Docket No. **SA-516**

Exhibit No. **22E**

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C.

MISSILE SELF DESTRUCT PERFORMANCE STUDY

(23 page)

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, DC

April 13, 2000

MISSILE SELF DESTRUCT PERFORMANCE STUDY

By Dennis Crider

A. ACCIDENT: DCA-96-MA-070

Location:	East Moriches, New York
Date:	July 17, 1996
Time:	2031 Eastern Daylight Time
Airplane:	Boeing 747-131, N93119

B. GROUP IDENTIFICATION

No group was formed for this activity.

C. SUMMARY

On July 17, 1996, at 2031 EDT, a Boeing 747-131, N93119, crashed into the Atlantic Ocean, about 8 miles south of East Moriches, New York, after taking off from John F. Kennedy International Airport (JFK). The airplane was being operated on an instrument flight rules (IFR) flight plan under the provisions of Title 14, Code of Federal Regulation (CFR), Part 121, on a regularly scheduled flight to Charles De Gaulle International Airport (CDG), Paris, France, as Trans World Airlines (TWA) Flight 800. Explosion, fire, and impact forces with the ocean destroyed the airplane. All 230 people aboard were killed.

D. DETAILS OF THE INVESTIGATION

INTRODUCTION

Shoulder launched missiles will self-destruct, detonating their warhead, after a certain length of time if they do not reach a target. A scenario was studied in which a shoulder launched missile (A Man Portable Air Defense System (MANPADS)) was fired at TWA 800 and self-destructed close enough to the airplane for a missile fragment to enter the center wing fuel tank. Examination of the structure revealed no evidence of a small high velocity impact hole in the structure of the wing center section fuel tank on the TWA flight 800 airplane.[1]

Three conditions must be true for a shoulder launched missile self-destruction to be a possible source of tank ignition.

- The missile must be close enough at detonation for a fragment to enter and ignite the tank.
- The missile must be orientated in such a manner at detonation that the fragmentation pattern intersects the tank.
- The missile must be far enough away at detonation that the airplane is not peppered with holes.

Two approaches were taken to investigate this scenario. The first was to investigate the encounter geometry required to get a fragment from a missile self destruction into the tank. The second approach was to investigate the performance of a missile guiding to an intercept of TWA 800.

SELF DESTRUCTION OVERVIEW

A Man Portable Air Defense System (MANPADS) typically is a cylinder with a sensor and guidance section in the nose followed by a warhead section and a motor at the aft end. Detonation of a missile warhead will disperse warhead fragments into a pattern around the last missile position. This fragmentation pattern is illustrated in figure 1 (rotating this 2 dimensional view about the long axis of the missile would yield the true 3-D pattern).

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[1] Only two holes were found in all the wreckage that had some high velocity characteristics. These were found in the pressure deck in the landing gear bay aft of the center wing tank. These holes showed impact from above (inside the airplane) at angles that did not converge to a common source. See Docket SA-516 exhibit 15B; Metallurgist's Factual Report, Report No. 97-81.

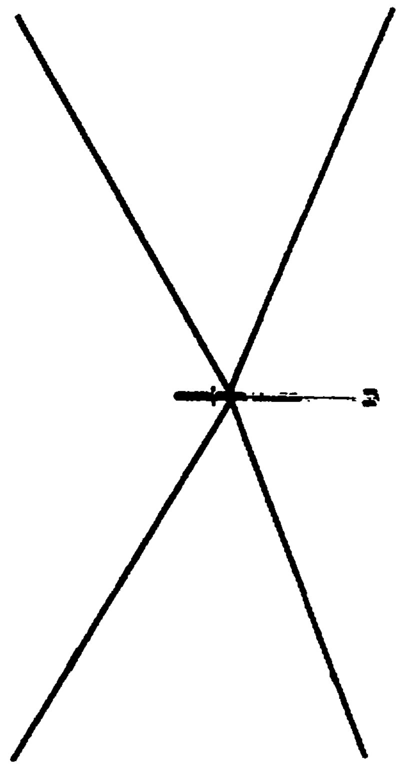

Figure 1; Missile fragmentation pattern

As the warhead fragments move into the fragment pattern volume, the particles rapidly disperse, reducing the number of fragments that would hit a given area as distance from the explosion increases. According to the Defense Intelligence Agency's Missile and Space Intelligence Center (MSIC), about 1000 fragments can be expected from a warhead detonation. Dispersing 1000 fragments into the fragment pattern of figure 1, the number of warhead fragments into a 10 ft by 10 ft spherical surface area can be calculated and is shown in figure 2. The number of fragments that would impact a given area decreases with the square of the distance of that area from the explosion.

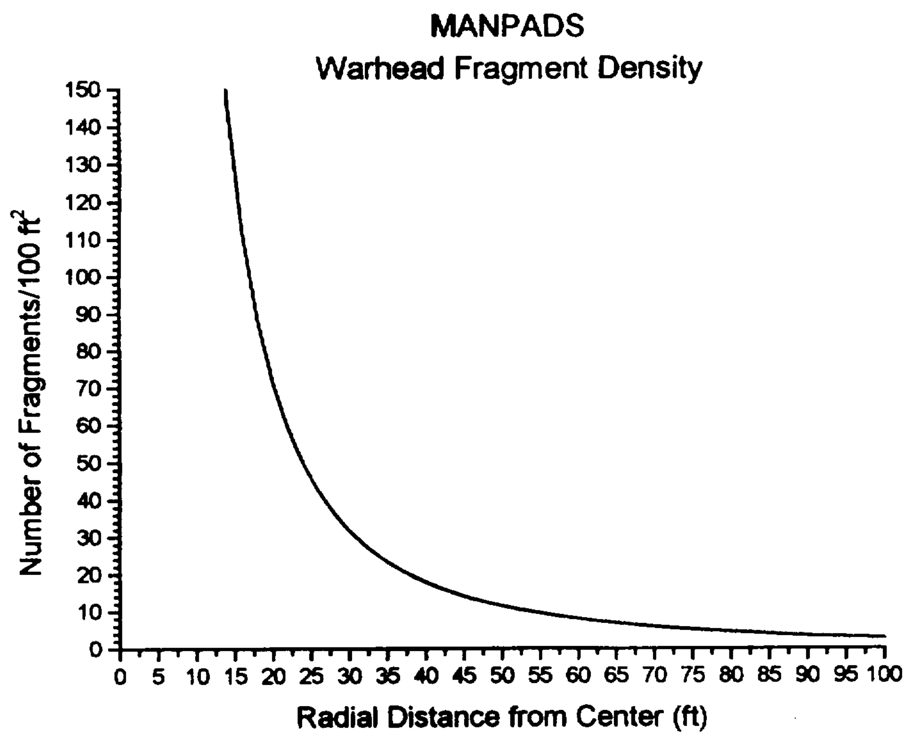

Figure 2; fragment area density

As an example, consider the missile encounter depicted in figure 3. The fragment pattern from a self-destruction with this encounter covers over 634 square feet of airplane surface area. About 140 square ft of this surface area is the side of the fuselage under the wing. The fragment density at this location is about 30 fragments per 100 square feet yielding a total of about 42 fragments. About 330 fragments (1/3 of the total) would impact the wing with the greatest fragment density directly above the missile.

