Utilizing HDTV as Data for Space Flight
By
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Abstract

In the aftermath of the Space Shuttle Columbia accident February 1, 2003, the Columbia Accident Investigation Board recognized the need for better video data from launch, on-orbit, and landing to assess the status and safety of the shuttle orbiter fleet. The board called on NASA to improve its imagery assets and update the Agency's methods for analyzing video.

This paper will feature details of several projects implemented prior to the return to flight of the Space Shuttle, including an airborne HDTV imaging system called the WB-57 Ascent Video Experiment, use of true 60 Hz progressive scan HDTV for ground and airborne HDTV camera systems, and the decision to utilize a wavelet compression system for recording.

This paper will include results of compression testing, imagery from the launch of STS-114, and details of how commercial components were utilized to image the shuttle launch from an aircraft flying at 400 knots at 60,000 feet altitude. The paper will conclude with a review of future plans to expand on the upgrades made prior to return to flight.

Aftermath

While recovery teams were still scouring the East Texas countryside for debris from the Space Shuttle Columbia, NASA's motion imagery and analysis communities were already discussing ways to improve the imagery available to Shuttle Program decision makers. High-speed motion picture film, mostly 35MM, was and remains the primary analysis imagery of Space Shuttle launches. Video cameras are used for real-time monitoring and "quick look" analysis in the hours after launch. The video cameras and recorders in place when Columbia launched on January 16th, 2003 were mostly put in place after the Challenger accident in the late 1980's. Video tapes from the various camera locations were assembled, edited, and then uplinked via satellite in the hours after a launch so NASA's various analysis laboratories could get a quick look before the motion picture film arrived the following day. This quick look gives the analysts a head start on which motion picture films to focus their attention, and lets the Shuttle Program Managers know if there is anything to worry about.

The Columbia was launched on January 16th, 2003. At 81.7 seconds after launch a piece of foam from the external tank came off and shortly after, struck the leading edge of the orbiter's left wing. The film from the tracker location with

the best view of the foam strike was obscured due to problems with the telescope lens. That left only the NTSC video from that location for analysts to determine the severity of the foam strike on the orbiter's wing.

Thus, improving Shuttle launch video acquisition and distribution systems became a priority in the aftermath of the Columbia Accident. The wish list of requirements for improvement included higher frame rates, progressive scanning, higher spatial resolution, and all-digital acquisition and distribution with consistent meta-data. Indeed, in the report of the Columbia Accident Investigation Board, the recommendation was made that NASA "Upgrade the imaging system to be capable of providing a minimum of three useful views of the Space Shuttle from liftoff to at least Solid Rocket Booster separation, along any expected ascent azimuth….Consider using ships or aircraft to provide additional views of the Shuttle during ascent." (*Columbia Accident Investigation Board Report Volume 1, Recommendation R3.4-1, page 62, August 2003*) Implementation and interpretation of this recommendation was left to NASA. At the time the report was published, NASA was working toward a Spring 2004 launch date.

The first challenge implementing this recommendation was to determine the best way to transport a high-volume of imagery data to analysis labs at the Marshall Space Flight Center (MSFC) in Huntsville, AL, and the Johnson Space Center (JSC) in Houston, TX within hours of a shuttle launch. The Kennedy Space Center (KSC) imagery analysis lab was less problematic due to its physical proximity to the launch site and tracking camera locations. A short market study had already determined that commercial 720P HDTV was the logical choice for replacing the existing NTSC cameras. How to record the HDTV and distribute the data was the challenge.

At the same time a study was undertaken to determine the best way to use "ships or aircraft to provide additional views of the Shuttle during ascent." Existing US government ship and airborne assets were looked into but presented either practical, logistical, or technical challenges that made them a poor choice for imaging the shuttle. NASA has in its fleet of research aircraft the last two Canberra WB-57F high-altitude aircraft that are still flying. The aircraft are capable of flying at altitudes higher than 60,000 feet and provide an excellent platform for imaging the shuttle during ascent. Thus began a project called the WB-57 Ascent Video Experiment, or "WAVE".

Next came the hard part of implementing workable systems using available commercial technologies in unique applications. Frame rate, compression technologies, and the harsh environment of high-altitude were obstacles to overcome in time for the eventual launch of the Space Shuttle Discovery in July 2005.

Frame Rate
"Real 60P"

As referenced earlier, the primary analysis imagery of Shuttle launches is motion picture film. Film tracking cameras in the vicinity of the launch facility operate at 100 frames per second. Each of these tracking camera sites has a companion video camera for quick look video and as a back-up if the film camera fails for some reason. Commercial 720P HDTV was chosen as a replacement for the NTSC cameras in place at the time of the Columbia launch. The analysis community reviews quick look video to get a head start on the analysis of the film. The switch from NTSC interlace to progressive HDTV presented analysts with an opportunity to match film frames if film and video cameras were synchronized. For this reason, the decision was made to run the HDTV cameras at a true 60 frames per second instead of 59.94.
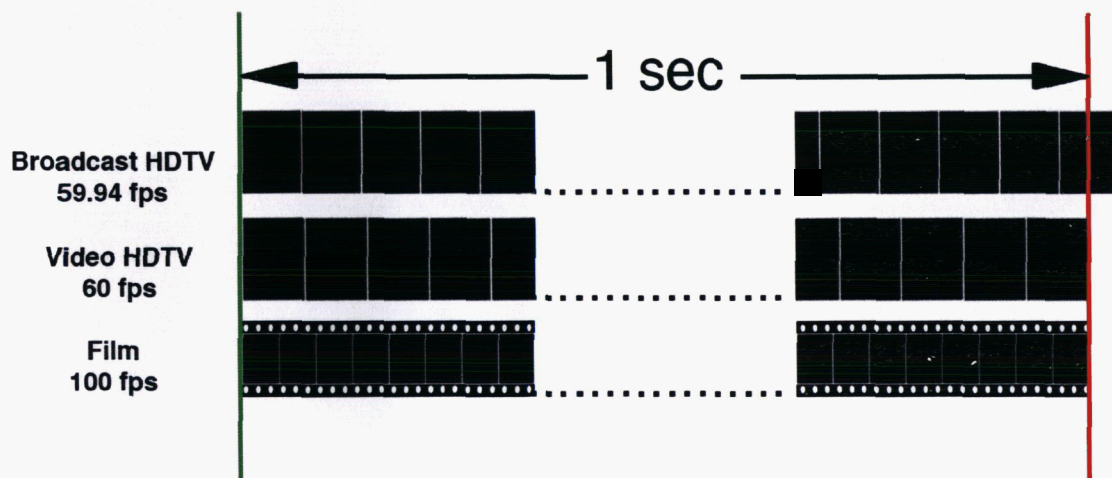
An issue with the Columbia imagery was that launch timing data, known as IRIG timing (Inter-range Instrumentation Group), did not match between cameras, either film or video. The time recorded on each videotape or film was correct, however, the Eastern Test Range (KSC and Cape Canaveral launch facilities), does not have a master synchronization system for all cameras. After investigation, it was determined that the film cameras in use can be shutter synchronized to IRIG timing signals. IRIG at the Eastern Test Range is referenced to GPS. With the use of GPS synch generators for the HDTV cameras, it would then be possible to synchronize all cameras to a common reference. However, with the video running at 59.94 frames per second and the film at 100 frames per second, the common frame point between film and video would only occur approximately once every 28 seconds. If the video cameras were to run at 60 frames per second in a synchronized system, then there is a common frame point at the beginning of every second of clock time. There is then a defined pattern of 60 video frames to 100 film frames that repeats every

second. This becomes important when the analysts are trying to correlate video quick look to specific frames of film.

