SSC18-XXX-X

Kestrel Eye Block II

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ABSTRACT

Kestrel Eye (KE) is a microsatellite technology demonstrator for the US Army Space and Missile Defense Command (USASMDC) / Army Forces Strategic Command (ARSTRAT) developed by Quantum Research International, Inc. and Adcole Maryland Aerospace (AMA). Kestrel Eye weighs approximately 50 kg and provides electro-optical images with tactically useful resolution as requested by the warfighters in theater. The warfighters in theater will task and receive data from the satellite during the same pass overhead. The data can be downlinked directly to provide rapid situational awareness to our Army Brigade Combat Teams in theater without the need for continental United States relays. By using a small satellite, the required logistics footprint in the field is reduced as compared to an Unmanned Aerial System (UAS). In addition, developing a constellation of small satellites increases survivability and provides graceful degradation as no individual satellite is critical to the functioning of the constellation. Once Kestrel Eye reaches production, it will have a relatively low cost at approximately $2 million per spacecraft and will have an operational life of greater than one year in low earth orbit. With its low cost, large numbers of satellites can be procured enabling the system to be dedicated to the tactical warfighter. Kestrel Eye was successfully deployed from the International Space Station on 24 October 2017. The performance of this satellite is now undergoing investigation to validate the specifications of the satellite are met. The checkout investigation is being performed jointly by a ground station in Huntsville, AL operated by USASMDC/ARSTRAT and one in Hawaii operated by United States Pacific Command (USPACOM). At the conclusion of those investigations, the satellite will undergo a series of exercise experiments to evaluate if similar satellites could support critical operations. If the experiments are successful, it is expected satellites of similar capability can be procured/operated at a low cost. This paper provides the background and development of Kestrel Eye as well as a current status of the orbital mission.[1]

INTRODUCTION

Imagine a small U.S. military unit about to be inserted into hostile territory. As the sun rises, the commander requests an updated image of the landing zone – and learns that several large military vehicles have moved into the vicinity overnight. The mission is rapidly scrubbed, saving U.S. lives and preserving the element of surprise for another day. This type of responsive imaging capability, controlled directly by the battlefield commander for situational awareness and rapid decision making, may soon be delivered to U.S. Combatant Commanders all over the world thanks to small satellite technology being integrated into the U.S. Army Space and Missile Defense Command / Army Forces Strategic Command (USASMDC/ARSTRAT) Kestrel Eye program. After Kestrel Eye is proven effective in a Joint Concept Technology Demonstration (JCTD) over the next year, this advance will set the stage for an affordable constellation of small Intelligence, Surveillance, and Reconnaissance (ISR) satellites with the capability to provide persistent coverage over a significant fraction of the entire globe.

Game-changing technology starts with a visionary idea. In 2005, Steve Fujikawa and Dr. George Sebestyen of Maryland Aerospace, Inc. (MAI, now Adcole Maryland Aerospace (AMA)) conceived of an imaging microsatellite and took their idea to the Defense Advanced Research Projects Agency (DARPA) Tactical Technology Office (TTO). DARPA recognized the value of the concept and provided MAI with funding to develop key technologies. Fujikawa named the fledgling program *Kestrel Eye* in reference to the keen vision of a

[1] Distribution A: Approved for Public Release, USASMDC/ARSTRAT Release #8018, dtd 08 Feb 2018

small, agile bird of prey. DARPA later transitioned the successful Kestrel Eye study to USASMDC/ARSTRAT in 2007, where the study was transitioned into the Kestrel Eye Block I program in 2008. Before Block I was completed, the Block II (see **Figure 1**) program was initiated as a JCTD in 2013. The Block II program significantly enhanced Block I by adding a star tracker for more accurate pointing, larger reaction wheels for more rapid slewing, and a propulsion system to control the relative phasing of a future constellation of Kestrel Eye ISR satellites.

Figure 1: Kestrel Eye Block II Satellite

MISSION

Kestrel Eye is a rapid response tactical imaging system and will extend the Unmanned Aerial Vehicle (UAV) paradigm into space. Spacecraft fly much higher than UAVs, providing views of much larger regions, coverage of denied areas, and less risk from ground-based threats. USASMDC/ARSTRAT believes that Kestrel Eye's Microsat technology will eventually lead to dramatically lower unit costs, allowing proliferated numbers of small satellites to enable a system dedicated to and operated directly by the warfighter in theater. USASMDC/ARSTRAT envisions that the small size and low cost of Kestrel Eye will allow for a large constellation that will provide affordable, persistent presence and graceful degradation in the event of losses – whether attributable to launch failures, on-orbit anomalies, or hostile action.