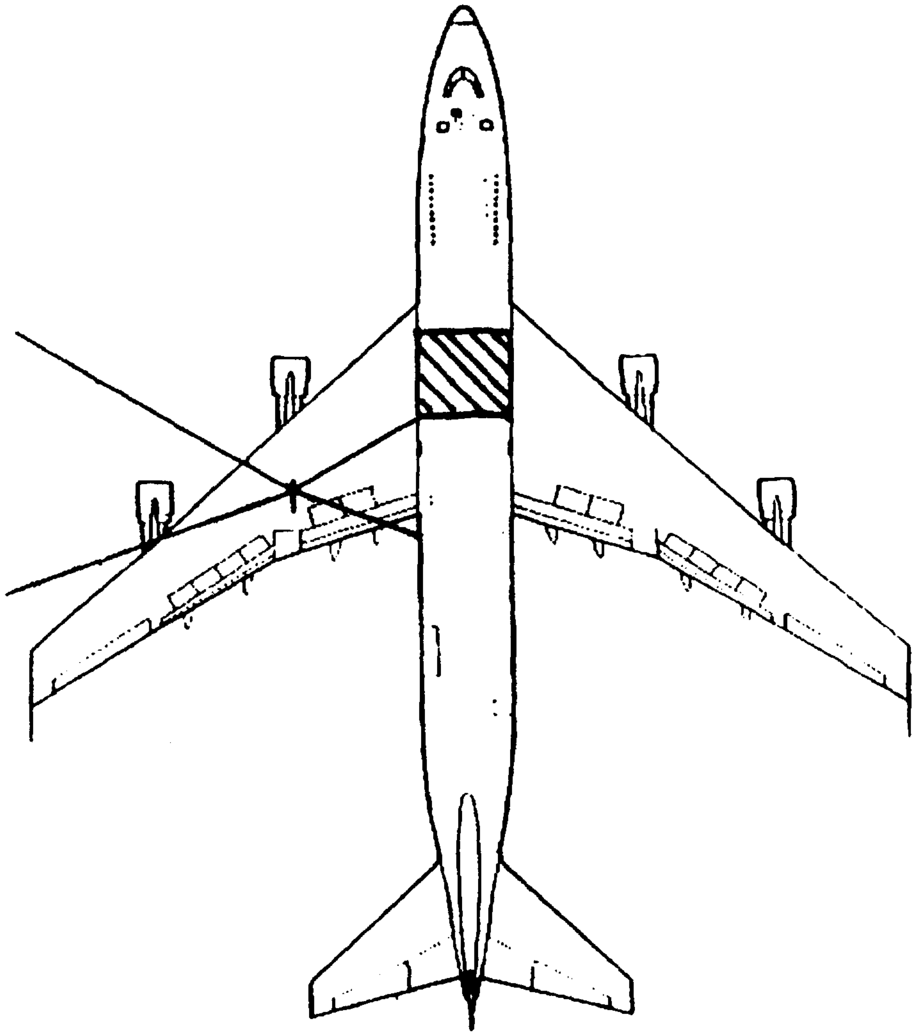

Figure 3; fragmentation pattern with warhead tracking perfectly in trail.

MANPAD warhead detonation produces fragments in a range of sizes. The damage from these fragments can range from penetration to cratering and pitting to nothing (if the impact speed nears zero). Damage will be dependent on mass of the individual fragments, the thickness and type of the material and the distance between the material and detonation.

According to MSIC the average MANPAD warhead fragment has a mass of less than 10 grains (0.0229 ounces). According to specialists at the Naval Air Warfare Center, Weapons Division at China Lake, warhead fragments can have a mass up to 40 grains. The Survivability/Vulnerability Information Analysis Center (SURVIAC) provided the Safety Board with data that showed that a 10 grain fragment hitting the tank bottom perpendicularly requires a velocity of over 3500 ft/sec to penetrate the bottom of the center wing tank. A 40 grain fragment hitting the tank bottom perpendicularly requires a velocity of over 2000 ft/sec to penetrate the bottom of the center wing tank. Fragments hitting the tank at an angle require considerably greater velocity to penetrate. For example, a 40 grain fragment hitting the bottom of the tank with a 60 deg angle requires a velocity of over 4500 ft/sec to penetrate the bottom of the tank. In addition SURVIAC stated that test data show that, when a fragment must pass through airplane skin before penetrating the component of interest, it loses both velocity and mass. Thus higher velocities are required to penetrate the component of interest.

MSIC provided the Safety Board with a test based speed decay rate for MANPAD warhead fragments. MSIC also reported that warhead fragments could have an initial velocity as high as 9000 ft/sec. Using the decay rate data provided and a 9000 ft/sec initial velocity, the velocity decayed below 2000 ft/sec in less than 40 ft. Thus, a warhead must detonate within 40 ft of the tank for a warhead fragment hitting the tank perpendicularly to have sufficient energy to penetrate the tank. Similarly, a 40 grain warhead fragment hitting the tank at a 60 degree angle must come from a detonation less than 17 ft away. Both these distances do not account for loss of fragment mass or velocity through the fairing below the center wing tank.

In order for a fragment to enter the center wing tank through the side wall, it must enter and pass through the inboard wing tank. The inboard wing fuel tanks bordering the sides of center fuel tank were full with fuel. Since jet fuel is considerably denser than air, the speed of a fragment decays much more rapidly in fuel than in air. Adjusting the test decay rate for fuel density shows that a fragment traveling through Jet fuel will slow from 9000 ft/sec to 2000 ft/sec in less than one inch.

ENCOUNTER GEOMETRY

Many possible missile encounters end their flight approaching the airplane from behind (such encounters will be discussed in later sections of this report). Figure 3 shows the fragmentation pattern for a missile tracking an inboard engine perfectly in trail and exploding at the rear of the engine. Note that a missile tracking the outboard engines would be more than 40 ft from the tank. Warhead fragments for the inboard engine encounter would hit the bottom of the center tank at a very shallow angle (about 6 degrees) in comparison to the perpendicular hit required to penetrate the tank at 40 ft range. Therefore the range required for penetration with a missile tracking the inboard engine would be less than the 17 ft required for penetration with a 60 degree hit. The center line of the inboard engine is over 30 ft from the bottom of the center wing tank. Thus, fragments from missiles perfectly in trail of any engine would not be able to penetrate the tank. However, a missile explosion tracking the engines would result in a large number of fragment holes in other areas of the aircraft structure.

