Part I: Reflections on the Israel Trip

I am very grateful to have been part of the Washington University Electrical and Systems Engineering trip to the Technion in Israel. One of the world's leading science and technology universities, the Technion strives to create knowledge and develop human capital and leadership for the advancement of the State of Israel and all humanity [1].

It is fascinating to see how engineering fits into the culture of Israel. Due to their political relationships with other countries and people groups, defense is very important to Israel. Upon graduating from high school, students complete a minimum of two years of military service. This life experience gives them a perspective during college that seems more focused on work and the outside world. Many of the student projects have potential military applications. Before the trip to Israel, I did not consider military purposes as interesting as other engineering applications. However, after seeing many examples and their importance while in Israel, I have become very interested in learning more.

Engineering at the Technion

Our group was able to visit many different engineering labs during our time at the Technion. This was a very valuable part of the experience because we saw many collaborative projects among Electrical and Systems Engineering and other fields. We learned about research in the departments of Electrical Engineering, Mechanical Engineering, Aerospace Engineering, Computer Science, and Biomedical Engineering. Professors also designed a control and robotics lab and a signal and imaging lab for us to complete to learn more about their areas of expertise.

Department of Computer Science at the Technion in Haifa, Israel

We also saw several student undergraduate research projects. The students put many hours and extensive effort into their work, and it was impressive to see what they accomplished.

At right, this firefighting robot can locate a flame in the maze and put it out.

Cultural Experiences

Buying falafel and shawarma from a vendor

In addition to engineering, we discovered more about the complex culture of the area and were able to visit many significant historical and religious places. We were able to spend time in many different cities including Tel Aviv, Haifa, Jerusalem, Nazareth, and even a Druze village. Our group also visited the Sea of Galilee and drove up in the Golan Heights. We swam in the Mediterranean Sea and floated in the Dead Sea. It was a delight to try many new kinds of food, and I miss the delicious kabob, falafel, baklava, and Bulgarian cheese now that I am back in the U.S.

Forming New Friendships

One great part of the trip was developing new relationships. I greatly enjoyed conversing with the students and faculty at the Technion. Our hosts made us feel very welcome and showed us incredible kindness and hospitality.

It was interesting to see what it might be like to be a university student in another country. But perhaps an even greater benefit was forming new friendships with students from the ESE department at Washington University. We got to know each other much better through our time abroad then we had through classroom experiences.

The Washington University Electrical and Systems Engineering students with Professor Nehorai after dinner in a Druze Village

Overall, the trip was an excellent experience. Much can be learned from seeing engineering from the perspective of another culture. I am very thankful for our gracious hosts in Israel, the members of the Electrical and Systems Engineering Department at Washington University who organized the trip, and our exceptionally generous donor who made this trip possible.

Part II: Report on Anti-Ballistic Missiles

Katherine Stammer

The Technion is famous for making breakthroughs in computer science, environmental engineering, medicine, nanotechnology, anti-terror, and many other areas [2]. In addition to the discoveries made at the university, many graduates go on to make notable achievements. One important example, the Arrow anti-ballistic missile defense system has been largely developed by Technion graduates working for the Israel Aerospace Industries [2].

