONS
Motor diameter, in. 12.24
Motor length, in. 22.5

MOTOR PERFORMANCE (70°F VACUUM)
Burn time/action time, sec 13.9/14.8
Ignition delay time, sec 0.02
Burn time average chamber pressure, psia.......1,550
Maximum chamber pressure, psia 1,950
Total impulse, lbf-sec......................................20,669
Propellant specific impulse, lbf-sec/lbm.............284.7
Effective specific impulse, lbf-sec/lbm 282.4
Burn time average thrust, lbf 1,455
Maximum thrust, lbf..1,980

NOZZLE
Initial throat diameter, in. 0.691
Exit diameter, in. 5.26
Expansion ratio, initial...58:1
TVC angle, deg.. ± 5 deg

WEIGHTS*, LBM
Total loaded..92.5
Propellant...72.6
Case assembly 14.3
Nozzle assembly...4.5
Total inert 19.8
Burnout 19.2
Propellant mass fraction 0.79

TEMPERATURE LIMITS
Operation... 40º-95°F
Storage .... 0º-130°F

PROPELLANT DESIGNATION
....TP-H-3340A

CASE MATERIAL
....................GRAPHITE-EPOXY COMPOSITE

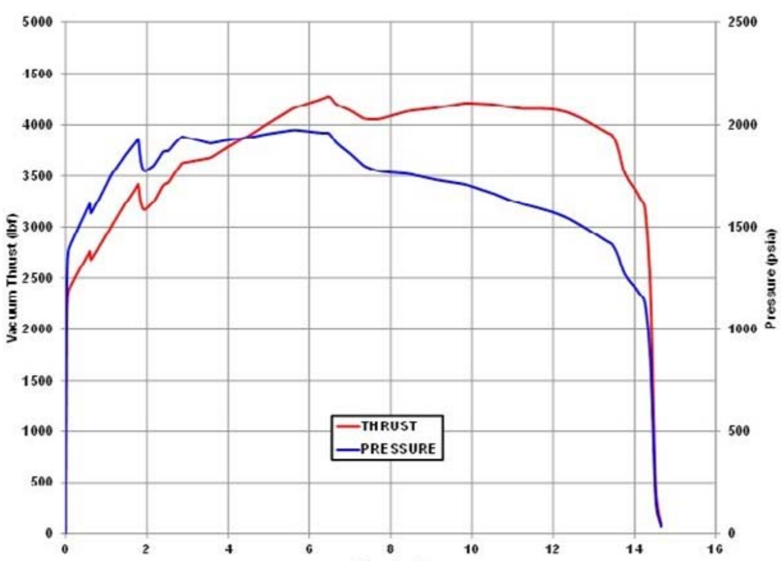
PRODUCTION STATUS
.... FLIGHT-PROVEN

*Includes actuators and cables only. Battery and controller weights and ACS are not included

ASAS™ 13-30V

FIXED AND VECTORABLE UPPER STAGE MOTOR

The Advanced Solid Axial Stage (ASAS) 13-30V is a high-performance upper-stage motor derived from the Mk 136 Standard Missile 3 (SM-3) Block IA/IB Third Stage Rocket Motor (TSRM). The motor is 39.3 inches long and nominally designed as an upper-stage motor. The motor uses a pyrogen igniter for highly repeatable ignition performance. The motor incorporates a ± 5-degree nozzle powered by an Orbital ATK Thrust Vector Electronic Control System (TVECS™) thrust vector actuation (TVA) system using electromechanical (EM) actuators.



MOTOR DIMENSIONS

Motor diameter, in. 13.5
Motor length, in. 39.3

MOTOR PERFORMANCE (70°F VACUUM)

Burn time, sec 14.3
Burn time average chamber pressure, psia....... 1,730
Maximum chamber pressure, psia 1,975
Total impulse, lbf-sec..................................... 55,180
Propellant specific impulse, lbf-sec/lbm 281.8
Effective specific impulse, lbf-sec/lbm 279.5
Burn time average thrust, lbf 3,825
Maximum thrust, lbf 4,275

NOZZLE

Initial throat diameter, in. 1.1
Exit diameter, in. 6.8
Expansion ratio, initial 38.3:1

WEIGHTS, LBM

Total loaded* 250.9
Propellant... 195.8
Case 40.2
Nozzle... 7.2
Total inert 55.1
Burnout* 53.5

TEMPERATURE LIMITS

Operation.. 45°-120°F
Storage .... 30°-120°F

PROPELLANT DESIGNATION TP-H-3340A

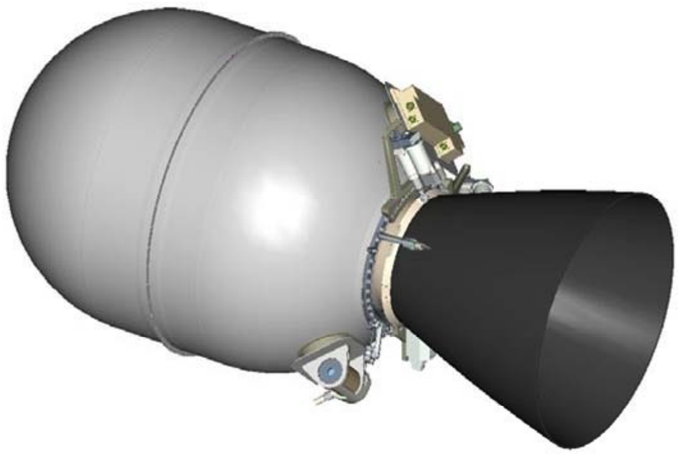
CASE MATERIAL
.... GRAPHITE-EPOXY COMPOSITE

PRODUCTION STATUS ....FLIGHT-PROVEN

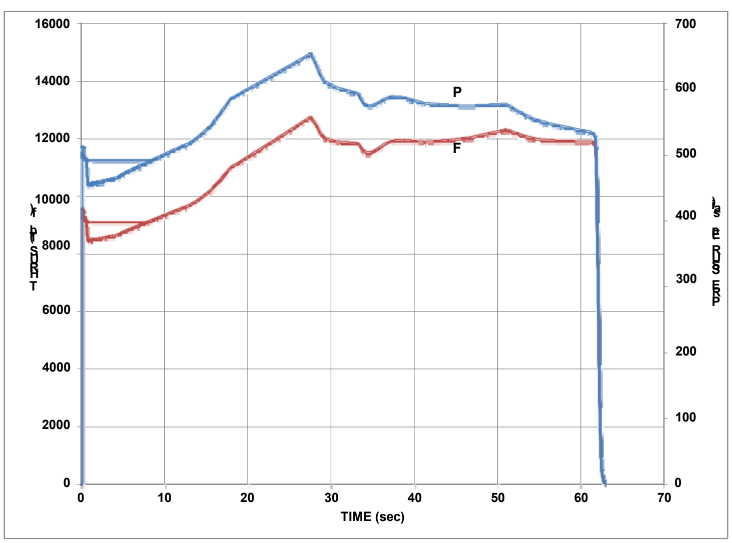
*Excludes ETA lines, safe and arm device, battery, and controller

STAR 37FMV

TE-M-1139



The STAR 37FMV rocket motor was developed for use as an upper stage motor for missions requiring three-axis control. The motor design features a titanium case, a 3-D carbon-carbon throat, a carbon-phenolic exit cone, and an electromechanically actuated flexseal TVC nozzle.



MOTOR DIMENSIONS

Motor diameter, in. 36.8

Motor length, in. 75.5

MOTOR PERFORMANCE (70°F VACUUM)

Burn time/action time, sec 62.7/63.3

Ignition delay time, sec 0.13

Burn time average chamber pressure, psia....................540

Maximum chamber pressure, psia....................642

Total impulse, lbf-sec 694,680

Propellant specific impulse, lbf-sec/lbm....................296.6

Effective specific impulse, lbf-sec/lbm 293.7

Burn time average thrust, lbf 10,980

Maximum thrust, lbf 12,500

NOZZLE

Initial throat diameter, in. 3.52

Exit diameter, in. 29.46

Expansion ratio, initial....................70.0:1

Type....................VECTORABLE ± 4 DEG

WEIGHTS, LBM

Total loaded*....................2,578.8

Propellant (including igniter propellant) 2,345.3

Case assembly 71.1

Nozzle assembly/igniter assembly (excluding igniter propellant)....................99.0

Total inert 236.7

Burnout*....................216.9

Propellant mass fraction 0.91

*Excluding ETA lines and S&A

TEMPERATURE LIMITS

Operation....................40°-90°F

Storage .... 40°-110°F

PROPELLANT DESIGNATION TP-H-3340

CASE MATERIAL....................TITANIUM

PRODUCTION STATUS.........DEVELOPMENT

Approved for Public Release
OSR No. 16-S-1432;
Dated 05 April 2016

APPENDIX III

Data on State-of-the-Art Missile Infrared Sensing and Guidance Systems

Contents

This appendix contains pieces of information about existing infrared homing systems used in various kinds of missiles. We have use this information to estimate the weight of the infrared homing and guidance package in the baseline interceptor.

Principles of Infrared Technology

A Practical Guide to the State of the Art

John Lester Miller

CHAPMAN & HALL
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Appendix 9A

Data Sheets for Representative Seeker Systems

High Endoatmospheric Defense Interceptor (HEDI) Seeker

Manufacturer: Hughes, El Segundo, California

Intended Application: SDIO

Availability: Developmental

Description:

HEDI is an SDI project to develop kinetic kill vehicles for terminal defense in the high atmosphere. Prototype designs have been built and tested.

Characteristics:

Bandpass: MWIR

Cooling: 77 K

FPA Format: Scanning 18 rows of 120 elements with the seeker using only two rows to enhance yield

Image: 240 × 240

Signal processing: A readout chip and three commercial-grade 80386 microprocessors

Information from W. William Scott. November 28, 1988. "Hughes Prepares Model of SDI Interceptor's Seeker for Flight Tests." Aviation Week and Space Technology, *75–76.*

Javelin Seeker

Manufacturer: Texas Instruments, Dallas, Texas, and Martin Marietta, Orlando, Florida

Intended Application: Anti-tank missile, replacement for Dragon

Availability: In development phase

Description:

Javelin is the new name for the A/AWS-M system. The system is a fire-and-forget missile with a separate command launch unit (CLU). The missile seeker employs an imaging LWIR FPA. The focal planes are made by SBRC as a primary source and Loral as a secondary. The command launch unit contains a thermal sight and a day E-O sight. The missile contains a high-performance image tracker, digital autopilot, and solid state arming system.

Characteristics:

Seeker Bandpass: LWIR

Seeker FPA Format: 64 × 64 staring

Seeker FPA Material: HgCdTe

CLU FPA: 240 × 1

Cool-Down Time: To 77 K in less than 9 seconds

Dewar Lifetime: 10 years

Projected Average FPA Cost: Approximately $13,000

FPA Manufacturers: Texas Instruments (25 percent) and SBRC (75 percent)

Development Costs: $350 million

Total Program Costs: > $2 billion

Information from C. Baker. June 24, 1991. "Army Relaxes Sensor Requirements on AAWS-M." Defense News, *39; July 15, 1991. "AAWS-M Scores Bullseye."* Space News, *2; May 11, 1992. "TI, Martin Select Loral as Second Source of Javelin Focal Plane Array."* Inside The Army, *11; and S. Whicker. 1992. "New Technologies For FPA Dewars,"* Proc. SPIE *1683, 102–112.*

LEAP Seekers

Manufacturer: Boeing, Seattle, Washington, and Hughes, El Segundo, California

Intended Application: SDIO, U.S. Army

Qualification: Space

Availability: Developmental

Description:

LEAP is an advanced technology integration program that is managed by the U.S. Army Strategic Defense Command for the Strategic Defense Initiative Organization. The program aims at developing, integrating, and demonstrating, through flight tests, the accuracy and high performance of lightweight kill vehicle subsystem technologies. The kill vehicle is designed for launch by ground- or space-based rockets and destroys its target by kinetic energy. The projectile consists of an advanced IR imaging sensor; a compact electronics unit, and inertial sensor assembly; a miniaturized high-performance divert propulsion system; thermal batteries; and a command link. All of these components are lightweight and state of the art. Sub-orbital flight tests are to be conducted out of White Sands Missile Range. A version of a Leap kill vehicle is pictured in Figure 10.1.

Characteristics:

Acceleration: 3.5 g

Dimensions: 40.6 cm in length and 15.2 cm in diameter

Seeker Aperture: 12.7 cm

Total Electronics Weight: 171 grams

Weight: About 6 kg with a 170 gram optical system and a 28 gram guidance computer

FPA: 128 × 128 imaging HgCdTe

Information courtesy of the U.S. Army Strategic Defense Command

---

Maverick Seeker

Manufacturer: Hughes, El Segundo, California

Intended Application: USAF, NATO, SDIO

Qualification: Full flight qualification

Availability: Off the line. Production line is open and operating.

Description:

The Maverick seeker contains a linear array of HgCdTe that can be scanned to produce an image. Sensitivity is about twice that of the TV-guided Maverick.