With the ambitious upgrades to trackers, cameras, and recording systems, it was decided to delay the master synchronization plan until after STS-114, but the 720P HDTV cameras for analysis were set to true 60 frames per second. The analysts reported an improvement in correlation to film frames, even with the entire system free-running. The stability of each camera was such that when the relationship between a video camera and its associated film camera were established, the analysts were easily able to calculate which film frames required closer scrutiny.

Compression
DCT vs. Wavelet

Quick look video of launch is, as the name implies, video reviewed soon after a Shuttle launch to determine whether events occurred that merit further investigation. The switch from analog NTSC to 720P HDTV presented the challenge of distributing all the data from more than fifteen HDTV cameras within hours of a Shuttle launch. Many of the cameras would record more than four minutes of video. At approximately 11 Gigabytes per minute for uncompressed HDTV, the bandwidth required to distribute all the data to MSFC and JSC within hours of launch exceeded what was available and practical. Thus began a series of tests to identify a compression algorithm that would not compromise the spatial and temporal data advances offered by 720P60 HDTV.

For all the testing, it was determined that the personnel at the image analysis facilities would compare different imagery and make the determination of what was acceptable. Different recording systems were brought in for testing. Frame grabs of each recording were sent to the image analysis facilities in a blind test mode. Each facility, using their own comparison test methods, rated the frame grabs compared to a frame grab made from the original source.

The initial review of recording systems presented DVCPRO-HD, at approximately 16 Megabytes per second aggregate, to be an ideal candidate. It was thought with the limitations of shooting through the typical atmospheric conditions of coastal Florida, the horizontal resolution reduction of DVCPRO-HD would not be a factor. With the network data circuits available, transmission time of DVCPRO-HD imagery was a good match to the time requirements levied for distribution of imagery. In order to test that hypothesis, a 720P60 HDTV camera was mounted to a tracking system. This tracker, known as the Distant Object Attitude Measurement System, or DOAMS, utilizes 2 telescopes with 22" primary mirror reflector telescopes. The telescope used for video has an effective focal length of 10,000 mm. A jet aircraft flying a circle pattern served as the target. The video was recorded on both DVCPRO-HD and HD-D5. In this case, the recordings were handed over to the KSC image analysis facility for frame grabs

and distribution to the other image analysis facilities. It was clear early on into the process that there was a significant difference between DVCPRO-HD and HD-D5. The word from the analysts was the minimum acceptable quality level was HD-D5, or non-compressed, if possible.

Shortly after that test, a Quvis wavelet recording system was tested. This system utilizes variable bit rate encoding. It showed performance superior to HD-D5, but typical data rates are 15-16 Megabytes per second, very comparable to DVCPRO-HD.

This started a whole series of tests that included non-compressed systems as well as Quvis wavelet and JPEG 2000 wavelet compression systems. One other requirement levied by the analysis community was no inter-frame encoding systems would be allowed. It was either intra-frame encoding or non-compressed. The tests included standard test signals, including multi-burst to 30 MHz. Several video scenes, electronically generated, were used to test the systems. Some live camera scenes were used, but as these were difficult to duplicate from test to test, they were left off after the first set of tests. The systems were evaluated by the test team and also by the image analysts. The test team used the traditional tools: waveform monitors, engineering grade monitors, and image analysis sets. The image analysis teams used what ever comparison methods they desired. The results were invariably the same. The Quvis wavelet recorder was virtually indistinguishable from any of the non-compressed systems. It never showed loss of resolution compared to the non-compressed systems.

One interesting finding from the tests is that all the recording systems that convert HD from YP_RP_B to RGB for recording do not provide an exact YP_RP_B duplicate on playback. The differences were slight, but when compared on a SyntheSys video analyzer, the differences were apparent. The analysis labs found the same issue. Only one recorder tested, which literally recorded the SMPTE-292 bit stream without modification, passed through the SyntheSys without showing any errors.

Based on the performance of the Quvis wavelet recording, it was selected to be used for recording of the analysis HDTV video. It should be noted that the JPEG2000 wavelet recorder tested was a first generation device and did not perform as well as the Quvis wavelet algorithm. That, however, was the only offering when the procurement decisions were made.

Another point of note is for the last recording test, HD-D5 was also included into the mix. As a testament to the state of the art of HDTV recoding, it graded out at the bottom of all the recorders tested.

The wavelet recorders are disk based and record data files. Distribution became a matter of gathering all the data files in one place and transmitting them to the

image analysis facilities. This was done by implementing a mirrored server system. In this system, any data file that is placed on any mirrored server node is replicated to the others. There is an ingest server at KSC. The other servers are at the JSC, and MSFC image analysis facilities. Disk drives from the various recorders were brought to the ingest server after the launch. As soon as a file was ingested, replication began. Imagery that had in the past taken up to 5 hours to begin flowing across an analog satellite link as composite video now began to show up as a clone copy of the original recording less than half an hour after launch. The goal of vastly increased image quality was achieved with faster delivery than ever before.

WAVE
The WB-57 Ascent Video Experiment

As soon as the Shuttle clears the tower it begins a rapid ascent away from tracking cameras located around the launch pad and miles north and south of the pad. Those cameras must image the Shuttle through the haze and humidity of the Florida sky as it rapidly heads downrange. In previous launches many of the debris events occurred when the shuttle well above 60,000 feet altitude and many miles downrange. Save for placing cameras on the Shuttle itself, which has been done, the best way to image the shuttle once that high and downrange is from an airborne platform.


**WB-57F
Aircraft**

As referenced earlier, NASA has within its fleet two modified Canberra WB-57F aircraft, capable of flying scientific instruments at altitudes in excess of 60,000 feet. Due to the short development time to prepare for what then was a Spring 2004 launch date, the imaging platform had to be based on existing available technologies. A gimbal system called the "fat boy", designed for the US Army by Southern Research Institute in Birmingham, AL, was to become the foundation

for the gimbal to be built to mount on the nose of the WB-57. The gimbal's computers as well as the recorders and video equipment had to be protected from the harsh environment of 60,000 feet, so a transition section was designed to go between the front of the airplane and the gimbal itself. Inside the gimbal would be the optical bench. The optical bench consists of the primary telescope, an HDTV and Near Infrared camera, and a SDTV camera and lens to provide a wide field of view to aim the prime telescope.