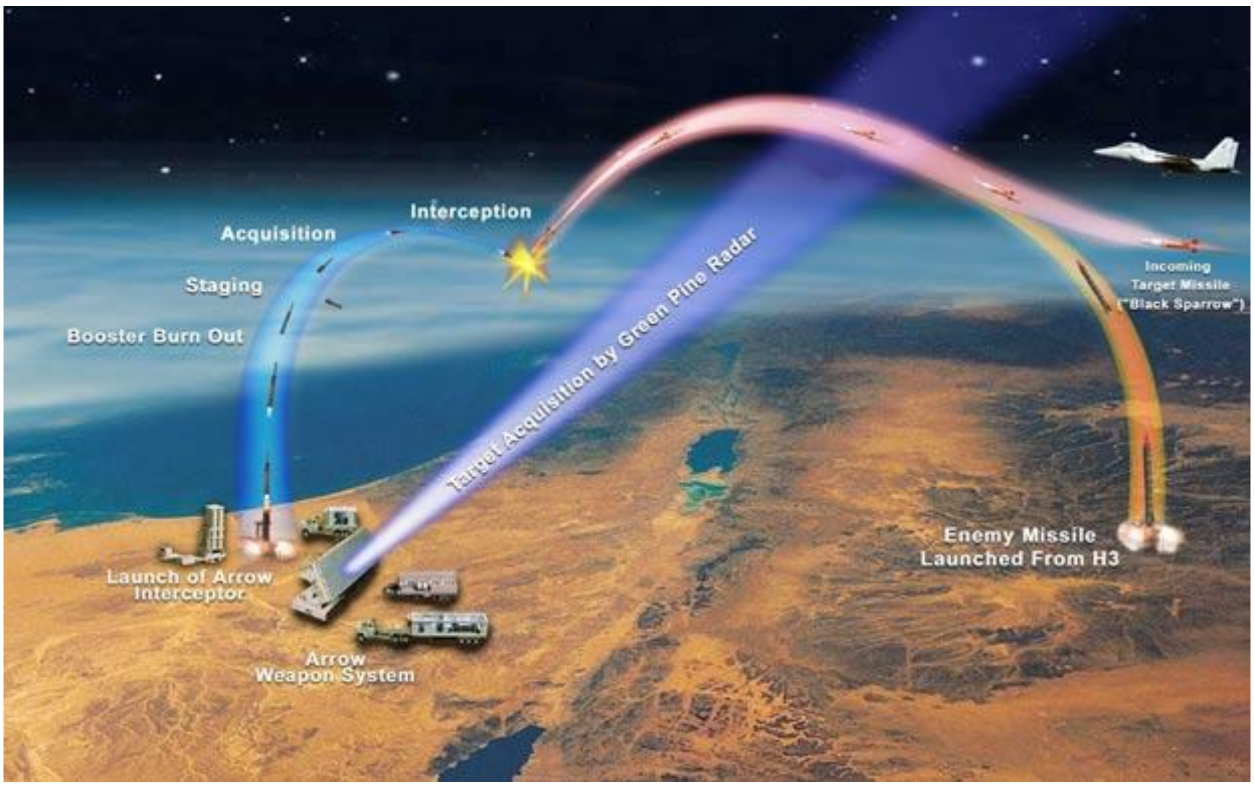

Figure 1
Overview o f Israel's Arrow anti-ballistic missile defense system

Anti-ballistic missiles are a type of antimissile missile designed to defend against attacks using ballistic missiles (see figure 1). They are used in both national missile defense, defending a large area from a small number of nuclear weapons, and theater missile defense, defending limited areas of military operations against short-range missiles. Anti-ballistic missiles are a type of surface-to-air missiles, meaning they are fired from the ground or ships and hit a target in the air, in this case another missile [3].

An understanding of an anti-ballistic missile system begins with an understanding of a ballistic missile. Missiles are weapon systems with guidance mechanisms, propelled through the air to a target. Most are long and thin to reduce air resistance and have wings and tails to enable steering. They range in size from a 4 foot missile that can target a tank or an airplane to a 60 foot missile that can fly across continents and destroy entire cities. Although some missiles are engine-less winged bombs, most are powered by a jet engine or rocket engine. With the exception of antimissile missiles, missiles generally contain an explosive warhead that can destroy the target. The distinguishing feature of a ballistic missile is the arching flight trajectory similar to that of a ball being thrown in the air. At the beginning of the flight of a ballistic missile, the engine powers the missile. The missile then coasts through the second part of the flight after the engine turns off, dropping down onto its target. It is guided only during the engine powered beginning of the flight. All other missiles, such as air-to-air, surface-to-air, and air-to surface, are considered nonballistic [3].