Operations Concept

Kestrel Eye was specifically conceived to simplify the process for collecting tactical imagery in a way that would significantly shorten the cycle time between the request for an image and delivery of the requested image back to the requesting warfighter. **Figure 2** illustrates the operations concept for Kestrel Eye in a simplified manner by the following three major process steps: (1) Battlefield commanders identify an area they wish to image using map coordinates such as latitude and longitude. The warfighter's request for imagery is relayed to a local command center that is connected by existing tactical communications networks. The request is prioritized and merged with other imagery requests from other units in the same theater and is then uplinked to the Kestrel Eye spacecraft as it rises over the battle area. (2) The Kestrel Eye satellite receives requests for multiple images and begins a sequence of maneuvers to capture as many requested images as possible in an optimized set of attitude slews. As the line of sight settles on each targeted coordinate, an image is snapped before beginning a slew to the next target. (3) The image is compressed and metadata is attached using National Imagery Transmission Format (NITF) standards. During the same communications pass, the captured image is rapidly transmitted to the ground and then communicated via tactical networks back to the requesting warfighter. The entire process can take place rapidly.

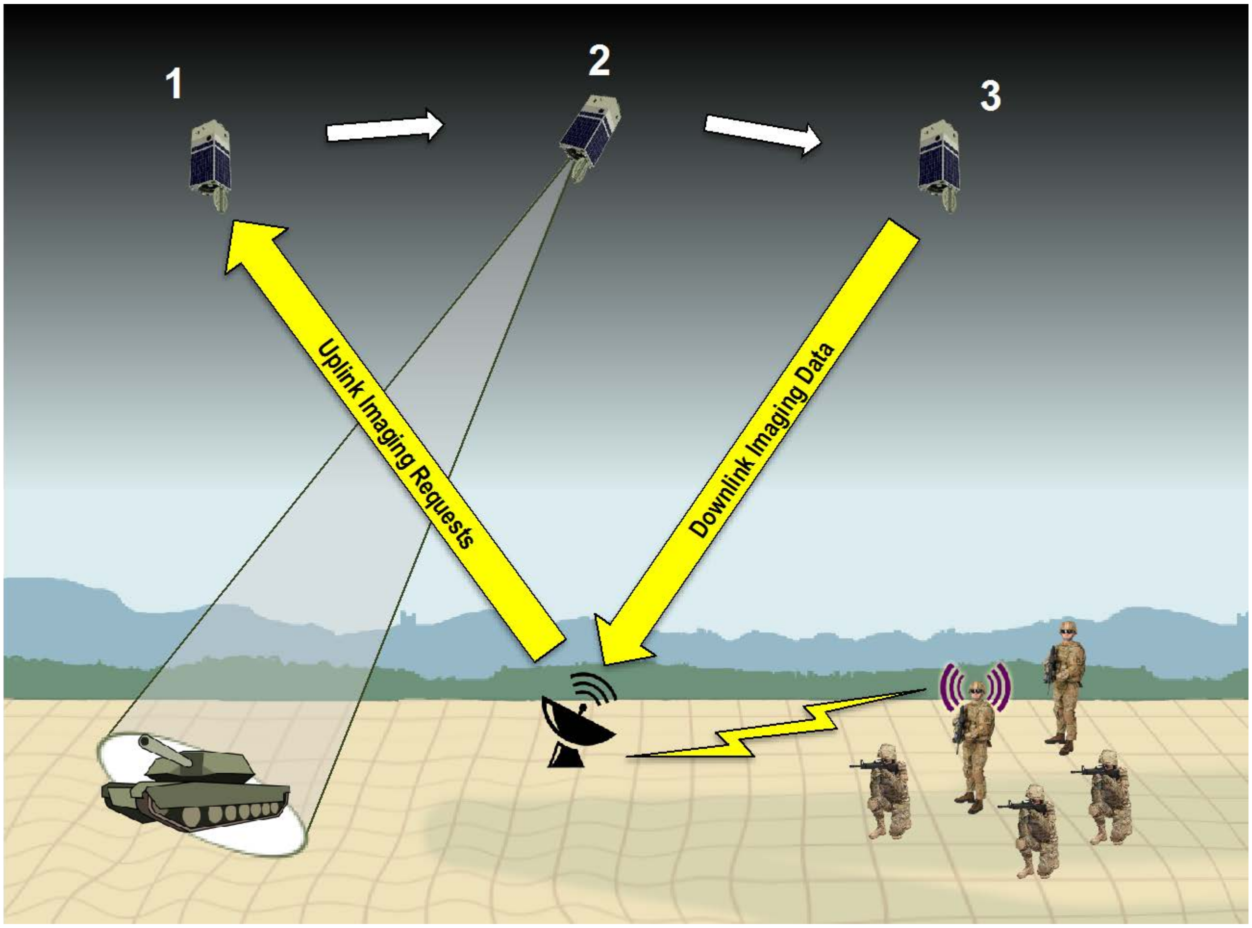

Figure 2: Simplified Kestrel Eye Operations Concept

SYSTEM OVERVIEW

The Kestrel Eye Satellite System is comprised of multiple elements including the Mission Payload, Spacecraft Bus, and Kestrel Eye Ground System (KEGS). Each of these elements is described in the sections that follow; representative examples of these elements have been used in the JCTD being currently conducted. At the conclusion of the JCTD, lessons learned from this activity can be applied in the development and fielding of an objective system.

MISSION PAYLOAD

The Kestrel Eye spacecraft is designed and built to be a tactical ISR satellite. As such, it is driven by and built around the characteristics of its mission payload. The core of the mission payload is a Harris Corporation 10-inch telescope, shown in **Figure 3.** This lightweight, compact, space-qualified telescope mounts to the spacecraft at three aft hard-points and provides an optical interface that easily couples to a Commercial-Off-The-Shelf (COTS) camera. This flexible interface allows the telescope assembly to be integrated to the spacecraft late in the flow and provides adaptability in the future as new cameras become available with either improved sensitivity or changes in imaging wavebands.

Figure 3: Harris 10-inch Telescope

The Harris Telescope mates to a high grade industrial COTS camera. The camera is an advanced, rugged and extremely programmable camera series focused on the military and aerospace market. The camera features a thermally optimized design, low noise, and large dynamic range. The camera uses industrial components assuring dependable use across both a wide temperature range and a wide vibration spectrum. The flexibility and interface of this unit provides for an easy upward growth path for Kestrel Eye. The combination of the Harris 10-inch telescope and the camera yields 1.5m Ground Sample Distance (GSD) imaging from the objective altitude of 500km.

Each image from the camera is captured using a COTS frame grabber and is then compressed onboard and formatted using NITF standards for transmission to the ground. The use of the NITF format for images allows these images to be easily transmitted, stored, retrieved, analyzed, ingested, manipulated, and exploited with readily available, widely promulgated tools used in the DOD and Intelligence Community.

SPACECRAFT BUS

AMA's Kestrel Eye Block II spacecraft bus is described in detail in the subsections that follow. Please refer to the Block Diagram in **Figure 4** and the configuration diagram in **Figure 5** for the subsections that follow.

Electrical Power Subsystem (EPS)

The Block II EPS uses four body-mounted solar arrays to generate power. This approach simplifies the spacecraft ConOps and configuration by generating power in virtually any attitude without the need to deploy solar arrays. The Separation Electronics Package (SEP) ensures that the spacecraft is not powered until separated from the Launch Vehicle. The SEP also contains circuitry that aids in safely powering down and recovering the system in the event of low states of battery charge. Upon separation, the arrays are connected to the charge regulator and battery charge electronics to charge the Lithium Ion (Li-Ion) battery. Borrowing from CubeSat and NanoSat roots, the Block II Li-Ion battery is comprised of sixteen battery cells typically used in laptop computers. These cells have been very carefully tested, screened, selected, and packaged to meet applicable safety standards and enhance the robustness and reliability of the Block II battery. Voltage regulation and power distribution electronics provide switched and regulated power to other subsystems as commanded.

