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Connecting Earth and Space: A History of GPS

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Connecting Earth and Space: A History of GPS

by

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Introduction

The Cold War between the United States and the Soviet Union fostered fierce competition, especially when it came to the Space Race. The two forces were determined to conquer the new arena of space before the other. As a consequence, techniques and technology for using the unprecedented environment rapidly developed throughout the 1950s and 60s.

One of the prominent technological advancements of the Space Race was the beginning of Global Navigation Satellite Systems (GNSS). These systems are made of constellations of satellites that transmit timing and position information, allowing a receiver to determine its location on the Earth. This technology, which began as a military research project, has grown to impact governments and civilians across the globe.

GNSS works by having a constellation of satellites positioned in known orbits. Since the orbits are known, the satellites are able to keep track of their position and time using atomic clock modules. The satellites broadcast this information back to Earth's surface. Receivers are configured to read in GNSS data, which allows the system to calculate its location based on the signals and timing of the received information.

Several countries have their own versions of GNSS constellations. The United States and the Soviet Union were the first to begin research and development of GNSS, but since then other countries have felt the need to develop their own. The following are the primary GNSS constellations currently in operation [1] :

- Global Positioning System (GPS), United States of America
- GLONASS, Russian Federation (Previously operated by the Soviet Union)
- Galileo, European Union
- BeiDou Navigation Satellite System (BDS), People's Republic of China
- Indian Regional Navigation Satellite System (IRNSS) / Navigation Indian Constellation (NavIC), India
- Quasi-Zenith Satellite System (QZSS), Japan

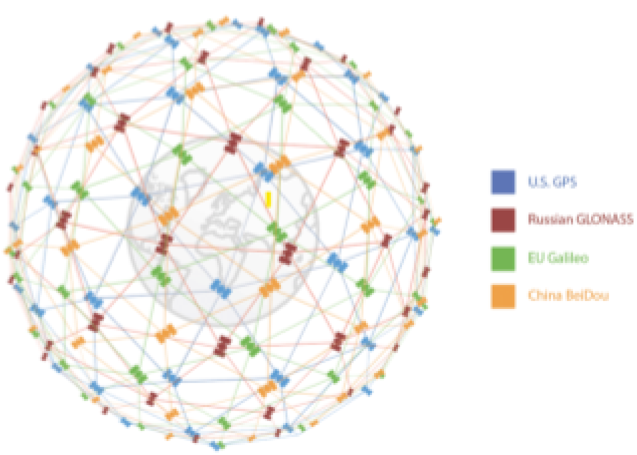

Figure 1. Global Navigation Satellite Systems
Image credit: Sparkfun

Each of these systems has stories of technological development and political intertwinings that could fill many books. Many of these nations even have reasons rooted in the others for operating their own navigation systems. This study focuses on the history of the Global Positioning System (GPS) developed and operated by the United States of America, while appropriately mentioning other nations when applicable. Specifically, the research will touch on how the development and operation of GPS has progressed throughout the years while also highlighting the historical connections of GPS with the state of Alabama, a technological hub of the southeast US. The rise of GPS has impacts across everything from military operations to civilian navigation, and even autonomous vehicle research and development. This engineering feat has had one of the most widespread impacts on humanity out of the space technologies that have been developed to date. The history of GPS as well as its future are worth studying to continue to use space developments as a manner of improving life on Earth.

Dawn of Satellite Navigation

Amid the Cold War, the United States and the Soviet Union were racing to create ballistic missiles as well as claim the victory of being the first country to reach the moon. As both rocket science and satellite technology continued to advance, the rivals became closer to achieving their goals. One of the accomplishments that each country worked toward was launching the world's first artificial satellite [2]. On October 4th, 1957, the Soviet Union would reach the goal by launching Sputnik I.

