The Golem at Large

what you should know about technology

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A clean kill?: the role of Patriot in the Gulf War

THE GULF WAR

In August 1990 Iraqi forces invaded Kuwait. The United States presented Iraq with an ultimatum – 'withdraw or face a military confrontation'. The Iraqi president, Saddam Hussein, responded by threatening to stage 'The Mother of All Battles'. Over the next four months the United States set about building up military strength in neighbouring Saudi Arabia with the intention of driving Saddam's army from Kuwait. Given Iraq's confrontational stance, this meant building a force capable of destroying all of Iraq's military resources.

Considering the scale of the imminent confrontation, and its distance from the American continent, the United States needed the backing of the United Nations and the military and political co-operation of many nations, notably Iraq's neighbours. A critical feature of this alliance was that a set of Arab states would side with the Western powers' attack on a fellow Arab state. As the old saying goes, 'my enemy's enemy is my friend', and at that time all the Arab states except Egypt had an enemy in common – Israel. On the other hand, America was Israel's staunchest ally, while Iraq was viewed as an important player in the confrontation with Israel. Thus the political alignment that the US needed to hold in place was continually in danger of collapse. It was crucial for American policy in respect of the forthcoming Gulf War that Israel did not take part in the conflict. Should Israel attack Iraq, creating circumstances in which the Arab states would be directly supporting Israel in its attack on an Arab ally in the Middle East conflict, it might become impossible for the other Arab states to continue to support America. Iraq's strategy was clear: they would try to bring Israel into the confrontation that had started with their invasion of Kuwait.

On 17 January 1991 the allies launched a massive air attack on Iraq that would last for five weeks. The war was over before the end of February following a devastating ground attack lasting four days. This is the setting for the argument that has raged about the effectiveness of the Patriot anti-missile missile.

On the first night of the air attack, Iraq fired six Scud missiles at Israel. The Scud was a Soviet-built missile extended in length and range by the Iraqis and known locally as the Al-Husayn. Thereafter Iraq launched many more Scuds at Israel, and at Saudi Arabia, especially at the American bases. On 25 February, a Scud hit an American barracks, killing twenty-eight and wounding ninety-eight military personnel. Otherwise, in spite of the fact that at least some Scuds landed and exploded, it was a failure in terms of its ability to damage men or materiel. As a propaganda and political weapon, however, it was, from the beginning of the war, potentially a potent force.

The Patriot was used in the Gulf War to combat the Scud. It was used first in Saudi Arabia and then it was rapidly deployed in Israel after the initial Scud landings. It may be that the military ineffectiveness of the Scud was due to the success of Patriot. It may be that irrespective of its military effectiveness, Patriot played an important role in keeping Israel out of the war; the fact is that Israel did not attack Iraq and the alliance held. During the course of the war the best information is that more than forty Scuds were directed at the allied forces and around forty at Israel. A total of forty-seven Scuds were challenged by 159 Patriots. The question is, how many Scuds did Patriot actually destroy?

WAR, SCIENCE, AND TECHNOLOGY

War is a confused and confusing business. Martin Van Creveld, the respected writer on military command, says on page 187 of his book *Command in War*, that war is 'the most confused and confusing of all human activities'. In the case of Patriot, technological fog and 'the fog of war' are found in the same place with quite extraordinary results. What we want to do is explain how it can be that it remains unclear whether the Patriot actually shot down any Scuds. Though

there are firm opinions on both sides, we still do not know whether the anti-missile missiles stopped Scuds from hitting Israel, stopped them from hitting Saudi Arabia, or failed to stop them at all.

The art of experimentation is to separate 'signal' from 'noise'. One would have imagined that one of the clearest 'signals' there could be would be the explosion of a ballistic missile warhead; one would think that this would be well out of the 'noise'. Either the Scuds were getting through and causing huge explosions, or the Patriots were destroying them and preventing the explosions – what could be a less ambiguous test of a technological system? It turns out that it was an extraordinarily poor test. The estimated efficacy of the Patriot missile in shooting down Scuds varies from around 100 per cent to around 0 per cent; some said every Scud warhead engaged was destroyed, some said not a single one was hit.

The story of estimates of Patriot's success starts at the beginning of 1991, during the war. Initially 100 per cent success was reported. The score steadily comes down to near zero by the time of a Congressional hearing in April 1992. The confidently stated figure initially moves to forty-two out of forty-five; to 90 per cent in Saudi Arabia and 50 per cent in Israel; to 80 per cent in Saudi Arabia and 50 per cent in Israel; to 60 per cent overall; to 25 per cent with confidence; to 9 per cent with complete confidence; to one missile destroyed in Saudi Arabia and maybe one in Israel. This is what happened as a result of ever more careful enquiries by US government agencies.

It is important not to misunderstand the figures at the lower end of the scale: they do not tell us how many Scuds were destroyed by Patriots; they are estimates of how many Scuds we can be confident were destroyed by Patriots. It may be that more Scuds were destroyed. But, if we are looking for a high degree of certainty, then our estimate has to remain low.