Characteristics:

Bandpass: LWIR

FPA: 16 element scanned with mirrors spinning at 3,600 rpm

Weight: A few kilograms

Information from D. Morrison. April 1991. "The Maverick and the Mark 1 Eyeball." Lasers & Optronics.

N-LOS (Non-Line Of Sight) Seeker

Manufacturer: TBD

Intended Application: U.S. Army weapon missile

Qualification: Flight qualification

Availability: Highly developmental

Description:

The Non-Line of Sight missile is an anti-helicopter and anti-armor missile designed to hit targets tens of kilometers away that are hidden by terrain.

Characteristics:

Missile Weight: 52 kg

FPA: Pt:Si of 256 by 256 or larger

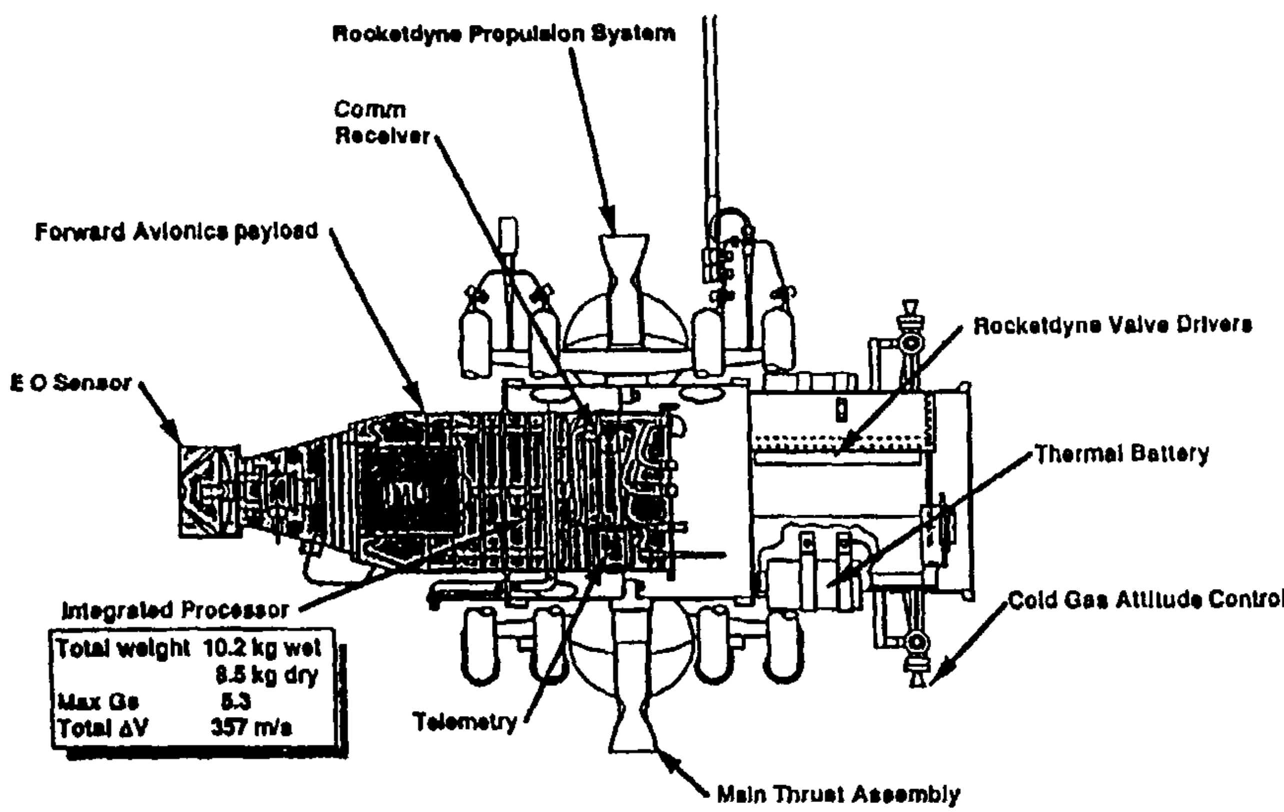
Production: Forecast of 90,000 units

Diameter: About 15.3 cm

Length: About 31 cm

Information from March 27, 1989. "Non-line Of Sight Missile Will Use Platinum Silicide Infrared Detectors." Aviation Week, *67–70.*

LEAP

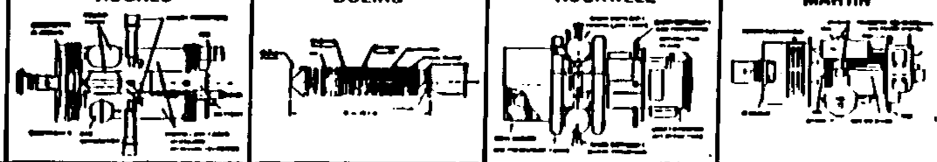


UNCLASSIFIED

FIRST GENERATION EXO INTERCEPTOR SUMMARY

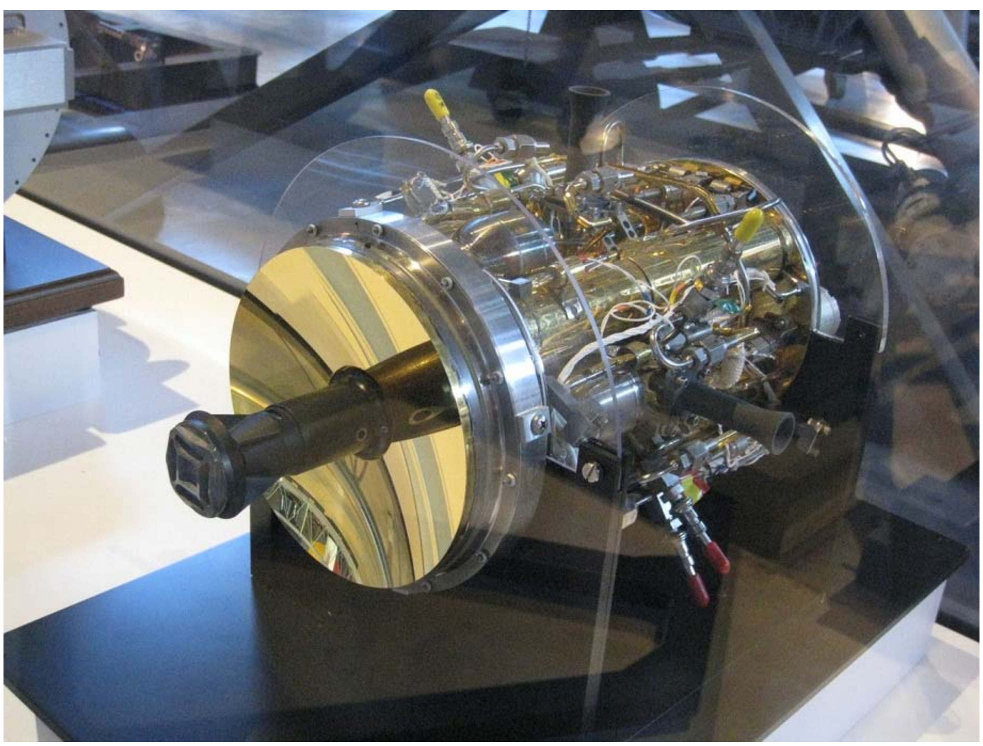
LEAP

SBI HERITAGE



	HUGHES	BOEING	ROCKWELL	MARTIN
MASS	6Kg	7.3Kg	17Kg	25Kg
ΔV	420 m/s	430 m/s	850 m/s	120 m/s
FPA	128 X 128 Hg Cd Te	64 X 64 Hg Cd Te	256 X 256 Hg Cd Te 128 X 128 SI	64 X 64 Hg Cd Te
SEEKER WAVEBAND	3 - 5 μm or 7 - 9 μm	3 - 7 μm	4 - 6 μm and 8 - 26 μm	4.35 - 4.45 μm and 7 - 10 μm
FOV	1.1°	1.0°	3.0°	0.84°
THROUGHPUT	4.2 MIPS	5.7 MIPS	6.2 MIPS	4.5 MIPS
IMU DRIFT (3σ)	<3°/hr	<4°/hr	<5°/hr	<3°/hr

UNCLASSIFIED



APPENDIX IV

Explanation of Why the Missile Defense Agency's *Early Launch* Concept Was Wrong, Leading to Gross Overstatements of EPAA Performance

Contents

This appendix documents how inaccurate technical assessments can led to vastly overstated estimated capabilities for an important missile defense weapon system. In this case, the Missile Defense Agency incorrectly adopted a strategy called "Early Intercept" predicting highly unrealistic defensive capabilities for the Aegis-based European Phased Adaptive Approach (EPAA). It cannot be ruled out that these predictions of defensive capabilities misled the White House – causing a misinformed decision to move forward with the EPAA on September 17, 2009.

The *early intercept* concept assumed that the powered flight of ballistic missiles could be projected with high precision once enough tracking data on an accelerating ballistic missile was obtained from external sensors. This then led to the inaccurate conclusion that the flight trajectory after ballistic missile burnout was also perfectly predictable – allowing for interceptors to be launched from much greater range and while the ballistic missile was still in powered flight. This assumption was fundamentally and conceptually incorrect, because ballistic missiles in powered flight can maneuver resulting in different powered flight trajectories and drastically different free-flight trajectories of their payloads. The real situation is that the defense does not have information about these maneuvers and because of this can fundamentally not determine a projected intercept point (PIP). Because of the lack of knowledge of programmable maneuvers n ballistic missile powered flight, interceptors must be designed from the beginning to make significant homing maneuvers against a fundamentally unpredictable targets. This is also why homing interceptors have been built for antiaircraft purposes.

MDA Claims Before President Obama's September 17, 2009 Announcement to Proceed with the PAA

Ascent Phase Intercept

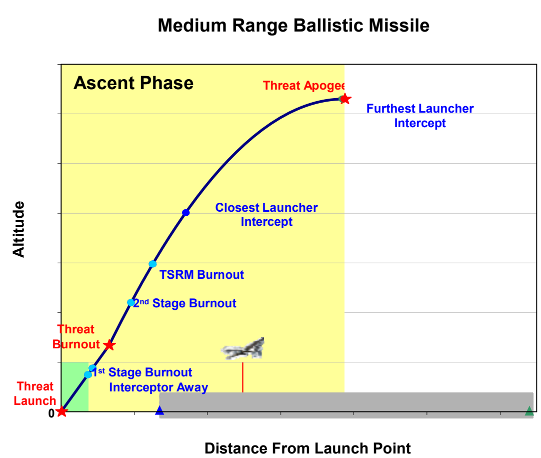
29 May 2009

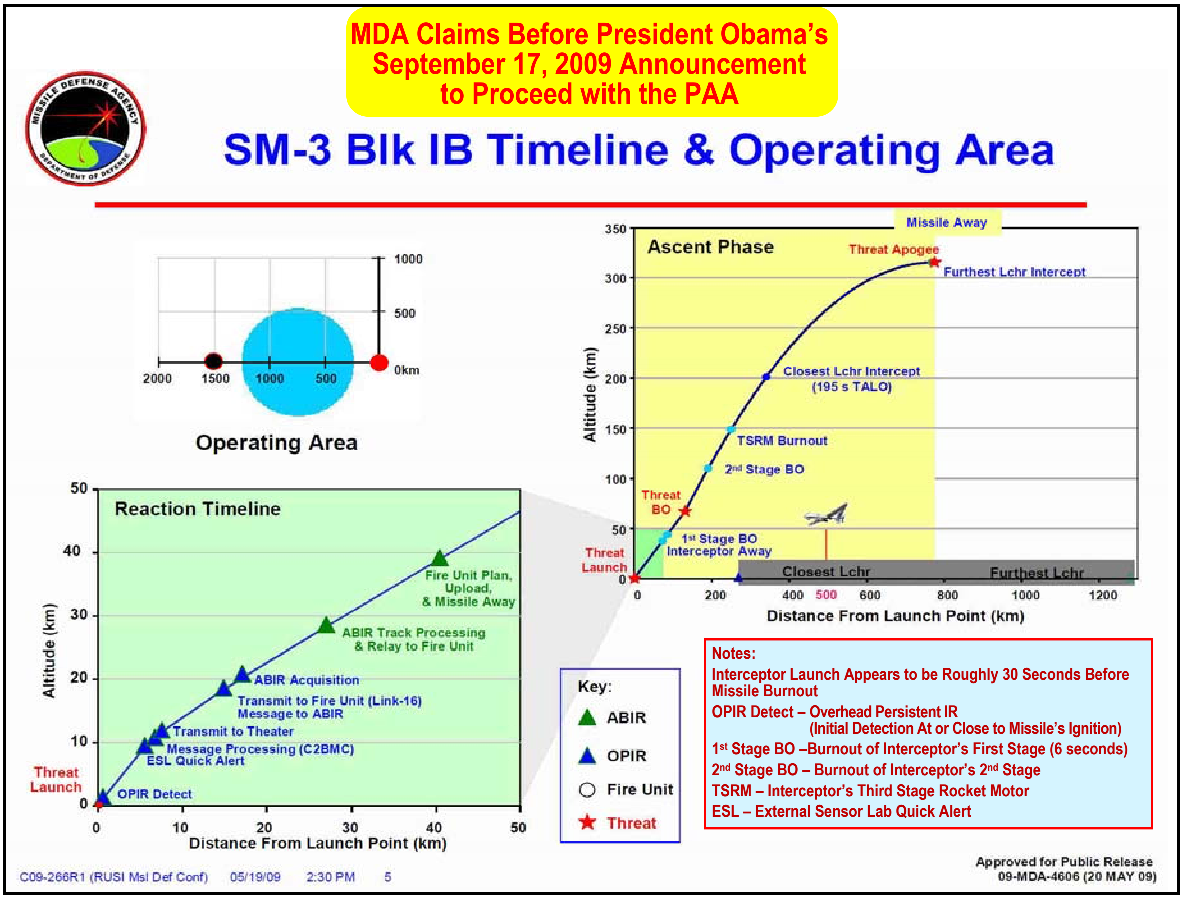
Mr. Keith L. Englander
Director of Engineering
Missile Defense Agency