The US then went into a frenzy still working on their own satellite while also worrying about the repercussions of the Soviet Union having a satellite overhead the US. One of the delays that slowed down the development of the first US satellite was that scientists wanted the system to be technologically advanced, while President Eisenhower was interested in putting up a less advanced satellite quicker [2]. The Soviet Union was having similar dilemmas which is why they ultimately decided to launch Sputnik I consisting of a less complicated design. It included a radio transmitter, batteries, and unsophisticated scientific measurement devices.

This time period of satellite development has roots in Huntsville, Alabama. In 1955 the US government approved a plan to launch a scientific satellite and was choosing who to fund for the project. The competition was between the Naval Research Laboratory and the army’s Redstone Arsenal. At the time, scientist Wernher von Braun was working at Redstone Arsenal to develop the Redstone and Jupiter ballistic missiles. Von Braun led the effort out of Redstone Arsenal in their attempt to secure the funding to launch the first US satellite. However, the government ultimately chose to send the funding to Project Vanguard at the Naval Research Laboratory so as to not interfere with the ballistic missile development in Huntsville [2].

Just four months after the launch of Sputnik 1, the US was able to join the space age with a successful launch of Explorer I, the first US satellite to orbit Earth. However, US scientists were also studying the Soviet Union’s Sputnik satellites, of which two had been launched by early November 1957. Scientists at John Hopkins University were observing the radio signal being transmitted from Sputnik I when they realized it exhibited a Doppler effect [3]. This doppler shift meant that the frequency of the radio signals changed based on the position of the satellite. The frequency increased as the satellite approached the observation area and decreased as it moved further away. Two of the leading scientists studying this phenomenon were physicists W. H. Guier and G. C. Weiffenbach out of the John Hopkins Applied Physics Laboratory (APL) [3]. Using a combination of the shape of the Doppler Shift curve and orbital mechanics, the two were able to determine an orbit of the satellite based on the measured frequency being transmitted. Guier and Weiffenbach also pioneered techniques of removing errors in the signal caused by the Earth's atmosphere [3].

The then chairman of the APL Research Center, F. T. McClure invented the concept of satellite navigation by essentially reversing the findings of Guier and Weiffenbach [3]. Instead of determining the satellite orbit from a known receiver location, the unknown position of a receiver could be calculated if the orbit of the satellite is known.

The US Department of Defense became interested in this research as they were trying to work out a way of tracking submarines to use for launches of Polaris missile systems [4]. The Polaris missiles were Intermediate Range Ballistic Missiles (IRBM) that used solid fuel, compared to liquid fuel, for the safety of the submarines. The underwater projectiles were being developed for the US Navy with the help of Redstone Arsenal.

Transit

With the interest of tracking missile-launching submarines, in early 1958 the US Department of Defense decided to fund a research and development project titled Transit. This project was based out of the John Hopkins APL, where the concept of satellite navigation was developed. The primary goals of Transit were to develop and produce a spacecraft able to carry the satellites, determine methods of modeling Earth's gravity in order to track orbital paths, and create user equipment for the system [4].

By 1959, the team at APL, led by Richard Kershner and included Guier, Weiffenbach, and McClure, was making substantial progress on the system. They had already created satellite tracking software, established five tracking stations, and constructed Transit 1A. Transit 1A was the first satellite developed for the project and was used as an experimental concept demonstration [5]. The goal of its launch was to show the capability and feasibility of a world-wide satellite navigation system that would provide positioning information in all weather conditions. Transit 1A was launched in September of 1959, but was unable to achieve orbit because the third stage of the launch vehicle failed to ignite. It achieved an altitude of around 400 miles before falling back to Earth. The satellite, although unable to make orbit, still allowed the researchers at APL to collect enough data to show the potential of the technology [5].

