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Unmanned Airborne Platforms For Disaster Remote Sensing Support

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1. Introduction

The remote sensing community is increasingly turning to Unmanned Aircraft Systems (UAS) for integration of sensors to support scientific and applications-oriented airborne missions. These UAS platforms are seen as providing support capabilities for applications that require long observation dwell times and/or require operations in regions that are generally too dangerous for manned aircraft to operate efficiently and effectively. One of the most viable utilities for UAS as remote sensing platforms is in supporting rapidly evolving disaster events, be they natural (wildfires, etc) or anthropogenic (chemical releases, etc). Civilian land, resources and disaster management agencies in the United States are critically examining the role of UAS for use in long-duration monitoring over disaster events. Some of the critical elements that must be included in the analysis are the availability or development of autonomous operating sensor systems for integration on these platforms, near-real-time data delivery capabilities from the platform sensor to the ground management teams, and data / information integration into strategic disaster mitigation / management activities. Additionally, there are a number of issues regarding adaptation of UAS in the National Airspace System (NAS) and how those UAS interact with manned airborne assets in an increasingly congested airspace. Advances in UAS platforms, sensor systems, data telemetry capabilities and data manipulation / visualization enhancements have been developed, demonstrated, and evaluated for wildfire situational use in the United States (Ambrosia, et al., 2008). Those capabilities will be described and will form a foundation from which to look towards future improvements to utilizing UAS to support the disaster mitigation / remote sensing community. An assessment of the critical operational and integration challenges are also addressed.

1.1 Background: Current Fire Observation Capabilities

Wildfires are highly dynamic phenomenon, and their progression, consumption rates, and intensity are not easily modeled or predicted. Varying vegetation composition, age class, and moisture content of a fire-prone region are key factors that affect rates of spread. Additionally, terrain, coupled with solar exposure and wind dynamics are key elements to predicting how and where fire will advance. Given the dynamic conditions of these

variables over the course of a wildfire event, it is critical to have current and timely intelligence on the fire location and condition of the fire-front, and unburned vegetation in the fire's path. This information, if provided frequently, allows the fire management team to plan fire attack appropriately, saving resources, time and possibly lives. A wildfire management team cannot attack or manage a fire without "intelligence" about the fire condition, location, speed, vegetation composition, access routes or numerous other factors. A key factor to managing a wildfire event is the ability to access satellite or airborne remote sensing information, at an appropriate temporal and spatial scale. The wildfire management agencies in the United States currently utilize satellite data provided by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor data to provide synoptic, 2-4 times-daily hot-spot detection of fire at continental scales (Giglio, et. al, 2003; Justice, et. al, 2002; Kaufman, et. al, 1998; Morisette, et. al, 2005; NASA - Goddard Space Flight Center, 2009; U.S. Forest Service 2009). The spatial resolution of MODIS is low / moderate (1000 meters), and is used to derive a regional estimate of fire distribution. Multiple daily observations allow some estimate of fire movement at large scales. Although the temporal frequency of the MODIS data is sufficient for individual incident management uses, the spatial resolution is insufficient for tactical fire management operations.

The U.S. fire management agencies cohesively manage national fire events through the National Interagency Fire Center (NIFC), located in Boise Idaho. The multi-agency operations coordinate the distribution of fire fighting assets for all major wildfire events in the U.S., and will assist in international operations when requested. As part of the NIFC operations, the organization maintains the National Infrared Operations (NIROPS). The NIROPS operate two manned aircraft, a Cessna Citation Bravo II and a Beechcraft King Air B-200, which employ thermal imaging systems onboard for wildfire mapping support nation-wide. During manned mission operations the NIROPS relies on night-time thermal infrared data capture to minimize hot spots false detects from thermally "bright" objects that may be evident during daytime missions. The two NIROPS aircraft operate at similar data capture attitudes (3050 meters (10,000 feet) Above Ground Level (AGL)), and have similar mission endurance capabilities (4-6 hour missions). During extended distance missions, the aircraft and crew will deploy to other bases of operation in the fire vicinity for multiple mission days.

The NIROPS have experimented with various data transfer capabilities including "drop tubes" containing hard copy image maps generated on the aircraft, as well as landing and handing off digital data storage media (USB "thumb" drives", etc) containing the thermal infrared (TIR) fire hot spot detection data. Recently, with the advent of moderate cost over-the-horizon (OTH) telemetry technology, transferring of data from an acquiring sensor on an aircraft is attainable. In 2009, both NIROPS aircraft will have near-real-time data telemetry capability from the thermal infrared sensor, but prior to that installation, fire crews relied on a data handoff following the plane landing after TIR acquisition. The process then required manual spatial data transfer of hot spot detections to incident team map bases. The process, from acquisition over fire to map generation of hot-spots, took over one hour.