The optical bench was designed by NASA's Space Optics and Manufacturing Technology Center at the Marshall Space Flight Center. Due to the short development time, the optics were based on a commercial 11" Celestron telescope. The light from the primary telescope was split into visible and near-infrared light and routed via a "folded" optic design to the commercial 720P60 HDTV camera and a commercial near-infrared camera. All of the cameras were placed in sealed custom-built canisters to protect them from the low temperatures and low pressure of high altitude flight.
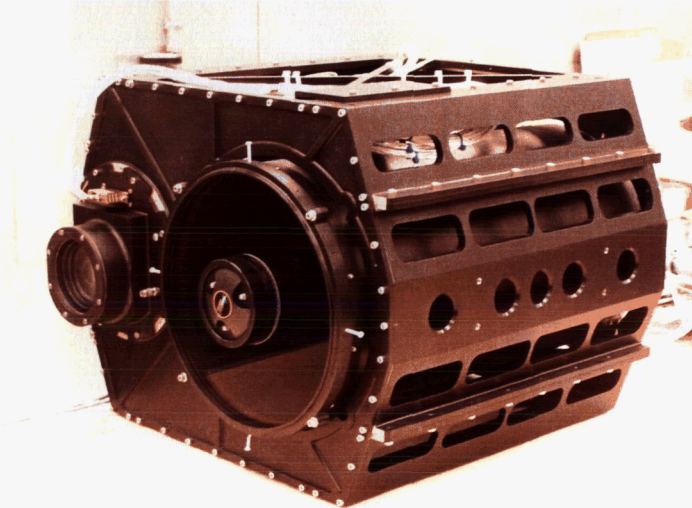

WAVE Optical Bench

There were a number of challenges in implementing this system. The short time frame for building the system, 11 months from the first approval to build to the first flights, mandated using off-the-shelf hardware as much as possible. The HDTV recording system for WAVE matched the ground systems with one important caveat, the use of solid-state RAM drives instead of disk drives. The transition section is pressurized at the same point as the crew cabin. That is 5 PSI above ambient altitude pressure. This means at 60,000 ft., the transition section was at 25,000 ft. pressure altitude. Standard sealed disk drives are only operable up to 10,000 ft. pressure altitude. This is not a technical problem, but it is expensive. The RAM drives to allow 30 minutes of recording time on the aircraft were more expensive than the recorders. The near infrared camera utilizes a ruggedized rack-mount server computer for camera control and image capture. It too had to be upgraded to RAM drives to survive the environment. In addition to the HDTV and the near infrared sources, the acquisition camera and

the track displays are also recorded. The acquisition recording is NTSC and has operational data overlays that are used by the equipment operator. The track recording can be down-converted HDTV, infrared camera, or the acquisition camera. The video recorded depends on what the operator has selected for tracking. The track display recording also has tracking data overlays. Both the acquisition and track recordings are done with DVCPRO-50 recorders working in DVCPRO mode. When first designed, the acquisition recording was going to be a clean feed in color. After the analysis community determined the recordings were of little value to them it was changed to the acquisition screen output. This is monochrome with color overlays. That recording is used for post-flight WAVE system analysis and does not require 50 mbps recording. The second recorder was initially going to record the near infrared camera. However, a change in camera systems resulted in recording the camera data on a computer. It was decided to keep the recorder in the system and use it to record the tracking screen display, also as a post-flight WAVE analysis tool. The DVCPRO recorders were not modified for flight use.

The ground recorders all record IRIG timing in the ancillary data space of the HDTV data stream from the camera. This was also a requirement for WAVE. An additional requirement was metadata of the aircraft's position and the gimbal angles be recorded. This is needed by the analysis communities in the event triangulation for 3D imaging is to be done. The ground cameras are all in fixed locations, so that data is not required for those recordings. To accomplish this, the IRIG timing inserter capability was expanded to include the required metadata. It was determined all of the data could be contained within a 38.4 kbps data stream even though there is considerably more ancillary data space available within a SMPTE-292 data stream. The aircraft each carry a GPS based IRIG generator, so that part was simple. The WAVE sensor package carries its own GPS and inertial navigation system. Software was developed for the data inserter to allow it to accept the additional data and insert it in the HD data stream. The data inserter requests a data packet per frame of video. Software was developed that aggregated all the required data into packets for the inserter. Quvis expanded a conversion application for wavelet files that allows the metadata to be displayed on a frame by frame basis or exported into a spreadsheet.

Throughout implementation of WAVE, a weight battle was fought on all fronts. It would have been possible to make the system much lighter and smaller if hardware had been repackaged. However, there was not time for this kind of activity. In the end, the off-the-shelf components performed well. There have been almost no failures that were caused by environmental problems. As a whole the system has worked extremely well.
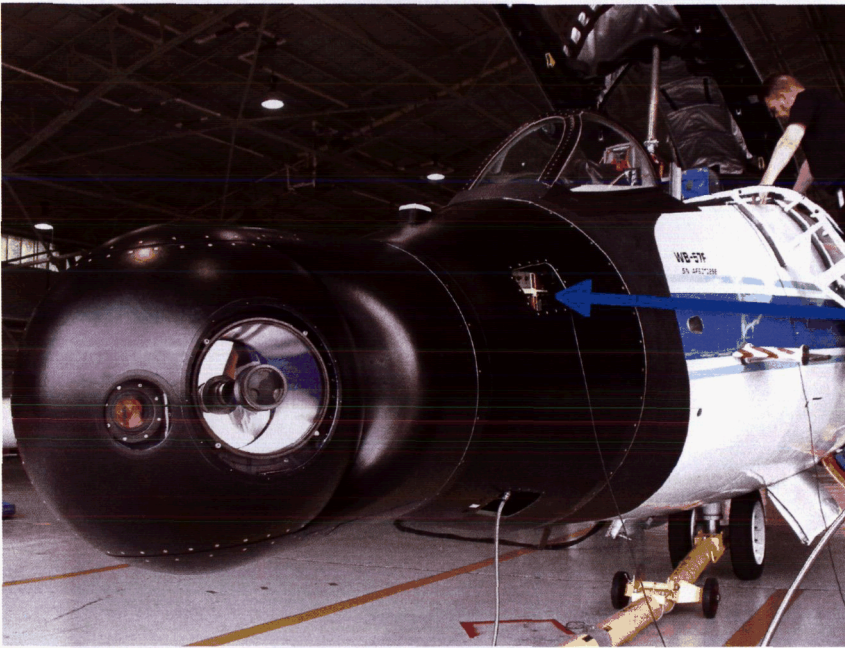
Sensor Mounted on WB-57F

Note hatch in transition section for access to download data

A big issue with WAVE is data retrieval. As can be seen, there is only a small port for accessing any of the recording systems. There is not room to access a removable drive in the wavelet recorder. The PC that records the infrared camera is not visible unless the equipment rack is removed from the transition section. Until the design was fairly mature, it was not known whether the video tape recorders would be accessible. A data download system was developed to allow all imagery data to be removed from the aircraft without removing any hardware or tapes. For the wavelet recorder, this required the HD-SDI output and an Ethernet connection to an access panel. For the infrared camera computer, Ethernet and USB ports were needed. IEEE-1394 connections from the DVCPRO recorders were also brought out. All but the HD-SDI signal were put onto a single connector. An umbilical cable was made to break out the various signals. While using a single connector was efficient, in practice it was somewhat like wrestling with an octopus. After the design was finalized, it was found the tape recorders were accessible for insertion and removal of tapes, and the USB connection to the computer was not needed for routine operations. A second umbilical was made with only the two Ethernet connections, which made life for the ground support team much easier!

RESULTS

When the Space Shuttle Discovery lifted off from launch complex 39B on July 26th, 2005, every second of its ascent was documented with more and better cameras than any previous Shuttle launch. It is no surprise then that events were documented that had not previously been seen, providing Shuttle managers with more data than ever to ponder whether the incidents were unique to this launch or something that occurred every launch but not seen by the cameras in use at that time.