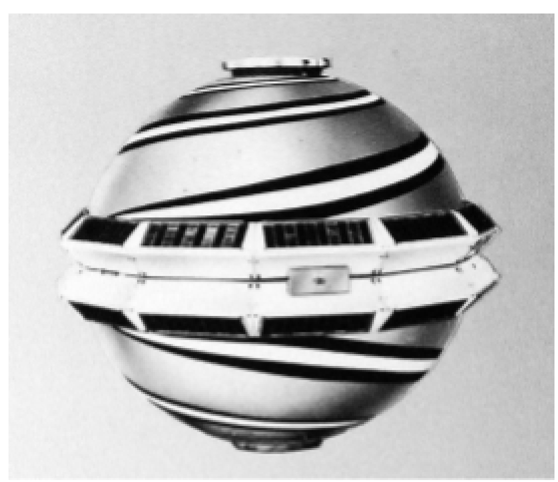

Figure 2. Transit 1B Satellite
Image credit: National Museum of the U.S. Navy

The second satellite of the program, Transit 1B, successfully launched in April, 1960. This was followed by a series of experimental satellites that allowed researchers to identify problem areas and improve the quality of the satellites. Experimental satellites continued through the series 1 through 4 of the Transit satellites.

One of the biggest challenges faced during the Transit project was the effects gravity had on the orbit of the satellites. This led to both APL and NASA expanding their efforts of modeling the Earth's gravitational field, as it was the largest contributor of position error at the time [5].

The series 5 satellites were called the operational prototypes. By this time, much work had been done to improve the navigation techniques and solve errors in gravitational variations. This generation had functioning navigation systems and was used to finalize decisions regarding power generation systems and orbital mechanics. The series 5-A and 5-C prototypes used solar power, while the 5-BN used nuclear power. The nuclear powered prototypes provided sufficient power, but the ultimate decision for the operational series was to go with solar-powered satellites. This was due to safety concerns of the radioactive material of the 5-BN series.

The final stage of the Transit project was the operational satellites, also called the Oscar satellites or the Transit O series. The satellites in this stage were similar to those of the series 5, however one improvement was the addition of hysteresis rods on the solar panels which aided in satellite stabilization in orbit [6]. The first 12 Oscar satellites had quality assurance issues that led to unsatisfactory missions. The Naval Avionics Facility in Indianapolis (NAFI) was in charge of building the satellites but were deemed unfit for the project after several failed missions in 1964 and 1965. Oscars 1 and 2 were launched into orbit but only operated for a few days. Oscar 3 failed to reach orbit and Oscars 5 and 7 operated for a few weeks. The project was sent back to APL who refurbished Oscars 4, 6, 8, 9, and 10 and improved their life-span to seven to eleven months [6]. APL also built the eleventh through seventeenth O series satellites and the project was transferred to RCA for eighteen onward.

The transfer of the Transit operational stage to APL and RCA opened a new chapter for the project. Starting with Oscar 12, and continuing to the last of the 32 Transit satellites, the lifetime of each one was more than 14 years in orbit [6]. The longevity of two of the satellites, Oscar 13 and 20, was over 20 years of operation. The Transit project officially ceased operations at the end of 1996.

The challenges at the beginning of Transit paved the way for developing techniques and improving the understanding of satellite navigation. It showcased the potential of space-based positioning and demonstrated the reliability of satellites. Transit was also pivotal in the development of Earth gravitation models and algorithms for tracking and predicting satellite orbits [4]. With satellites orbiting the Earth providing reliable two-dimensional location data, Transit was the world's first satellite navigation system.

Global Positioning System (GPS)

While the Transit project was developing its later stage satellites, other parties were also working on technologies that would improve navigation.

The United States Naval Research Laboratory (NRL) established the Timation project 1964 with the goal of establishing the ability to transmit accurate time data. The project, short for ‘time navigation’, developed spacecraft containing very accurate atomic timepieces capable of transmitting timing information. This information would allow a navigator to determine the two-dimensional location of their ship [7]. In 1967, the first Timation satellite was launched which initiated the use of crystal oscillator and atomic clocks in space.

