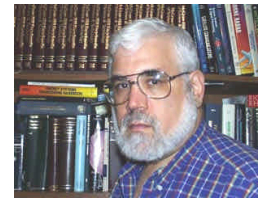


## Optical Evidence Indicating Patriot High Miss Rates during the Gulf War

[http://www.fas.org/spp/starwars/congress/1992\\_h/h920407p.htm](http://www.fas.org/spp/starwars/congress/1992_h/h920407p.htm)

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Massachusetts Institute of Technology



**Committee on Government Operations**  
**U.S. House of Representatives**  
**April 7, 1992**

Thank you very much for the opportunity to testify before this committee on this most important question of Patriot's performance during the Gulf War.

Prior to taking an academic position at the Massachusetts Institute of Technology at the rank of full professor I was the Assistant for Weapons Technology in the Office of the Chief of Naval Operations. In that job, it was my duty to identify technical issues that have policy implications in both Navy and National nuclear weapons programs. Because I supported the Chief in his role as a member of the Joint Chiefs of Staff, I was directly involved in detailed analyses of Soviet Anti-Ballistic Missile systems, the Closely Spaced Based MX, the President's Strategic Defense Initiative, the TRIDENT weapon system, nuclear war planning, and the like.

I have been a strong advocate for a technically and scientifically sound program of strategic defense research. Such a program should be an essential element of our national security planning. Indeed, because strategic defenses could be of central importance to aspects of our national security, it is essential that strategic defense programs be pursued with the highest standards of technical integrity.

I have previously pointed out that there appears to be a lack of evidence to support claims of high Patriot effectiveness in the Gulf War and that an analysis of publicly available data, such as that on ground damage in Israel, raise questions about such claims.

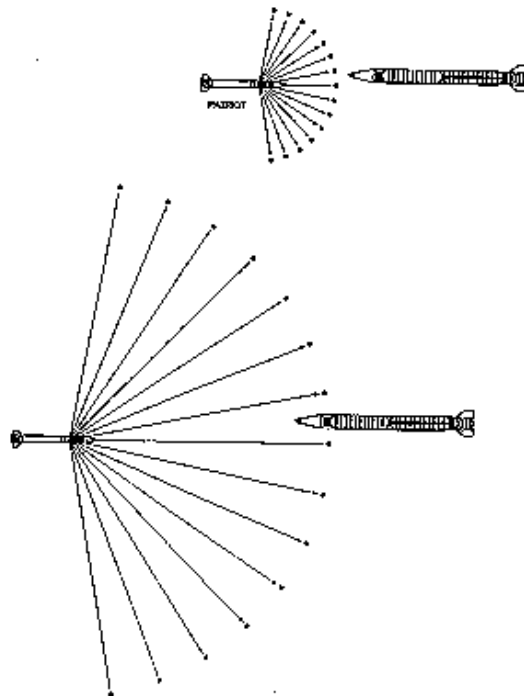
Today I would like to describe the results of recent technical studies I have performed using unclassified videotapes of Patriots attempting to intercept Scud warheads. The results of these studies are disturbing. They suggest that Patriot's intercept rate during the Gulf War was very low. The evidence from these preliminary studies indicates that Patriot's intercept rate could be much lower than 10 percent, possibly even zero. That such a conclusion can be reached from press video, which is a very crude tool by scientific standards, is disturbing. One would not anticipate that press video would have adequate space or time resolution to reach such a conclusion. However, as I will show you during the course of my presentation, most of the Patriot miss distances are so large that even press video is able to provide unambiguous evidence of misses.

This is illustrated by the six photos attached to my testimony, derived from video data that was obtained from ABC News. The photos show the sequence of events during the engagement of a Scud by two Patriot interceptors in Riyadh. Before I discuss the photos, let me give you a few basic pieces of information that will make their meaning obvious. The Patriot can be thought of as a platform which carries a shotgun that sprays pellets at the target it is to destroy. Since the Patriot warhead fires roughly 1000 pellets in the forward direction and in a roughly hemispherical pattern, if the Patriot fires its pellets at a range much greater than 5 to 10 meters from its target, it will be increasingly unlikely that even one pellet will hit the target. Thus, a 30 meter miss distance is nine times less likely to damage the target than a 10 meter miss and a 100 meter miss is 100 times less likely to damage the target (see figure 1).