There are groups taking part in this debate with quite clear goals. In 1992, representatives of Raytheon, the manufacturer of the Patriot system, continued to claim that it had shot down most of the Scuds. On the other hand, Theodore Postol, the MIT academic who first drew public attention to doubts about optimistic claims for Patriot's success, continues to believe that he can prove that Patriot was an almost complete failure, and continues to press the case forward. Our interest and curiosity is sparked not by the actual

success or otherwise of Patriot, but by the difficulty of settling the argument. We are not going to dwell on the interests, nor are we going to offer any conclusions as to whose evidence is biassed and why; we want to show only that the problem of measurement is hard to solve; we do not have, and cannot have, a clean scientific kill.

Was Patriot a success?

To say that the first casualty of war is truth is to miss the rather more important point that a principal weapon of war is lies. Disinformation confuses the enemy, while favourably biassed reports of success stiffen the resolve of one's own side and demoralise the opposition. It is, then, hardly surprising that, during the course of the war, Patriot was said to be a huge success. Not only was this important for the balance of morale, but it was vital that it was widely believed among Israel's populace that Saddam Hussein's forces were not being allowed to inflict damage on the Jewish State without opposition. It is fair to say that whether or not the politicians believed what they were saying, it would have been naive and unpatriotic of them to say anything other than that Patriot was a flamboyant success. It would be wrong to draw any conclusions for science and technology in general from wartime statements; wartime claims about the success of the missile reflect the demands of war rather than the demands of truth. Two weeks into the war, on 31 January, General Norman Schwarzkopf said, 'It's one hundred per cent so far. Of thirty-three engaged, there have been thirty-three destroyed.' A month into the war, on 15 February, President Bush said that forty-one out of forty-two of the missiles had been 'intercepted'.

After wars are over, the role of patriotic propaganda becomes less clear. Two weeks after the end of the war, on 13 March 1991, US Army officials told Congress that forty-five out of forty-seven Scuds had been intercepted by Patriots. Two months after the war's end, on 25 April 1991, the Vice-President of Raytheon, suppliers of the missile, said that Patriot had destroyed 90 per cent of the Scud missiles that were engaged over Saudi Arabia and 50 per cent of those engaged over Israel.

Any spokesperson for Raytheon has, of course, a clear interest in stressing the effectiveness of his corporation's product. Not only will

a good reputation bolster future sales of the missile itself, but the proof of an anti-missile missile on the battlefield gives a boost to the prospect of whole new weapons systems. It gives credibility to the idea of a defence against the increasingly powerful nuclear, chemical, or biologically-armed missile arsenals belonging to so-called 'rogue states'.

Though the Israeli military seem to have been unimpressed by Patriot even during the war, US public confidence in its success was first dented by a professor from MIT's Defense and Arms Control Studies Program – Theodore Postol. In a fifty-page article, entitled 'Lessons of the Gulf War Experience with Patriot, published towards the end of 1991, Postol, drawing partly on Israeli sources, claimed that Patriot's performance 'resulted in what may have been an almost total failure' (p. 24). Much of what we will describe in this chapter has emerged as a result of Postol's critique.

Postol's work gave rise to a hearing before a Committee of Congress in April 1992 on 'Performance of the Patriot Missile in the Gulf War'. This provides a considerable source of unclassified information on the operation of Patriot and the arguments surrounding it. Much of the evidence given before the Congressional hearing by experts supports Postol's claims about the failure of the US Army to prove the success of Patriot, while disagreeing with his methods and his claims that he could prove it was a complete failure. In particular, Postol has used publicly available video-tapes to show that Patriot explosions did not disable Scuds because they did not occur in close proximity to the Scud warhead. The other experts claim that the frame-rate of commercially available video-tape is too slow to indicate the moment of explosion – Patriot would have travelled too far between frames. This bitter disagreement and its ramifications linger on at the time of writing (1997) but it is interesting that the enmity has not led to any disagreement about the lack of confidence in the high estimates of Patriot's success. Steven Hildreth, a 'Specialist in National Defense, Foreign Affairs and National Defense Division Congressional Research Service', disagrees with Postol's methods in the strongest terms. He stated, during the Congressional hearing: 'I think his case is worthless. I can say that.' Nevertheless, Hildreth claimed that using the US Army's own methodology, one can have confidence that only one Scud warhead was 'killed' by Patriot. This is

not to say that only one warhead was killed, but that there is no really strong evidence for other successes.

Postol's work, and the Congressional hearing, attracted, in the summer of 1992, a twenty-five page riposte from Robert M. Stein, the Manager of Advanced Air Defense Programs for the Raytheon Company and a further response from Postol. Stein repeated an earlier comment made by Brigadier General Robert Drolet, US Army Program Executive Officer for Air Defense: 'In Saudi Arabia, Patriot successfully engaged over 80 per cent of the TBMs (tactical ballistic missiles), within its coverage zone [and] in Israel . . . Patriot successfully engaged over 50 per cent of the TBMs in the coverage zone.'