Separately, the United States Air Force (USAF) was studying methods of tracking three-dimensional positioning and navigation. Proposed by the Aerospace Corporation, ‘Project 621-B’ conceptualized the use of an algorithm incorporating pseudo-random noise to create ranging signals [4]. This concept created the foundation for three-dimensional positioning using signals transmitted from satellites. The Aerospace Corporation would go on to provide many engineers to work on the developing navigation system.

Because the NRL and USAF were both working on navigation techniques, the US Deputy Secretary of Defense decided to combine the two projects. Using the preciseness of atomic clocks from NRL and the three-dimensional techniques being studied at the USAF, a team was created to realize a navigation system that went beyond the capabilities of its predecessor Transit. The project, established on April 17, 1973, was called the Navstar Global Positioning System (GPS) Joint Project Office (JPO). The office would be led by Colonel Brad Parkinson, who was the first head of JPO and stayed in that position for six years [4].

Figure 3. NAVSTAR Promotional Sticker
Image credit: Colorado State University

The development of the GPS has evolved over the years and has consisted of three primary generations, called blocks. The first block was the developmental stage and consisted of the first satellites to become operational. The second block focused on making improvements to the current technology, and the third block is the modernization of the system, introducing new capabilities [8].

Block I

The first contract for the space development of GPS was awarded to Rockwell International in June 1974. They were tasked with creating a navigation payload that would launch on the NRL satellite NTS-2 and to develop the first three GPS prototype satellites [4]. The contract was later expanded to include 11 total satellites.

In June 1977, NTS-2 was launched and the first GPS signal was transmitted from space [4]. The satellite failed after orbiting for only eight months, but in February of 1978, the first GPS prototype satellite was successfully placed into orbit. By the end of 1978, there were four prototypes in place that allowed scientists to test the three-dimensional navigation capabilities. Since the constellation was small, the time and location of the signals was limited, but it still proved useful in showcasing the navigation capabilities. In September of 1980, the system was tested by an Aries Polar Flight which was flying over the north poles [4]. The aircraft was able to receive the navigation signals and successfully lock onto the satellite constellation.

The Block I generation established the two L-band navigation communications, which consisted of L1 at 1575.42 MHz and L2 at 1227.60 MHz [9]. These signals were transmitted back to Earth containing the positioning data needed to establish a location on the Earth's surface. The system was originally available for military use only, however, after a Korean airlines flight went off course and was shot down by a Soviet aircraft, US President Reagan declared in 1983 that GPS would be available for civilian use [4]. The US military put one condition on the release of GPS called Selective Availability (SA), which deliberately downgrades the accuracy of the system. The SA techniques were implemented by intentionally creating a "jitter" in the timing of the atomic clocks on the satellites. This caused the location data to jump around with an accuracy of around 100 meters. The military was still able to access the correct positioning data by entering a classified key to authenticate the application with an accuracy of 10 to 20 meters.

Another aspect of the GPS that was being developed in tandem with the satellites was the ground and user segments, which was awarded to General Dynamics in 1974 [4]. Development of the ground station control systems were implemented in California at Vandenberg Air Force Base (AFB) and the user segment was contracted to Magnavox out of Arizona. The user segment included the receivers that would gather the satellite signals. The testing of the receivers began in 1977 and used artificial signals until the actual satellite signals became available [4]. GPS satellites and receivers were being tested by the Navy as early as October of 1978 for two dimensional navigation.

Block I satellites continued to be launched through October of 1985, with eleven satellites making up this block. These satellites were slated to have operation lifespans of five or less years, but many of them outlasted the prediction with the last Block I satellite being retired in 1995. The Block I satellites could operate for three to four days without contact to the ground control centers, which are vital in ensuring the orbit and clocks are properly calibrated [8]. Another limitation of Block I is that the positioning information was not available at all times because of the limited number of satellites orbiting the earth. This also consequently impacted the accuracy (which was 10 to 20 meters for military use at the time) as a receiver was only able to reference a limited number of satellites.