Communications Subsystem

The Block II spacecraft uses two quadrifilar helix antennas on the (typically) nadir-facing end of the spacecraft and two patch antennas on the (typically) zenith-facing end. These four antennas – one receive and one transmit antenna each on the nadir and zenith ends – are connected to the command receiver and telemetry transmitter respectively using directional couplers. This arrangement allows for continuous communications to the ground at any attitude with improved link margins in attitudes where the quadrifilar helix antennas are facing the ground. The Quasonix S-Band command receiver and telemetry transmitter are COTS products originally built for aircraft use but readily adapted for spacecraft applications. These units signal to the ground using Offset Quadrature Phase Shift Keying (OQPSK) modulation at data rates of > 1 Mbps on the downlink using a variable power transmitter.

Command and Data Handling Subsystem (C&DH)

The Block II C&DH Subsystem consists of three 4-inch square CubeSat form-factor boards including the AMA System Interface Board (SIB), a COTS PC-104 Image Processor, and the COTS Active Silicon Phoenix Frame

Grabber. The SIB provides all of the in-flight interfaces to the ground for command reception and telemetry transmission as well as all software and hardware interfaces for command processing. The Frame Grabber provides the direct interface to the camera to capture and store images for transmission to the imager, for processing. The imager is used for computationally intensive activities such as image processing and NITF formatting prior to transmission to the ground system.