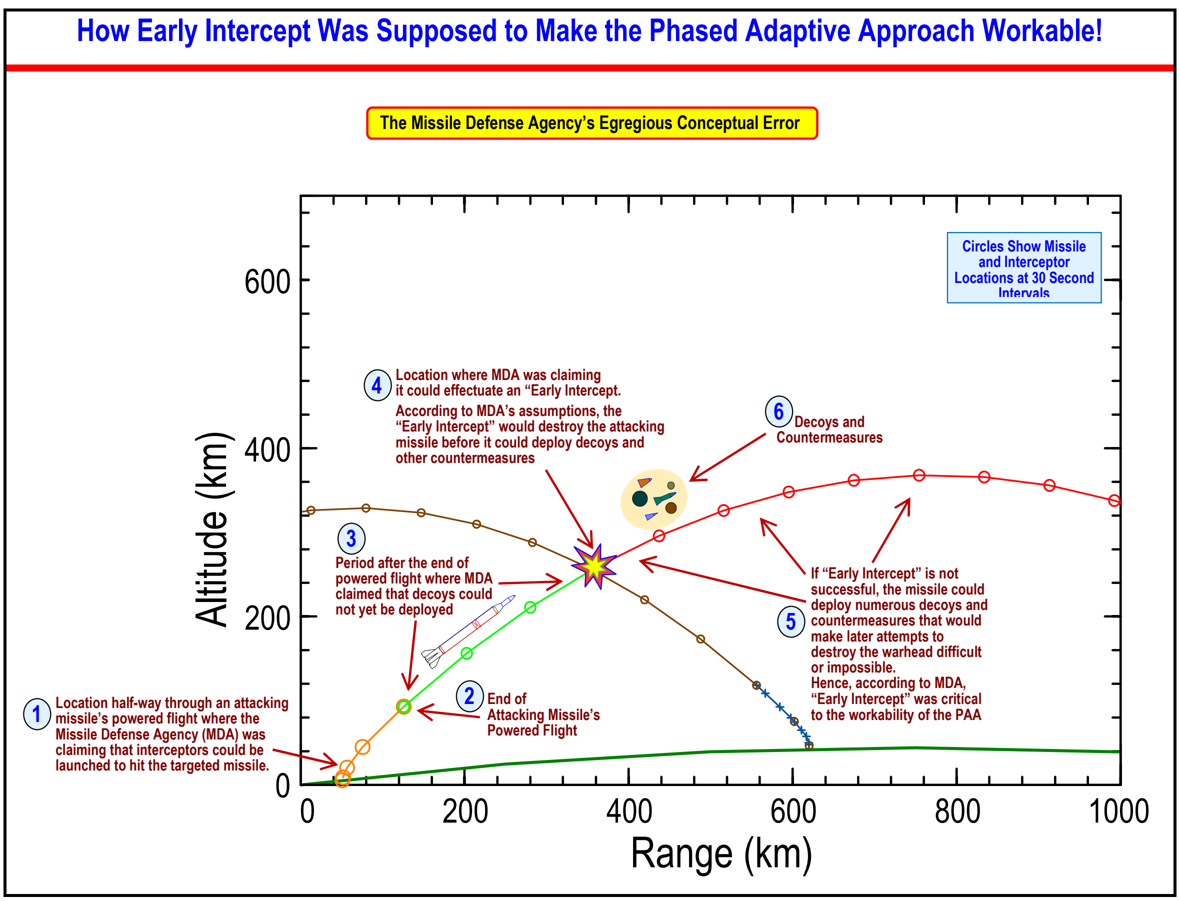
MDA Claims Before President Obama's September 17, 2009 Announcement to Proceed with the PAA

Why Ascent Phase Intercept?

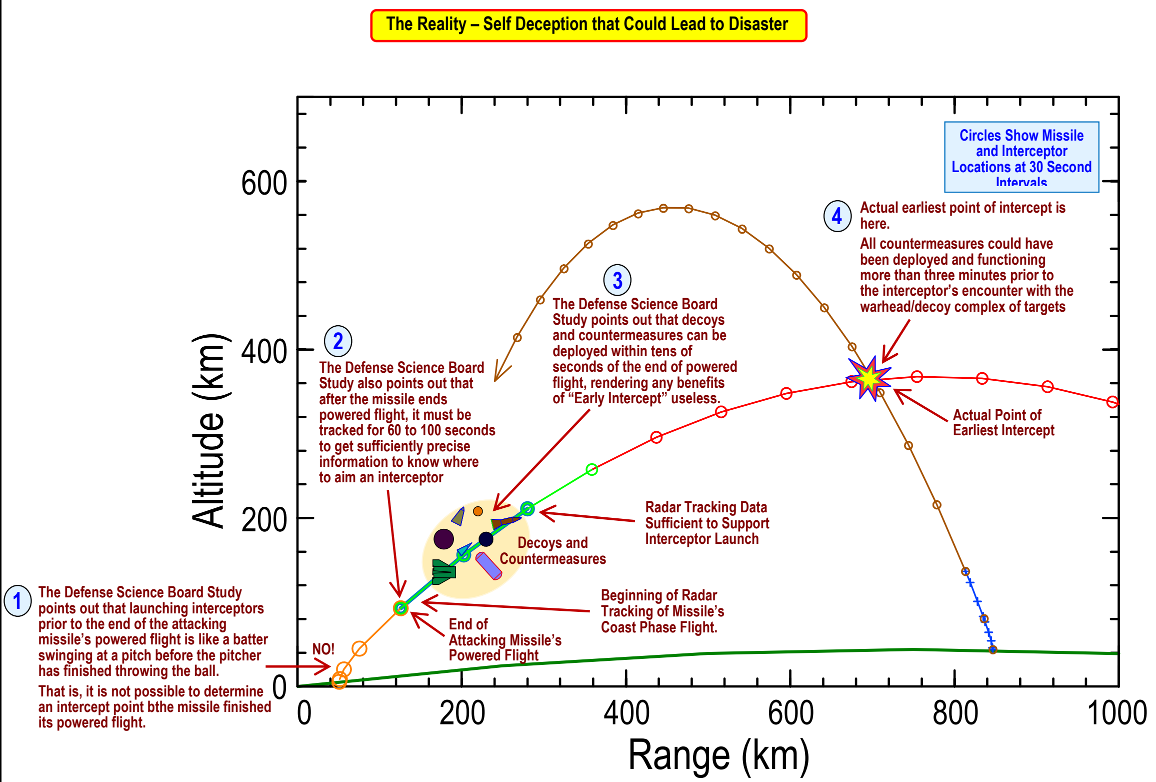
- Ascent Phase intercept will help us achieve key operational- and cost-efficiencies
  - Chance to kill before countermeasures deploy with easier intercepts than boost phase
  - Greater chance to shoot-look-shoot (doubles inventory efficiency)
  - Optimized asset locations to maximize standoff distances
  - 2002 Defense Science Board Report recommended it for emphasis
- What's changed since 2002: Leveraging Today's Technologies
  - Interceptors with substantial burnout velocities
  - Rapid closure of fire control loops demonstrated with hardware-in-the-loop
  - Over-the-horizon sensors for netted coverage
  - Affordable, continuously-available sensors




MDA Claims Before President Obama's September 17, 2009 Announcement to Proceed with the PAA
MISSILE DEFENSE AGENCY
DEPARTMENT OF DEFENSE
SM-3 Blk IB Timeline & Operating Area
1000
500
0km
2000
1500
1000
500
Operating Area
Reaction Timeline
Altitude (km)
Distance From Launch Point (km)
Threat Launch
OPIR Detect
ESL Quick Alert
Message Processing (C2BMC)
Transmit to Theater
Transmit to Fire Unit (Link-16) Message to ABIR
ABIR Acquisition
ABIR Track Processing & Relay to Fire Unit
Fire Unit Plan, Upload, & Missile Away
Ascent Phase
Missile Away
Threat Apogee
Furthest Lchr Intercept
Closest Lchr Intercept (195 s TALO)
TSRM Burnout
2nd Stage BO
Threat BO
1st Stage BO
Interceptor Away
Closest Lchr
Furthest Lchr
Distance From Launch Point (km)
Key:
ABIR
OPIR
Fire Unit
Threat
Notes:
Interceptor Launch Appears to be Roughly 30 Seconds Before Missile Burnout
OPIR Detect – Overhead Persistent IR (Initial Detection At or Close to Missile's Ignition)
1st Stage BO –Burnout of Interceptor's First Stage (6 seconds)
2nd Stage BO – Burnout of Interceptor's 2nd Stage
TSRM – Interceptor's Third Stage Rocket Motor
ESL – External Sensor Lab Quick Alert
C09-266R1 (RUSI Msl Def Conf) 05/19/09 2:30 PM 5
Approved for Public Release 09-MDA-4606 (20 MAY 09)


How Early Intercept Was Supposed to Make the Phased Adaptive Approach Workable!
The Missile Defense Agency's Egregious Conceptual Error
Circles Show Missile and Interceptor Locations at 30 Second Intervals
1 Location half-way through an attacking missile's powered flight where the Missile Defense Agency (MDA) was claiming that interceptors could be launched to hit the targeted missile.
2 End of Attacking Missile's Powered Flight
3 Period after the end of powered flight where MDA claimed that decoys could not yet be deployed
4 Location where MDA was claiming it could effectuate an "Early Intercept. According to MDA's assumptions, the "Early Intercept" would destroy the attacking missile before it could deploy decoys and other countermeasures
5 If "Early Intercept" is not successful, the missile could deploy numerous decoys and countermeasures that would make later attempts to destroy the warhead difficult or impossible. Hence, according to MDA, "Early Intercept" was critical to the workability of the PAA
6 Decoys and Countermeasures
Altitude (km)
Range (km)
0
200
400
600
800
1000

The Defense Science Board's Corrections to the Missile Defense Agency's Claims About "Early Intercept"



APPENDIX V

Very Rough Estimates of the Cost of Airborne Patrol Concepts Based on the Predator-B versus the F-35

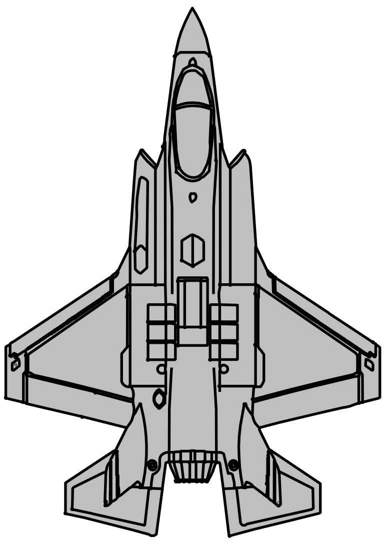
Contents

This appendix contains rough cost estimates for Airborne Patrol concepts based on the use of either the Predator-B or the F-35 airborne platforms. As noted earlier in this paper, the F-35 platform would have no greater effectiveness than Predator-B; both would need a long-range anti-ICBM interceptor of adequate speed and divert capability for the Airborne Patrol. Existing technology indicates that an appropriate interceptors can be built that could be carried by either the F-35 or the Predator-B.