WHAT EVERYONE AGREES ABOUT PATRIOT

There are some features of the confrontation between Patriot and the Scud that everyone agrees about. Patriot was originally designed to shoot down aircraft rather than missiles. It had to be altered for use in the Gulf War and the design, development, manufacture, and deployment of the modified missile was carried through with heroic speed. There was a mistake in the missile software. This caused a timing error which meant that when the Scud fell on the Dhahran barracks, killing and wounding more than 200 people, no Patriot had been fired at it. This, however, does not detract from the major engineering feat that was involved in making the Patriot work at all in the Gulf War circumstances, nor is the software problem germane to other Scud engagements.

The version of the Scud missile used by the Iraqis during the Gulf War had been lengthened to extend its range. Its warhead seems to have been lightened and extra fuel tanks appear to have been added – perhaps cannibalised from other Scuds. Thus modified, the range was around 400 miles and it travelled some 40 per cent faster than had been anticipated by Patriot's developers.

The Al-Husayn rocket motor burns for about one-and-a-half minutes, taking the rocket to a height of around 35 miles, during which time it is guided along a pre-programmed trajectory. After this, all guidance ceases. The Al-Husayn then coasts for another 5 minutes, reaching a maximum height of around 100 miles, before

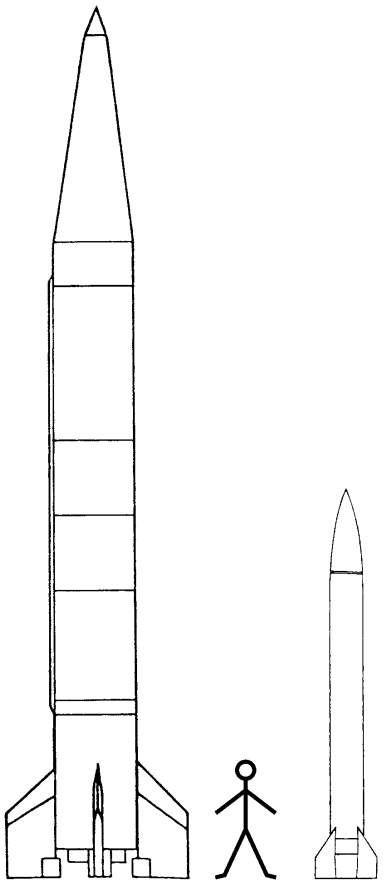

Figure 1.1. Scud and Patriot (scale very approximate).

re-entering the atmosphere. It takes about another minute to impact with the ground. The rocket reaches a maximum speed of about 5,500 miles per hour before the atmosphere begins to slow it. At the point at which a Patriot might typically make an interception, perhaps 10 miles above the ground, the Al-Husayn might be travelling at about 4,400 miles per hour and would be less than 10 seconds from impact.

The Patriot's rocket motor burns for about 12 seconds, by which time it has been accelerated to more than 3,800 miles per hour. Thereafter it coasts to the target under guidance by its fins. The target is illuminated by ground-based radar. To have any chance of hitting the target, Patriot has to be pointed toward its potential impact point before launch. Because of the speed at which everything happens, only relatively small adjustments to the trajectory are possible during flight. To intercept at a height of around 10 miles, Patriot has to be launched when Scud is at a height of around 20 miles. Radar tracking of Scud must begin a few seconds earlier while it is at a height of, perhaps, 25 miles. The Patriot can be launched only once the path of the Scud's fall has been worked out, along with the potential impact point.

At the point of potential destruction, the closing speed of Scud and patriot will be about 8,000 miles per hour or 12,000 feet per second.

Needless to say, the whole interception manoeuvre must be under computer control. Indeed, so critical are the parameters that Patriot is usually set to launch automatically, without human intervention, though a manual launch option is available.

Patriot is intended to destroy a missile by exploding its own warhead in close proximity to its target's warhead. Patriot's warhead is jacketed in lead projectiles intended to penetrate vital parts of the Scud. The explosion of Patriot's warhead accelerates the lumps of lead to a speed of around 5,600 miles per hour. It is salutary to realise that the products of the Patriot warhead's explosion travel more slowly than the relative speed of the two missiles. Not only does this give one a sense of the speed at which events transpire, it also shows that there is very little room for mistakes over the time and place at which the Patriot warhead must explode. If Patriot's warhead explodes after it and Scud have crossed in the sky, there is no chance that the products of the explosion will catch up with the departing missile. Even if Patriot passes very close to its target, the time window for an effective detonation is very short. If Patriot misses the window by one-thousandth of a second, the relative positions of Scud and the interceptor will be different by about 12 feet. Instead of penetrating the explosive charge or fusing mechanism of the Scud, the lead projectiles will miss entirely, hit the empty fuel tanks, or cut the missile into pieces, leaving the explosive device intact.