Within minutes of the launch, analysts at MSFC, JSC, and KSC had more and better video to review than ever before. The clarity and precision of the HDTV video was impressive. The video from WAVE, in spite of the jitter, showed scorching on the nose of the External Tank not seen before, and the shock wave phenomenon is likely to be studied for many months to come. Analysts were able to review bit-for-bit clones of what was shot in the field (and the air) within hours of launch, with precise metadata that is frame accurate. NASA was able to leverage commercially available products and technologies to completely change the way Shuttles are documented, resulting in a safer program and more real data from which program managers could make decisions.

In the coming years NASA hopes to leverage commercial development of higher frame rate, higher spatial resolution digital cameras, improved compression algorithms, and improved optics and tracking systems.

Utilizing HDTV as Data for Space Flight

STS-114
Return To Flight
Imaging Upgrades
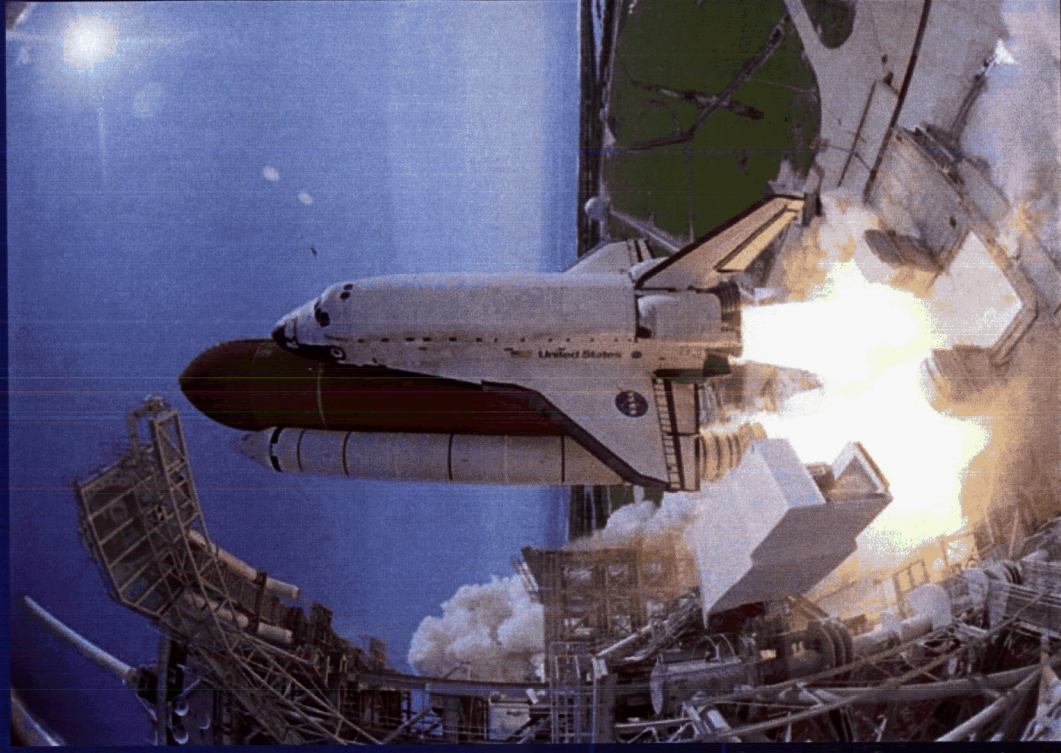
Overview

- *Columbia* Accident Investigation Board (CAIB) Report Recommendations R3.4–1 and R3.4–3 Directed NASA to Upgrade Imagery Capability

- Three Major Projects Undertaken
  - Ground Camera Ascent Imagery Project (GCAIP)
  - WB–57 Ascent Video Experiment (WAVE)
  - Enhanced Launch Vehicle Imagery System (ELVIS)–External Tank Camera

- Major Activities
  - Technical requirements gathering
  - Systems testing
  - Implementation

Support Requirements

- Image Acquisition
  - Upgrade film and video cameras
    - Maintain film quality
    - Improve video quality
      - HDTV or better
      - Deliver digital clones of video recordings

- Image Distribution
  - Deliver digital video data in same timeframe as the previous analog system
    - Initial video delivered launch plus 30 min
    - Completion of video by launch plus 8 hr

- Image Archival and Management
  - Digital archive and management system to allow access equal to or better than before with tape-based archiving

Video Acquisition Standard

- High-Speed Digital Video considered
  - Frame rates desirable
  - Record time insufficient when format decisions made

- 720p Adopted
  - Off-The-Shelf cameras available
  - Multiple long-form recording formats available

Frame Rates – Real 60p

- Desirable for video cameras to match 100 FPS film rate
  - Not practical with off-the-shelf solutions
  - Close correlation of film to video is the next best solution
  - 59.94 fps video only gives a match point approximately once per 28 seconds
  - 60 fps provides a match point once per sec
    - Correlation of a 60 fps video frame to 100 FPS video frame(s) is the same for every second during the run

Frame Rate Comparison

1 s

Broadcast HDTV
59.94 fps

Video HDTV
60 fps

Film
100 fps

Comparison of Frame Rates

16.67 ms	16.68 ms
10 ms	

ms

Film
100 fps

Video HDTV
60 fps

Broadcast HDTV
59.94 fps

Compression

- Noncompressed HDTV
  - Not practical for cost of circuits from Florida to Alabama and Texas

- DVCPRO-HD Initial Candidate
  - Test setup in typical conditions
    - HD camera on tracking mount
    - Shooting through 10–30 mi of atmosphere to aircraft target
    - Differences were noted when compared to HD-D5
    - HD-D5 became benchmark
      - Data rate too high

- Multiple Tests of Compressed and Noncompressed Systems
  - QuVIS Wavelet indistinguishable from noncompressed
  - Data rates on typical scenes are equal to DVCPRO-HD

Metadata, Distribution, and Archiving

- Range Timing (IRIG) Inserted as VANC Data
  - Additional metadata required by WAVE

- Dedicated Distribution network to KSC, JSC and MSFC Image Analysis Facilities
  - Mirrored imagery servers at KSC, JSC and MSFC
    - Files loaded onto one server automatically replicate to the other two
    - QuVIS recordings are files
      - Copies at sites are identical to original recordings

- Image Archive Server
  - All image data files are archived on separate server
  - No physical ties to mirrored server system