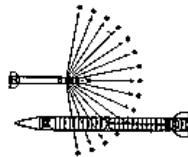
This means if miss distances much larger than 100 meters are observed, the result will be a near zero probability that even one pellet from the interceptor will have hit the target. In addition, since the Patriot fires its pellets into the forward direction, if it flies by the target warhead and detonates, the pellets will be traveling away from the target rather than toward it (see figure 2).

We are now in a position to understand the photos attached to my testimony.

The videos from which the photos are derived were shot in Riyadh during the latter part of January 1991. The sequence begins with the launch of a Patriot, which is then followed by the camera for 17 seconds, until it detonates near a Scud target. In photo 1 we see a bright spot with a wake behind it, which is the intact falling Scud. To the upper right of the Scud and below its wake is the remnant of the fireball from the detonating Patriot. Since the video clip shows the Patriot climbing on a near vertical trajectory for roughly 17 seconds before it detonates, this indicates that the Patriot detonation occurred at roughly 12 kilometers altitude.



**Figure 1**



**Figure 2**

The diameter of the fireball from the Patriot detonation is roughly 100 meters, and it is clear from both the photo and the videotape that the Patriot detonated many hundreds of meters behind the Scud. For these conditions, the probability that a fragment from the Patriot warhead would have hit the Scud is zero. In addition, since the Scud is traveling at between 7 and 8 times the speed of sound, the very weak shock wave from the distant detonation will also never overtake the Scud.

Photo 2 shows the Scud at about 1.4 seconds later, when it is at an altitude of roughly 10 kilometers. The shape of the wake shows evidence that the Scud was following a helical i.e. corkscrewing, trajectory as it fell. The bright elongated region at the bottom of wake is the train of debris from the disintegrating missile, which has broken apart under the aerodynamic stress of reentry. Leading the trail of debris is a distinct bright spot, which is the intact warhead that has broken off from the body of the missile. Below and to the right of the warhead is a finger of wake that suggests another large object might also be emerging from the cloud of Scud debris, possibly a large piece of Scud tankage.

Photograph 3 shows the situation only one tenth of a second later. In this time, the warhead has traveled about 200 meters, but it is quickly moving ahead of the much lighter debris, which is rapidly slowing down due to the effects of aerodynamic drag. To the right of the warhead, and slightly below it, there is a second bright spot which is roughly at a distance of 50 to 70 meters. This bright spot is probably a piece of tankage, which was evidenced in the previous photo as a finger of wake. One thirtieth of a second later, in photo 4, the small bright spot becomes an intense ball of light of roughly 100 meters diameter. This is the fireball from a second detonating Patriot. The fireball is so large that it overlaps the location of the warhead. Photo 5, taken one tenth of a second later, shows the warhead continuing forward, as it moves away from the nearly stationary luminous cloud of the exploding Patriot. Photo 6 shows the warhead detonating on the ground roughly 11 seconds later. Thus it appears that the second Patriot homed on and intercepted a piece of tankage, probably in part because the warhead was a stealthy target relative to that of the tankage.

This is only one engagement. Let me now describe the results of my limited but ongoing analysis of many videotapes of Patriot/Scud engagements – engagements like that illustrated in the photos attached to my testimony.

I have assembled a body of press video evidence that contains roughly 30 percent of Patriot/Scud engagements in both Israel and Saudi Arabia. This is only a small part of a much larger body of press video records that were made during the Gulf War. However, since there was dense cloud cover for a significant period during the War, it remains to be seen whether additional information about Patriot's Gulf War performance can be derived from these additional records.

