

### The Patriot Missile Failure

On February 25, 1991, during the Gulf War, an American Patriot Missile battery in Dhahran, Saudi Arabia, failed to intercept an incoming Iraqi Scud missile. The Scud struck an American Army barracks and killed 28 soldiers. A report of the General Accounting office, GAO/IMTEC-92-26, entitled Patriot Missile Defense: Software Problem Led to System Failure at Dhahran, Saudi Arabia reported on the cause of the failure. It turns out that the cause was an inaccurate calculation of the time since boot due to computer arithmetic errors. Specifically, the time in tenths of second as measured by the system's internal clock was multiplied by 1/10 to produce the time in seconds. This calculation was performed using a 24 bit fixed point register. In particular, the value 1/10, which has a non-terminating binary expansion, was chopped at 24 bits after the radix point. The small chopping error, when multiplied by the large number giving the time in tenths of a second, lead to a significant error. Indeed, the Patriot battery had been up around 100 hours, and an easy calculation shows that the resulting time error due to the magnified chopping error was about 0.34 seconds. (The number 1/10 equals  $1/24+1/25+1/28+1/29+1/212+1/213+\dots$ . In other words, the binary expansion of 1/10 is 0.0001100110011001100110011001100.... Now the 24 bit register in the Patriot stored instead 0.0001100110011001100110011001100... binary, or about 0.000000095 decimal. Multiplying by the number of tenths of a second in 100 hours gives  $0.000000095 \times 100 \times 60 \times 60 \times 10 = 0.34$ .) A Scud travels at about 1,676 meters per second, and so travels more than half a kilometer in this time. This was far enough that the incoming Scud was outside the "range gate" that the Patriot tracked. Ironically, the fact that the bad time calculation had been improved in some parts of the code, but not all, contributed to the problem, since it meant that the inaccuracies did not cancel.

#### Effect of Extended Run Time on Patriot Operation

Hours	Seconds Calculated	Time Inaccuracy	Approximate Shift In (Seconds)	Range Gate (Meters)
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0	0	0	0	0
1	3600	3599.9966	.0034	7
8	28800	28799.9725	.0025	55
20(a)	72000	71999.9313	.0687	137
48	172800	172799.8352	.1648	330
72	259200	259199.7528	.2472	494
100(b)	360000	359999.6667	.3433	687

- a. Continuous operation exceeding about 20 hours—target outside range gate
- b. Alpha Battery ran continuously for about 100 hours

On February 26, the next day, the modified software, which compensated for the inaccurate time calculation, arrived in Dhahran. According to Army officials, the delay in distributing the software from the United States to all Patriot locations was due to the time it took to arrange for air and ground transportation in a wartime environment.

The range gate's prediction of where the Scud will next appear is a function of the Scud's known velocity and the time of the last radar detection. Veloc-

ity is a real number that can be expressed as a whole number and a decimal (e.g., 3750.2563...miles per hour). Time is kept continuously by the system's internal clock in tenths of seconds but is expressed as an integer or whole number (e.g., 32, 33, 34...). The longer the system has been running, the larger the number representing time. To predict where the Scud will next appear, both time and velocity must be expressed as real numbers. Because of the way the Patriot computer performs its calculations and the fact that its registers are only 24 bits long, the conversion of time from an integer to a real number cannot be any more precise than 24 bits. This conversion results in a loss of precision causing a less accurate time calculation. The effect of this inaccuracy on the range gate's calculation is directly proportional to the target's velocity and the length of the the system has been running. Consequently, performing the conversion after the Patriot has been running continuously for extended periods causes the range gate to shift away from the center of the target, making it less likely that the target, in this case a Scud, will be successfully intercepted.

The Patriot Missile. Performance in the Gulf War Reviewed  
by Alexander Simon, 15 July 1996

The Patriot missile has been hailed by some military advocates as the great defender of American troops (in Saudi Arabia) and Israeli civilians during the Gulf War. Furthermore the Patriot's Gulf War performance has been pointed to as a reason to pursue national missile defense as well as theater missile defense. Others claim that the Patriot was ineffective in stopping Iraqi Scuds (particularly in Israel) and is a perfect example of why BMD (Ballistic Missile Defense) or "Star wars" as its detractors refer to it will not work. Five years after the Gulf War, the debate still continues.