Missile Components

Many guided missiles are powered by rocket engines, generating thrust by expelling gases at a high pressure. The engine uses an enclosed combustion chamber to burn chemicals and produce pressurized gases. The nozzle at the end of the chamber forces the exhaust through a narrow opening, converting the pressure into thrust.

The propellants, or chemicals used for rocket engine fuel, are usually solid and shaped into a hollow cylinder. If liquid propellants are used they are contained in special tanks in the missile's body (see Figure 2). The propellants include a fuel to be burned and an oxidizer to provide the necessary oxygen for burning. The oxidizer can be liquid or solid, matching the form of the fuel.

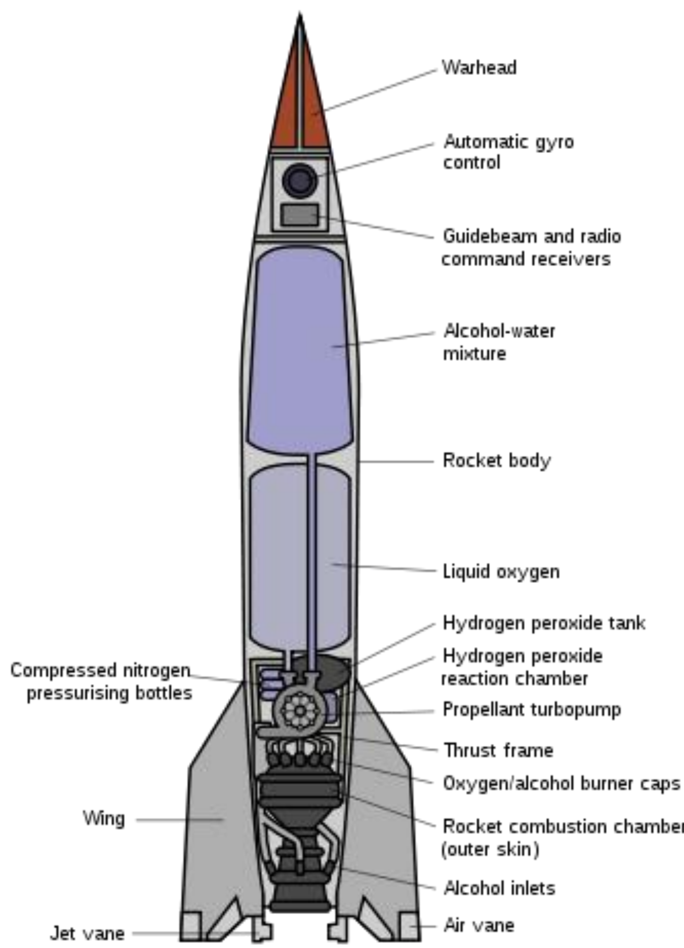

Figure 2
Diagram of a liquid-propellant missile

Jet engines also power some missiles. Unlike rocket engines, they are able to take in air as they fly, providing oxygen for burning fuel. This reduces the weight of propellant, enabling a jet-engine-powered missile to fly farther than a similarly sized rocket-engine-powered missile. However, jet engines are often more complex than rocket engines and are unable to operate in outer space [3].

The missile is kept on course through guidance and control systems. The two main types of control systems used are aerodynamic controls and jet reaction forces. Aerodynamic controls make use of rotatable wings and movable surfaces to change the flight path. The trajectory can be altered with jet reaction forces by altering direction of the propulsion unit's thrust or by using additional jet reaction units [4].

Various launching equipment is used, depending on the setting for the missile launch. Ships can use vertical launch systems, grids of launchers in the deck allowing multiple missiles to be ready for fire. They may also use armor-clad boxes mounted on the deck or missile canisters. Missiles can be launched from the ground using mobile vehicles or at times shoulder-fired tubes. Underground shafts called silos are also used. Certain launching methods are more effective depending on the size of the missile and the length of its flight trajectory [3].