To design an interceptor system that will identify incoming missiles, track them, determine their trajectory in a few seconds, fire a rocket at an estimated point of arrival, guide the interceptor to that point allowing it to make last second adjustments, and explode a warhead as it approaches the incoming missile, all at a closing speed of 8,000 miles per hour, is a remarkable achievement. It is still more remarkable when it is remembered that Patriot was originally designed to do something else. But all this achievement will be to no avail unless the warhead explodes at exactly the right time in exactly the right place. What might look like a perfect interception from the ground may have done nothing but damage the no longer essential parts of the incoming rocket's fuselage.

In Chapter 3 we distinguish 'demonstrations' from experiments and tests. War, because of its confusion and the extreme tension and terror under which soldiers operate, is not conducive to demonstrations. In war, most of the time, most things are going in unexpected directions. The Iraqi version of the Scud missile demonstrates this principle to perfection. Because the Al-Husayn had been lengthened and the warhead lightened, the Scud's aerodynamic and mechanical properties had changed. The unintended outcome was that Al-Husayn could re-enter the atmosphere after its long coasting flight in space in a variety of orientations, wobbling more or less depending on a variety of factors. Consequently it had a tendency to break into pieces during its descent through the atmosphere; the break-up could take place at different heights depending on the orientation and the wobble. The unevenly shaped pieces would then spiral to earth or take a still more random path depending on their shape and how they were affected by the airflow over them. The Iraqis had inadvertently designed a missile with decoy warheads capable of making the equivalent of evasive manoeuvres!

If the Scud broke up early in its flight the radar would 'see' what appeared to be two or three objects hurtling into the atmosphere instead of one. The Patriot system would automatically launch rockets to intercept all of these pieces, and in the early days Patriot stocks fell alarmingly. If the Scud broke up late in its flight the single Patriot, or pair of Patriots, launched to destroy one target would, during the course of the flight, suddenly be presented with several targets instead of one.

Thus, not only did Patriot have to destroy missile warheads when it had been designed to shoot down airplanes, it had to destroy a missile which behaved as though it had been built, by a very sophisticated design team, so as to avoid interception.

Two lessons can be taken from Patriot's performance in the face of the Iraqi Scuds' unexpected 'design feature'. One might say that Patriot worked even better than anticipated because it had to deal with unanticipated behaviour of its target. One might, on the other hand, draw the conclusion that anti-missile defensive systems will always be fighting the last war and evasive measures that cannot be anticipated will always defeat the defensive umbrella. Scud illustrates that these things will happen even when the missiles are built and launched by an unsophisticated military power; they give us pause for thought about what a sophisticated offensive force might do.

Later in the war it was learned that the dense, heavy warhead could be distinguished from the 'decoys' because it was slowed less by the atmosphere, but waiting long enough before firing to allow the difference to become clear meant that Patriot could not be launched until the Scud had fallen to a relatively low altitude. It appears that the Israelis switched from automatic firing mode to manual mode when they found out how to distinguish warhead from separated fuel tank and other debris, thus preventing their Patriot stock from being exhausted in the first days of the conflict.

CRITERIA OF SUCCESS

The debate about the success of Patriot turns on two interwoven issues. There is the question of what counts as success, and there is the question of whether Patriot achieved success under each of the many possible definitions.

Robert Stein, Raytheon's representative, published comments in the summer of 1992 exemplifying some of the things which might count as success; he mentions neither interceptions nor explosions:

> Patriot's very credible performance and success can be measured by the events as they occured. The coalition did not falter. Israel did not have to mount offensive actions against Iraq, and was able to stay

> out of the war. Widespread loss of civilian life was not inflicted. . . . And in the end it was Saddam who sued for peace, not the coalition.

We can think of the potential criteria for success from the inside out, as it were; we start from the moment of embrace of Patriot and Scud and work our way to less proximate consequences. The list in Table 1.1 represents some possible outcomes of the deployment of Patriot.

In this list, 'dudded' means that the warhead fails to explode when it hits the ground as a result of Patriot's effects; 'damaged' means that the warhead explodes but with reduced force (as might happen if part of the explosive charge were distorted or separated); 'diverted' means that a warhead travelling towards an area where it might inflict death and destruction was diverted to an unpopulated area; 'intercepted' means that the radar tracking and flight control of the Patriot was as expected, that Patriot approached the Scud and its warhead fired, but it was not certain that the Scud warhead was damaged.

The relationship between the last seven criteria of success, which we call 'indirect criteria of success', and the first fifteen, which we call 'direct criteria of success', is not a straightforward matter of cause and effect. The mere deployment of Patriot, along with the broadcasting and widespread acceptance of stories of its success, could be enough to bring about results 15 to 21, even if Patriot actually failed on the direct criteria. Patriot could have been said to have been a great success, either in the war or in the subsequent peace (a success for the US arms industry), even if it had not intercepted or damaged a single Scud; what is crucial is that people believed and believe that it did. Ted Postol, a long-term opponent of Star Wars spending, is, as he sees it, trying to prevent Patriot gaining the sort of false reputation which would justify further expenditure on an anti-missile technology which, he believes, is bound to fail. Postol, in other words, is trying to prevent consequences 20 and 21 coming about because he believes that, in reality, consequences 1, 2, 4, 5, 7 and 8 did not happen.