Block II

In February of 1989, the first Block II satellite was launched and the new generation became fully operational by August of the same year [4]. There were several similarities between the Block II satellite and its predecessors, such as the atomic clocks (two rubudium and two cesium), and the continued use of the L1 and L2 frequency bands [10].

One of the primary advantages of the Block II satellites is that they were designed to operate for longer periods of time without receiving updated information from the controls segment of the system [13]. Another difference between Block I and Block II was the angle of orbit with respect to the equator. Block I was launched with an angle of 63 degrees, while Block II was launched with an angle of 55 degrees, to improve coverage [10]. Block II satellites were the first to implement the Selective Availability that President Reagan had earlier announced. This meant that certain signals were reserved for military use that could be accessed using a classified authentication method, while others could be used for civilian purposes.

Block II was instrumental in the advancement of the GPS constellation and therefore led to sub generations within itself. This includes the original Block II and then expanded to Block IIA, Block IIR, BlockIIR(M), and Block IIF. Each of these generations were improvements from the previous generation.

Rockwell International was awarded Block II and later went on to improve the system with the Block IIA satellites. The original Block II satellites consisted of nine spacecraft that were launched between 1980 and 1990. Compared to the Block I satellites, Block II had encrypted data and could operate for 14 days before requiring an upload from the ground control segment [13]. The longest lasting of the Block II satellites was decommissioned in 2007, after outliving its estimated 7.3 year design life [13].

The Block IIA, “Advanced”, satellites expanded upon the Block II satellites. They operated from November 1990 to November 1997, with a total of 19 satellites in orbit. The Block IIA satellites primarily improved the length of time without communication to the ground control segment. These satellites could operate for up to six months without receiving messages, however, such conditions would degrade the reliability of the timing and location data [13].

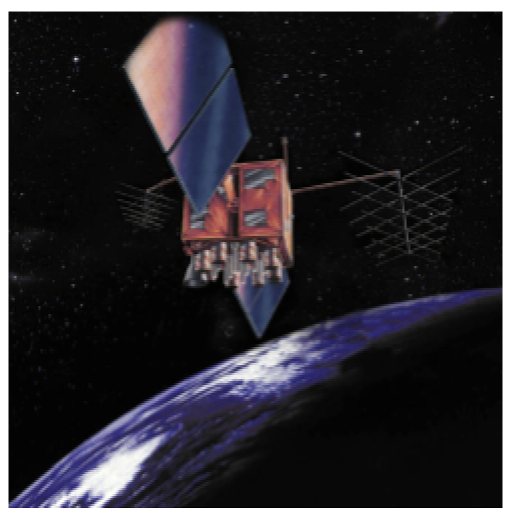

Figure 4. GPS Block IIR Satellite
Image credit: US Government

Lockheed Martin upgraded the satellites for Block IIR, or Block II “Replenishment”, to have better clocks. Between July 1997 and November 2004, the satellites were launched to provide better accuracy and longer station to satellite communication sessions [13,15]. This generation also improved the autonomous capabilities of the spacecraft allowing for the on-board computer to make orbit corrections [13]. It was also decided that Selective Availability would be disabled during this generation, because augmentation methods were being developed by civilians that improved the accuracy to essentially bypass the SA inaccuracies. This change took effect in May 2000 under the direction of President Bill Clinton and altered access so that the military and civilians were able to receive the similar data [1]. This changed the civilian accuracy from around 100 meters down to between 10 and 20 meters. There are still some of the Block IIA satellites in use of the GPS constellation to date.

In 2005, Lockheed Martin’s set of Block IIRM satellites began launching. These eight Block IIR “Modernized” satellites added new frequency bands to the list. Instead of civilians only having access to one frequency band, civilians now had access to a second frequency band, L2C [15]. The military also gained access to the new M code frequency band and a demonstration of the L5 band was conducted, allowing an increase in security and accuracy [13,15].