Careful cataloging and analysis of the roughly ten to twelve engagements from Saudi Arabia and four from Israel reveal the following:

1. There are roughly 25 clear observations of Patriot interceptors missing Scud targets as the Patriots detonate in the sky over Saudi Arabia.
2. The miss distances observed in all but 2 to 4 intercept attempts are hundreds of meters or more. In these intercept attempts, it was difficult to estimate miss distances because of the viewing angle of the camera. For example, in one case, the Scud was moving in a direction roughly towards the camera and a Patriot detonated behind the Scud in its wake. In this case, estimates of miss distances are even more uncertain.
3. There is one clear example of a successful intercept of a target over Riyadh, but it is not clear whether the target was a Scud warhead or a large piece of tankage.
4. There is clear evidence that interceptors dove into the ground in Saudi Arabia. There is also evidence in one, and possibly two, video records taken in Saudi Arabia that interceptors also suffered rocket motor failures and then fell to the ground.
5. There is evidence of a timing or acquisition problem between the Patriot fire units and interceptors. This is indicated by the occasional detonation of interceptors at very low altitude very shortly after launch (about 3.5 and 4 seconds after launch, having traveled distances of only .7 to .9 kilometers). It is possible that these interceptors self destructed early in flight because they failed to receive guidance information through radio links from the Patriot radar or otherwise malfunctioned.
6. A significant number of Patriot misses appear to have been due to late launch of interceptors or non-optimal choices of intercept points. As a result, these Patriots flew trajectories that later placed them so far from target Scuds that it was not possible to achieve intercept points near target Scud warheads. When this occurred, the Patriots detonated at ranges of hundreds or thousands of meters from target Scuds.
7. The breakup of Scuds can clearly be observed in many of the video records. When the Scud breaks up a luminous thick track of debris can be clearly seen led by a bright spot, which is the warhead. The video data shows that Patriots sometimes engaged Scud missiles prior to their breakup. However, in the cases where there are clear video records, the Patriots failed to intercept Scud missiles or warheads both prior to and following the breakup of the Scuds.
8. The video evidence shows no indication, as claimed by Raytheon and Army spokesmen, that the geometry of intercept attempts in Saudi Arabia was more favorable than that which occurred in Israel. This can be determined by viewing the videotapes while noting that certain engagement geometries are considerably more favorable to achieving successful intercepts relative to others. The optimal Patriot intercept trajectory is one in which the Patriot flies directly up the expected trajectory of a Scud target. Stated differently, the optimal Patriot attack trajectory is one in which the interceptor makes a head on attack against the Scud target. This intercept trajectory is optimal because it minimizes the need for a Patriot to make large lateral maneuvers as it closes on the Scud target. Patriot trajectories which cross the expected trajectory of Scud targets are highly non-optimal as the Patriot needs to make large lateral maneuvers to effect an intercept.
9. A significant number of Patriot misses observed on the videotapes occurred in the wake of Scud warheads, often hundreds of meters or more behind the warhead. It appears that in these cases the Patriots flew by the relatively stealthy Scud warhead and instead homed on pieces of debris in the wake behind the target.

It is easy to show that the data collected in these video records, although fragmentary, implies with very high probability that Patriot did not achieve an 80 percent intercept rate in Saudi Arabia.

If one assumes that the video observations of Patriot/Scud engagements represents a valid random sampling of engagements, it is possible to estimate the odds of seeing 1 Patriot hit and 25 misses for any presumed intercept rate. For the case of Saudi Arabia, Raytheon and the Army assert that the intercept rate was 0.8 or better.

We start by noting that there were 47 engagements of Scuds, and 158 interceptors were fired, which indicates that three interceptors were on average fired at each Scud. We note that if **P hit** is the probability that an interceptor hits a target Scud, **P intercept** is the probability that at least one of the three fired interceptors hits the Scud. The relationship between these two quantities is given by the equation,

$$\mathbf{P\ intercept} = 1 - (1 - \mathbf{P\ hit})^3$$

where **P intercept** is the probability that the warhead is destroyed by one of the three interceptors and **P hit** is the probability that a given interceptor destroys the target.