Another feature of lists such as that in Table 1.1 is that success according to one criterion can be presented in such a way that it is easy to read it as success under another criterion. Thus, two out of the four claims that were mentioned at the outset: President Bush's

Table 1.1 *Criteria of success for Patriot vs. Scud*

Direct criteria of success	
1	All, or nearly all, Scud warheads dudded.
2	Most Scud warheads dudded.
3	Some Scud warheads dudded.
4	All, or nearly all, Scud warheads damaged.
5	Most Scud warheads damaged.
6	Some Scud warheads damaged.
7	All, or nearly all, Scud warheads diverted.
8	Most Scud warhead diverted.
9	Some Scud warheads diverted.
10	All, or nearly all, Scuds intercepted.
11	Most Scuds intercepted.
12	Some Scuds intercepted.
13	Coalition lives saved and property damage reduced.
14	Israeli lives saved and property damage reduced.
Indirect criteria of success	
15	Morale of civilian populations boosted.
16	Israel kept out of the war.
17	'Coalition did not falter.'
18	'Saddam . . . sued for peace not coalition.'
19	Patriot sales increased.
20	New anti-tactical missile programme given credibility.
21	Strategic Defense Initiative ('Star Wars') revivified.

'forty-one out of forty-two', and the US Army's forty-five out of forty-seven' referred to 'interception' not destruction. Whether this was a deliberately sophisticated use of words intended to give one impression while making a far less significant claim, is not clear. Senator Conyers cross-examined the US Army's Brigadier General Robert Drolet on this point during the 1992 Congressional hearing. The testimony speaks for itself:

> *Conyers*: Well was he [President Bush] in error?
> *Drolet*: No, sir.
> *Conyers*: So he was correct when he said forty-one out of forty-two Scuds were intercepted?

Drolet: Yes, Sir.
Conyers: You have records to back that up?
Drolet: Intercepted?
Conyers: Yes, sir.
Drolet: Yes, sir. He did not say killed or destroyed. He said intercepted. That means that a Scud came in and a Patriot was fired. But he did not say and we did not say, nor did we ever say, that it meant all of the Scuds were killed.
Conyers: He didn't mean that they were killed? He meant intercepted, meaning what in military jargon?
Drolet: . . . He just means that a Patriot and a Scud crossed paths, their paths in the sky. It was engaged.
Conyers: They passed each other in the sky?
Drolet: Yes, sir.

The indirect criteria of success

Sales, anti-tactical missiles, and Star Wars

Of criteria 19 to 21, we have little to say. It is interesting that many commentators, not least Robert Stein, were anxious to separate the last criterion from the others. As one commentator, who was hostile to Postol's view, put it during the Congressional hearing:

> . . . it has become fashionable to say, 'if Patriot, therefore, SDI' . . . an extrapolation from Patriot success to the probable future success of interceptors intended to hit strategic ballistic missiles armed with nuclear weapons.
>
> This is logically an absurd statement to make . . . A strategic defense system I would suggest, will probably get it right some time around the second or third nuclear war.
>
> *(Statement of Peter D. Zimmerman, Visiting Senior Fellow, Arms Control and Verification Center for Strategic and International Studies. Congressional hearing pp. 154–5)*

The anxiety seems to be to separate the positive lessons of Patriot for the development of defences against *tactical* ballistic missiles, from the credibility-sapping *Strategic* Defense Initiative meant to develop systems to shoot down the much faster inter-continental ballistic missiles. What is more, it is important to argue that Patriot and its ilk do not lead to a full-scale anti-ballistic missile system because there is

an international treaty banning such developments. Those who want to develop Patriot-like missiles have to decouple them from the banned programme, whereas Postol argues that developing one is a surreptitious way of developing the other. At this stage of the argument, the success of Patriot in destroying Scuds is almost irrelevant.

Only history will tell whether Patriot was a success on criteria 19 to 21, but current evidence suggests that in respect of criterion 20 the Patriot experience was certainly not negative; anti-tactical ballistic missile systems are being developed, though Raytheon has a smaller part in this programme than they hoped for.

The local political role of Patriot

Of criteria 15 to 18, the argument is even more difficult to analyse. The history of warfare is a notoriously difficult topic because it is so invested with the interests of nations, armies, regiments, and generals, while the events themselves take place under circumstances where record-keeping is of less priority than survival.