System Overview

Image Acquisition

Digital Video Imagery

NTSC Analog
From AF Sites/OTV

Existing Sat Dist

Digiphoto Cameras

Digital Photo **BCI**

Ext Sources

Comp HD/SD /other Fmts

HDTV

Comp HD Wavelet QL

Archive Server

Push

Film Imagery
70mm, 35mm, 16mm

16mm Fallback

35mm Primary

70mm Primary

Film Develop/Archive Process

Mirrored Service Server

Distribution

Onboard Imagery
JSC B 36 SX Server

JSC IAF

MSFC IAF

KSC IAF

Primary Film Prints

Physical Transport

Pad Perimeter Camera Sites

HDTV Cameras
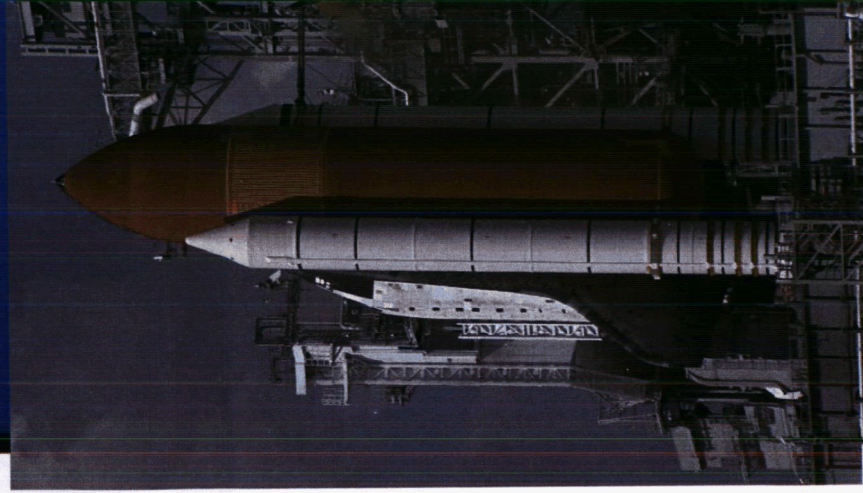
Medium-Range Camera Sites

★ HDTV

CAPE CANAVERAL

ATLANTIC OCEAN

KENNEDY SPACE CENTER

MERRITT ISLAND

INDIAN RIVER

COCOA

Long-Range Sites

HDTV

NTSC

CAPE CANAVERAL

KENNEDY SPACE CENTER

MERRITT ISLAND

INDIAN RIVER

COCOA

NASA
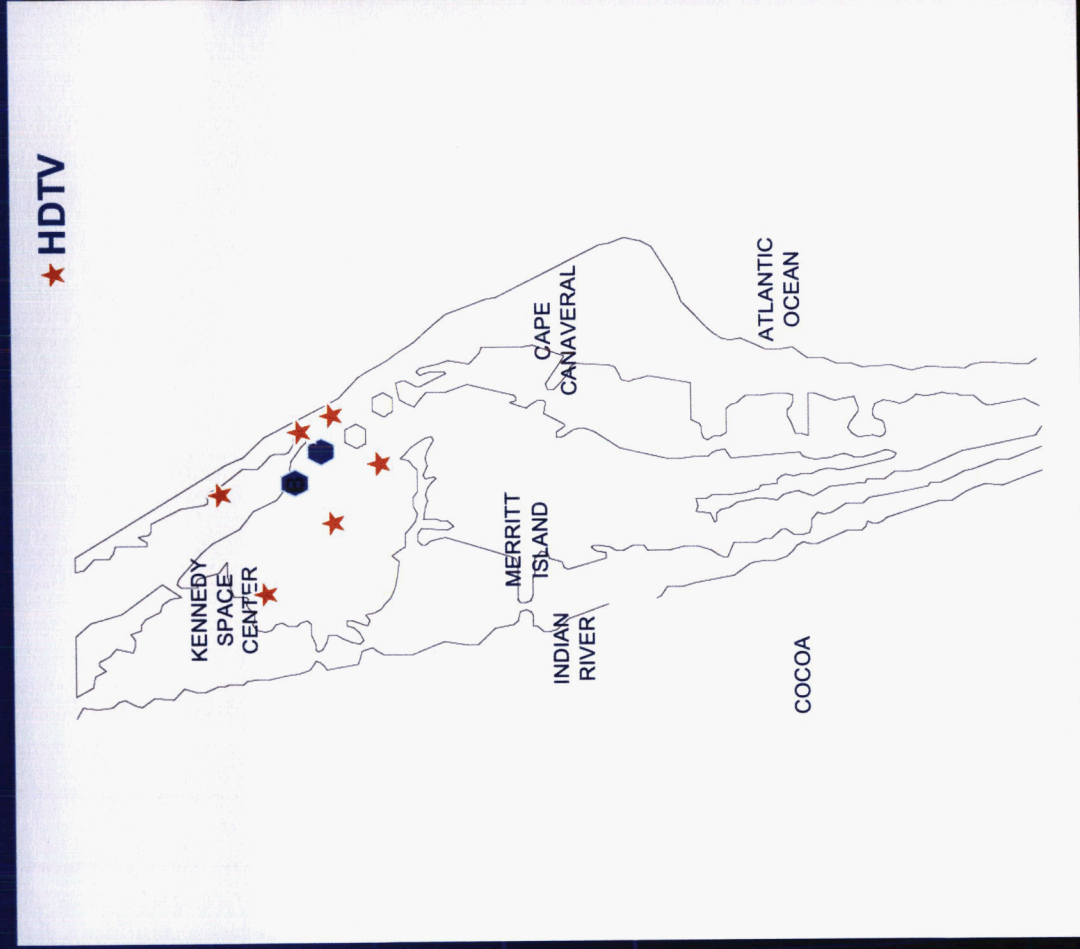
Photo Tracking Mounts
IFLOTS
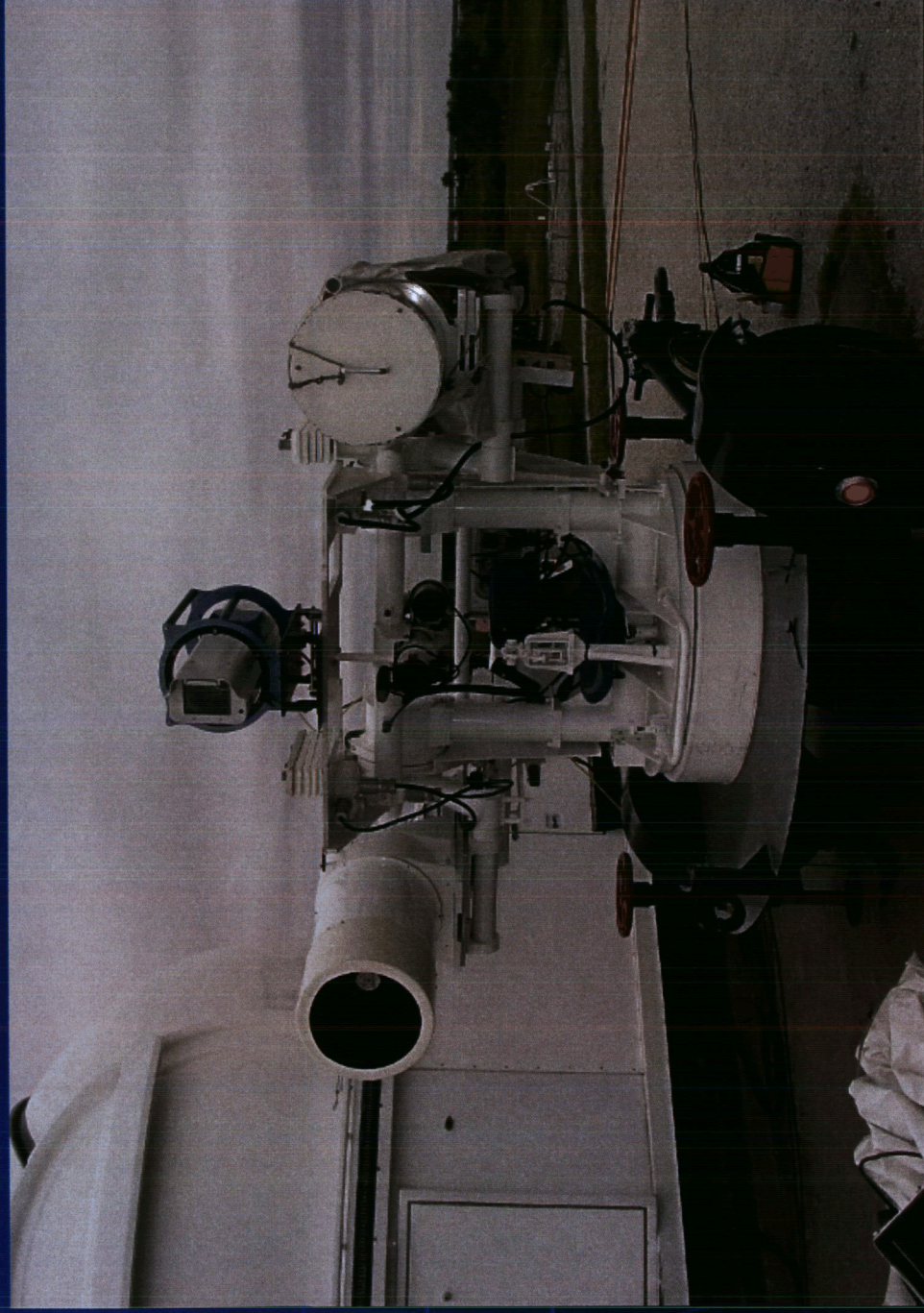
Film and rotated HD Camera mounted on an IFLOT tracker