The above expression is easily inverted to obtain **P hit**, the probability that an interceptor randomly observed on video camera destroys a Scud. The expression for **P hit** is,

$$\mathbf{P\ hit = 1 - (1 - P\ intercept)^{1/3}}$$

Since it is asserted that **P intercept** is .8 or higher, then if three interceptors were on the average fired per engagement, then **P hit** should be about .42. If two interceptors were instead fired on the average then **P hit** should be .55. Thus, a random sampling of video records of Patriot/Scud engagements should show roughly one out of two intercept attempts arguably hitting, destroying or detonating near Scud warhead targets. There is no evidence for such a high rate of hits in the records I have assembled. The probability of observing **m** Patriot hits and **n** Patriot misses in a random sample of video clips from Saudi Arabia is then given by,

$$\mathbf{Probability\ of\ Observing\ m\ Hits\ and\ n\ misses = [(m + n)! / m! n!] P\ hit^m (1 - P\ hit)^n}$$

where **P hit** is the probability an interceptor hits a target warhead, **m** is the number of observed hits, and **n** is the number of observed misses.

If the intercept rate is .8, the odds against a random sample of Patriot Scud engagements showing 25 misses and 1 hit are greater than 60,000 to 1. If the intercept rate is instead .6, the odds against randomly observing 25 misses and 1 hit are greater than 300 to 1. Even if the intercept rate is .4 the odds against seeing 25 misses and 1 hit are about 17 to 1.

It is therefore clear that, in the absence of any evidence to the contrary, the video evidence makes an overwhelming circumstantial case that Patriot did not come close to achieving an 80 percent intercept rate in Saudi Arabia. For this case to be refuted, Raytheon and the Army *must be able to provide video evidence from Saudi Arabia which shows that on the average roughly one out of two interceptors hit Scud warheads.*

Video and press evidence, along with statements made by Raytheon officials leads to another potentially important new conclusion about Patriot's Gulf War performance that can now be supported with publicly available evidence. The conclusion is that *Patriot ground impacts in Tel Aviv and Saudi Arabia were likely consequences of Patriot software error, rather than of operator error.*

The evidence that leads to this conclusion comes from video clips of Patriot interceptors diving into the ground in *both* Saudi Arabia and Israel. I have video clips showing the trajectories followed by the three interceptors that impacted in Tel Aviv. Two of the interceptors follow low, flat, descending trajectories into the ground and one climbs at an angle of roughly 45 degrees, then turns almost 180 degrees in azimuth. It then dives at a near 45 degree angle into the ground. The video records of trajectories of the impacting interceptors in Tel Aviv are remarkably similar to the trajectories of impacting interceptors in Saudi Arabia. There is, for example, a video clip of a Patriot in Dahran climbing, turning roughly 140 degrees in azimuth, and then diving into the ground. This trajectory is remarkably similar to that of the turning and diving interceptor in Tel Aviv. There are also video clips of Patriots flying low, flat, diving trajectories followed by impacts taken in Riyadh and in Dahran. These trajectories are remarkably similar to those observed in Tel Aviv.

Thus, the video evidence indicates that interceptors dove into the ground following similar trajectories in *both* Israel and Saudi Arabia. In addition, statements made by Robert Stein of Raytheon and Nachman Shai the chief spokesman for the Israeli Army, and interviews with Israeli air defense personnel reported by Reuven Pedatzur, who is here testifying today, are all in agreement that Patriot was still being operated in the automatic mode on the night of January 25, 1991 in Tel Aviv. These data therefore indicate that the interceptor impacts were the result of software errors in the Patriot system.

The real issue here is not whether Patriot was a *technical* success or failure in the Gulf War. Patriot was a success in terms of its tremendous positive psychological and political impact for the coalition. The Scuds were, in fact, not easy targets nor was the Patriot an optimal missile defense system. Prior to the war, I might have considered a 10 percent success rate as a pretty good performance by Patriot.

The real issues are whether the performance of Patriot has been misrepresented, how such a misrepresentation could have occurred, and the effects of such misrepresentations on the crucial national debate on the future role of missile defenses in U.S. defense policy. I call on the Army and Raytheon to enter this debate in a serious way. They should produce the evidence, from publicly available videotapes, that roughly one out of two Patriots could arguably have hit Scud targets over Saudi Arabia.

Thank you very much for the opportunity to talk to the committee today.