Airborne Patrol Investment and Operational Costs
Based on F-35 versus Predator-B

Investment Cost per Station ≈ 12-25 Times Higher

On-Station Fuel Consumption ≈ 30 Times Higher (Small Part of Overall Costs)



Number of F-35 Sorties to Keep One on Station for 24 Hours =10

(10 F-35's at one sortie per day and 2.4 hrs on station; or 3.3 F-35's for 3 sorties/day; or 96 F-35's at planned utilization of 1 flying hour per day)

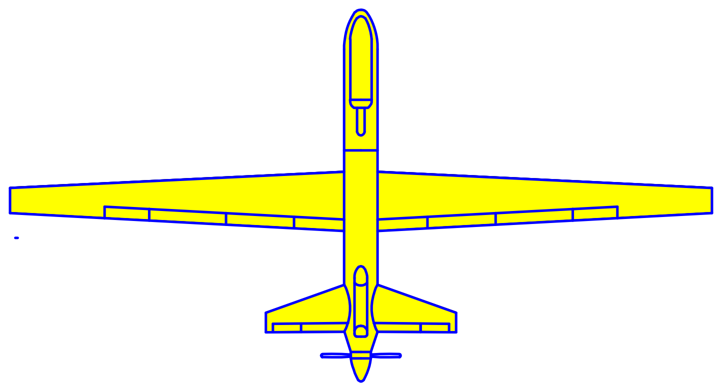
Fuel per Hour
On-Station Consumed = 6,167 lbs

Operating Cost for One-Station of Continuous Presence for 10 Years of Operation = $4.39 Billion

F-35 Maximum Takeoff Weight ~70,000 lbs

Fuel Load: 18,500 lbs

Cost of an F-35
$100 Million



Number of MQ Sorties to Keep One on Station for 24 Hours =1.2

Fuel per Hour
On-Station Consumed = 195 lbs

Operating Cost for One-Station of Continuous Presence for 10 Years of Operation = $525 Million

Predator-B Maximum Takeoff Weight ~10,500 lbs

Fuel Load: 3,900 lbs

Cost of an MQ-9
$20 Million

DoD Data Used for Rough Estimate of Airborne Patrol Operational Costs

$$\text{Cost per Flying Hour} = \frac{\text{Fuel} + \text{Consumables} + \text{Depot Level Repairs}}{\text{Flying Hours}}$$

These costs include:
Consumable materials, repair parts, depot-level repairs, and Intermediate maintenance

F-35A

Cost per Hour of Flying to Operate F-35: $28,455 per flying hour
Source: US Air Force, Office of the Under Secretary of Defense Comptroller

Predator-B

Cost per Hour of Flying to Operate Predator-B: ~$4,000 per flying hour
Source: Department of Defense MQ-9 Reaper Unmanned Aircraft System (MQ-9 Reaper), Selected Acquisition Report (SAR), DD-A&T(Q&A)823-424, 2017

Rough Estimate of *Operational* Costs Follows Below:

Cost per Flying Hour to Operate MQ-9: $\$5{,}000 \frac{\text{Dollars}}{\text{Flying Hour}}$

Cost per Flying Hour to Operate F-35? $\$30{,}000 \frac{\text{Dollars}}{\text{Flying Hour}}$

Predater-B Operational Costs for Ten Year System Deployment:

We assume that a Predater-B can patrol on station for roughly 20 hours during a sortie (the actual number is far higher for the version with a 73-ft wing span). We further assume that 2 hours is consumed getting on station and 2 hours is consumed returning home.

As a result, 1.2 sorties must be flown during a day to cover a station for 24 hours.

The arithmetic leading to a rough estimate of operating costs over a ten-year period is shown below:

For Predater-B:
1.2 × 24 Hours Flight Hours = 28.8 Flying Hours
required to keep a plane on station for 24 Hours

Cost for One MQ-9 On Station for for 24 Hours:

$$\$5{,}000 \frac{\text{Dollars}}{\text{Flying Hour}} \times 28.8 \frac{\text{Flying Hours}}{\text{Day on Station}} = \$144{,}000 \frac{\text{Dollars}}{\text{Day on Station}}$$

Operating Cost for One MQ-9 on Station for 24 hours/Day for 10 Years:

$$\$144{,}000 \frac{\text{Dollars}}{\text{Day on Station}} \times 365 \frac{\text{Days}}{\text{Year}} \times 10 \text{ Years} = \mathbf{\$525M}$$

F-35 Operational Costs for Ten Years On Station:

We assume that an F-35 can fly for roughly 4 hours during a sortie. We further assume that 0.8 hours is consumed getting on station and 0.8 hours returning home. We also assume that the aircraft must have 30 minutes of reserve fuel as part of the operations.

This leads to an assessment that the F-35 can be on station for 2.4 hours of a 4 hour mission.

For simplicity in the arithmetic we assume that each F-35 sortie can cover a station for 2.4 hours.

As a result, 10 F-35 sorties must be flown during a day to cover a station for 24 hours, for 40 Hours of flight time. This number is sometimes called the Base Loss Factor[1], which for this case is 10.

The arithmetic leading to a rough estimate of operating costs over a ten-year period is shown below:

Cost for One F-35 Sortie per Day:

$$\$30{,}000\,\frac{\text{Dollars}}{\text{Flying Hour}} \times 4.0\,\frac{\text{Flying Hours}}{\text{Sortie}} = \$120{,}000\,\frac{\text{Dollars}}{\text{Sortie}}$$

Operating Cost for One F-35 on Station for 24 hours/Day for 10 Years:

$$\$120{,}000\,\frac{\text{Dollars}}{\text{Sortie}} \times 365\,\frac{\text{Sorties}}{\text{Year}} \times 10\text{ Years} \times 10\,\frac{\text{Sorties}}{\text{Day}} = \mathbf{\$4.39B}$$

Rough Estimate of *Capital* Costs Follows Below:

Number of Predator-B's that Need to be Purchased
to Keep a Single Airborne Missile Defense Station populated for 24 Hours per Day

Roughly one predator sortie per day, using 2 Predators each flying every second day, but MQ-9 experience is more favorable.

Number of F-35's that Need to be Purchased
to Keep a Single Airborne Missile Defense Station populated for 24 Hours per Day

Roughly 10 F-35 sorties per day, if an F-35 can fly a 4-hr mission each day. Ratio of Needed F-35's to Predator-B's ~ **5:1 to 20:1**

Cost Ratio of F-35 to Predator-B = $100 million / $20 million = **5**

Aircraft acquisition Cost Ratio for F-35 Relative to Predator-B
to Keep a Single Airborne Missile Defense Station populated for 24 Hours per Day ~ **25:1 to 100:1**

In summary

The operational cost for a single station occupied by an MQ-9 drone carrying two anti-ICBM interceptors is $144,000 per day.

The operational cost for a single station occupied by an F-35 aircraft carrying two anti-ICBM interceptors is $1.2 million per day-- a factor 8.33 times as large; the cost of the aircraft required is larger by a factor 25 to 100 for the F-35.

[1] The Base Loss Factor is simply the number of ships or planes needed to be able to keep a single ship or plane on-station at all times. See *A Conceptual and Analytical Study of the Utility of Speed in Naval Operations*, Volume II, Appendix, http://www.dtic.mil/dtic/tr/fulltext/u2/a081573.pdf

APPENDIX VI

Key Slides from the Airborne Patrol Report of November 27-29, 2017

MIT
Science, Technology, and
National Security Working Group

Airborne Patrol to Destroy DPRK ICBMs in Powered Flight

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Washington, DC
November 27-29, 2017

Purpose and Motivations for the *Airborne Patrol Against DPRK ICBMs*

Summary

The DPRK has demonstrated missiles with near-ICBM range and tested underground nuclear or thermonuclear explosives of yield estimated to be 100 or even 250 kilotons—comparable in yield to many of the current U.S. strategic warheads. Although there is not evidence that the DPRK has mastered the technology of a ruggedized warhead and reentry vehicle that would survive the 60 G deceleration and heating of atmospheric reentry at ICBM range, they could do so in time.

It is also not clear that any of the DPRK's nuclear weapons can yet be carried to ICBM range, but that also is only a matter of time.

We sketch here an "*Airborne Patrol System to Destroy DPRK ICBMs in Powered Flight*" incorporating the well established MQ-9 Reaper (Predator B) remotely piloted aircraft (RPA), The Big Wing version of the MQ-9 has a loiter time of some 37 hours at 500 miles from its airbase in South Korea or Japan, carrying two Boost-Phase Intercept missiles assembled of available rocket motors, e.g., from Orbital ATK. A two-stage rocket would provide 4 km/s, with a 75 or 55 kg homing payload providing an additional 2.0 or 1.5 km/s divert velocity, and carrying a 25 kg seeker that would home optically on the booster flame and the ICBM's hard body.

All of the technologies needed to implement the proposed system are proven and no new technologies are needed to realize the system .

The baseline system could technically be deployed in 2020, and would be designed to handle up to 5 simultaneous ICBM launches.

The potential value of this system could be to quickly create an incentive for North Korea to take diplomatic negotiations seriously and to destroy North Korean ICBMs if they are launched at the continental United States.

The proposed *Airborne Patrol System* could be a "first-step system" that can be constantly improved over time. For example, we have analyzed the system assuming that interceptors have a top speed of 4 km/s with a 25 kg seeker. We believe that faster, or lighter and smaller interceptors can be built that would increase the firepower of the system and *possibly* its capability against somewhat shorter range ballistic missiles like the Nodong – which poses a threat to Japan.

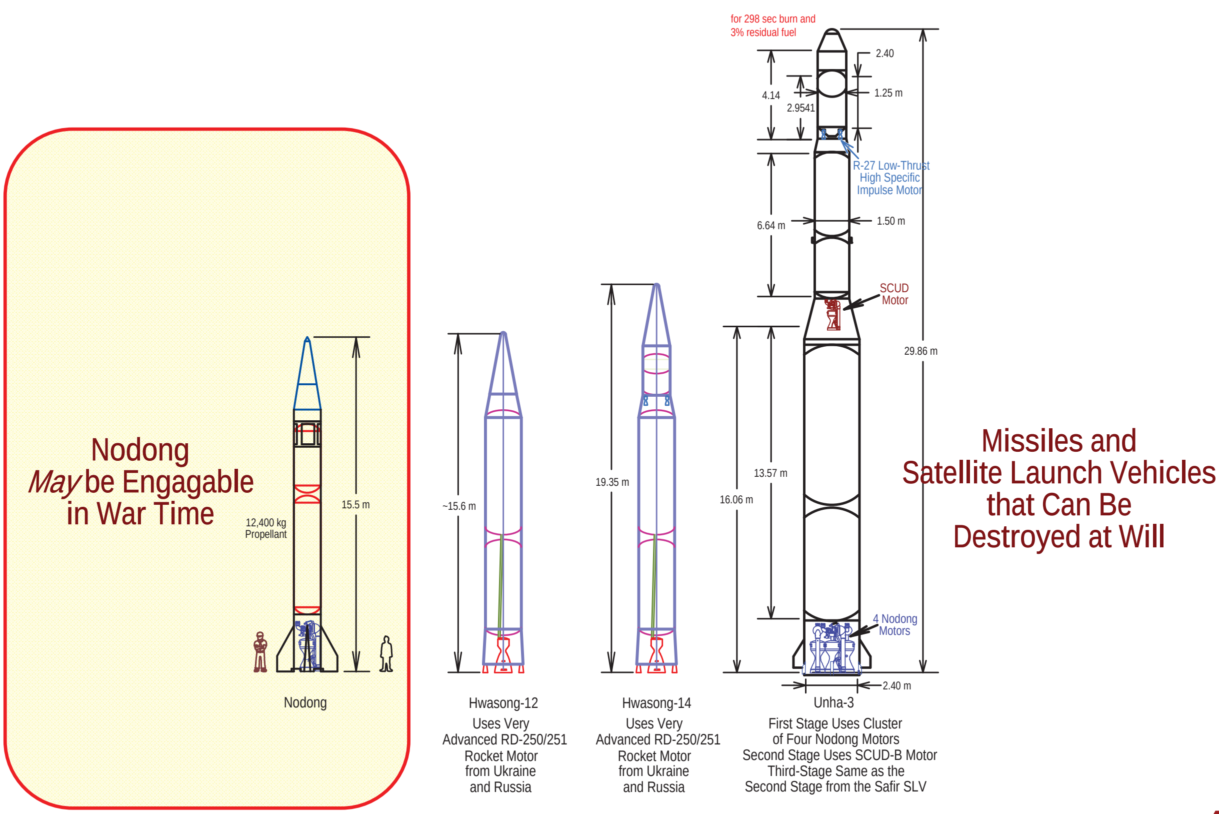
Since the *Airborne Patrol System* would be based on the use of drones that would loiter outside of North Korean airspace, the electronic countermeasures needed to defeat distant surface-to-air missile defenses would be easy to implement because of the long-range between the drones and the air-defense radars.

The availability of relatively inexpensive high-payload long-endurance drones will also improve, along with the electronic countermeasures systems to protect them.