Photo Tracking Mounts
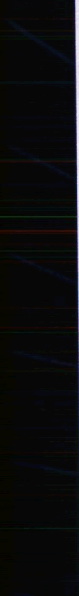## KTM

Operator

KTM Outfitted With HD and Film Cameras

Photo Tracking Mounts
DOAMS
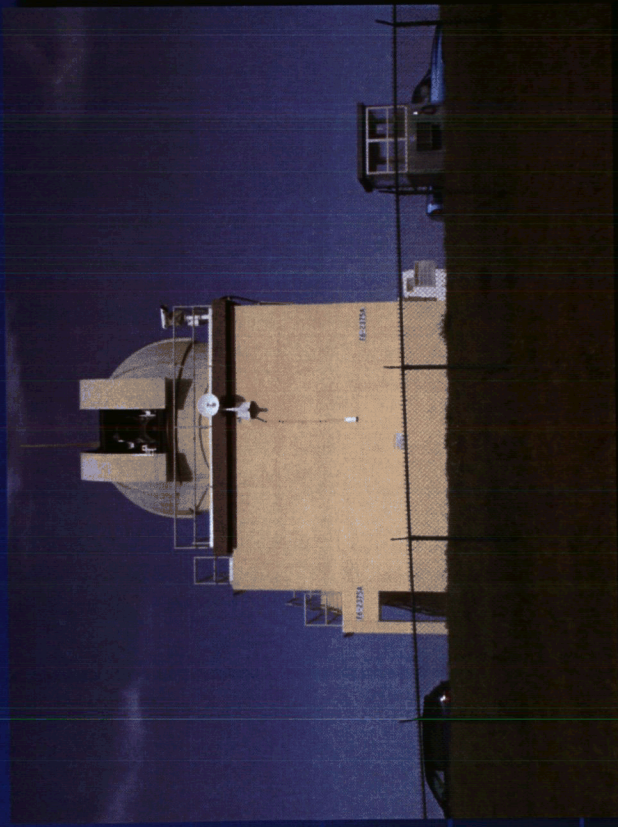
DOAMS Tracker (Note Two Lenses)