From May 2010 to 2013, Boeing launched the last set of Block II satellites, Block IIF. Block IIF, known as both Block II “Future” and Block II “Further”, has improved atomic clocks and expanded upon the additional L5 frequency band. The life expectancy of the satellites was improved to be 12 years and the onboard navigation units were able to create new messages. [15]

During development of the Block II systems, the ground and control segments also needed to be updated to keep up with the progress. The main control segment of the ground segment, located at Schriever Air Force Base, got a major remodel which included upgrading mainframe computers and distributing the architecture [4]. This also meant creating an alternate control center at the Vandenberg tracking station and upgrading antennas and receivers.

Block II has provided much of the development of GPS to date and has fabricated reliable spacecraft that have outlived their expected operational lifespan. Many of the Block II satellites, starting at the “Advanced” stage, are still used in the current GPS constellation. Block II saw the accomplishment of operational capabilities of GPS when 24 satellites were functional within the system. Although accuracy throughout Block II remained at 20 meters or less throughout its progress, it saw increased lifespans, the introduction of the M and L5 bands, as well as improved atomic clocks onboard. Though several accomplishments and improvements have been made within Block II, Block III is projected to advance GPS to even greater heights.

Block III

Block III is the current generation of the GPS constellation and development. In 2006, Lockheed Martin, funded by the USAF, was chosen to conduct a system design review (SDR) to develop a concept for modernizing the next stages of GPS. The company was then awarded the opportunity to pave the way for the next generation of GPS with the development and fabrication of the first Block III satellites [4].

The new generation of satellites was originally slated to hold a naming convention of Block IIIA, IIIB, and IIIC. However, the current documentation from Lockheed Martin has moved to calling the current satellites simply Block III with future plans of developing the Block III Follow On stage (IIIF) [16].

One of the primary upgrades to the system that is achieved with Block III is the development of anti jamming technologies [13]. Whether intentionally or deliberately, GPS jamming is relatively easy and is becoming more of a problem as it can disable the user from receiving position data. These satellites also improve accuracy up to three times and allow for a modular design should improvements be needed later [16]. The first Block III satellite was scheduled to be launched in 2014, but significant delays pushed this back. On December 23, 2018 the first Block III satellite was launched, with the second in August of the following year. To date there are six Block III satellites that have been launched and made operational within the constellation. There are also four more Block III satellites that have been created and are on reserve for launch when needed.

These satellites have a 55 degrees orientation with respect to the equator, similar to Block II. They also currently have a wide variety of broadcast frequencies, spanning across L1, L2, L3, L4, L5, and L6 bands, along with new military codes [11]. Block III as a whole will have increased timing data from the three rubidium clocks and the hydrogen MASER clocks [13].

Block IIIF will expand upon the current Block III satellites. Lockheed Martin is currently under contract to create up to twenty two satellites as a part of this stage [16]. The Block IIIF will implement even greater anti jamming capabilities (up to 60 times greater) to ensure GPS access to the US military and allied forces. It will also implement a laser retroreflector array which will improve accuracy and new payload that will expand the capabilities of search and rescue missions to be satellite-supported [13].

The accuracy of GPS has been improved to five to ten meters with the improvements made using the current Block III satellites. The future additions of Block IIIF expect to increase the accuracy of the system to one to three meters.

The Block III and IIIF are modernizing the GPS constellation and integrating new and innovative ideas into the system. The current Block III satellites are already improving the system and replacing the older generations as needed, while the Block IIIF are still in development and will eventually create state of the art navigation capabilities.

Additional Improvements

As GPS has developed and been opened for civilian use, external parties have developed their own methods for improving the accuracy of the signals that are received from the GPS satellites. These methods are called augmentation systems since they are not a part of the GPS itself [1].