The explosive part of the missile is the warhead. They may destroy the target through metal fragments, shock waves, nuclear explosives, and other means. All missiles have a fusing system that triggers the explosion of the warhead. Some missiles may contain multiple warheads, enabling them to attack multiple targets. After the missile approaches the peak of its trajectory, the warheads separate and move in the direction of their individual targets [3].

Missile Guidance

Missile guidance can take place at all three of the flight path phases: boost, midcourse, and terminal. Missile guidance systems have a flight path control system and an altitude control system. The altitude control system controls the motion of the missile. The flight path control system uses feedback to calculate the necessary changes to keep the missile on track to hit the target. It then signals the altitude control system to correct for changes in the environment [5].

Figure 3
Citron Tree Fire Control System, part of the Arrow Theater Ballistic Missile Defense System

Preset paths cannot be changed once the missile is in flight. They can only be used in situations where it is assumed that the target motion will not change during the missile's flight. Variable guided flight paths make use of updated data to alter the path of the missile, enabling the interception of targets with unpredictable motion. The position of the target is continuously evaluated so the optimal path can be computed. The computations assume that the motion of the target will not change over a short time interval [4].

Different sensors can be used to detect the target. Selection is made based on the flight distance, conditions, accuracy required, and target. Radio, radar beams, heat, light, television, and the earth's magnetic field have all been used to detect targets.

Anti-Ballistic Missiles

Anti-ballistic missiles may target a ballistic missile at any point in its flight path. As the ballistic missile is accelerating from its rocket booster, boost phase intercept can occur. Mid-course intercept takes place when the ballistic missile is hit at the middle of its flight trajectory. As the ballistic missile is moving downward toward the target, terminal intercept can take place. Boost phase intercept is often considered the best scenario due to the fact that it destroys the ballistic missile while the warhead is attached and is still over enemy territory. However, it requires surveillance over enemy regions to determine when and where missiles are being launched [6].

Israel's Arrow

In light of the acquisition of advanced missiles by Arab states, development of Israel's first anti-ballistic missile defense system, the Arrow, began in 1986 upon the signing of a memorandum of understanding with the United States. Overseen by the Israeli Ministry of Defence's Homa Administration and the U.S. Missile Defense Agency, the project has been funded and developed jointly by Israel Aerospace Industries and Boeing. Over $2.4 billion have been invested in the project by Israel and the United States [7].