The Patriot missile was designed in the late 1970's as an anti-aircraft weapon. However, it was modified in the 1980's to serve as a defense against incoming short range ballistic missiles. Until the Gulf War the Patriot had not been tested in combat.

The Patriot system has a 7.4 foot long missile powered by a single stage solid propellant rocket motor that runs at mach 3 speeds. The missile itself weighs 2200 pounds and its range is 43 miles. The Patriot is armed with a 200 pound high-explosive warhead detonated by a proximity fuse that causes shrapnel to destroy the intended target. Each Patriot missile system has eight m-901 storage/transportation containers that serve as launchers, and every launcher contains four missiles. The launchers are hooked to an m-860 trailer. The system possesses an MSQ-104 engagement control station, which is mounted on an M-818 tractor. The Track Via Missile guidance system is the basis of the overall system.

The system is built around radar and fast computers. The missile is launched and guided to the target through three phases. First, the missile guidance system turns the Patriot toward the incoming missile as that missile flies into the Patriot's radar beam. Then the Patriot's computer guides the missile toward the incoming Scud missile. Finally, the Patriot Missile's internal radar receiver guides it toward the interception of the incoming missile. (Boyne, Walter Colonel U.S.A.F. (Ret) Gulf War-A comprehensive guide to people, places

and weapons Signet 1991)

During the Gulf War, the Patriot was assigned to shoot down incoming Iraqi Scud or Al-Hussein Missiles launched at Israel and Saudi Arabia. The U.S. Army which was in charge of the Patriots claimed an initial success rate of 80% in Saudi Arabia and 50% in Israel. Those claims were scaled back to 70 and 40 percent. (See

Frontline, WGBH Educational Foundation: "The Gulf War" and "Gulf War-A comprehensive guide to people, places and weapons" by Boyne, Walter Colonel U.S.A.F. (Ret), Signet 1991) (Part of the reason the success rate was 30% higher in Saudi Arabia than is Israel is that in Saudi Arabia the Patriots merely had to push the incoming Scud missiles away from military targets in the desert or disable the Scud's warhead in order to avoid casualties, while in Israel the Scuds were aimed directly at cities and civilian populations. The Saudi Government also censored any reporting of Scud damage by the Saudi press. The Israeli Government did not institute the same type of censorship. Furthermore, the Patriot's success rate in Israel was examined by the IDF (Israel Defense Forces) who did not have a political reason to play up the Patriots success rate and even had reasons to downplay the Patriot's success rate. The IDF counted any Scud that exploded on the ground (regardless of whether or not it was diverted) as a failure for the Patriot. Meanwhile the U.S. Army who had many reasons to support a high success rate for the Patriots, examined the performance of the Patriots in Saudi Arabia.)

A 10 month investigation by the House Government Operations subcommittee on Legislation and National Security concluded that there was little evidence to prove that the Patriot hit more than a few Scuds. Testimony before the House Committee on Government Operations by Professor Theodore Postol (a professor of Science, technology and National Security Policy at M.I.T.) On April 7, 1992 and reports written by professor Postol raised serious doubts about the Patriot's performance. After examining video evidence of the Patriot's performance in Israel during the Gulf War and conducting his own tests, professor Postol claimed that the Patriot had a very low success rate.

"The results of these studies are disturbing. They suggest that the 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 ten percent, possibly even zero." (Statement of Theodore A. Postol before the U.S. House Of Representatives Committee on Government Operations, April 7, 1992)

Reuven Pedatzur (an Israeli military affairs analyst for the daily Ha'aretz and a Reserve IAF pilot) also testified before the committee. Pedatzur conducted his own independent research (independent of the Israeli military). Pedatzur pointed out the problem that the Al-Hussein missiles would often break up when reentering the atmosphere "stretching the target" and making the Scuds actual warhead a much more difficult target to identify for the Patriot's computer.