Differential GPS, or DGPS, was developed in the late 1980s. The primary goal behind DGPS was to counteract the Selective Availability of the current GPS signals, which had an accuracy of around 30 meters [14]. A grounded reference station with very accurate ECEF (Earth Centered, Earth Fixed) coordinates would broadcast correctional data to local GPS receivers. So long as the receivers are within a certain range, they would have about one to three meters of accuracy. This calculation is done by comparing the pseudo random codes (PRN) of the base stations received GPS signal [13,14]. Although this increase in accuracy is better, DGPS would continue to be improved to create an even greater level of accuracy.

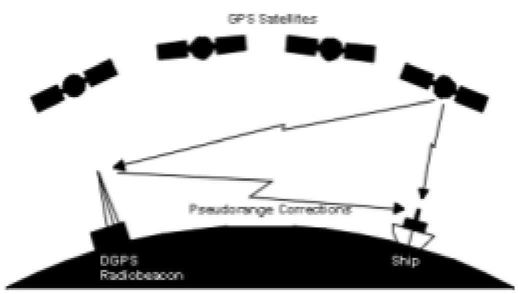

Figure 5. Differential GPS Concept
Image credit: Sparkfun

Real Time Kinematics (RTK) is a technique built on the theory of DGPS. Invented in the 1990's, RTK uses a base station that broadcasts correctional data to local GPS receivers, like DGPS. However, RTK uses the phase of the GPS signal to perform a more rigorous error calculation in order to create the correctional data. By this technique, one to three meters of accuracy from DGPS can now become centimeter level accuracy, also in real-time [19].

Future Developments

With the continuing development of geospatial and navigation applications, it is inevitable that GPS technologies and techniques will continue to improve. For instance, several predicted factors will greatly increase the reliability of GPS. If more satellite constellations were to be launched, there would be a correlating increase in GPS reliability and accuracy [12].

Furthermore, the satellites are beginning to include passive hydrogen MASER (PHM) atomic clocks, which further increases the timing accuracy. With the PHM atomic clock, the error is only 0.00000036 seconds, resulting in a much smaller offset. This clock upgrade will greatly diminish the inaccuracy of previous GPS readings [12].

Another improvement is implementing CORS, Continuously Operating Reference Station. CORS is essentially RTK and Precise Point Positioning (PPP) techniques on a larger scale. CORS involves a grid of multiple base RTK stations, which improves the signal to noise ratio. This also allows more coverage area for any rover modules using the stations. [12]

It is also planned for the Block III satellites to continue to develop and implement new technologies. One aspect of this is by significantly improving the anti jamming capabilities of the satellites currently slated for up to sixty times greater [16]. Another dimension of satellite navigation is expanding the technology to new applications. One such plan is to add Distress Alerting Satellite System (DASS) repeaters to the spacecraft starting at Block IIF [13]. This will open new possibilities in the field of search and rescue, allowing satellite-supported missions. Increasing accuracy to sub-meter may also open the doors to more reliable autonomous operations for both ground and air-based vehicles.

Alabama Contributions

Throughout this study, there have been many mentions of the satellites that have been launched to achieve the development of the GPS constellations. Although much of the research and fabrication of these satellites was completed around the country in states such as Maryland, Colorado, and California, there is a place in the history of GPS that would not have been possible without the contributions made in Alabama.

In the early stages of satellite navigation, the field of geodetic studies rapidly grew. First beginning at APL to understand the effect the gravitational field had on satellites, NASA decided to create its National Geodetic Satellite Program in 1964 to aid in these efforts. As a result, NASA developed a geodetic payload, called Lageos, that was designed from the NASA Marshall Space Flight Center in Huntsville, Alabama [5].