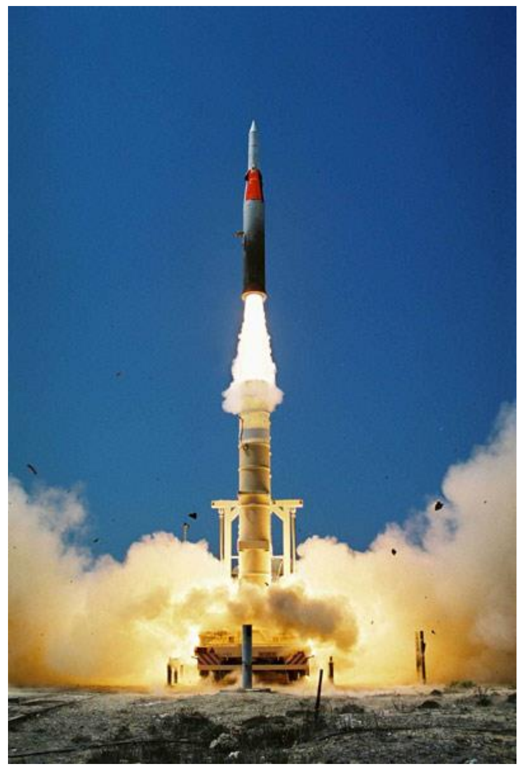

Figure 4
A successful launch for Arrow 2

Arrow 1

A three-phase plan was designed for the creation of the Arrow system. First, the Arrow 1, an experimental anti-ballistic missile, was created. A solid propellant missile, it stood 7.5 meters tall and weighed 2000 kg. Using infrared homing, the Arrow 1 could hit a target up to 50 km away. The Arrow 1's first test launch on August 9, 1990 was terminated early after failures in the ground tracking radar. A second launch on March 25, 1991 and a third launch on October 31, 1991 were also aborted due to malfunctions. A successful test finally took place on September 23, 1992. Continued testing led to a launch on June 12, 1994, in which the Arrow 1 successfully intercepted a target missile [8].

Arrow 2

The second phase of the Arrow plan was the development of a smaller, faster, and more accurate anti-ballistic missile, the Arrow 2 (see figure 4). Its first successful test destruction of a missile took place on August 20, 1996. Following more testing, the first operational Arrow 2 was delivered to the Israeli Ministry of Defense on November 29, 1998 [I]. Since then, continued improvements and testing have taken place. A ballistic target missile called the "Black Sparrow" has been effectively destroyed in many tests at various altitudes and speeds [8].

Arrow 3

The Arrow project has now moved into its third phase. The Arrow 3 will have a longer target detection range and superior target tracking and discrimination. Advanced sensors are being considered, such as airborne electro-optical sensors that can be deployed on unmanned aerial vehicles. As seen in figure 5, a key advancement is the pivoting seeker, a technology that allows more flexibility and accuracy in target detection [9]. Sensors may utilize visible and infrared elements to enable sensing in poor lighting conditions. Also important is the potential use of an exo-atmospheric kill vehicle that enables the missile to maneuver in space propelled by a rocket motor. The Arrow currently uses explosives that destroy its target, but plans are to destroy missiles through contact forces (similar to a bullet) rather than explosives.

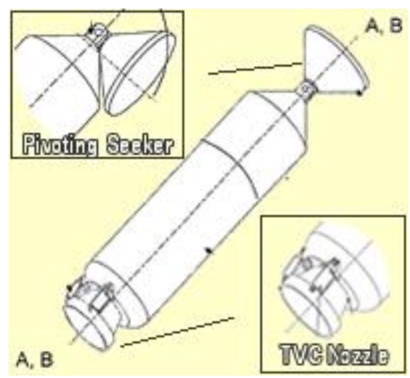

Figure 5
The seeker rotates to achieve optimal angles for target detection

Current Status

The Arrow is currently part of a layered system of missile defense in Israel. The existing Arrow Weapon System is designed to attack short-range ballistic missiles. Each battery system includes approximately 50 missiles, launchers, Green Pine tracking radar, Citron battle management center, and Hazelnut Tree launcher control center (see Figure 6). At this time, there are two batteries, and a third battery is being considered [10]. The system is mobile, so it can be placed where necessary in times of conflict. Each battery is capable of tracking 14 enemy missiles simultaneously. The maximum altitude of interception is approximately 50 km, and the range is approximately 90 km [6].

The Green Pine is a solid state radar operating in search, detection, tracking, and missile guidance. It is able to detect targets up to 500 km away and speeds at up to 3000 m/s. A Super Green Pine has also been developed that can detect targets up to 900 km away. The Green Pine's radar system illuminates the target so the Arrow missile can be directed to it with a precision of 4m [11].

The Citron battle management center downloads data from radar and other sources. It contains powerful signal processing capabilities that automatically manage threats. Inside, a sky situation coordinator, intelligence officer, resource officer, post mission analysis officer, senior engagement officer, and commander have computer workstations displaying a map of the battle area.