The NIROPS aircraft operate with an instrument engineer on-board to maintain the instrument and provide the necessary processing of the data for telemetry distribution to ground incident managers. Each of these processes can be streamlined or automated to

reduce the instrument engineer interaction. Further, automation of instrument collections and on-board image processing can yield significant time savings over “manual” operations of the same functions. UAS, with their long-flight-durations, provide an efficiency improvement over manned aircraft, by allowing either long-term lingering over a single fire event, or by allowing multiple fires to be imaged over the 24-hour duration capability of the platform. The remote / long-duration operations capabilities and tools developed to support those operations are described in the following sections.

1.1.1 NASA Involvement in Fire Observations

- The National Aeronautics and Space Administration (NASA) and the United States Forest Service (USFS) have been collaborating to develop, demonstrate and utilize innovative airborne and satellite remote sensing tools and capabilities for gathering, distributing and analyzing near-real-time wildfire information (Ambrosia, et al., 2009). NASA has been at the forefront of aeronautics research in UAS technologies and has added both small and large UAS platforms to its portfolio of science / research aircraft. UAS platforms, like the Northrop-Grumman *Global Hawk*, and the General Atomics Aeronautical Systems, Inc. (GA-ASI), *Ikhana* (MQ-9 Predator-B), are operated by NASA to support the agency’s science mission objectives, which includes earth and atmospheric research, telecommunications, autonomous sensor operations and applied science missions in support of other partner agency goals. NASA is also at the forefront of satellite-derived autonomous data processing of sensor system information sets, and those same capabilities can be designed for cross-cutting use on UAS. Autonomous processes of sensor-derived spectral information reduces the “data-to-information” lag time common with standard manual processing streams. Autonomous image processing and manipulation allows the derivation of Level II information to be created from baseline spectral data through the development of complex spectral algorithms. Autonomous geo-rectification processes greatly reduce the amount of time for the information to be ingestible in a digital spatial context. Developments and use of both “line-of-sight” (LOS) and OTH data telemetry systems improve space-borne and airborne science mission data-sharing capabilities. On-board data telemetry systems allow the distance-sharing of data sets collected remotely to be transmitted from the UAS to a disparate investigator or science community. These capabilities are critical to support near-real-time image utility by disaster managers on rapidly changing events, such as wildfires and have been integrated and demonstrated and are described in the context of the following sections.

1.2 Wildfire Research and Applications Partnership (WRAP)

The Wildfire Research and Applications Partnership (WRAP) is a joint effort between the National Aeronautics and Space Administration (NASA) and the U.S. Forest Service to explore innovative technologies to improve remote sensing observations of fire events. Since 2003, the WRAP project demonstrates and transitions emerging observation and information technologies to operational utility by wildfire management agencies. Because of this unique partnership between wildfire personnel and the NASA, academia, and industry science and technology community, the wildfire management agencies are better poised to utilize and integrate the demonstrated capabilities to improve wildfire intelligence and reduce wildfire losses and mitigation expenditures. The WRAP project effort focuses on the

fire management community providing the requirements and metrics for improving wildfire observational strategies. The NASA and USFS team members then develop / mature technologies that meet the metrics and requirements defined by the fire community. This process is formalized in the WRAP project's Tactical Fire Remote Sensing Advisory Committee (TFRSAC) creation, which is described in the following sub-section.

1.2.1 Tactical Fire Remote Sensing Advisory Committee (TFRSAC) - The technology transfer successes of the WRAP project are the result of an innovative technical and scientific team structure that marries fire management personnel with science and engineering team members from NASA, academia and industry. The Tactical Fire Remote Sensing Advisory Committee (TFRSAC), chaired by partners from the US Forest Service meet twice annually to discuss and highlight critical wildfire observational technology- and information-gaps. The TFRSAC group engages the NASA / academia / industry members to design new solution sets to fill those gaps within that disaster management community. The partners engage in technology development, enhancement, maturation, demonstration, and technology transfer to that wildfire community to ensure that the capabilities meet the requirements of the fire community. The TFRSAC members become technology enablers, allowing rapid operational integration, meeting the specific requirements of wildfire managers and wildfire technologists. This partnership group has been highly successful in maturing, demonstrating and integrating NASA-derived capabilities in UAS utility, sensor system design, telecommunications systems improvements, image-processing algorithm development, intelligent systems design, inter-sensor systems coordination (sensor-web) and data visualization capabilities.

The objectives of the WRAP and TFRSAC-led efforts were to:

- Demonstrate the efficiency of long-duration observational capabilities of a UAS for disaster management support;
- Develop and demonstrate new sensor design concepts for multi-mission operations on UAS platforms. This includes maturing system architecture to allow long-duration autonomous operations (+24 hours), high altitude operations, and large data collection and storage capabilities;
- Develop and demonstrate new sensor capabilities that utilize increased spectral domains to improve autonomous fire-characterization.
- Demonstrate over-the-horizon data telemetry capabilities that allow efficiency in provision of critical, near-real-time sensor information from a remote UAS platform;
- Provide sensor-derived, GIS-compatible, geo- and terrain-rectified, Level II processed data on wildfire conditions to incident management teams within 15-minutes of acquisition.