The "static" fragmentation pattern shown in the figure 3 approximates the actual pattern that is a function of both the velocity of the missile relative to the air mass and the velocity of the fragments relative to the missile

MISSILE PERFORMANCE

The performance of a missile guiding to an intercept of TWA 800 was investigated using program MISSILE. MISSILE is a Windows based program developed at the Safety Board that simulates a missile flight from a launch position to an airplane on a given flight path. The program assumes that the missile follows it's proportional guidance perfectly, that is there is no lag between the guidance command and the response of the missile. The missile will follow its guidance until its maximum maneuvering capability is reached. At this point the missile will turn in the commanded direction at the maximum rate possible.

MISSILE uses aerodynamic, thrust, weight, geometry and destruct time data obtained from the Naval Air Warfare Center, China Lake. China Lake also provided sample flight time histories that were used to validate the program. In an effort to bracket the possible missile performance range, China Lake provided data for a low performance and a high performance missile. Due to the sensitive nature of the data, these missiles were not identified to the Safety Board. The low performance missile is referred to as SAM1 while the high performance missile is referred to as SAM2.

Program MISSILE requires as input a dataset containing the characteristics of the missile and a dataset containing the wind profile. The missile is launched from coordinate 0,0 at a pitch lead angle and azimuth lead angle specified by the user in a dialog box (figure 4). The position and velocity vector of the target at launch are specified by the user in a second dialog box (figure 5).

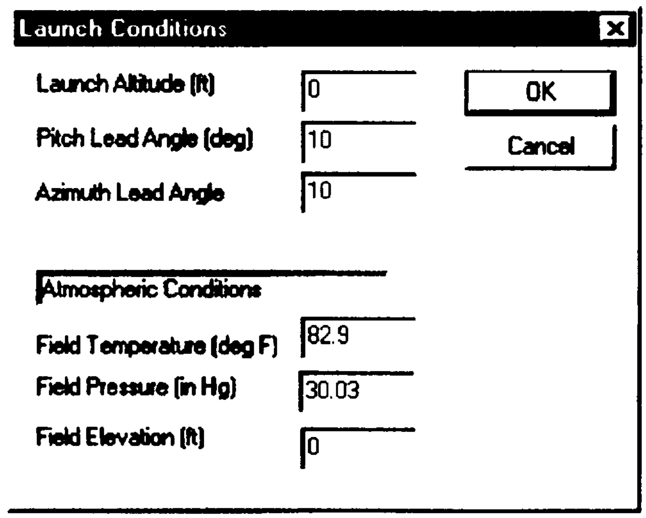

Figure 4; example launch conditions dialog

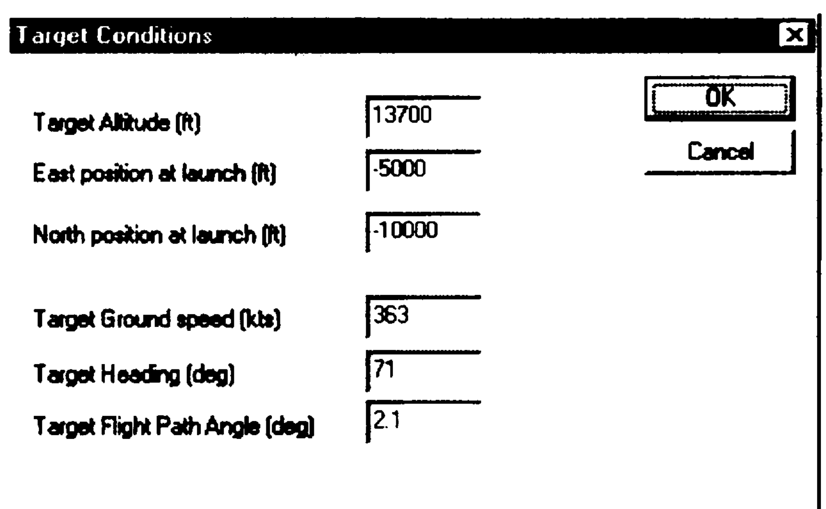

Figure 5; example target conditions dialog

Weather conditions at sea level were 30.03 in Hg and 82.9 F. Winds used in the study are summarized in the following table. These winds were interpolated to even altitudes from upper air data contained in the meteorological factual report (exhibit 5A).

Altitude	Wind Direction (deg)	Wind Speed (kts)
0	270	12
1000	270	12
2000	280	14
3000	285	17
4000	290	17
5000	303	19
6000	310	19
7000	315	17
8000	320	16
9000	330	12
10000	335	12
11000	320	12
12000	295	16
13000	290	16
14000	300	17
15000	303	19
16000	305	21
17000	315	29
18000	315	33

At the time of simulated missile launch, TWA800 was climbing through 13700 ft on a heading of 71 deg at a ground speed of 363 kts and a flight path angle[2] of 2.1 deg.

A flight to a self destruction consists of approximately eight seconds of engine burn[3] followed by a high speed coast to a timed self destruction at 15 seconds (for SAM1 & SAM2; some missiles fly longer).

Airplane position when the missile was launched was iterated to find the locus of airplane positions at the time of launch that would result in an encounter at the 15 second self-destruction time. To achieve a self destruction within 40 feet of the

[2] Flight Path Angle is the angle between the vertical and horizontal velocity components of the airplane.
[3] 8.4seconds for SAM1, 7.8 seconds for SAM2.

airplane, the initial airplane position had to be moved, on average, about 50 ft outside the locus defined above (though it ranged to over 100 ft).

A missile's guidance in essence maintains the target at a constant closing angle relative to the missile body. Better results are obtained by maintaining an angle to aim at a spot in front of the target. This angle is called a lead angle. For example, if a target airplane is approaching a MANPAD operator directly, the operator could sight the target and then raise the missile's launch angle ten degrees. This is a 10 degree pitch lead. Note that there is no need for an azimuth lead since the target is heading straight for the operator. However, if the target aircraft was passing abeam of the MANPAD operator, the operator could sight the target and then rotate the missile launch angle ahead 10 degrees. This is a 10 degree azimuth lead. Note that there is no need for a pitch lead in this situation. A 10 degree azimuth lead was used for these simulations when appropriate.

SAM1 Performance

The airplane positions at missile launch that yield an encounter at the 15 second self destruction time for the lower performance missile, known as SAM1, are given in figure 6.