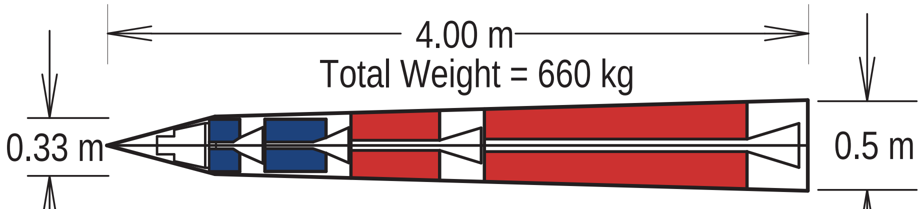
Key Patrol System Elements

- Ballistic Missile Targets to Be Engaged
- Attack Interceptors
- Platforms for Attack Interceptors

North Korean Missiles and Satellite Launch Vehicles that Can Be Destroyed After Launch at Will

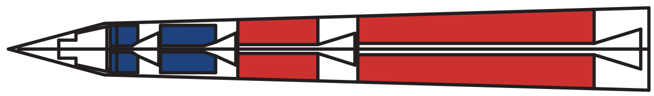


Estimated Weight and Propulsion Characteristics of 4+ Km/Sec Airborne Interceptor that Uses Achievable Rocket Motor Technologies



Interceptor with 25 kg Optical and Homing Payload and Additional 2km/sec Divert Velocity

Total Weight = 500 kg



Interceptor with 25 kg Optical and Homing Payload and Additional 1.5km/sec Divert Velocity

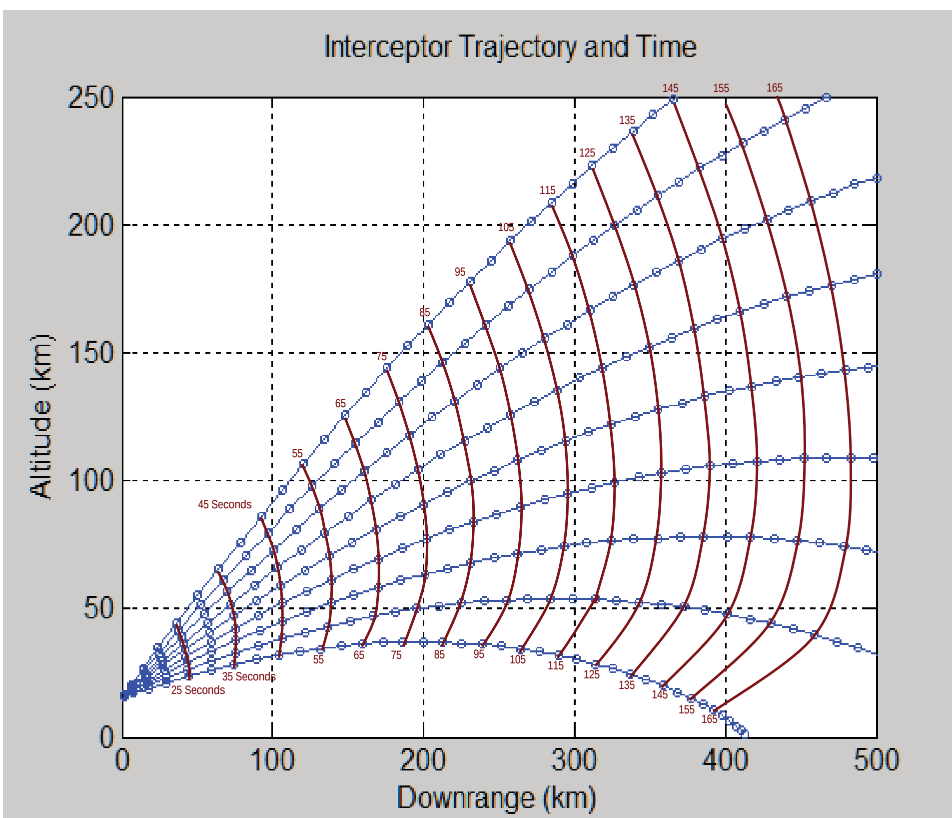
Attack Interceptor with Kill Vehicle that has ΔV=2 km/sec

Total Weight of Interceptor	1449.43 lbs (657.34 kg)
Payload Weight	165.38 lbs (75.00 kg)
Speed at Burnout	4.00 km/s
First Stage Motor Weight	959.84 lbs (435.30 kg)
First Stage Propellant Weight	767.87 lbs (348.24 kg)
First Stage Structural Weight	191.97 lbs (87.06 kg)
First Stage Structure Factor	0.20
First Stage Specific Impulse	270 sec
First Stage Burnout Speed	2.00 km/s
Second Stage Motor Weight	324.22 lbs (147.04 kg)
Second Stage Propellant Weight	259.37 lbs (117.63 kg)
Second Stage Structural Weight	64.84 lbs (29.41 kg)
Second Stage Structure Factor	0.20
Second Stage Specific Impulse	270 sec
Second Stage Burnout Speed	2.00 km/s
Thrust Level of First Stage	20446.79 lbs (9272.92 kgF)
Thrust Burn Time of First Stage	10.14 seconds
Thrust Level of Second Stage	4604.37 lbs (2088.15 kgF)
Thrust Burn Time of Second Stage	15.21 seconds

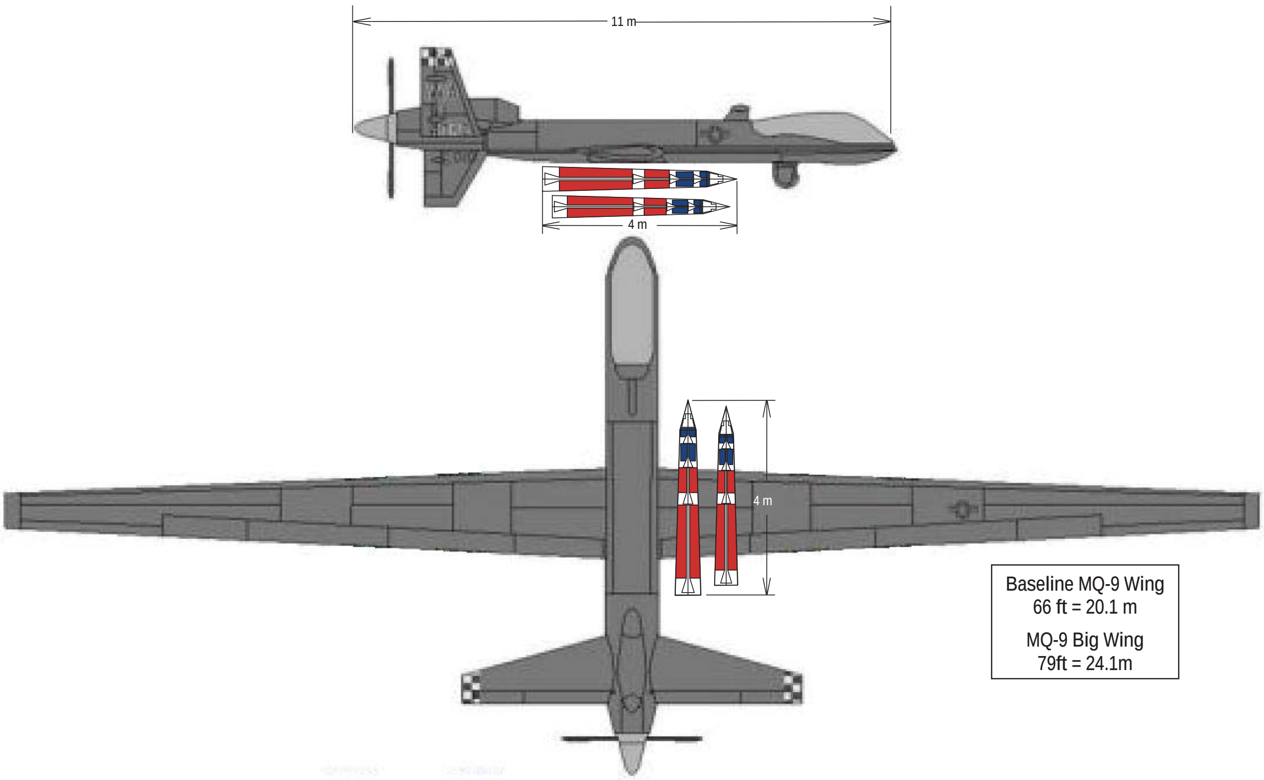
Attack Interceptor with Kill Vehicle that has ΔV=1.5 km/sec

Total Weight of Interceptor	1082.24 lbs (490.81 kg)
Payload Weight	123.48 lbs (56.00 kg)
Speed at Burnout	4.00 km/s
First Stage Motor Weight	716.68 lbs (325.03 kg)
First Stage Propellant Weight	573.34 lbs (260.02 kg)
First Stage Structural Weight	143.34 lbs (65.01 kg)
First Stage Structure Factor	0.20
First Stage Specific Impulse	270 sec
First Stage Burnout Speed	2.00 km/s
Second Stage Motor Weight	242.08 lbs (109.79 kg)
Second Stage Propellant Weight	193.67 lbs (87.83 kg)
Second Stage Structural Weight	48.42 lbs (21.96 kg)
Second Stage Structure Factor	0.20
Second Stage Specific Impulse	270 sec
Second Stage Burnout Speed	2.00 km/s
Thrust Level of First Stage	15266.93 lbs (6923.78 kgF)
Thrust Burn Time of First Stage	10.14 seconds
Thrust Level of Second Stage	3437.93 lbs (1559.15 kgF)
Thrust Burn Time of Second Stage	15.21 seconds

Trajectories that Can be Flown by Interceptor with 25 Second Acceleration Time and 4 km/sec Burnout Speed



Relatively Inexpensive Drone that Is Already Available and Tested*



Drone-Based Systems for Post-Launch Precision Tracking to Support Interceptor Homing

System Precision Tracking on Drones

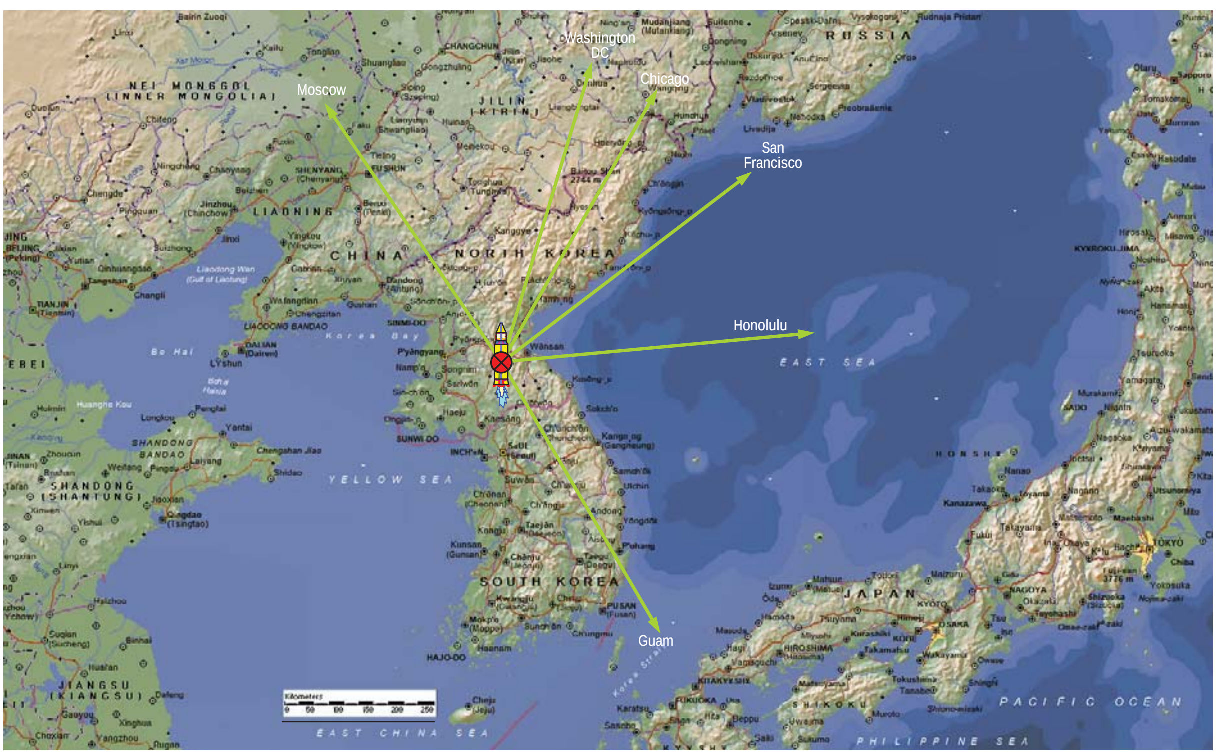
- Each deployed interceptor carrying drone available for stereo viewing of boosting targets
- Focal plane array operating in the 3-5 micron wavelength band for above cloud tracking
- Focal plane array operating in the 0.5-2.2 microns wavelength band for see-to-the ground detection
- Small field-of-view focal plane array video in the visible wavelengths for tracking and kill assessment