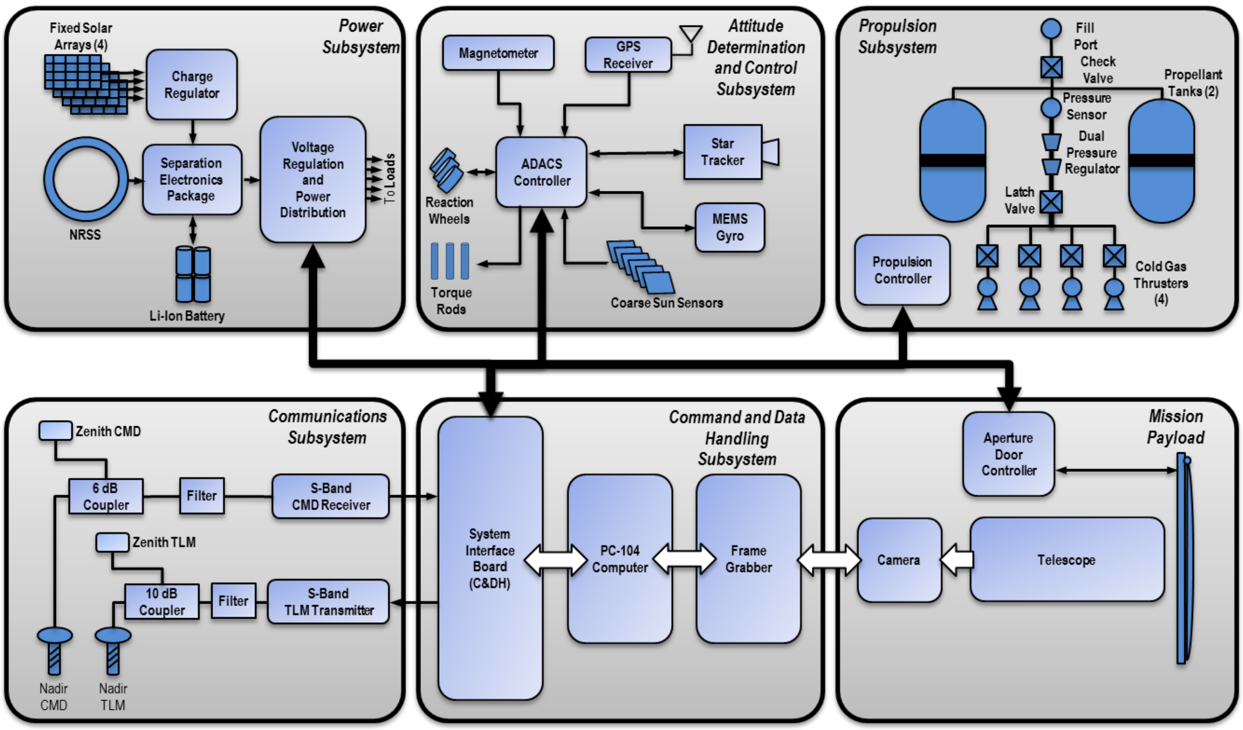

Figure 4: Kestrel Eye Block II Spacecraft Block Diagram

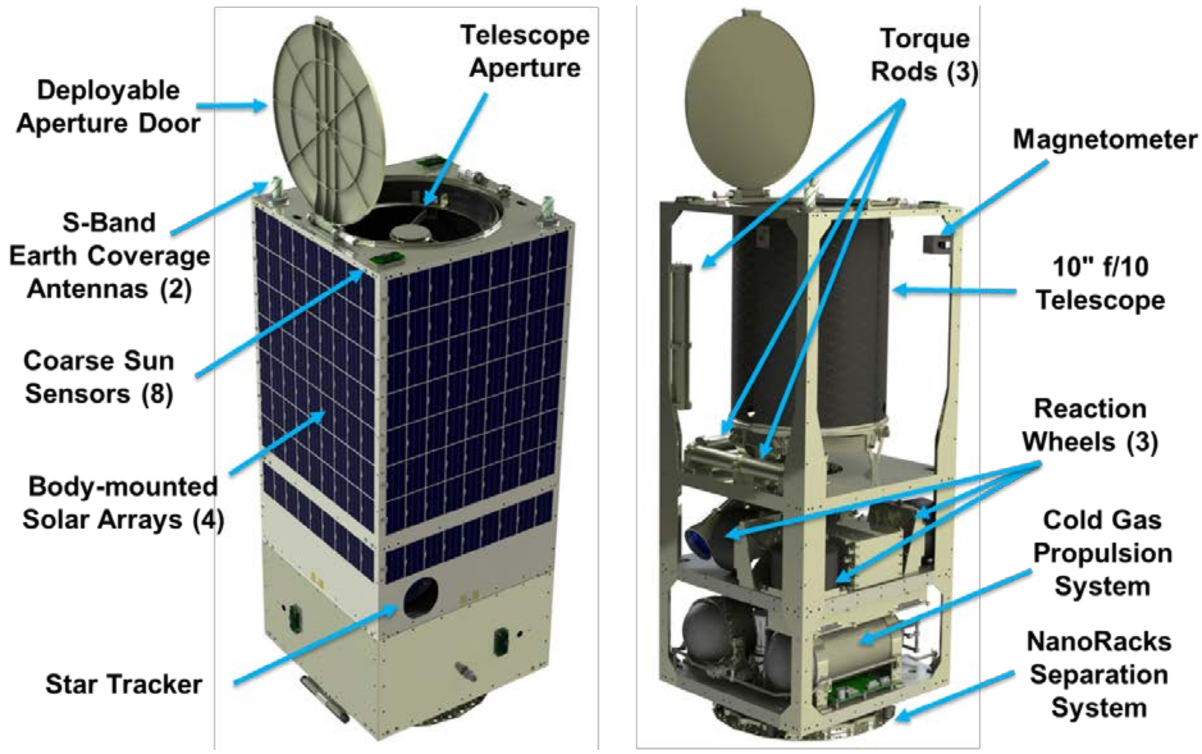

Figure 5: Kestrel Eye Block II Spacecraft Configuration

Attitude Determination And Control Subsystem

The Block II Attitude Determination And Control Subsystem (ADACS) employs multiple flight-proven components to ensure reliable pointing of the Block II spacecraft. Attitude knowledge is chiefly derived from a single flight-heritage Star Tracker. The ADACS also uses a MEMS gyro and eight Coarse Sun Sensors mounted on the six cardinal sides of the spacecraft as well as a magnetometer for momentum management. Attitude control is realized using three orthogonally mounted flight-heritage reaction wheels as well as three magnetic torque rods for momentum management. The ADACS electronics are an AMA-designed module derived from both the Block I ADACS computer and AMA's existing product line of CubeSat ADACS components. The ADACS also uses a COTS GPS receiver to enable on-board orbit determination.

Propulsion Subsystem

One of the key differences between Kestrel Eye Block I and Block II is the addition of a propulsion subsystem. This subsystem is primarily intended to allow multiple Block II spacecraft to be employed in a constellation. A constellation consisting of multiple planes of evenly spaced Kestrel Eye vehicles would provide for nearly continuous availability of tactical imaging, i.e., one spacecraft would be rising shortly before or after another spacecraft is setting over a particular area. Proper dispersion and phasing of spacecraft requires a modest delta-V capability aboard each spacecraft. Block II therefore employs a simple cold-gas propulsion subsystem to provide this delta-V. The Block II propulsion subsystem uses two composite-overwrapped pressure vessels to store up to nitrogen gas. The subsystem includes a pressure sensor to provide telemetry of the remaining delta-V, dual pressure regulators, a magnetic latch valve, and four flight-proven cold gas thrusters located on the four corners of the Propulsion Deck surrounding the NanoRacks Separation System (NRSS). The four thrusters are canted outwards to provide 3 axis torques. The actuation of each thruster is duty-cycle controlled by the propulsion controller in a closed-loop system that actuates rate to control spacecraft attitude during delta-V maneuvers. The spacecraft must cease imaging operations and change attitude to align the long axis of the spacecraft in the desired delta-V direction before beginning a propulsive maneuver; after the maneuver, the spacecraft returns to its nominal attitude to resume imaging operations.