Figure 6. Atlas V Rocket
Image credit: NASA

The concept of three-dimensional satellite navigation is largely credited to engineers from the Aerospace Corporation. Although the navigation engineers who pioneered the design of the navigation system were based primarily out of Virginia, the Aerospace Corporation now has an office in Huntsville, Alabama. It is focused on furthering the future of space and missile defense by supporting projects at the Missile Defense Agency, NASA’s Marshall Space Flight Center, United Launch Alliance, and the Missile and Space Intelligence Center.

The largest contribution to GPS that has come out of Alabama is the launch vehicles that enabled the placement of satellites into orbit. A majority of the rockets that held the navigation satellites as payloads were designed or fabricated in northern Alabama.

The first Transit satellite to make orbit, Transit 1B, as well as many more Transit satellites through the series 5, was launched on a Thor-Ablestar rocket. This rocket was a product of transitioning the Thor intermediate-range ballistic missile (IRBM) into a rocket. Much of the testing done for the Thor missile and later rocket generations was done in Huntsville at the Redstone Arsenal.

The following generations have been launched on many different vehicles including the Delta II, Delta IV, Falcon 9, and Atlas V with future plans of using Vulcan Centaur rockets. The Delta IV, Atlas V, and Vulcan Centaur rockets have all been manufactured in Decatur, Alabama by the United Launch Alliance (ULA). It is currently planned that all future launches of the GPS Block III satellites will be launched using Vulcan Centaurs as the launch vehicle. All of these rockets will be produced in Decatur, AL, with ULA expanding the facility in 2024 to reach its goal of launching 25 Vulcan Centaur rockets a year.

Conclusion

From 1957 to today, satellite navigation has made tremendous progress throughout its developmental life. What started as a political and military stratagem has now become heavily popularized for everyday civilian usage as well as military aid.

From the beginning concepts of satellite navigation being developed through the tracking of the Soviet satellite Sputnik, the idea would grow into a much larger and more important project for the United States over the coming decades. The military endeavor had its origin as the developmental Transit system designed to demonstrate the concept of satellite navigation, successfully showcasing two-dimensional reliability. As other entities continued to study three-dimension navigation and improved timing data, the Global Positioning System (GPS), as it is known today, would be officially born in 1973.

The GPS constellation has gone through many improvements throughout the years. The generations of GPS - Block I, Block II, and Block III - have built on the lessons learned from those that came before it, and they implemented the latest technologies with the goal of creating available location information across the globe. Inaccurate readings from the first satellites and selective availability have even inspired the innovation of augmentation techniques to achieve centimeter level accuracy. The future of GPS, currently lying in Block III, aims to implement new technologies that innovate navigation satellites to advance applications in ways unheard of before.

The navigation and positioning data retrieved from GPS satellites is used in an expansive amount of fields across the globe. Civilians will be most familiar with the navigation capabilities for wayfinding. This includes path planning for getting from one destination to another such as through a smartphone or vehicle application. Tracking capabilities are also being added to smart devices, such as phones and watches, to track health-related information, such as the amount of steps taken, and exercise tracking, such as the path and mileages of a run. GPS is also an integral part of aviation, ensuring that aircraft are able to stay on path and make it to the correct destination. Unmanned aircraft and ground vehicles are also beginning to rely more on positioning information as the push for autonomous vehicles grows within the tech industry.

The root motivation for GPS had begun as a military endeavor and has continued to remain useful to US forces as it has developed. With the original goal of tracking submarines for the launch of inter-continental ballistic missiles, GPS has been instrumental in tracking ships navigating the seas. Through guided munition strikes to tracking troops in the field and aiding in search and rescue missions, the US military would not be in the position it is today without the help of GPS navigation. The system is even being improved for anti jamming capabilities to ensure the safety and reliability of the system for military uses.

As seen from the predicted future developments, the trajectory of GPS's success seems unbounded. GPS has shown invaluable to both civilian and military uses and has gained the merit to continue development. Plans are currently stated to continue research and upgrades through Block IIIF until at least 2034, with the likelihood of furthering the development in future years.

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