Homing Sensor on Interceptor

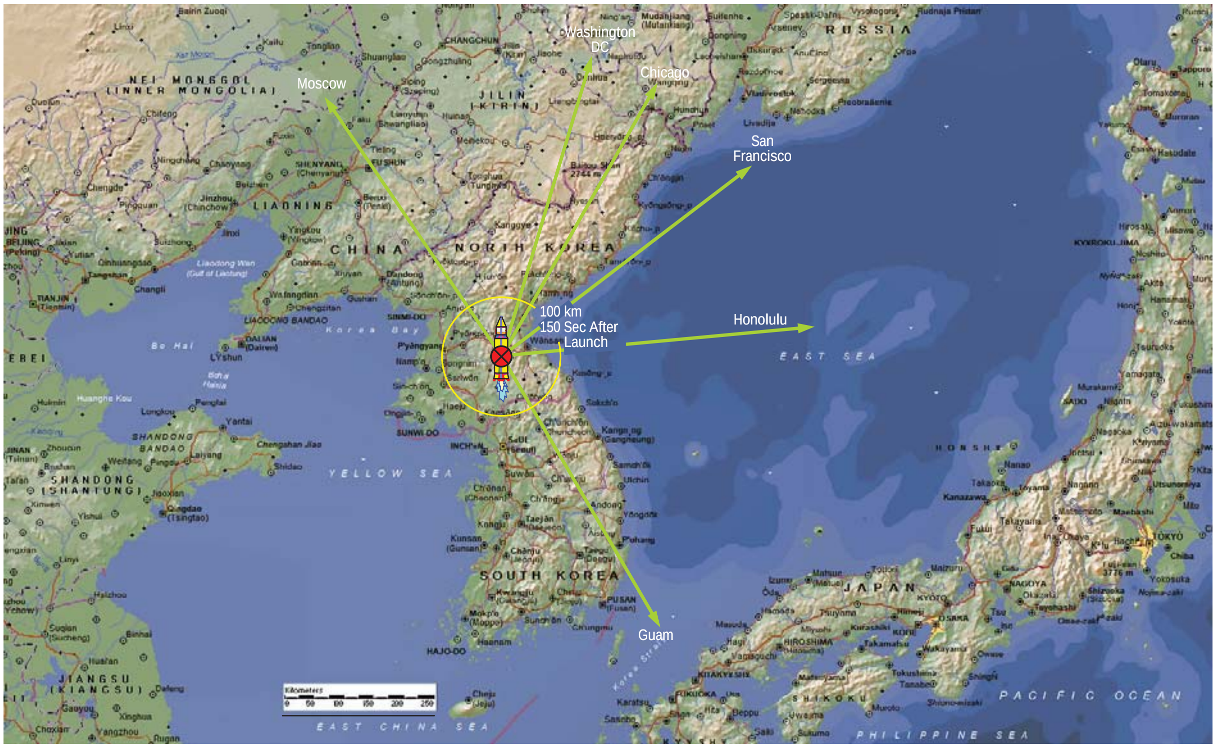
- Focal plane array operating in the 3-5 microns wavelength band for long-range homing
- Megapixel visible or near-infrared focal plane array for accurate long-range images of target body
- Laser illuminator and lidar for endgame target details and range-to-target data

Geographical and Military Factors Relevant to the Deployment and Operation of the Attack System

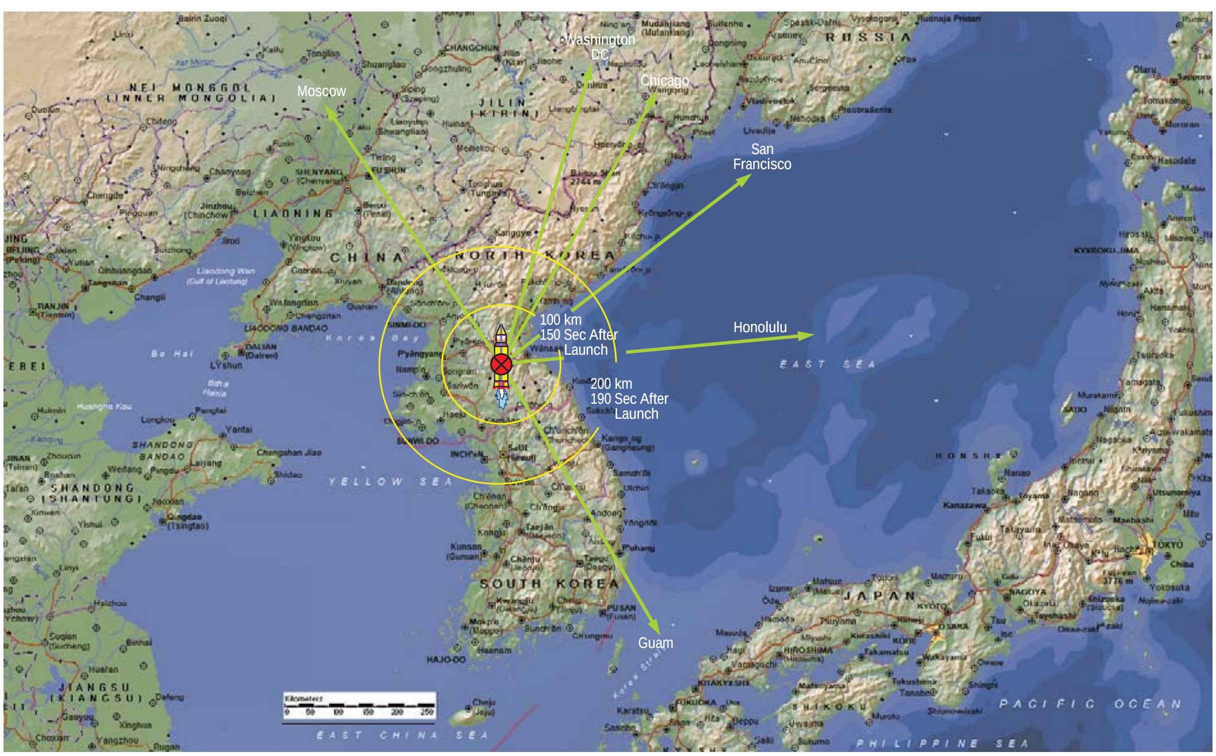
Directions to Different Target Cities or Military Bases for the Hwasong-12 or Hwasong-14 Long-Range Missiles



Distance Travelled by Hwasong-12 and Hwasong-14 During the First 150 Seconds of Powered Flight

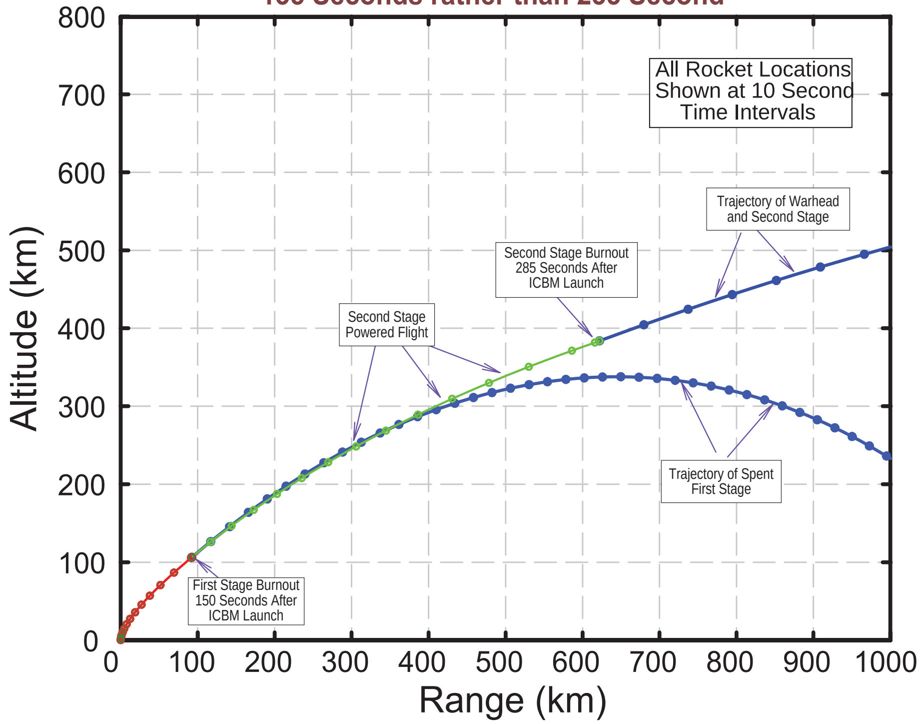


Distance Travelled by *Upgraded* Hwasong-14 Second Stage During the First 190 Seconds of Powered Flight (40 Seconds After Staging))



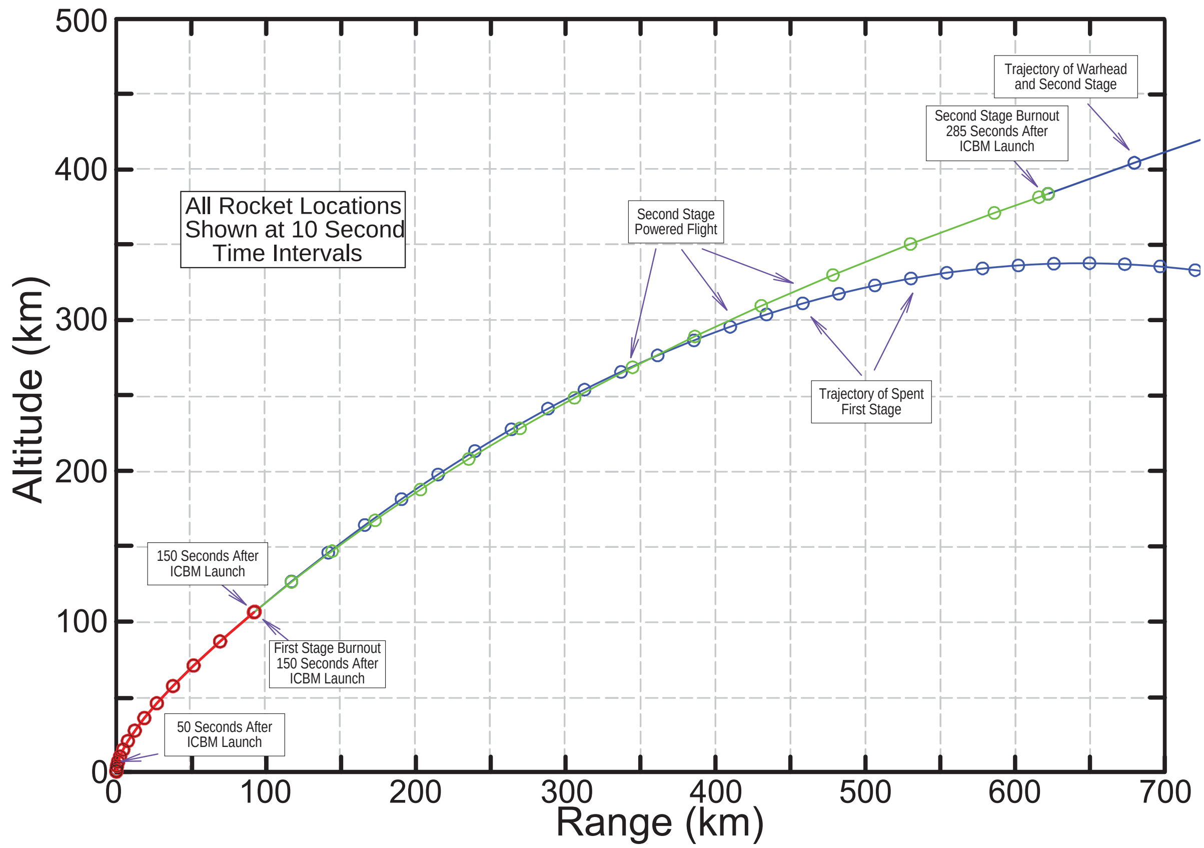
Powered Flight and Initial Coast Trajectories of the First Stage and Payload of an Upgraded Hwasong-14 North Korean ICBM*

Hwasong 14 ICBM with Fast Burning Liquid Second Stage
135 Seconds rather than 233 Second

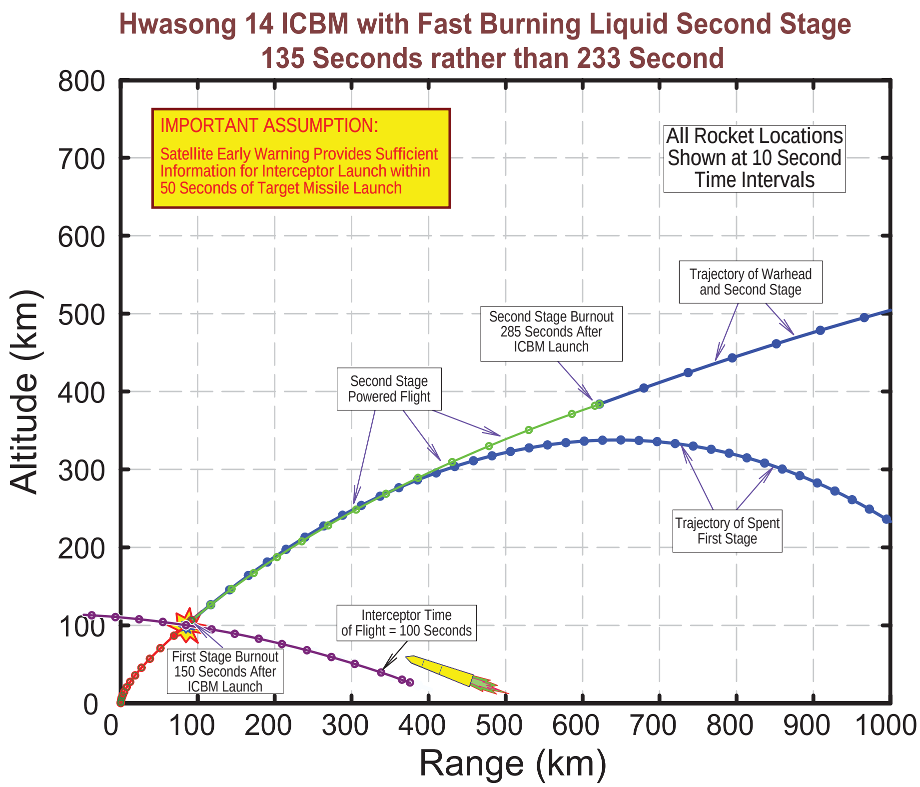


* The upgraded Hwasong-14 assumes a second stage that uses four vernier motors from the R-27 SLBM. The actual Hwasong-14 tested on July 4 and July 28, 2016 has only two vernier engines and has an upper stage powered flight time twice as long as the presumed "upgraded" Hwasong-14 shown here.