2. Western States Fire Mission Configuration Overview

The Western States Fire Mission (WSFM) demonstrations, a major component of the WRAP project, is a multi-agency collaborative effort to explore, develop and evaluate emerging technologies for possible adaptation by fire and other disaster response agencies. This configuration was not developed with a focus on any particular business or cost model, but was driven by scientific and technical needs assessments. The WSFM approach was

requirements-driven as defined by the TFRSAC. The primary focus was to streamline the process and increase the quality and efficiency of wildfire characterization to incident personnel. The project leveraged NASA emerging technologies in UAS, sensor systems, communications, autonomous intelligent systems operations, and sensor-web expertise.

To meet the goals, an operational concept was developed to test and evaluate the following capabilities:

- Broad-area UAS coverage with long-duration day / night capability, and near-real-time broad-band communications telemetry capabilities;
- A calibrated multi-spectral visible through thermal-infrared sensor with onboard processing for near-real-time geometric image correction, geo-location, image analysis, and communications management;
- A Wildfire - Collaborative Decision Environment (W-CDE) for data visualization, mission planning, and situational awareness;
- A real-time, GIS data-base of selected derived wildfire sensor products (GeoTIFF, multi-band imagery, on-board derived hot spot detection products);
- Training and outreach to fire management personnel and data analysts.

The WSFM architecture concept is shown in Figure 1.

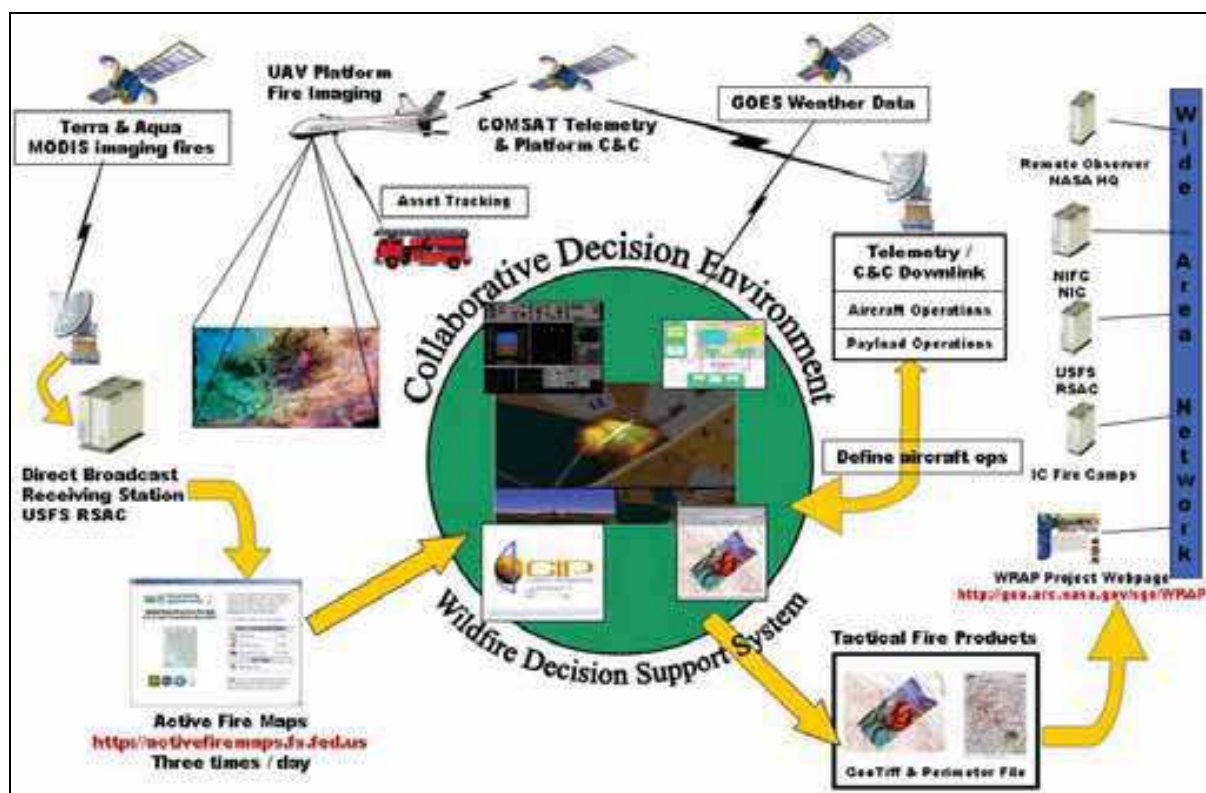


Fig 1. The Western States Fire Mission operational concept highlights the communications architecture for UAS sensor imaging over wildfire disaster events. This configuration integrates additional information sources into a Wildfire - Collaborative Decision Environment (W-CDE), and allows sharing of data elements with a disparate disaster management community.