Shuttle Pads

Pad Perimeter View
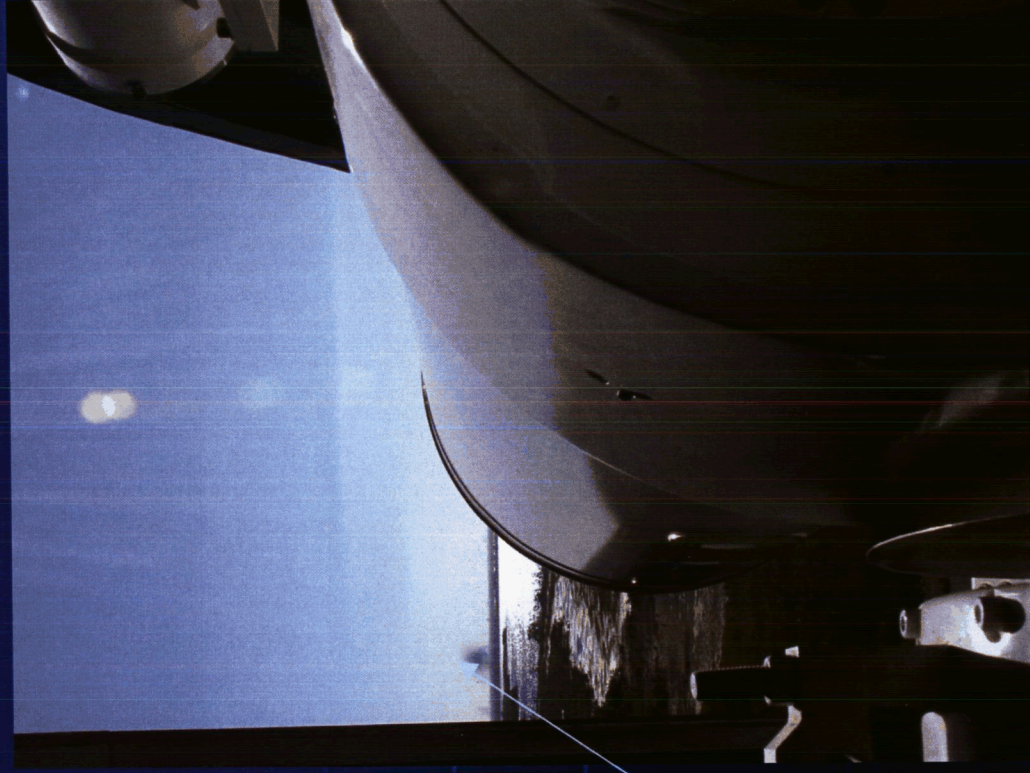
Medium-Range View

Long-Range View

File Ingest Operations
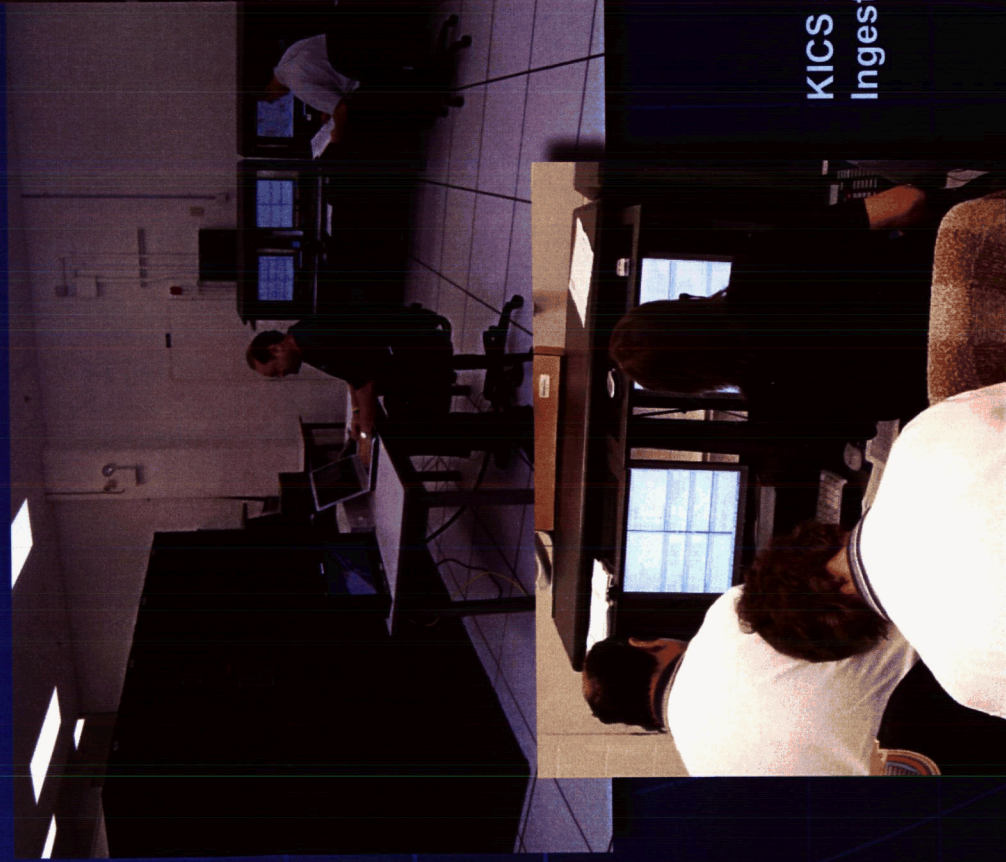
KICS Systems Administrators Posting the
Ingested Files to the Mirrored Service

Launch Control Center Operations

QuVIS Wavelet Recorders

Operator at Console Operating PAD HD Camera Control Units

Ingest the Harddrives From the Field Into the Quvis Units for Posting Onto the Mirrored Service

WAVE Background

WB–57 Ascent Video Experiment (WAVE)

- WAVE is in response to CAIB Report Recommendation R3.4–3 *"Consideration should be given to using mobile assets (ships or aircraft) to provide additional views of the vehicle during ascent."*

- WAVE utilizes NASA's WB–57F High-Altitude Research Aircraft

Overview

- WAVE System Consists of
  - Optical bench & gimbal system
  - Transition section with electronics and recorders
  - Back cockpit operational controls
- Bench, gimbal, and transition section on nose of aircraft
- Provides ascent view from 60,000-ft
  - Flight path designed to put aircraft even with Shuttle at SRB separation
  - 120,000-ft slant track distance
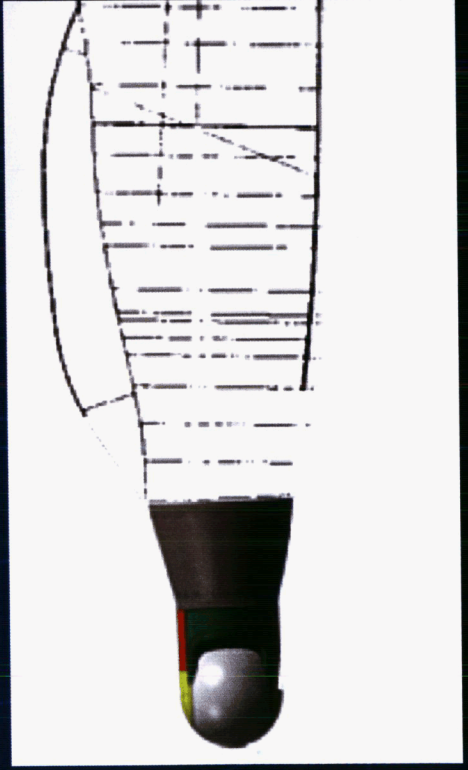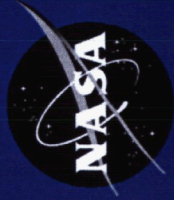
WAVE Project

- NASA In-House Project
  - Project Management
    - NASA DTV program
    - WB-57 program
    - Aerospace Corporation
  - Hardware Implementation and Fabrication
    - MSFC Space Optics Manufacturing Technology Center (SOMTC)
      - Optical bench design and fabrication
      - Prime telescope optics
    - Southern Research Institute (SRI)
      - Turret, gimbal, and transition section design and fabrication
    - NASA DTV Program
      - Cameras, monitoring, and recording equipment
  - Software Development
    - Southern Research Institute (SRI)
      - Control and tracking systems
    - MSFC Telescience Resource Kit (TReK) Support Team
      - NIR camera control and recording software
      - Metadata insertion software
  - Operations
    - WB-57 program
      - Aircraft modifications and operations
    - Ames Research Center Remote Sensing Branch
      - Sensor maintenance and operations support
    - NASA DTV program
      - Sensor maintenance and operations support

Optics and Cameras

- 4150mm Primary Lens
  - 11-in primary aperture reflector lens
  - Same lens for both HDTV and NIR
  - Dichroic beam splitter and turning mirrors to split optical wavelengths
- HDTV Camera
  - 1280x720 60p box camera (same as ground system cameras)
    - 0°8-ft horizontal angle of view for HDTV (13% of 1°)
    - 277-ft x 156-ft FOV at 120,000-ft (20 nm)
- Near IR Camera
  - 640x480 30p
  - 900–1700 nm wavelength
  - 0°13-ft horizontal angle of view for NIR (22% of 1°)
  - 462-ft x 370-ft FOV at 120,000-ft (20 nm)
    - NIR camera has larger sensor which gives greater FOV than HDTV
- NTSC Acquisition Camera
  - 22X Lens
  - 16°4-ft horizontal FOV wide
    - 6.4 mi x 4.8 mi FOV at 120,000-ft (20 nm)
  - 0°44-ft horizontal FOV tight
    - 1540-ft x 1155-ft FOV at 120,000-ft

Acquisition Camera FOV

Acquisition Camera Lens at Maximum Zoom
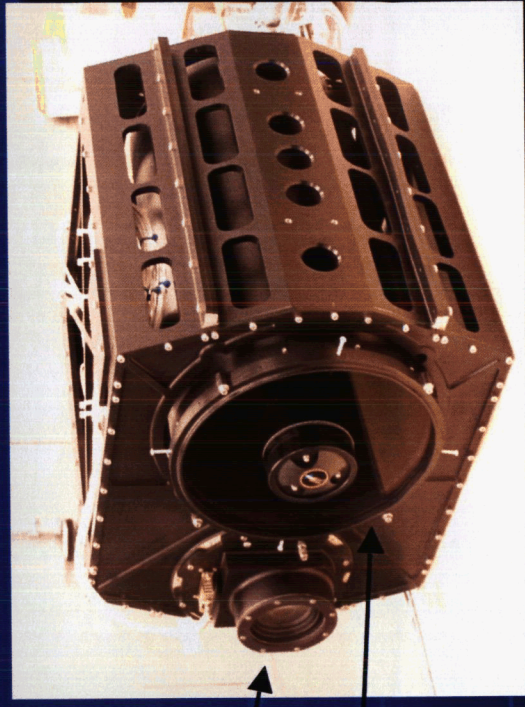—20 nmi Range