"The data analysis also showed that when the Al-Hussein's disintegration began, the Patriot's radar would pick up a stretching of the target and briefly lose lock-on. Lock-on was required within two to three tenths of a second, but

by then the radar was locked on to the tail end of the warhead or the back part of the missile." (Reuvan Pedatzur in Testimony before the House Committee on Government Operations, April 7, 1992)

Many other analysts also came to this conclusion. The inaccuracy of the Patriot may not have been entirely a problem with the Patriot, but rather due to the poor design or redesign of the Scud and the fact that many Iraqi Scuds (Al-Husseins) broke up reentering the Earth's atmosphere leaving the Patriot without a firm single target. (In the debate over designing a national ballistic missile defense, this fact is interesting to note. If a nuclear warhead was attached to a Scud or another similar missile, would a Patriot be able to guarantee the destruction of the nuclear armed Scud warhead each and every time? In a conventional war a Scud missile landing in the desert or the sea instead of a populated city is acceptable. However, if that same Scud is armed with nuclear materials, then relying on a Patriot as a form of defense may indeed be quite foolish.) The Iraqis changed the configuration of their Scud (Al-Hussein) Missiles from their original Soviet designs in order to make them move faster. They were successful in making the Al-Husseins faster than the original Soviet Scuds but this also caused the Al-Husseins to break up upon reentering the atmosphere thus causing problems for the targeting system of the Patriot. The Patriot's system was even altered to detonate the Al-Hussein missile's warhead before it broke up. However, according to Pedatzur it still did not work.

"Yet even in this instance the Patriot's warhead was activated too late, exploding after already having gone by the Al-Hussein's warhead and too far away for it's fragments to have an effect." (Reuvan Pedatzur in Testimony before the House Committee on Government Operations April 7, 1992)

The Patriot was also in an automatic mode (operated purely by computer) rather than manual mode (operated by partially computer and partially by human command). Pedatzur claims that switching from automatic mode to manual mode helped somewhat with targeting but it was still very difficult to target the Patriot missiles toward what became multiple targets when the Scuds began to break up.

Postol, after presenting a great deal of mathematical and scientific data, claimed that the Patriot's computer system is unable to identify multiple targets.

"These data clearly indicate that the interceptor impacts were the result of software errors in the patriot system." (Statement of Theodore A. Postol before the U.S. House Of Representatives Committee on Government Operations, April 7, 1992)

Contrary to the testimony of Pedatzur and Postol was the testimony of Charles A. Zakret. Zrakret is a scholar in residence at the Center for Science and International Affairs of the Kennedy School of Government, Harvard University. Prior to that he had been President and Chief Executive Officer of the MITRE Corporation. The MITRE corporation is a Federal Contract Researcher for the Department of Defense. MITRE conducted a classified study on C3I Systems used in the Patriot Missile during the Gulf War. Zakret is also a member of The Council On Foreign Relations (which has strong relations with Saudi Arabia.

For more information on this subject, see "Gun Belt in the Beltway" by Robert Vitalis Middle East Report, November-December 1995, Vol 25 No.197, P.6 ).

Zraket testified that

"the methodology described by Professor Postol and Mr. Pedatzur in their articles was not scientifically valid and therefore did not prove that Patriot didn't work in The Gulf War. Also, they had offered no substantive analysis of the results in Saudi Arabia, where deployment of Patriot, the level of training of operational crews, and the nature of the Scud engagements were quite different from the situation in Israel." (Testimony of Charles A. Zraket before the House Subcommittee on Government Operations, on April 7, 1992)

Zraket believes that since the Patriot was originally designed as an anti-aircraft weapon it worked particularly well against the Scuds.

"To fully understand the Patriots accomplishment in the Gulf War, it is useful to recall that up to late 1986, Patriot was strictly a highly effective air defense system. After a decision was made in 1984 by the army to give it an anti tactical ballistic missile (ATBM) capability, a series of modifications and additions were made to the system's software (PAC-1) and to the missile warhead and fuze (pac-2). These upgrades were then fully tested, manufactured and deployed in Saudi Arabia on time for Desert Storm. This system was designed to defend military targets such as bases against relatively short-range tactical ballistic missiles." (Testimony of Charles A. Zraket before the House Subcommittee on Government Operations on April 7, 1992)

Zakret's conclusions were the following.

"1) Patriot Performed in The Gulf War at least as well and probably much better than might have been expected beforehand, given the unanticipated nature of the threat. It was a credible, effective performance that warrants credit to the U.S. Army, the IDF, Raytheon and the other contractors who built the system.