This configuration allows the WSFM team to observe critical fire components, develop a process flow for autonomous data intelligence management, develop a simplified common operating picture, plan missions within the framework of the COP (the W-CDE), monitor flight operations on UAS aircraft, and provide near real-time fire intelligence to the Incident Command system. The following sections will explore these technologies in greater detail.

2.1 UAS

Our fire mission requirements and expectations for UAS performance included broad-area access to the NAS, with long-duration day / night capability, and near-real-time broad-band satellite telemetry capabilities for remote command / control of the sensor payload and sensor data telemetry. The new NASA *Ikhana* UAS had all these key attributes and made it a capable platform to demonstrate support of disaster incident monitoring.

The NASA *Ikhana* UAV is a modified General Atomics – Aeronautical Systems, Inc. Predator-B (MQ-9) Unmanned Aerial Vehicle (UAV), designed specifically for supporting NASA science missions. “*Ikhana*” is a Native American Choctaw word meaning intelligence, conscious or aware. The name is descriptive of the research goals NASA has established for the aircraft and its related systems. The *Ikhana* is capable of ~24-hour duration, 150-200 knots airspeed, ~13720 meters (45,000 feet) altitude, and flight legs of over 7408 kilometers (4000 nautical miles) (Figure 2). The platform is remotely controlled by a pilot on the ground seated at a console located in the Ground Control Station (GCS). The sensor system operator, seated at a console located in the GCS can monitor and control the AMS-Wildfire sensor payload carried aloft by the *Ikhana*. The *Ikhana* home base is NASA-Dryden Flight Research Center (DFRC) at Edwards Air Force Base (EAFB), California. The *Ikhana* was first put into service for NASA in January 2007, and flew its first science missions in support of wildfire observations in August 2007. The *Ikhana* is ideally suited to support long-endurance / duration missions, where critical observation-time over a dynamic event is required. Special coordination with the Federal Aviation Administration (FAA) was required to safely operate the *Ikhana* UAV in the National Airspace (NAS).



Fig. 2. The NASA *Ikhana* UAS with the sensor pod mounted under the left wing.

2.2 Command / Control / Data Communications Telemetry

The aircraft flight controls, payload system controls, and the payload sensor data are operated through a communications linkage with the GCS. There are two kinds of ground communications to the aircraft: LOS and satellite OTH systems. A portable ground data terminal provides two-way control and sensor communication when the aircraft is within radio line-of-sight (approximately 130 kilometers (70 nautical miles)). A geo-synchronous communications satellite, operating at Ku-band frequencies, provides OTH uplink and downlink between the UAS and GCS. The Ku-band system has bandwidth capacity of 3.0 megabits-per-second (Mbps), where 1.0 Mbps is used for data transmission, and 2.0 Mbps is used for video data transmission, a small bandwidth is required for platform command and control. This telemetry link allows data from the onboard imaging sensor (described in the next section) to be sent from the UAS to the GCS and then redistributed through the Internet to the community.

2.3 Autonomous Modular Scanner – Wildfire (AMS-Wildfire) Sensor

The AMS-Wildfire sensor is an airborne multi-spectral imaging line scanner capable of high-altitude autonomous operations on both manned and unmanned aircraft (Figure 3). The sensor is a highly modified Daedalus AADS-1268 scanning system that can support resolutions of 1.25 milliradian and 2.5 milliradian, with an angular field of view of 43° or 86° respectively. Spatial resolution is determined by altitude and the primary aperture size (1.25 mrad or 2.5 mrad). Operating from an example altitude of 7011 km (23,000 feet) mean sea level (MSL); ~20,000 feet Above Ground Level (AGL)), with a 2.5 mrad setting, the pixel spatial resolution would be 15 meters (50 feet). The system is configured with twelve spectral channels ranging from the visible through short-wave-, mid-, and thermal-infrared (VIS-IR-TIR) (Table 1). The thermal-infrared (TIR) channels have been calibrated for accurate (~0.5° C) temperatures discrimination of hot targets, up to ~1000°C.



Fig. 3. The NASA AMS-Wildfire instrument arranged in the sensor payload pod tray. The scan-head is located under the cylindrical white thermal blanket at the top-left of the pod tray, while the white pressure vessel in the center contains the digitizer and electronics. Other components include the power supply and various controlling electronics.