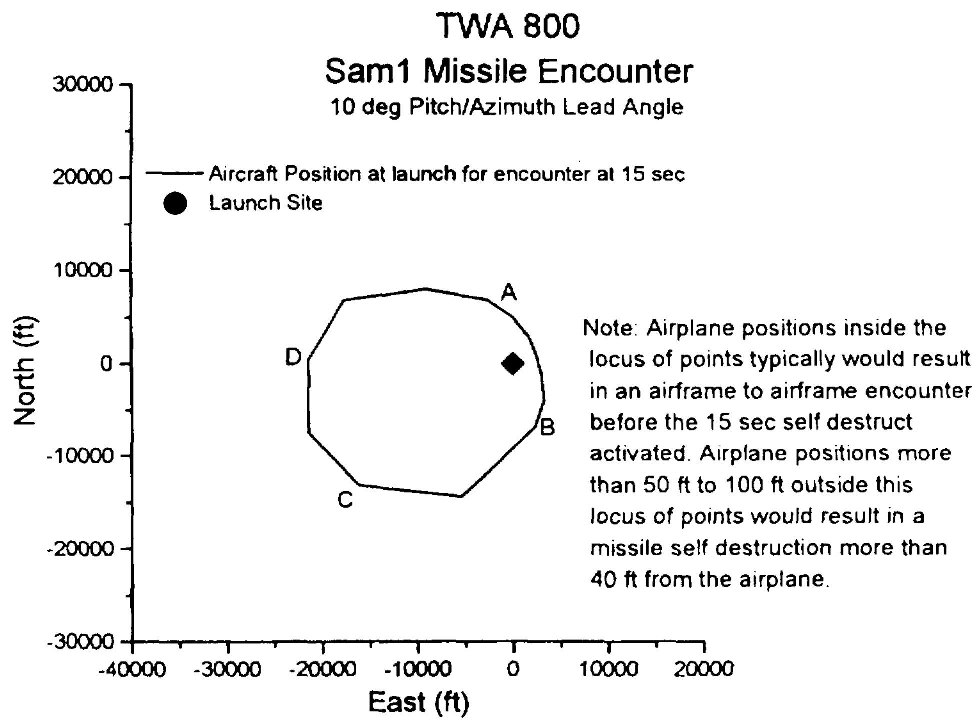

Figure 6; SAM1 self destruction footprint

When the airplane is at points A and B in figure 6 at the time of missile launch, the missile will approach the airplane from behind. Figures 7 and 8 show the final missile encounter for the case when the airplane is at point A at launch time. Figures 9 and 10 show the final missile encounter for the case when the airplane is at point B at launch time. Moving along the locus curve to points C and D, the missile transitions to an approach from the side and below. Figures 11 and 12 show the final missile encounter for the case when the airplane is at point C at launch time. Figures 13 and 14 show the final missile encounter for the case when the airplane is at point D at launch time. Note that the North view in the altitude plots may give a distorted impression of the climb angle for launches when the airplane is at points C and D. The actual climb angles at the encounter are 57 and 56 degrees respectively. Note also that, for the figures, the missile is assumed to be targeting the airplane[4] to provide a good detonation location for getting a missile fragment into the tank. Also note that the 747 graphic used in all altitude views in this report is a side view that has not been adjusted for the 71 deg heading.

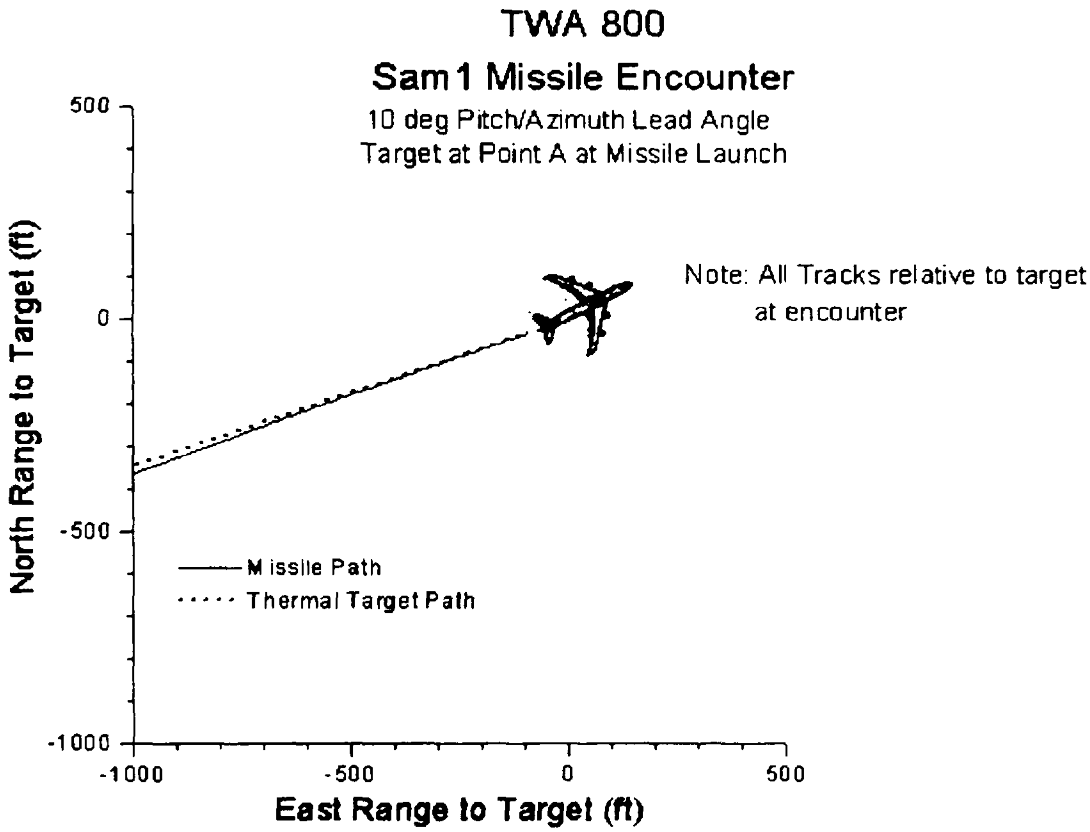

Figure 7; Map view of encounter with target at point A at launch

[4] This report does not consider the probability of locking onto a hot element such as the engines or the air-conditioning packs in comparison to a cooler element such as a light or sun reflection.