Consider criterion 16, Patriot's role in keeping Israel out of the war. The *Washington Post* reporter, Rick Atkinson, says, in his history of the Gulf War, *Crusade: The Untold Story of the Gulf War*, that the Israeli military soon came to believe that the Patriot was performing poorly and they referred to Schwarzkopf's optimistic press comments as 'the Patriot bullshit'. He says however, enjoying, one presumes, the usual reporter's licence with quotations marks:

> Yet even the Israelis recognised the political and military utility in lauding the missile. When an Israeli officer suggested publicly disclosing qualms about Patriot, Avraham Ben-Shoshan, the military attache in Washington, snapped, 'You shut up. This is the best weapon we've got against the Scuds because it's the only weapon. Why tell Saddam Hussein that it's not working.' (p. 278)

In contrast, General Sir Peter de la Billiere, the commander of British forces during the conflict, does not mention Patriot at all in his biographical discussion, *Looking for Trouble*. He claims that it was British SAS ground patrols, deployed into Western Iraq on 22 January, that put an end to the Scud threat to Israel:

> . . . [they] operated with such effectiveness that no further Scuds were launched at Israel after 26 January. Once again, experience

> confirmed that the SAS had repeatedly demonstrated in Europe – that no amount of electronic surveillance is as effective as a pair of eyes on the ground. (p. 411)

We would prefer not to venture into the minefield of competing accounts that comprise military history except to note that other accounts say that thirteen Scuds fell on Israel between 28 January and 25 February, wounding 34 people and damaging around 1,500 apartments and 400 houses.

Criterion 15, we would venture, was almost certainly met. It must boost the morale of a civilian population to know that your side is shooting back; the very act of resistance is cheering irrespective of how successful that resistance is. It is said that later in the war civilians took up positions on rooftops to watch the Patriot versus Scud battle. This must be better for morale than cowering in shelters.

Death and destruction

Turn now to criteria 13 and 14. Did Patriot save lives and prevent damage to property? There is no direct evidence in Saudi Arabia because we do not know what damage would have been caused and how many lives would have been lost if Patriot had not been deployed. We know that many servicemen and women were killed when a Scud hit a crowded barracks, and we know that Patriot was not deployed on that occasion, but it is impossible to be certain that deployment would have made a difference. Therefore, the fact that the greatest loss of life occured on an occasion when Patriot malfunctioned cannot be taken to show that functioning Patriots were effective. We will see this more clearly as we proceed.

The case of Israel is more interesting because we have a 'before and after' comparison. Scuds began to fall on Israel on 17 January but Patriot was not deployed until around 20 January. A number of missiles missed the towns at which they were putatively aimed, but Postol says that thirteen unopposed Scuds fell onto Tel Aviv and Haifa before Patriot was deployed, damaging 2,698 apartments and wounding 115 people. After Patriot began to be used, he says, fourteen to seventeen Scuds were engaged over the two towns and 7,778 apartments were damaged with 168 people wounded and one killed. Postol says that on the face of it, three times as much damage

Figure 1.2. Trails of Patriot anti-missile missiles over Haifa, Israel. One appears to dive into the ground.

was caused by roughly the same number of Scuds during the Patriot defence period compared to the pre-Patriot period. He admits, however, that since the amount of damage to each building was not assessed in detail it is hard to rely on these rather slim statistics. He concludes, nevertheless, that there was no evidence to suggest that the damage decreased in the time of Patriot. The number of injuries seems to have increased, and Postol suggests that some of these may have been caused by Patriot itself. With Patriot deployed there would certainly be much more in the air that would, at best, come down again at high speed, and at worst, come down intact, exploding on

contact. There is evidence that some Patriots became confused by radar signals reflected from buildings, and that others chased Scud fragments into the ground.

Stein, in his reply to Postol, says that in fact far more missiles were directed at the Israeli cities after the deployment of Patriot, and that since the damage inflicted on the apartments was superficial, there is 'clear evidence that Patriot reduced ground damage other than in the category of "broken windows" '. (p. 222) He goes on to compare the relatively low loss of life and minimal damage in Israel with the severe damage and loss of life caused by tactical ballistic missiles in Iran's war with Iraq. He also goes on to compare the events in Israel with 'the lives lost in the Dhahran barracks when no defense countered the TBMs'. (p. 222)[1]

The direct criteria of success

Interception and diversion

There has been little heated debate about whether Patriot *intercepted* most of the Scuds it engaged since interception says nothing about destruction, damage, or diversion. Let us define an 'interception' as meaning that the Patriot passed through a point, or potentially passed through a point, near to which its detonation would have dudded or damaged the Scud warhead.

We can say with certainty that not every Patriot launched intercepted a Scud. Some, especially in the early days, intercepted fuel tanks and other debris; some probably intercepted buildings, and some probably intercepted the ground. But this would be normal in a wartime situation.

Dhahran aside, there is no reason not to suppose that in every case, or nearly every case, that a Scud track appeared to be aimed at a populated area and was 'engaged', that one or more Patriots intercepted it in the sense expressed by Brigadier General Drolet – 'a Patriot and a Scud crossed paths, their paths in the sky'. Interception in this sense can be determined by radar traces; it does not require that we know what happened to the Scud after the Patriot exploded. This reliability of interception would be a considerable engineering feat, sufficient to bolster hopes for a successful anti-tactical missile system in the future, whether the Scuds were damaged or not. Of

course, this is merely a start: it would remain to be proved that the Patriots could do significant damage to their targets, something still hotly disputed by Postol and others.