Spectral Band	Wavelength, μm
1	0.42- 0.45
2	0.45- 0.52 (TM1)
3	0.52- 0.60 (TM2)
4	0.60- 0.62
5	0.63- 0.69 (TM3)
6	0.69- 0.75
7	0.76- 0.90 (TM4)
8	0.91- 1.05
9	1.55- 1.75 (TM5)
10	2.08- 2.35 (TM7)
11	3.60- 3.79 (VIIRS M12)
12	10.26-11.26 (VIIRS M15)
Total Field of View: 42.5 or 85.9 degrees (selectable)	
IFOV: 1.25 mrad or 2.5mrad (selectable)	
Spatial Resolution: 3 – 50 meters (variable based on alt)	

Table 1. AMS-Wildfire 12-channel scanner specifications.

Major hardware and software modifications to the AMS-Wildfire instrument allow autonomous or remote operations of the sensor aboard a UAS platform during extended mission profiles.

As the AMS line scanner collects a series of scanlines over a wildfire event, the raw spectral data are sent to a computer processor on-board the platform to further process into useful information data sets for delivery to a telemetry system and distribution to receiving nodes on the ground. The on-board autonomous data processing is described in the following section.

2.3.1 On-Board Data Processing – The on-board data processing system was designed to autonomously complete the acquisition, pre-processing, information extraction, and output product generation from the raw spectral data collected by the AMS-Wildfire sensor system. The on-board processing includes fire detection “hot spot” algorithm processing, image generation, and geo-rectification of all data sets. Each of these processes is automated, requiring an initiation by the sensor engineer operating from the GCS. AMS-Wildfire sensor data are first autonomously converted to temperature/radiance data, and the thermal channels are further converted to a “brightness temperature measurement. An appropriate fire detection algorithm is applied to those derived image data sets. The resultant data sets are then autonomously processed to create geo-rectified visual raster products and hot-spot detection vector files. The vector and raster products are transmitted via the *Ikhana* Ku-band SatCom telemetry system to the ground.

2.3.1.1 Fire Hot-Spot Detection Algorithm - For fire hot-spot detection, a multi-channel temperature threshold algorithm, based on that developed by the Canadian Center for Remote Sensing (CCRS), was implemented (Li, et al., 2000a, Li, et al., 2000b, Flasse and

Ceccato, 1996, and Cahoon, et al. 1992). The CCRS algorithm was originally developed for use with satellite (AVHRR) imagery (Li, et al., 2000b), but has been adapted for use on various airborne sensor systems, including the AMS-Wildfire sensor.

The fire hot-spot detection algorithm uses the 3.6 μ m channel of the AMS-Wildfire sensor to define a fire temperature threshold, and two or more additional channels to further refine this classification. Multi-channel thresholding improves commission errors encountered when using a single mid-wave thermal infrared channel-derived temperature value alone. The threshold values used in the algorithm (AMS channels 11 and 12 and, for daytime missions, channel 7; see Table 1) are parameters which can be variably set by the operator during a mission. The fire hot-spot detection algorithm is calculated as:

If:

*Band 11 (3.60- 3.79 μ m) > Band 11 minimum temperature (e.g. 380° K) and
Band 12 (10.26-11.26 μ m) > Band 12 minimum temperature (e.g. 240° K) and
Band 11 – Band 12 > Difference minimum (e.g. 14° K),*

And (if available),

Band 7 (0.76- 0.90 μ m) < Reflectance maximum (e.g. 0 .3) (to screen high-reflectance commission errors),

Then,

Pixel is classified as a fire hot-spot

The hot-spot algorithm-defined vector data set is provided as an additional data product transmitted over the telemetry link.

2.3.1.2 Geo-Rectification – Image data sets from the AMS-Wildfire sensor are autonomously geo-rectified on-board the *Ikhana* on a processor. The fully automated geo-rectification processing utilizes meta-data from an Applanix Position and Orientation System for Airborne Vehicles (POS AV) model 310 system. The POS AV-310 integrates precision Global Positioning Satellite (GPS) data with inertial technology to provide near-real-time and post-processed measurements of the position, roll, pitch and heading of airborne sensors. Photogrammetric projective transformation equations are used to determine the position of each pixel in the scanline as projected to the ground, with “ground” being determined by the on-board digital elevation model (DEM) data for the area being over-flown. The onboard DEM consists of a composite data set of one-arc-second Shuttle Radar Topographic Mission (SRTM) 30-meter spatial resolution elevation “tiles” which are mosaiced real-time as needed, creating a seamless DEM for the entire western United States (USGS SRTM website, 2008). The SRTM DEM data are used to define the geospatial context (latitude / longitude, elevation) reference for geo-rectification of the sensor line-scanner data. Each of the AMS-Wildfire data pixels are geo-referenced based upon the relationship between the location of the sensor / platform (which defines the pointing vector of the line-scanner pixel at acquisition time) and the latitude, longitude, and elevation of the terrain (from the SRTM data).