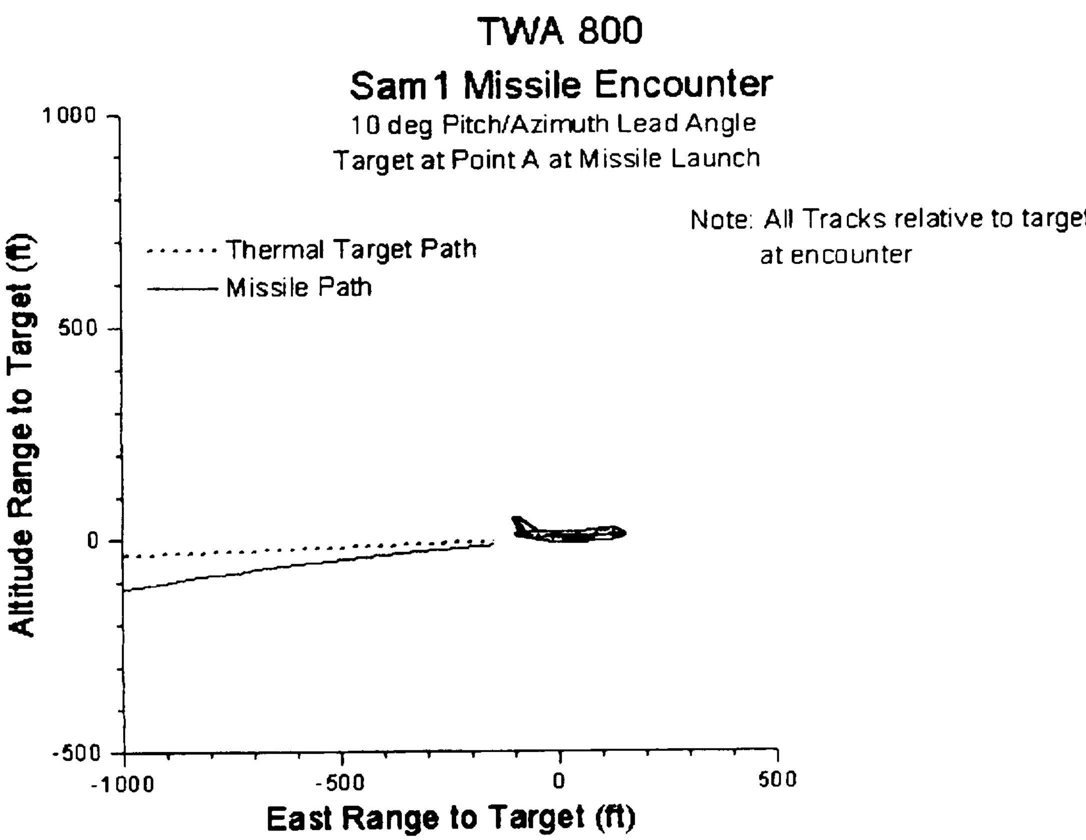

Figure 8; Altitude view of encounter with target at point A at launch

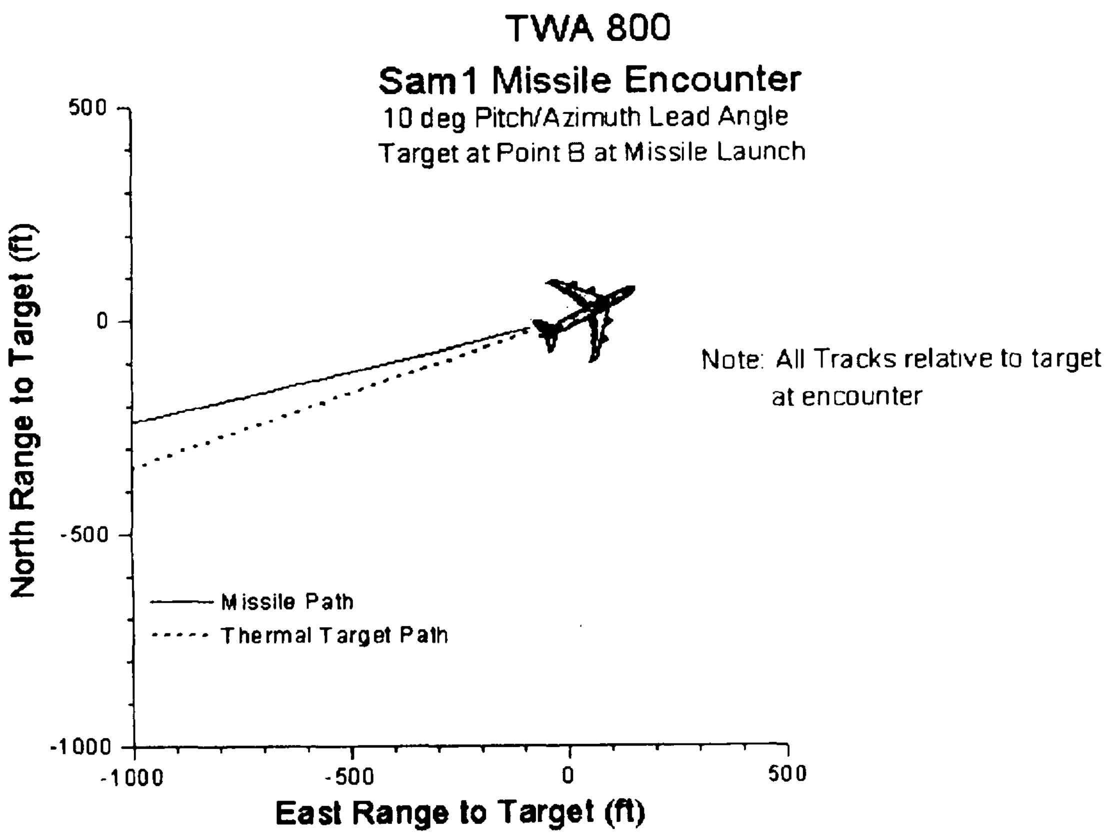

Figure 9; Map view of encounter with target at point B at launch

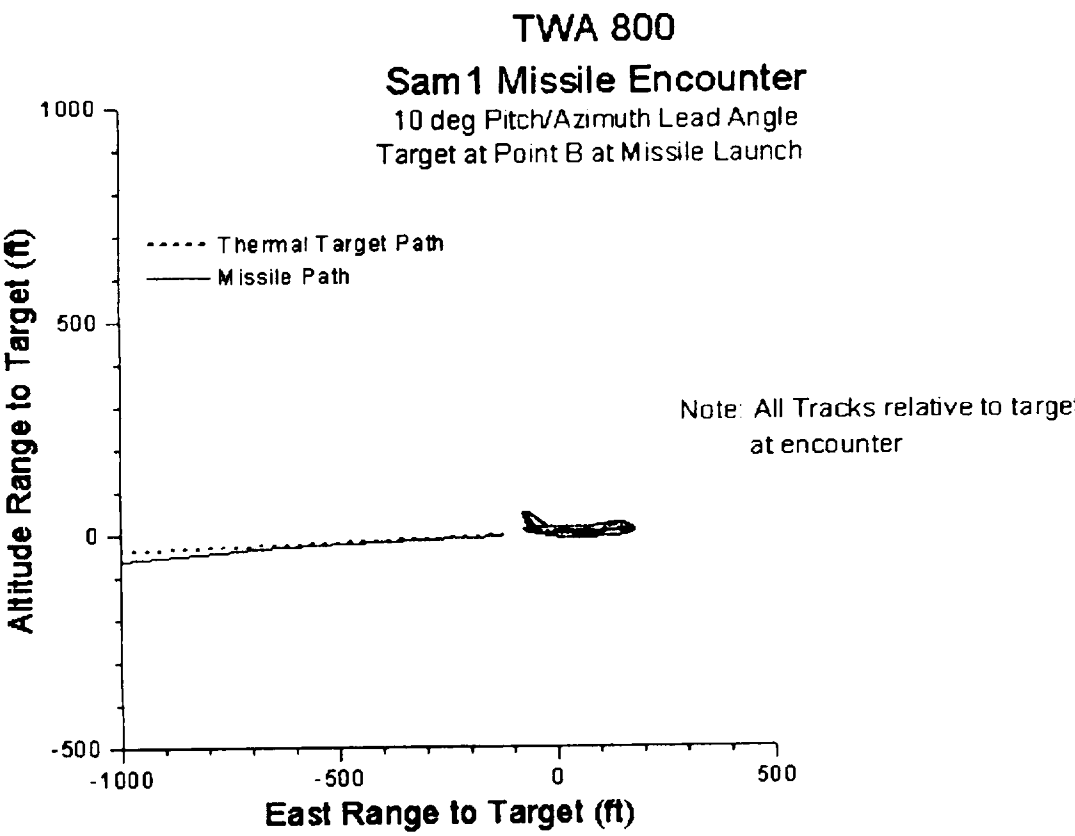

Figure 10; Altitude view of encounter with target at point B at launch