GROUND SYSTEM

The responsiveness of the Kestrel Eye Satellite System is ultimately dependent upon the transportability and ease of use of the ground system. Modern military forces need to be on the move; any ground system that is not compliant with this need would negate the value of the entire Kestrel Eye concept. The ground system for Kestrel Eye is designed and built to be readily transportable, easily deployed, rapidly set up, and adaptable to warfighter operations in the field. The ground system for Kestrel Eye is comprised of two major elements, which are the GATR Tracking Ground Station Antenna and the Kestrel Eye Ground System (KEGS).

The original ground station for KE was developed to support the singular KE Block I satellite and was intended to be used in a laboratory setting. A targeting utility was demonstrated early in the KE Block I program with hardware-in-the-loop and the Kestrel Eye Dynamic Simulator (KEDS), which allowed the satellite imaging capability to be demonstrated, promulgating the vision for KE. Refinement of architecture requirements and feedback from representative user forums in 2013 and 2014 helped shape the ground station requirements and use cases. The main requirements for the ground station were to enable the user to easily choose a target of interest (point-and-click) and receive the satellite image during the same satellite access time (pass). In summer 2014, the KE team began work on developing the KEGS, incorporating the design upgrades, architecture differences and user feedback.[i]

Figure 6: GATR-TRAC Ground Station Antenna

GATR Ground Station Antenna

GATR inflatable satellite antennas are characterized by GATR Technologies (a division of CUBIC Corporation) as "the most portable satellite antennas in the world". Compared to other deployable rigid dishes of comparable size, GATR's unique design enables extreme portability, reduced cost of ownership, reliability in extreme environments, and ease of set up. The GATR 2.4 meter antenna is GATR's flagship product; a single-band GATR 2.4 meter antenna system can be packed into two cases weighing less than 99 pounds each. For Kestrel Eye, GATR Technologies has adapted their GATR 2.4 meter antenna to create the GATR-TRAC antenna, shown in **Figure** 6. This Low Earth Orbit tracking version can be packed into four airline checkable cases. GATR-TRAC is an innovative twist on a unique product and a major step forward in transportable satellite ground station technology. The antenna reflector surface is a stretched membrane inside of the spherical outer shell of the inflatable structure. A differential pressure between one side of this interior membrane and the other, combined with the size, shape, and reinforcing members of the membrane, create the very exacting surface tolerances needed for a reflective antenna surface capable of operations at frequencies up to Ka-Band. For GATR-TRAC, the entire spherical antenna structure is placed on rollers set atop a rotating platform. The motion of the sphere on these rollers creates elevation mobility and the rotation of the platform creates azimuth pointing. GATR-TRAC uses a computer that ingests satellite ephemerides to calculate open-loop program-track antenna vectors based on latitude, longitude, and azimuthal orientation. The antenna feed is mounted on the outer surface of the sphere. The GATR-TRAC is then connected to KEGS.

Kestrel Eye Ground System (KEGS)

KEGS is a transportable rack of equipment shown in **Figure** 7) containing a Quasonix receiver, transmitter, gigabit switch, data processing unit, and a GPS receiver for time and location services. A ruggedized laptop computer is included to provide for user interface to KEGS.