As regards diversion, the Al-Husayn was a very inaccurate weapon; unopposed it could not be expected to land within two or three kilometres of a well-defined target. Even the rockets that were tracked coming in did not have a predictable landing point because of the random aerodynamic forces caused by the break-up. The Army says that Scuds usually landed within 2 or 3 kilometres of predicted impact points.

Thus, the rocket that did so much damage to the Dhahran barracks could not be said to have 'hit its target' though it is possible that had it been opposed it might have been diverted. On the other hand, it might have been a matter of chance alone that Patriot did not divert another warhead onto an occupied building. Given the level of control, 'diversion' could be at best a chancy business. In any case, a diversion is a very different thing in the case of conventional explosive as opposed to chemical, biological, or nuclear warheads. Chemical and biological warheads will be affected by the direction of the wind; nuclear warheads would need much more diversion than a conventionally armed missile if it is to make a difference.

Dudding and damaging

All the above said, it is, on the face of it, surprising that we do not know whether Patriot reduced the number of 500 kilogram explosions that would otherwise have taken place in crowded cities. Because of the tiny margin for error of the Patriot warhead detonation if it was to damage the Scud warhead, we cannot know the answer to this from direct observations of Patriot interceptions. We have, therefore, to work out what happened from the actual Scud explosions and observations of ground damage.

Observations of explosions and ground damage are doubly confounded. On the one hand, even if every Scud warhead was dudded this would not mean there would be no damage. Bits of missile can hit the ground and cause a great deal of damage even when they are not fully functional. Thus, heavy warheads travelling at more than 3,000 miles per hour hit with the force of an explosion; the energy of the impact can even cause a flash of light which looks like an

explosion. Fuel tanks, containing residues of rocket propellant, actually do explode when they strike.

It seems also that some Patriot warheads exploded at ground level, either by mistaking buildings for targets or because they chased Scuds, or Scud fragments, into the ground. Postol's video-tapes provide good evidence of ground-level Patriot explosions. Here we have an interesting question: does a ground-level Patriot explosion count toward the success of Patriot or against it? The answer depends on the criteria of success. If criteria such as 13, 14 or 15 are held in mind – reduction of damage to lives and property, and bolstering the morale of civilian populations, then a Patriot inflicting damage on the country it is meant to defend is seriously bad news. On the other hand, if one adopts the accountant's mentality and concerns oneself solely with criteria such as 1 through 9, 19 and 20, which have to do with Patriot's actual effectiveness against the Scud and its significance for the development of better systems, then the more ground damage that can be shown to have been caused by Patriot, the less of that ground damage can have been caused by Scud, and the more effective Patriot might have been at damaging Scud. Around here the argument becomes a little dizzying.

Working in the other direction, a Scud might land and do no more damage than might be expected from its energy of impact and exploding fuel, and this might be counted as a success for Patriot while in fact the Scud would not have exploded anyway; the Scud warhead might have been a dud! At least one 'warhead' landed which contained nothing but a lump of concrete – it seems that the Iraqis were running out of missiles equipped with fully functioning warheads towards the end of hostilities. In any case, we do not know how efficient they were at launching fully functioning missiles in the first place. Because of allied control of the skies, the Iraqis could not use fixed sites, as they could in their war with Iran; they were forced to use mobile launchers under conditions of secrecy and darkness and we cannot know how many warheads were properly prepared.

To understand the effectiveness of Patriot under criteria 1 through 6 it was vital to investigate ground damage outside urban areas as well as inside them. Furthermore, it now seems that the ground damage surveys were not conducted until some time after

the war. The survey was conducted by 'one engineer working in Saudi Arabia for 5 days in February 1991, and 19 days in March 1991 . . . it relied heavily on photographs and interviews with military personnel assigned to the Patriot units, and . . . site visits were always made days or weeks after an impact when craters had often been filled and missile debris removed.' (Congressional hearing, report from US General Accounting Office, p. 78.) The Army's first report of Patriot effectiveness was also vitiated because the report included information on only about one-third of the Saudi engagements, although the Project Manager's assessment cites it as a source for all engagements. Furthermore, the report assumed that Patriot destroyed Scud warheads in the air unless warhead damage was found on the ground, while some units did not even attempt to locate damage. (p. 86)

One can now understand why it was that, by the time of the Congressional hearing, firm estimates of the success of Patriot had been dramatically lowered. The Army was now down to a claim of 60 per cent success rate, though that included engagements in which there was a low confidence of success. The Army also provided a 25 per cent success rate claim but that included 16 per cent of cases where the Patriot came close to the Scud without strong evidence that it destroyed or damaged it. Representatives of the US General Accounting Office said:

> . . . there is no way to conclusively determine how many targets the Patriot killed or failed to kill.
>
> About 9 percent of the Patriot's Operation Desert Storm engagements are supported by the strongest evidence that an engagement resulted in a warhead kill – engagements during which observable evidence indicates a Scud was destroyed or disabled after a Patriot detonated close to the Scud. For example, the strongest evidence that a warhead kill occured would be provided by (1) a disabled Scud with Patriot fragments or fragment holes in its guidance and fuzing section or (2) radar data showing evidence of Scud debris in the air following a Patriot detonation.
>
> *(Congressional hearing, p. 108)*

Steven Hildreth, we may recall, considered that, using the Army's own criteria, one could be certain of only a single warhead kill.