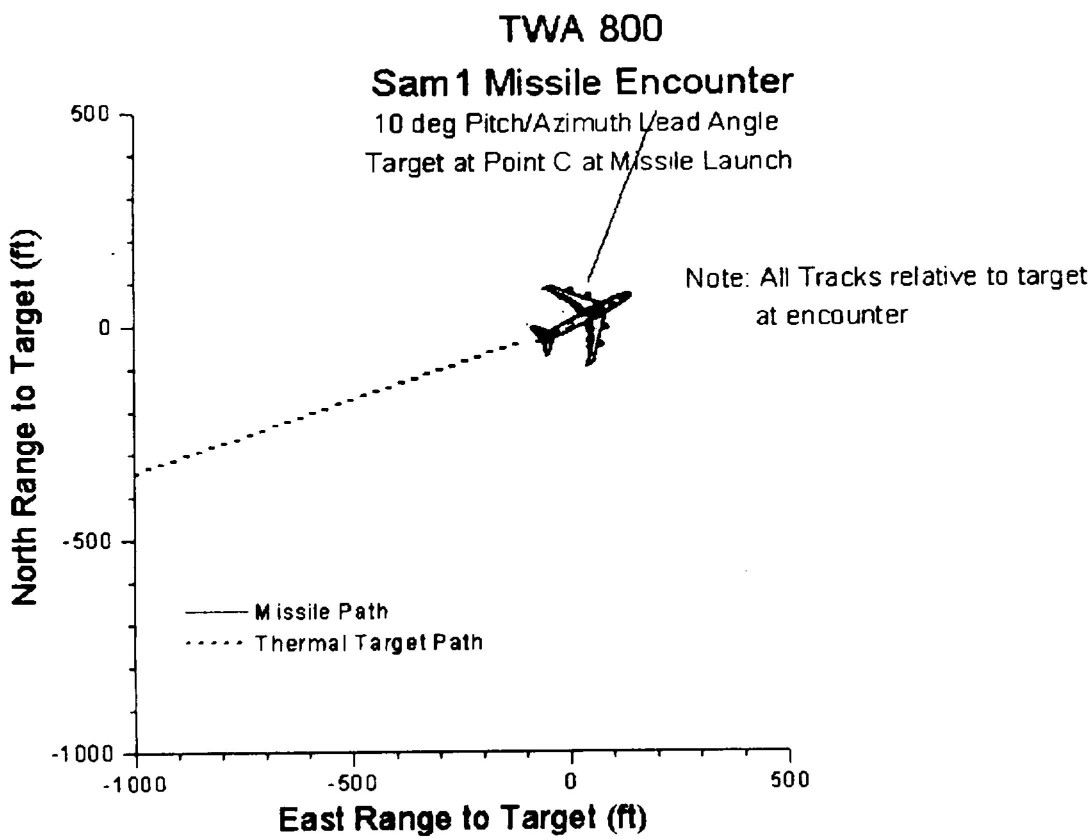

Figure 11: Map view of encounter with target at point C at launch

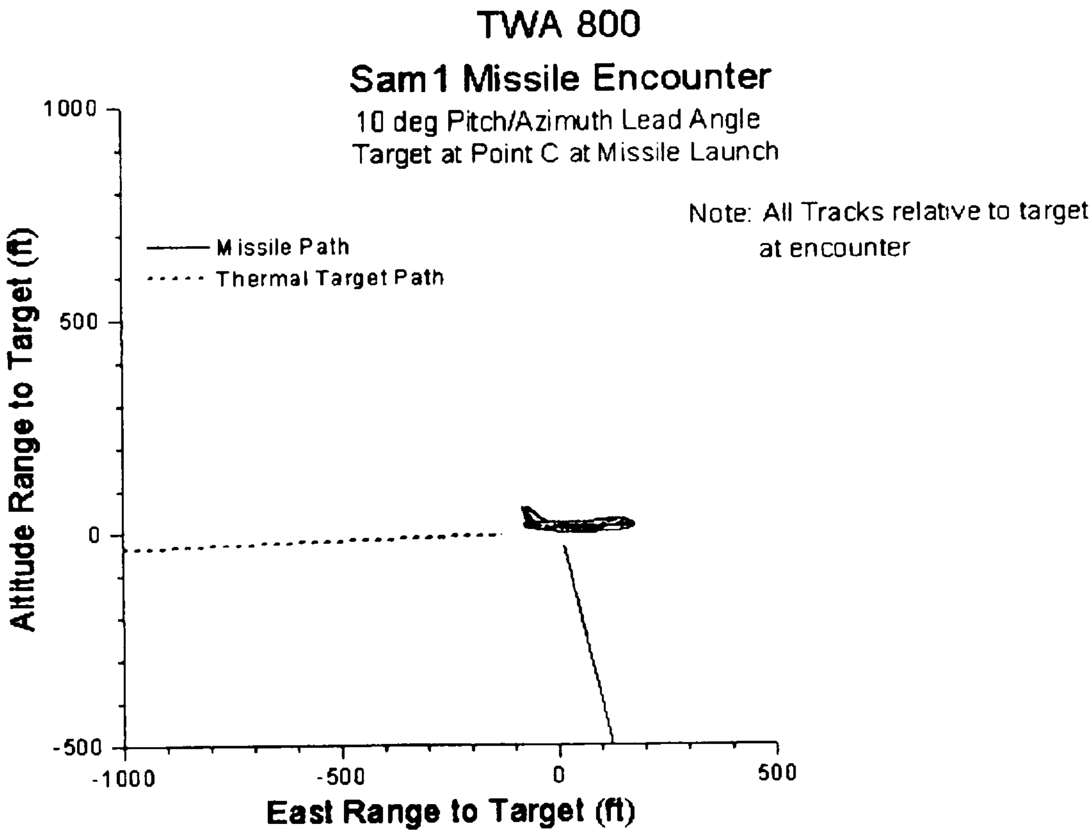

Figure 12: Altitude view of encounter with target at point C at launch

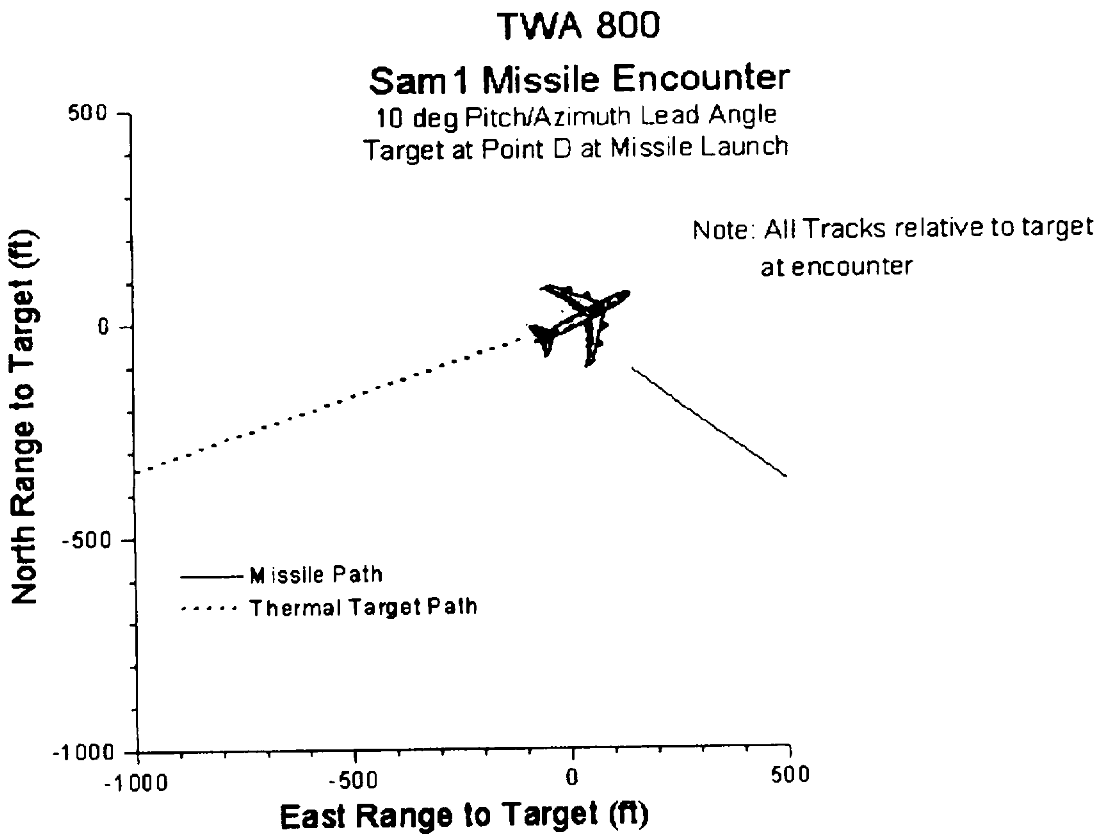

Figure 13: Map view of encounter with target at point D at launch