The on-board product generation, algorithm processes, and geo-rectification processes takes approximately 30-seconds (0.5 minutes) per image-file frame (1200 lines of AMS-Wildfire spectral data). With the additional data transmission time (via satellite telemetry) and

ground-based quality control assessment, the total process time (to final delivery to a server for Internet distribution) is within fifteen minutes defined as a metric for near-real-time data delivery.

The geo-rectified data sets and imagery are sent from the on-board link module image-processing computer to the telemetry system. The GeoTIFF files are moderate file sizes (-1 – 3 Mb per frame), allowing for minimal transmittance time through the telemetry link to the GCS, where they are then sent to servers at NASA for redistribution through the Internet.

2.4 Ground Services

The geospatial processing services for the serving of the near-real-time AMS-Wildfire derived data products were implemented utilizing open standards, promulgated primarily by the Open Geospatial Consortium (OGC). The pointers to the image data were of five types:

- A pointer to the raw spectral data availability via anonymous file transfer protocol (FTP);
- A pointer to the data via an OGC-compliant Web Map Server (WMS), used by Geographic Information System (GIS) clients (such as ESRI ARC users);
- A pointer to the data via an OGC-compliant Web Coverage Service (WCS), used primarily by other processing services, including fire and smoke modeling teams;
- A pointer to a GoogleEarth Keyhole Markup Language (*kml*) file; and,
- A pointer to a thumbnail-sized version of the file for quick-look viewing of the data.

The AMS-Wildfire data can therefore be accessed and ingested into a desktop GIS, WMS- or WCS-accessed system, or be visualized using any standard web browser, or Google Earth.

2.5 Wildfire - Collaborative Decision Environment (W-CDE)

A simplified, fire data integration and visualization solution tool was developed using NASA and Commercial-Off-The-Shelf tools. The Wildfire Collaborative Decision Environment (W-CDE) was developed originally to support data and sensor sharing for the NASA's Mars Exploration Rover program, and was modified to allow use as a data- and information-sharing tool for wildfire disaster managers. The W-CDE allows the integration of numerous web-enabled data sources to be collaboratively viewed and implemented to aid in determining appropriate fire management strategies. Simplifying the fire data visualization capabilities, NASA expanded the capabilities of the GoogleEarth® free-ware package as a "front-end" to allow the integration of multiple, pertinent fire-related data elements into a single package. These elements included the integration of real-time satellite weather information, predicted and actual cloud cover, predicted winds, satellite-derived fire "hot-spot" detections, Remote Automated Weather stations (RAWS) throughout the western US, National Weather Service Fire Critical Weather information, *Ikhana* aircraft tracking positional information, sensor information and real-time imagery feeds, Federal Aviation Administration (FAA) flight restrictions data, maps and information, airspace information, National Interagency Fire Center's Large Fire Location data, wildfire management team's Infrared mission support requests, and real-time lightning detection

data (Figure 4). Incident command teams were provided access to the W-CDE through a network link to the data “mash-up” service.