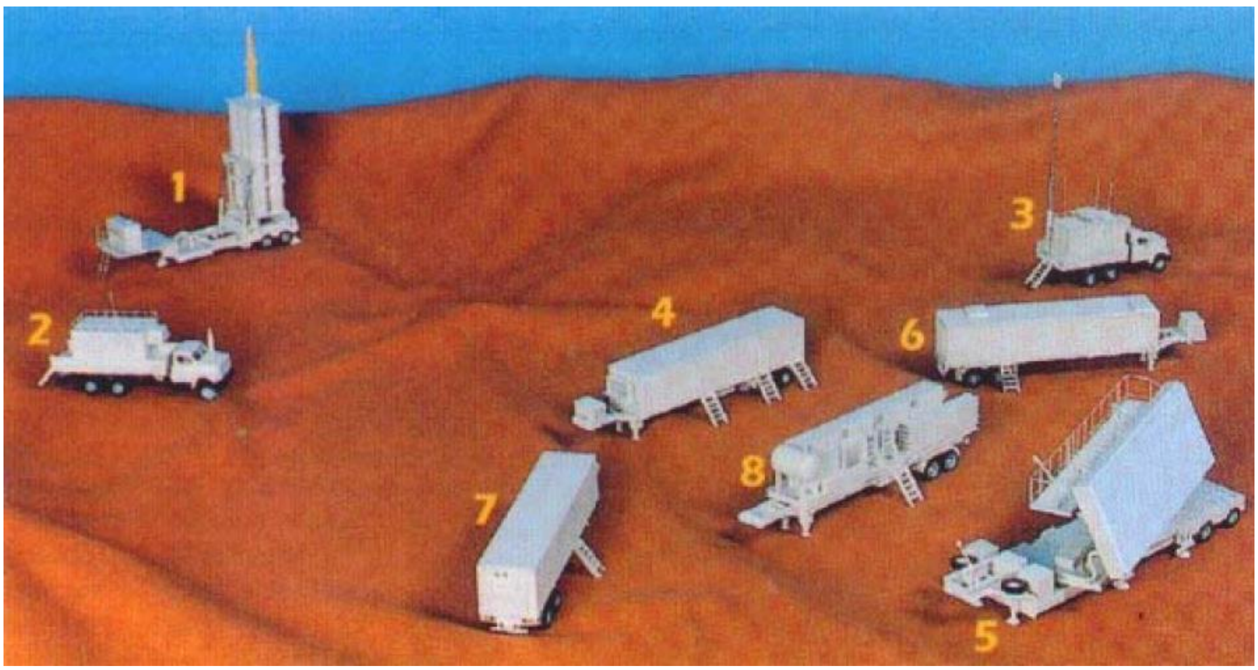

Figure 6
Arrow missile battery notional deployment
(1) Launcher (six canisters), (2) Citron battle management center, (3) Communications center, (4) Hazelnut launcher control center, (5) Green Pine radar antenna, (6) Radar control center, (7) Radar power unit, (8) Radar cooling unit.

What We Can Learn

Due to the controversial nature of missile development, there are many restrictions regarding research in this area. However, many of the technologies that were improved for use in missiles can also be applied to other areas. Knowledge gained from missile research could be applied to various aerospace applications such as civilian flight and space exploration. Control systems are also used in construction machinery, robotics, aircraft, ships, and many other applications [12].

As mentioned above, sensors are being designed for the Arrow 3 that utilize both visible and infrared elements. Previously at Washington University in St. Louis, research involving infrared sensing has been done by undergraduate students. A number of projects are currently in progress involving different aspects of robotic sensing. A future project would be to implement both infrared and visual sensing in a robot and develop a system that is able to combine both inputs of information for more effective source localization.

There are a number of non-military applications that can be considered. The sensing could be applied to pest removal, such as bug zappers and mouse traps. It could also be used for improved surveillance for businesses, homes, properties, and border control. Sensing could also help prevent collisions, for example, vehicle crashes. An application of missile technologies to personal defense would be to create tiny missiles that could hit bullets, preventing them from injuring police officers, civilians, or military personnel. Advanced sensing, guidance, and tracking capabilities enable many improvements to existing devices as well as the potential to create new and more sophisticated inventions.

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