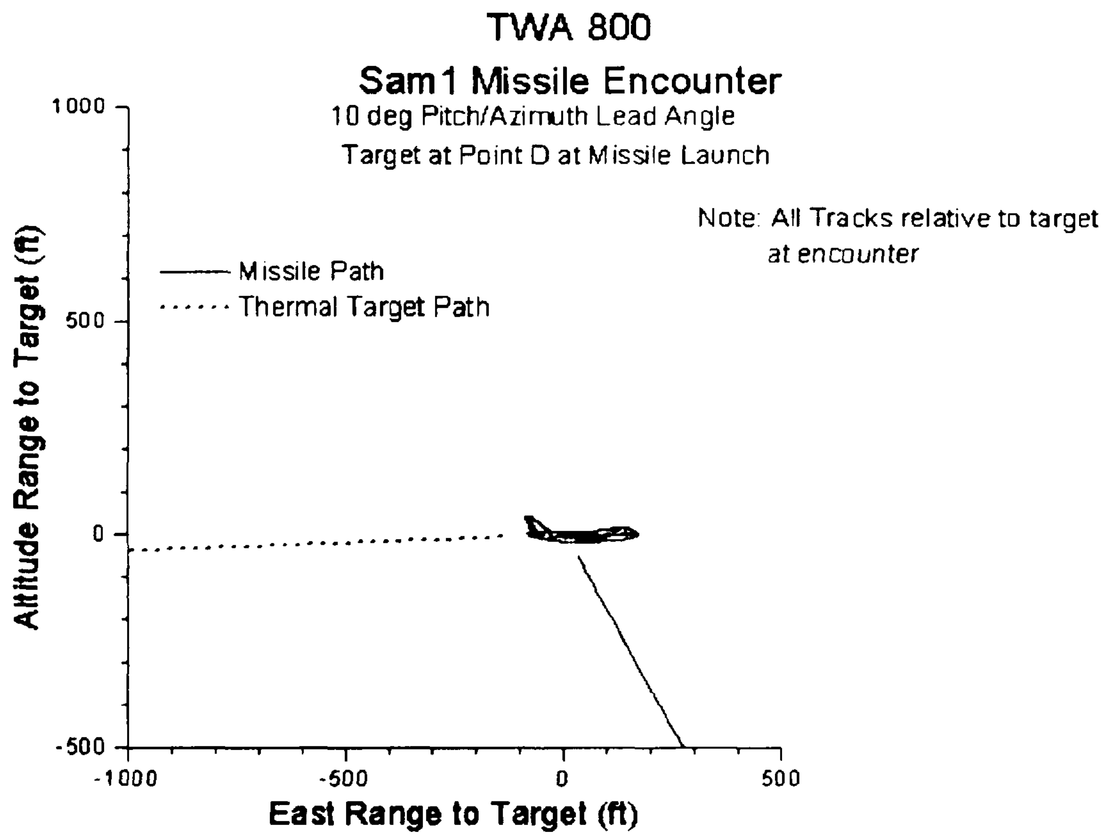

Figure 14: Altitude view of encounter with target at point D at launch

For the case when the airplane is at point A at launch time, the engine will burn out at 10126 ft. At this time the missile has a flight path angle of 52 deg, is on a heading of 31 deg, and is 4462 ft from the airplane.