Early Powered Flight and Initial Coast Trajectories of the First Stage and Payload of an Upgraded Hwasong-14 North Korean ICBM*



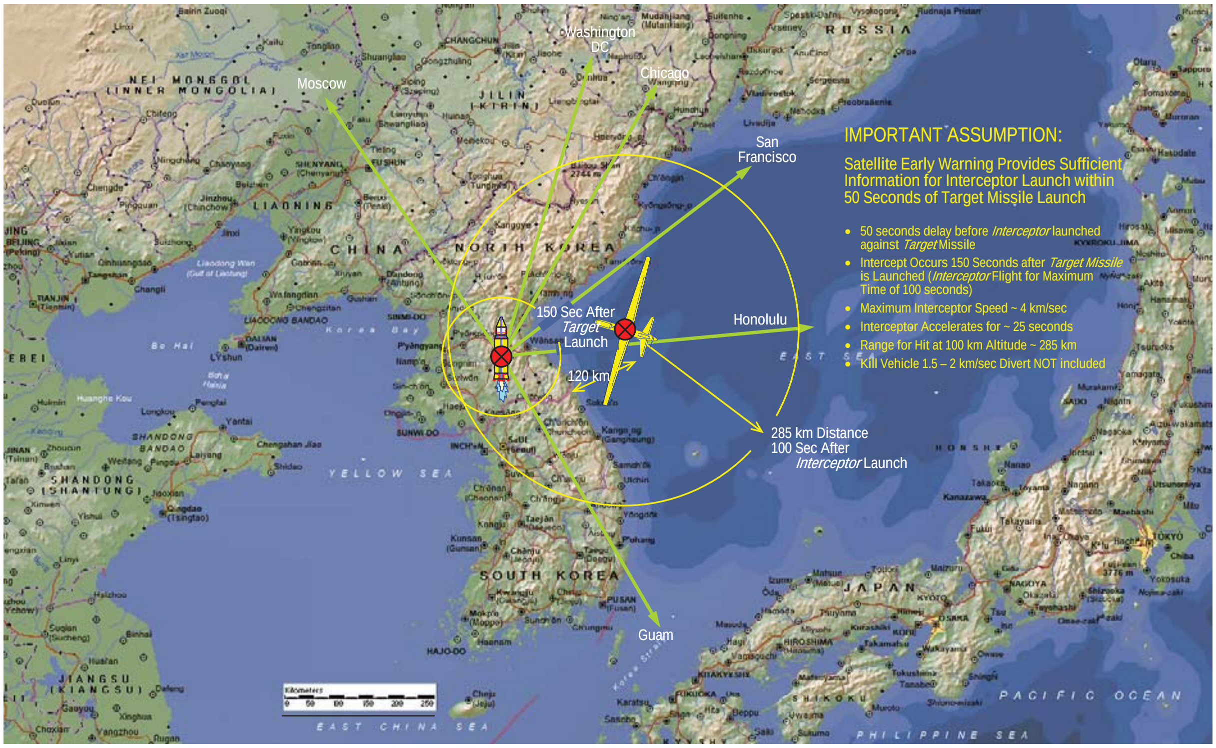
Interceptor Lethal Engagement Range against the Hwasong-12 or the First Stage of the Hwasong-14 Is About 320+ Kilometers



* The upgraded Hwasong-14 assumes a second stage that uses four vernier motors from the R-27 SLBM. The actual Hwasong-14 tested on July 4 and July 28, 2016 has only two vernier engines and has an upper stage powered flight time twice as long as the presumed "upgraded" Hwasong-14 shown here.

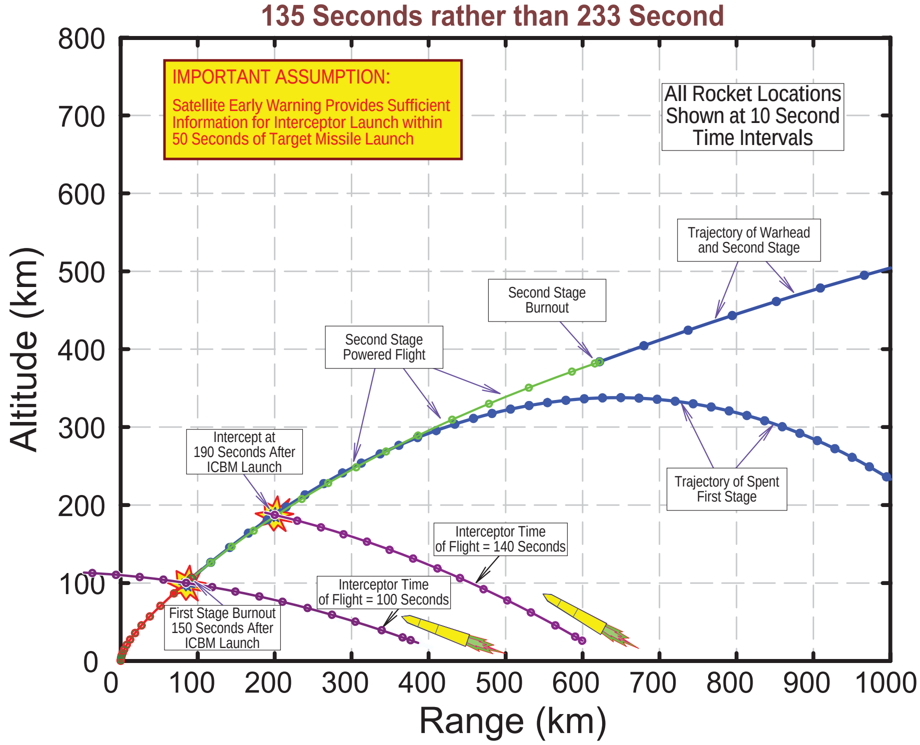
Shoot-Down Capabilities Against ICBMs and Satellite Launch Vehicles

Interceptor Lethal Engagement Range against the Hwasong-12 or the First Stage of the Hwasong-14 Is About 285+ Kilometers



Interceptor Lethal Engagement Range against the Hwasong-14 During Early Powered Flight of Its Second Stage Is About 390+ Kilometers

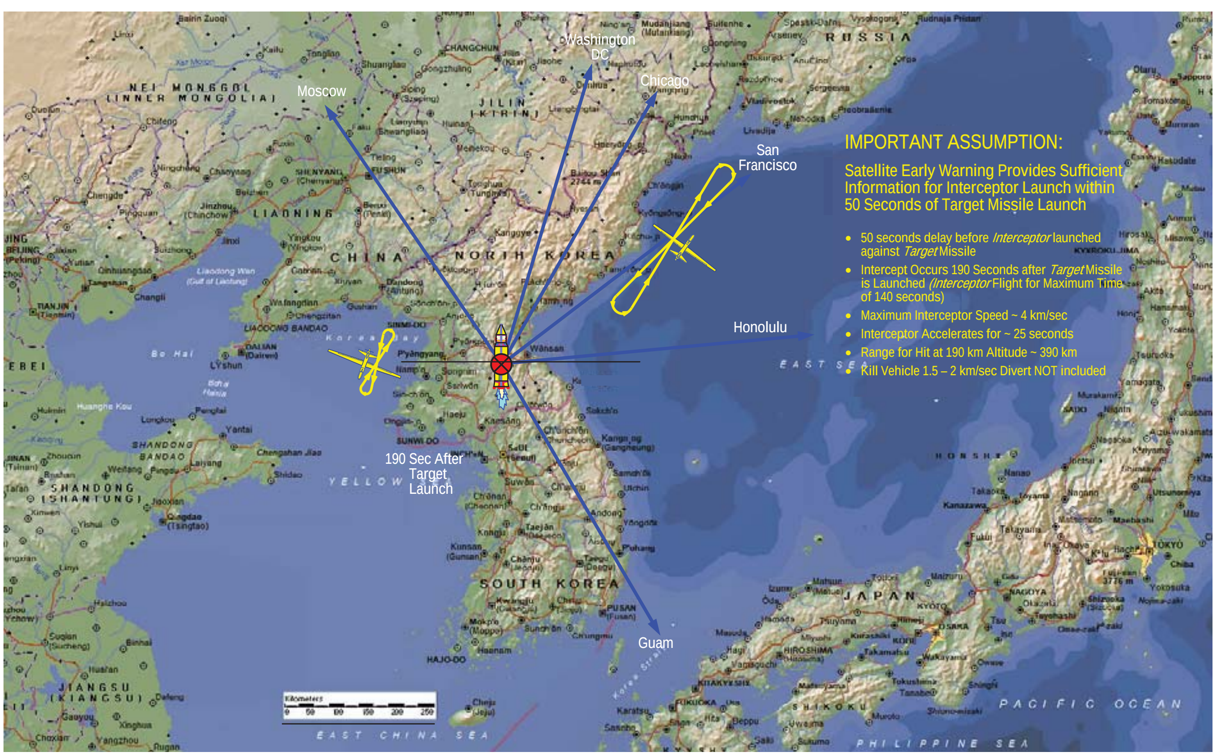
Hwasong 14 ICBM with Fast Burning Liquid Second Stage 135 Seconds rather than 233 Second



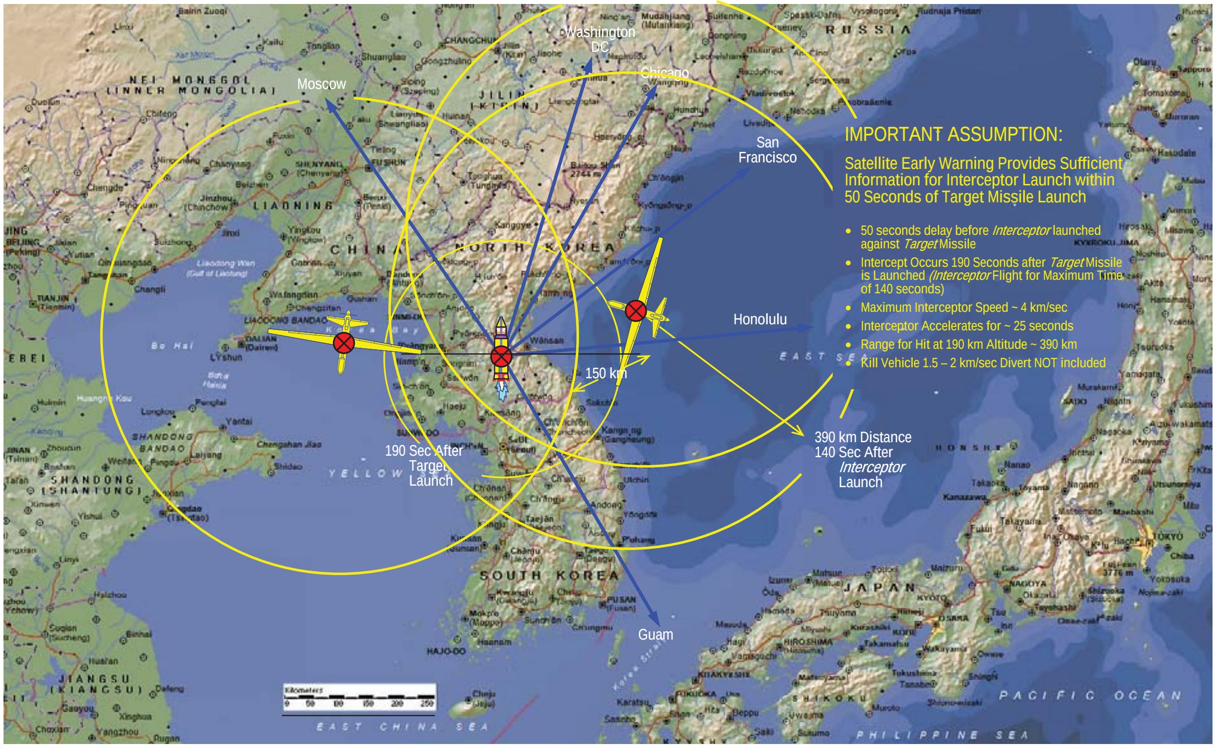
* The upgraded Hwasong-14 assumes a second stage that uses four vernier motors from the R-27 SLBM. The actual Hwasong-14 tested on July 4 and July 28, 2016 has only two vernier engines and has an upper stage powered flight time twice as long as the presumed "upgraded" Hwasong-14 shown here.