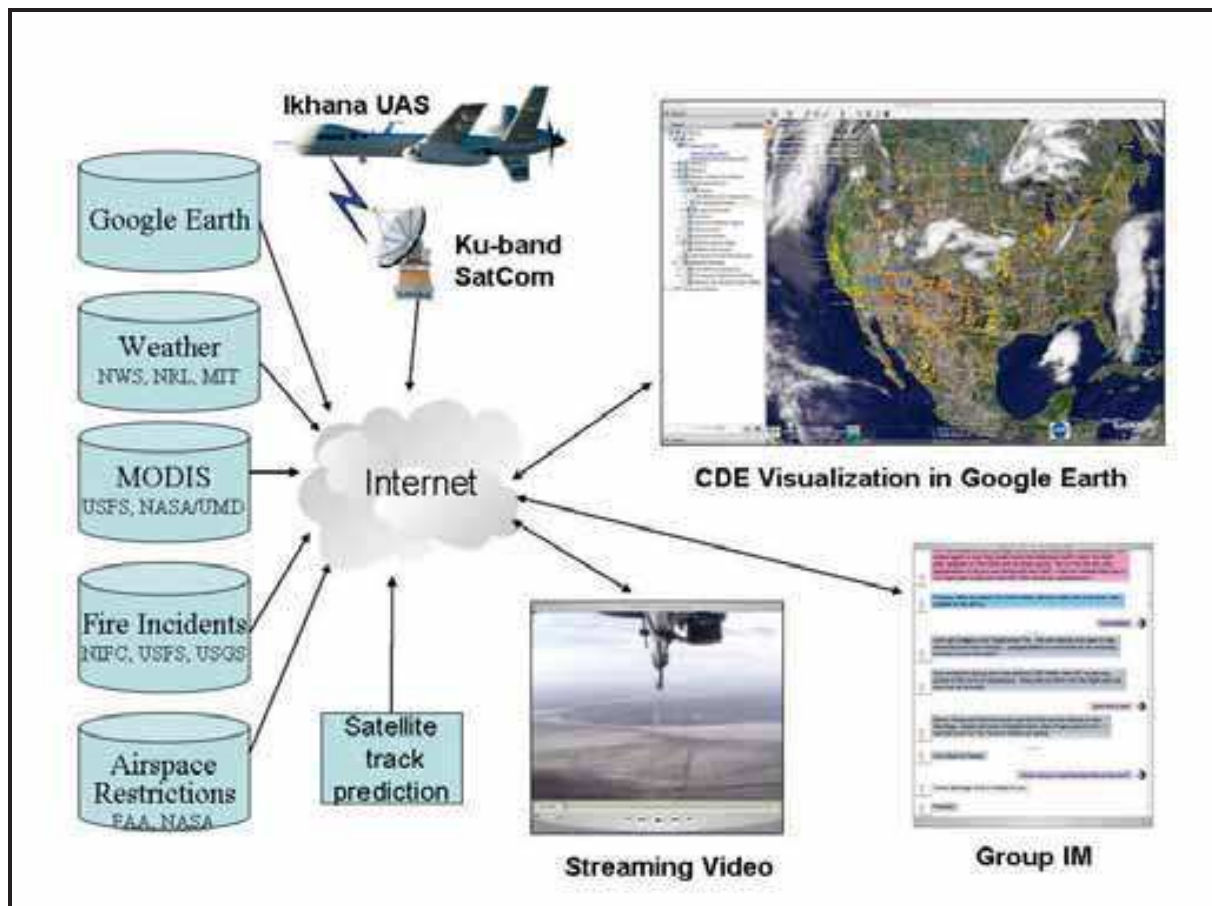


Fig. 4. Components of the Collaborative Decision Environment. The visualization element of the W-CDE employs GoogleEarth. The critical fire data elements (left side) that compose the additional visualization components are a “mash-up” of data from various web served data locations. The W-CDE also allows integration of instant messaging (IM) and provision of streaming video data from the acquiring UAS platform, in addition to the 3-D visualization of the AMS-Wildfire sensor-acquired data.

3. WSFM Missions

The WSFM focus is getting the right information, to the right people, at the right time. Missions planning was done in partnership with the NIFC National Incident Coordination Center (NICC) and the California state fire agency (CalFire) to ensure useful fire data products were generated on-board and transmitted to ground servers for distribution to web-supported Incident command teams in minutes. Highlights of WSFM UAS mission execution steps and results are summarized in the following sections.

3.1 Mission Planning

Mission planning requires knowledge of where the image targets (fires, incident infrared data requests, fire science targets, etc.) are. Additionally, operational constraints (aircraft

performance, FAA- and NASA-imposed keep-out (no fly) zones, FAA Certificate of Authorization (COA) requirements and weather constraints, etc...) impact mission planning. To efficiently perform the WSFM series, it was imperative to assemble and real-time-update the image target information and mission constraint criteria into the W-CDE (Figure 5).