For the case when the airplane is at point B at launch time, the engine will burn out at 10377 ft. At this time the missile has a flight path angle of 52 deg, is on a heading of 110 deg, and is 4434 ft from the airplane.

For the case when the airplane is at point C at launch time, the engine will burn out at 8570 ft. At this time the missile has a flight path angle of 45 deg, is on a heading of 220 deg, and is 9392 ft from the airplane.

For the case when the airplane is at point D at launch time, the engine will burn out at 8437 ft. At this time the missile has a flight path angle of 44 deg, is on a heading of 285 deg, and is 9795 ft from the airplane.

Referring to figure 3 as well as the encounter figures, it can be seen that the fragmentation pattern from missiles in chase (figures 7 to 10) will intersect the tank only when the missile detonates at very close range. As discussed previously, the wings are closer to the missile than the center tank area and would be expected to get a high number (the example showed 240) of fragment impacts if the missile was targeted at an inboard engine. Fragmentation patterns from missiles approaching from the side and below (figures 11 to 14) could intersect the center tank if the missile was targeting a thermal source on the opposite wing.

SAM2 Performance

The airplane positions at launch that yield an encounter at the 15 second self destruction time for the higher performance missile, known as SAM2, are given in figure 15.

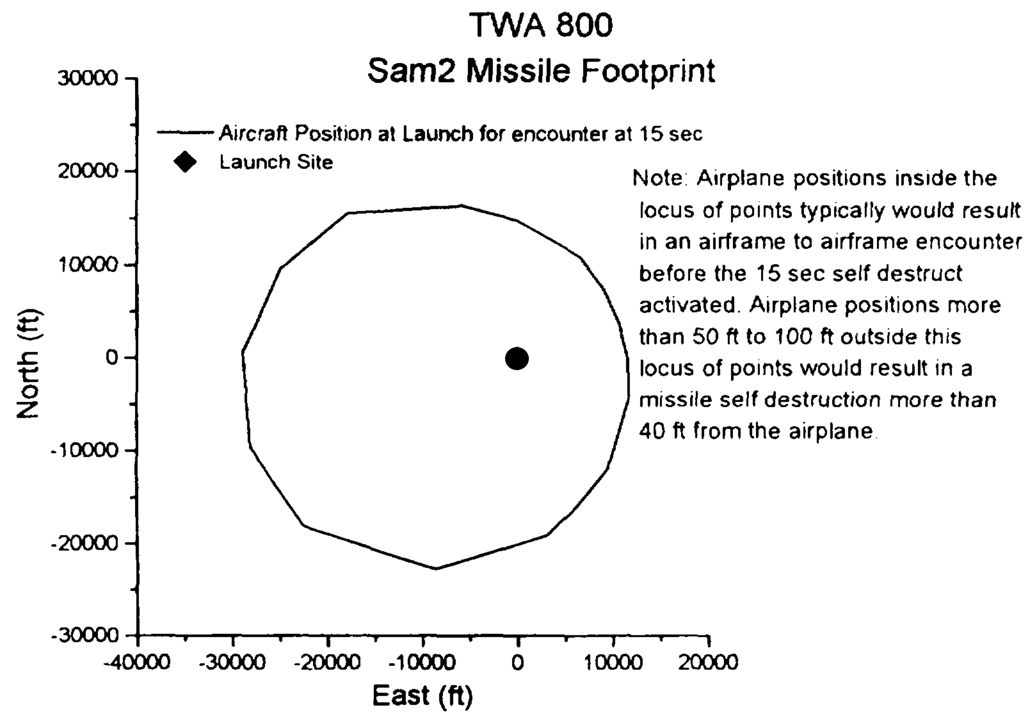

Figure 15; Footprint of target positions for various missiles encounter results for SAM2

As can be seen, the higher performance significantly increases the size the self-destruction time footprint. The combination of greater range and slightly shorter engine burn time results in SAM2 being further away from TWA 800 at engine cutoff than SAM1. Using points at the same azimuths from the launch site as SAM1, the engine will burn out at 9264 ft for the case when the airplane is at point A at launch time. The distance to the airplane increases from 4462 ft to 7608 ft. For the case when the airplane is at point B at launch time, the engine will burn out at 8835 ft. The distance to the airplane increases from 4434 ft for SAM1 to 8205 ft for SAM2. For the case when the airplane is at point C at launch time, the engine will burn out at 8254 ft. The distance to the airplane increases from 9392 ft for SAM1 to 13335 ft for SAM2. For the case when the airplane is at point D at launch time, the engine will burn out at 8140 ft. The distance to the airplane increases from 9795 ft for SAM1 to 13270 ft for SAM2.

CONCLUSIONS

A missile engine would have shut down near the midpoint of the MANPADs flight. At this point the missile would be a considerable distance away from TWA800.

There is a large area around the missile launch point that an airplane must be within at missile launch for the missile to intercept the airplane before the missile self-destructs. However, a MANPADs self-destruction within 40ft of the airplane requires the airplane to be in a very narrow band around this large area. Many, if not most, positions within this narrow band will not result in an encounter geometry that could send warhead fragments into the center wing tank.

A warhead fragment heading to the sides of the tank would be rapidly slowed below tank penetration speed by the fuel in the inboard wing tanks. A fragment heading into either the front or back of the tank would need to be from a detonation very close to the airplane skin to penetrate the tank. When the detonation is close to the fore and aft location of the tank, short range is required because of the shallow fragment approach angle. When the detonation is displaced fore and aft from the tank, the required geometry places the detonation near the skin of the airplane. In either case, a high density of fragments would be expected on the airplane skin.

A detonation directly below the center tank could allow a fragment to penetrate the tank while also resulting in the lowest fragment impact density to the airplane. At the maximum range for a 40 grain MANPAD warhead fragment to enter the tank from a detonation directly below (40ft), more than 20 fragments would be expected to impact a 100 square foot (10 ft by 10 ft) area of the airplane. For detonations not directly below the tank, the fragment impact angle to the center wing tank becomes shallow. This would require a detonation closer to the center wing tank and because of the geometry, closer to other airplane structure. This would produce a higher fragment impact density than noted above.

As an example, figure 3 depicts a close-range detonation under the wing that would result in approximately 330 fragments impacting the underside of the wing and fuselage structure.

Dennis Crider

Dennis Crider

Aerospace Engineer Performance