REACHING TOWARD THE LABORATORY

The experts giving evidence to the Congressional hearing agreed that to be sure about how well Patriot succeeded the battlefield would have had to have been equipped more like a laboratory or test range. High-speed photography might have revealed the exact moment of explosion of Patriot's warheads and their relationship to that of the Scud, but high-speed photography is not an option on the battlefield: 'The Chief Engineer said high-speed photography cannot be used to collect data unless the trajectory of both the Patriot and its target are known in advance so that multiple cameras can be set up along their flight paths. He also said this was not possible during Operation Desert Storm because obviously the time and location of Scud launches were not known in advance.' (Congressional hearing, p. 108, GAO report.)

Another expert, Charles A. Zracket, whose qualifications are given before the Congressional Committee, as 'Scholar in Residence, Center for Science and International Affairs, Kennedy School of Government, Harvard University, and the past President and Chief Executive Officer of the Mitre Corporation', states that '. . . the uncertainty of determining Patriot's actual shot-by-shot performance in the gulf war comes about from the lack of high speed, high resolution photography and digital data radar recordings of intercepts that could provide direct and valid scientific data'.

There is also a possibility that a transmitter could have been attached to each Patriot that would have sent a continual stream of data back to the ground about its movements. This is known as 'telemetry'. Early in the war it came to be believed that telemetry equipment had caused a Patriot to fail and, thereafter, it was not attached to any of the missiles based in Saudi Arabia. The Israelis do appear to have used such equipment on at least a few Patriots. The GAO said that the telemetry data could have shown whether the Patriot passed within a range where it had a high probability of destroying the Scud and had time to detonate before the Scud flew past the intercept point. (p. 109) This, of course, would not prove whether the Patriot actually did destroy the Scud but would have resolved some of the ambiguity about whether the explosion happened at the intended time and intended place.

In the evidence of the experts one sees a yearning for science in place of messy wartime reports: 'direct and valid scientific data' could put an end to this untidy debate.

There is a nice parallel between the performance of Patriot itself, and the performance of the monitoring equipment. Knowing what we know now we could, perhaps, redesign Patriot to intercept and destroy many more of the Al-Husayns. Patriots would be deployed in good numbers and optimum locations with well-trained crews well before the start of the war. The crews would already understand closing speeds and the typical trajectories and flight patterns of the missile warhead and its fortuitous decoys; new software would have been written accordingly. One might speculate that multiple Patriots would be directed at each warhead, each given slightly different fusing parameters. The software timing fault would have been rectified and the equivalent of the Scud that fell on Dhahran would be attacked and, perhaps, destroyed. In this scenario, Patriot would inflict clean kill after clean kill. As always, if only we could fight the last war again we would do it so much better. But then, we would not so much be fighting a war as rehearsing a large-scale manoeuvre and putting on a demonstration within its confines.

In the same way, the experts, knowing what they know now, understand what would be needed to produce a clean 'scientific kill' – an exact and unambiguous account of Patriot's encounters with its targets. Just as military men dream of fighting a war in which there is never any shortage of information or supplies, while the enemy always does the expected, so experts have their dreams of scientific measurement in which signal is signal and noise follows the model given in the statistical textbooks. As the generals dream of manoeuvres, so the experts dream of the mythical model of science.

But even manoeuvres and demonstrations rarely go to plan. Little is learned from a manoeuvre in which nothing goes wrong and, as we will see in our Chapter 3, demonstrations go wrong too, and even when they go right it is not clear what their implications are. Even when we have unlimited access to laboratory conditions, the process of measurement does not fit the dream; that was the point of our earlier book – the first volume of the Golem series. The point is not to show that the understanding of Patriot was beset by the fog of war, but to see that this fog was just a dense version of the fog through

which golem science always has to strain to see. If the vision ever clears so far that we can get our shot in and produce a clean kill, then, as in the military situation, it is not likely to happen until after the metaphorical third 'nuclear war'; and by then it is usually too late for the purpose we have in mind.

NOTE

[1] It has to be said that much of Stein's defence of Patriot's performance turns on statements of authorities which refer to, but do not detail, classified information. Furthermore, he presses home the message that the use of modified Scuds in the Gulf War is a warning for the future that the threat of offensive actions will not deter dictators from firing ballistic missiles at their enemies and that it is important to develop defensive systems against these threats. In his response, such messages, along with references to the more general criteria of success that come lower down our list, outweigh detailed analysis of Patriot's performance.