Figure 7: KEGS Transportable Rack

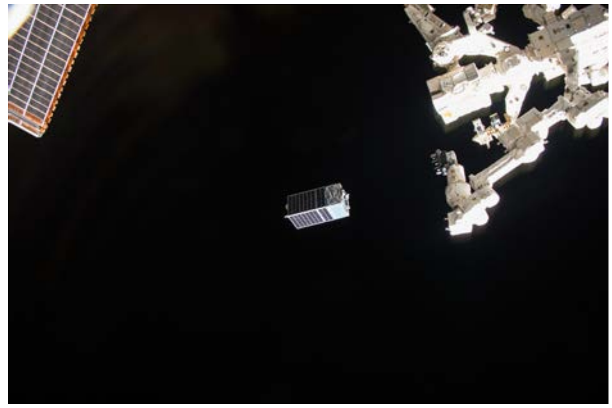

Figure 8: Kestrel Eye being deployed from the ISS on 24 Oct. 2017

KEGS software was developed jointly between the AMA and USASMDC/ARSTRAT engineers with the former focusing on satellite interactions (i.e. commanding and telemetry) and the latter focusing primarily on the user interface software (i.e. targeting and mission planning). This government-contractor blend has resulted in greater understanding on both sides of the development as well as a natural peer review.

The high level of integration and teaming on this program has improved the risk posture of the KE JCTD and KEGS. The architectural design supports the KE Block II satellite and provides a good platform to demonstrate its utility in the intended applications. The lessons learned and skills developed in support of this effort are being directly transitioned into USASMDC/ARSTRAT's Ground Station efforts.

LAUNCH

The design, fabrication, integration, and functional test of the Kestrel Eye Block II payload, spacecraft, and ground system was completed on October 20, 2016. Environmental testing of the AMA Block II spacecraft was completed in November 29, 2016

Thanks to launch and deployment sponsorship by the Department of Defense Space Test Program, Kestrel Eye was launched August 14, 2017 as a payload aboard the SpaceX Falcon 9 rocket as part of an International Space Station CRS-12 cargo resupply mission. The Kestrel Eye Block II spacecraft was placed in a protective shell within a Crew Transfer Bag (CTB), strapped down, and launched. Once at the International Space Station (ISS), it was removed from the internal volume of the Dragon Cargo Resupply Service (CRS) Visiting Vehicle and remained in storage until the deployment opportunity.

When deployment conditions were satisfied and deployment had been scheduled, the spacecraft was removed from its launch container, attached to the Japanese Experiment Module (JEM) slide table interface, and positioned in the JEM airlock for deployment. The airlock was depressurized, the airlock door opened, and the NanoRacks Kaber System (with Kestrel Eye attached) was grappled by the SPDM arm, positioned for deployment (aimed in retrograde attitude), and deployed by actuating the NanoRacks Separation System (NRSS). The deployment occurred on Oct. 24, 2017 as shown in **Figure 8**. At the time of this writing, it is orbiting at approximately 250 miles above Earth and is expected to operate for less than two years.

JOINT CAPABILITY TECHNOLOGY DEMO

After successful deployment, the On-Orbit Checkout process was started, to be followed by the technical demonstration and a military utility demonstration. The Tech Demo is a scripted series of operations intended to demonstrate the proper performance of all aspects of the Kestrel Eye satellite including bus and payload functions. A baseline for all parametric telemetry including system voltages, currents, pressures, and temperatures will be established. Communications system data rates and performance thresholds will be tested. All subsystem modes will be checked out. Attitude determination and control accuracy will be characterized. Energy balance parameters will be confirmed. Images will be captured in a variety of conditions and associated metadata will be verified. Finally, realistic tasking scenarios will be conducted to exercise all elements as well as to verify and rehearse all planned processes and procedures.

The final stage of the JCTD will be a Military Utility Demonstration. The Military Utility Demo will emulate usage of Kestrel Eye in its intended application. The designated Combatant Command will conduct this demo under realistic conditions in collaboration with representative military personnel to assess the utility of the Kestrel Eye concept. The Military Utility Demonstration will result in recommendations for an objective Kestrel Eye Satellite System.

CONCLUSION

Kestrel Eye has come a long way in the years since it was originated in 2005. The Block I vehicle - and now the Block II vehicle - has been designed and built. Kestrel Eye Block II was launched and the capability that Dr. George Sebestyen and Steve Fujikawa imagined when they conceived of Kestrel Eye has been realized. A target will be tasked for imaging and the requested image will be rapidly returned. That moment will put the warfighter on the threshold of a capability that battlefield commanders have sought since the dawn of space-based ISR more than fifty years ago.

[i] M. Ray, M. Nixon, et. Al., "US Army Small Space Update", Proceedings of the 30th Annual AIAA/USU Conference on Small Satellites, Logan, UT, USA, Aug 2017