Box Represents HDTV FOV

HDTV FOV

HDTV Match to Previous Image
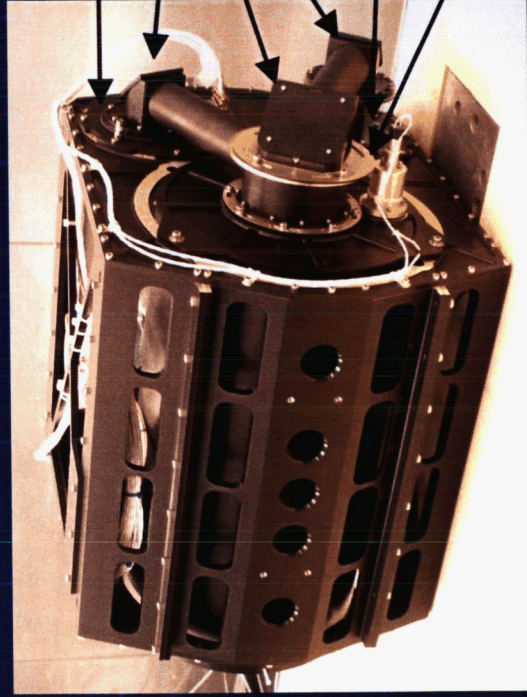~20 nmi Range

Optical Bench

Acquisition Camera and Lens

Primary Lens

HDTV Camera

Turning Mirrors

NIR Camera

Dichroic Beam Splitter

Optical Bench

Optical Bench Installed in Turret
(Without Outer Skins)

Recording

- All Recorders and Control Electronics are in the Transition Section from the Turret to the Aircraft Cockpit
  - HDTV recording
    - QuVIS wavelet
      - Required RAM drives
      - Compatible with ground system recordings
      - Range timing inserted in VANC
      - Metadata inserted in VANC
        - Aircraft position
        - Gimbal angles
  - NIR recording
    - Raw files recorded to dedicated computer with RAM drives
    - After download, images are processed into usable format
  - Acquisition and tracking recording
    - Acquisition video, and tracking video recorded as DV tape
    - Monochrome with tracking status overlays
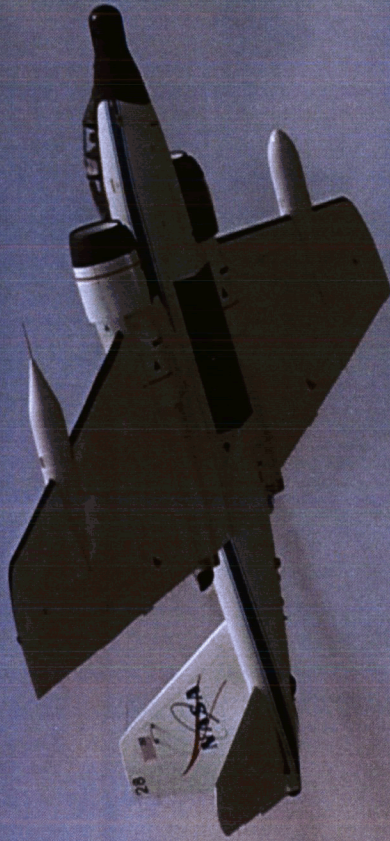   - Primary function is post–flight system analysis

Turret on WB–57
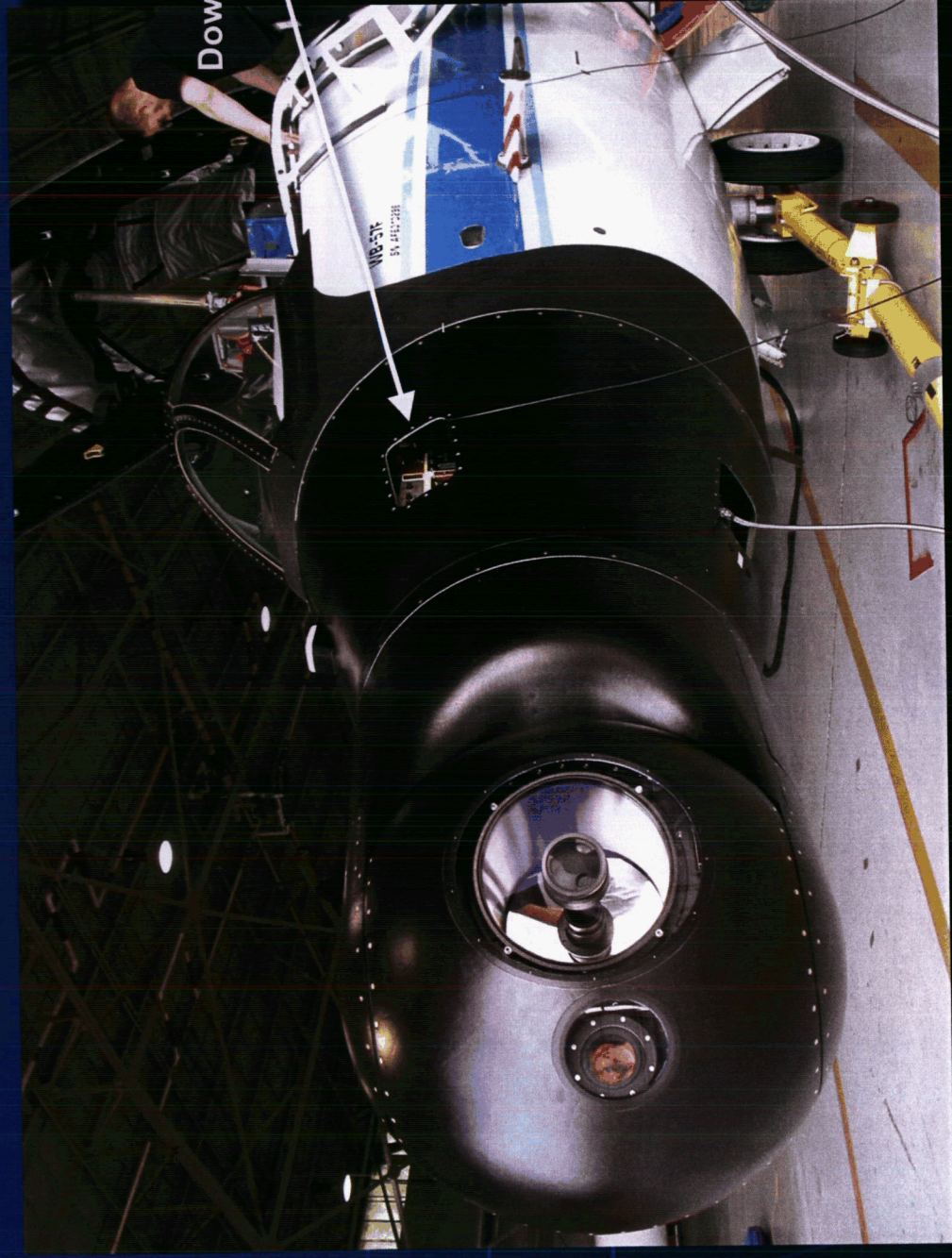
Download Access Panel

Turret and Transition Section Mounted on Aircraft

Download Access

First Flight

High Flight Operations