2) I believe that the most reliable evidence available indicates that the ground damage and casualties were significantly reduced over what they might have been in Saudia Arabia and Israel if Patriot had not been deployed.

3) Patriot performed more than well enough to warrant high-priority support for future upgrades, especially since their cost is relatively small compared to the capabilities that will be provided."(Testimony of Charles A. Zraket before the House Subcommittee on Government Operations on April 7, 1992)

Peter D. Zimmerman of The Center For Strategic and International Studies also testified that day. Zimmerman testified that:

"initial reports such as the one which appeared to claim 41 o out of 42 Scuds had been intercepted were not credible. No Missile system is that good, even after long combat experience, and certainly not the first time out." (Testimony of Peter D. Zimmerman before the House Government Operations Committee April 7, 1992)

Zimmerman also held the view the Scuds were generally not successful. He compared the Patriot performances in Israel and Saudi Arabia and found each of them to be limited.

"Consider the situation in Israel. On average four Patriots were launched at each incoming Scud which was engaged. This expenditure of interceptors was due to the standard firing doctrine and the fact that, early in the war, some interceptors were fired against debris and false targets. According to Israel Defense Forces reports, somewhat fewer than one half of all attempted intercepts met with success-the origin of the U.S. Army's figure of almost 50% success. Certainly no more than one Patriot from the quartet launched for each engaged Scud will intercept successfully (if the first hits, the Scuds trajectory is likely to be so perturbed that the second Patriot will not fuze close to the target etc.).

And so for every eight Patriots launched, there will be only one success. From a box of random unlabeled videotapes of intercepts over Israel, seven out of every eight will show misses, demonstrating that it is a lot easier to find video of misses than of hits. There are reasonable estimates which suggest that about 80% of the intercepts were successful.

In Saudi Arabia an average of three interceptors was launched at each Scud which was engaged, so one random film clip in three would show a hit if 100% of all engaged Scuds had been destroyed. That was not the case, so the fraction of videotapes showing successes would actually be less than one out of three or 27%. The correct result for Saudi events is that only about 27% of all random news videotapes would show successes but 73% would show misses. The Saudis situation is not significantly different from the Israeli case, and in neither instance would one find very many successes." (Testimony of Peter D. Zimmerman before the House Government Operations Committee, April 7, 1992)

Also testifying before the committee was Richard Davis, Director of Army Issues National Security and International Affairs Division. Davis testified that

"Our review indicated in general that the Army and supporting contractors overcame significant obstacles to provide tactical missile defenses in Saudi Arabia and Israel, but that the Project Manager's assessment that the Patriot was successful against 70 percent of Iraqi Scuds was not supported." (Testimony of Richard Davis Director Of Army Issues National Security and International Division before the House Government Operations Committee, April 7, 1992)

The Patriot is currently deployed in South Korea as well as in Saudi Arabia. Former Senator and Presidential candidate Robert Dole has proposed a theater based missile defense for all U.S. allies in the Asian Pacific region including Taiwan. The updated version of the Patriot known as the Pac3 would be used in this case. This would be based on the concept of containing China and North Korea. However, Richard Fisher of the conservative Heritage Foundation (who supports Dole's idea of theater missile defense) agrees that Patriot technology alone cannot provide adequate defense.

"The Patriot system can defend only a particular point, such as a presidential palace, not an entire area." (See "Asian Star Wars", Far Eastern Economic Review, June 6, 1996)

Five years after the Gulf War the debate over the effectiveness of the Patriot missile continues. However, the implications of the debate extend far beyond

the ramifications of the Gulf War. The debate over theater missile defense and national missile defense as forms of BMD (Ballistic Missile Defense) is directly connected to the debate over the performance of the Patriot. This is why a serious and sober examination of the Patriot's only combat performance must continue.

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- Evaluation of U.S. Army Assessment of Patriot Antitactical Missile Effectiveness in the War Against Iraq, Steven A. Hildreth, Congressional Research Service, prepared for the House Government Operations Subcommittee on Legislation and National Security, April 7, 1992.

World Wide Web:

Frontline, WGBH Educational Foundation

- Federation of American Scientists – search their web page for lots of good primary source materials.

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