Interceptor Lethal Engagement Range against the Hwasong-14 During Early Powered Flight of Its Second Stage Is About 390+ Kilometers

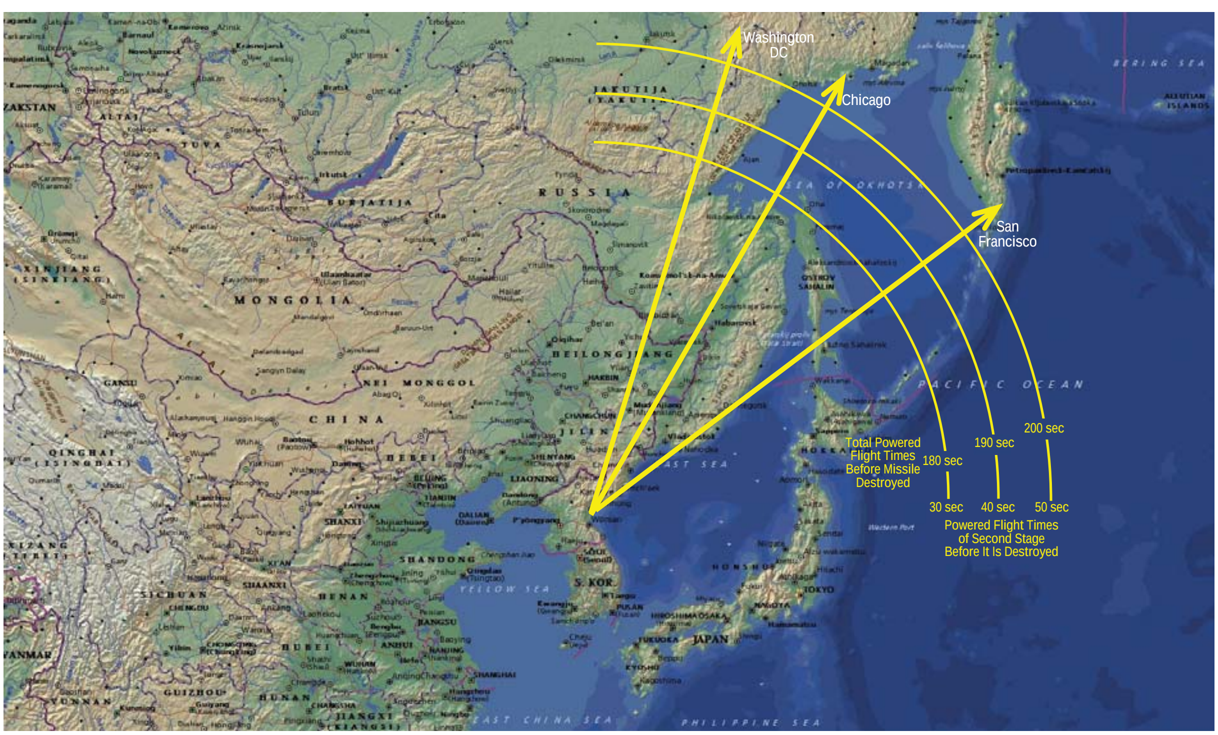
Drone Patrol Patterns against the Hwasong-14 Intercept of Its Second Stage During Early Powered Flight Is About 390+ Kilometers



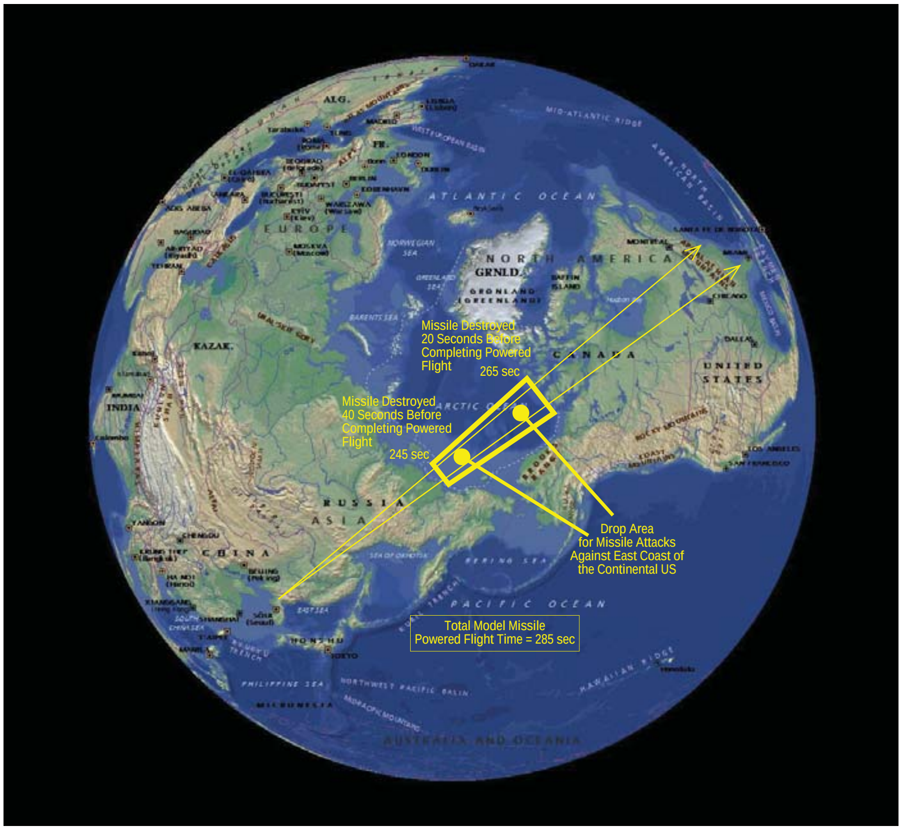
Drone Patrol Coverage against the Hwasong-14 Intercept of Its Second Stage During Early Powered Flight Is About 390+ Kilometers



Impact Areas of the Hwasong-14 Debris after Being Hit at Different Times After Launch



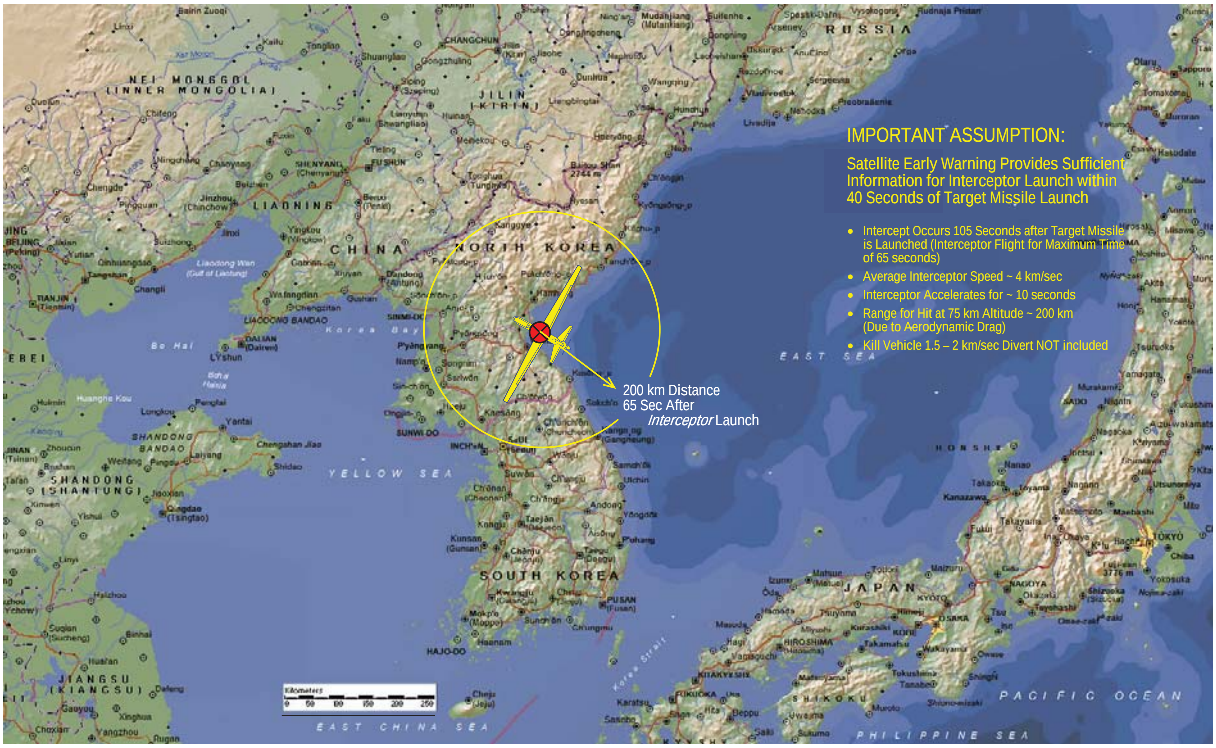
Impact Areas of the Hwasong-14 Debris after Being Hit at Different Times After Launch



APPENDIX

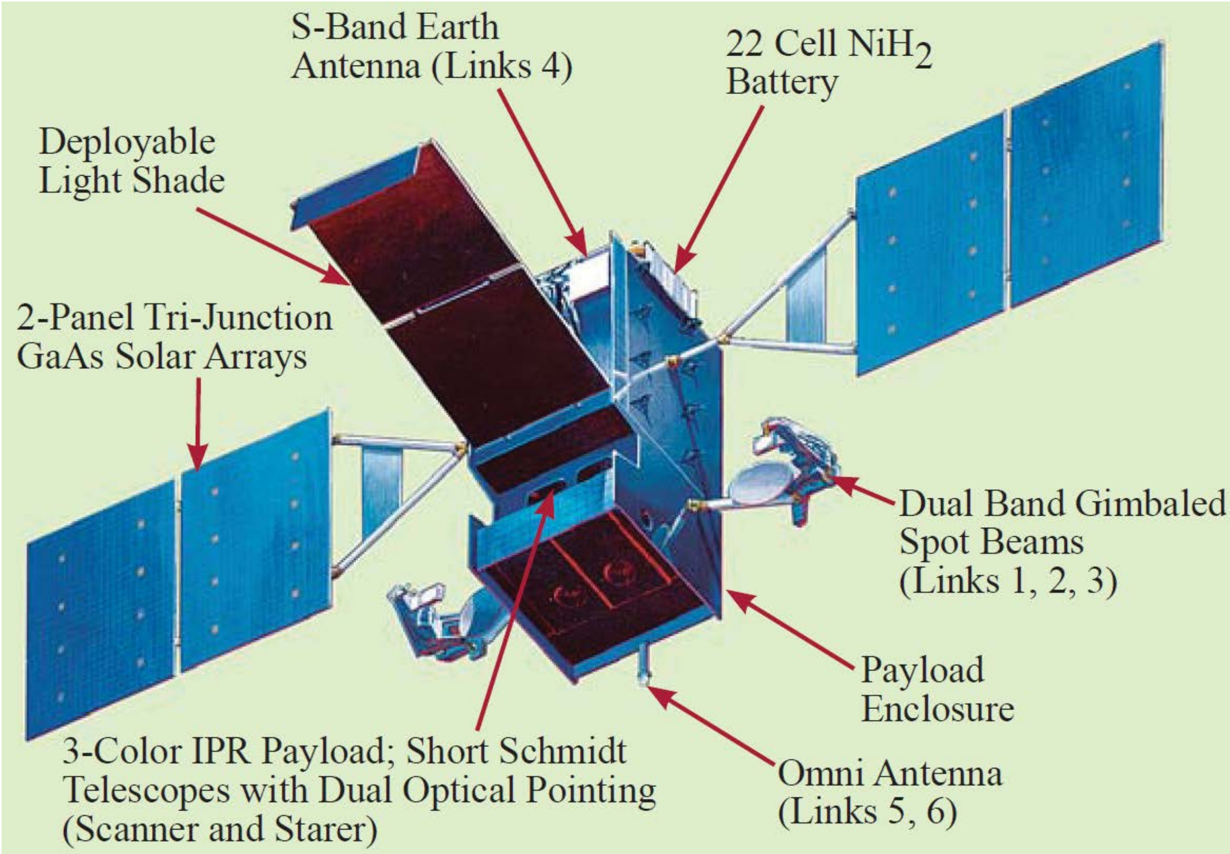
Capabilities in War

If War Starts – GO IN AFTER THE NODONGS!
Interceptor Lethal Engagement Range against the North Korean Nodong



APPENDIX

A Key Enabling Technology
Near Instantaneous Launch Detection and Tracking from Satellites



Satellite Features

- A2100 derived spacecraft, 12-year design life, 9.8-year MMD
- ~10,000-lb predicted wet weight at launch
- 3-axis stabilized with 0.05 deg pointing accuracy; solar flyer attitude control
- RH-32 rad-hardened single board computers with reloadable flight software
- ~2800 watts generated by GaAs solar arrays
- GPS receiver with Selected Availability Secure Anti-Spoof Module (SAASM)
- ~1000-lb infrared payload: scanning and staring sensors
  - 3 colors: short-wave, mid-wave, and see-to-ground sensor-chip assemblies
  - Short Schmidt telescopes with dual optical pointing
  - Agile precision pointing and control
  - Passive thermal cooling
- Secure communications links for normal, survivable, and endurable operations

100 Mbs data-rate to ground

~500+ lb Infrared Sensor Payload: Scanning and Staring Sensors

SWIR~2.69-2.95 µm, MWIR~4.3 µm, and 0.5-2.2 µm (see-to-ground)