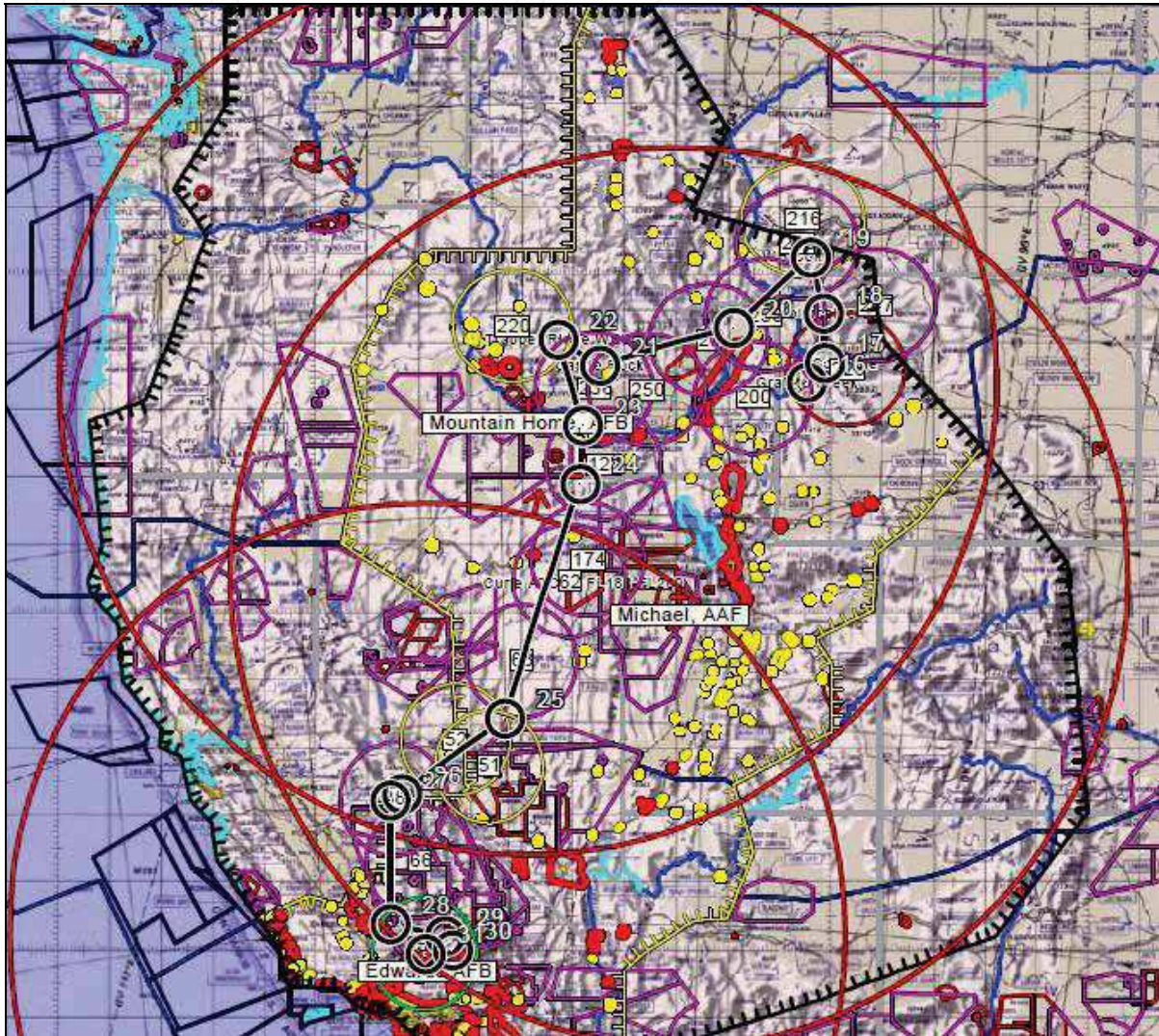


Fig. 5. Graphic of *Ikhana* UAS flight planning for operations over emerging wildfire events. Planned flight route displayed as black line; turn points of UAS defined as small black circles along flight plan route. Large red circles represent 400 nm distance range of potential secondary emergency landing locations (three identified for western U.S. Purple smaller circles represent tertiary emergency landing locations (50-mile radius along flight track). Yellow and red polygon areas on map represent population density centers where certain UAS operations are restricted or not allowed as per the FAA regulations.

The WSFM planning efforts begin two to three days before a mission, and results in two mission plans being developed. A preliminary mission plan filed with the FAA 48-72 hour prior to take off, highlighted the route of flight and denoted imaging targets as various loiter

areas (circular operational areas, typically 15-nm radius). This preliminary plan was used by the FAA to alert FAA flight sector controllers to the NASA *Ikhana* UAS activity in their assigned areas of responsibility. For this preliminary plan, targets are selected from the W-CDE, with coordinated input from the National Interagency Fire Center (NIFC), or other responding agencies such as Cal Fire. Additional requests for imaging (science targets, satellite calibration/validation coincident collections) are also considered. Operational radiuses are assigned to each target, considering extent of imaging, and required maneuvering room. A route of flight is then generated to efficiently transit to each target, while avoiding keep out zones. Take off times are planned to optimize imaging times, and are often modified to address operational constraints (Figure 6).



Fig. 6. Flight Plan for FAA defining *Ikhana* fire imaging mission route (black line), UAS turn / linger points (small black circles), tertiary landing locations along flight route (purple circles), restricted-flight / no flight zones (yellow / red polygons), and major lingering imaging locations (fire areas) (blue circles). Data displayed on a digital air navigation chart.

Hours before an *Ikhana* fire imaging mission is initiated, a detailed mission plan, showing the route of the flight (avoiding the FAA / NASA Flight Safety-imposed restricted / keep out areas) and a detailed imaging plan for operations around the imaging targets was completed. The pilots use this detailed plan during the mission to methodically image the target areas. Detailed mission plans build on the preliminary plan, by adding imaging waypoints (start/stop points for imaging runs) in each of the fire imaging areas. For the WSFM, the entire mission planning was done in the W-CDE. Waypoints (latitude/longitude) for all the targets and turning points, are generated, saved as a *kml* file, and compiled into both a text and a Microsoft EXCEL® file highlighting all waypoints, with distance between waypoints and duration of mission through the waypoint series. A completed Mission Plan includes waypoint files and a graphic of the mission plan for visual verification (Figure 7).

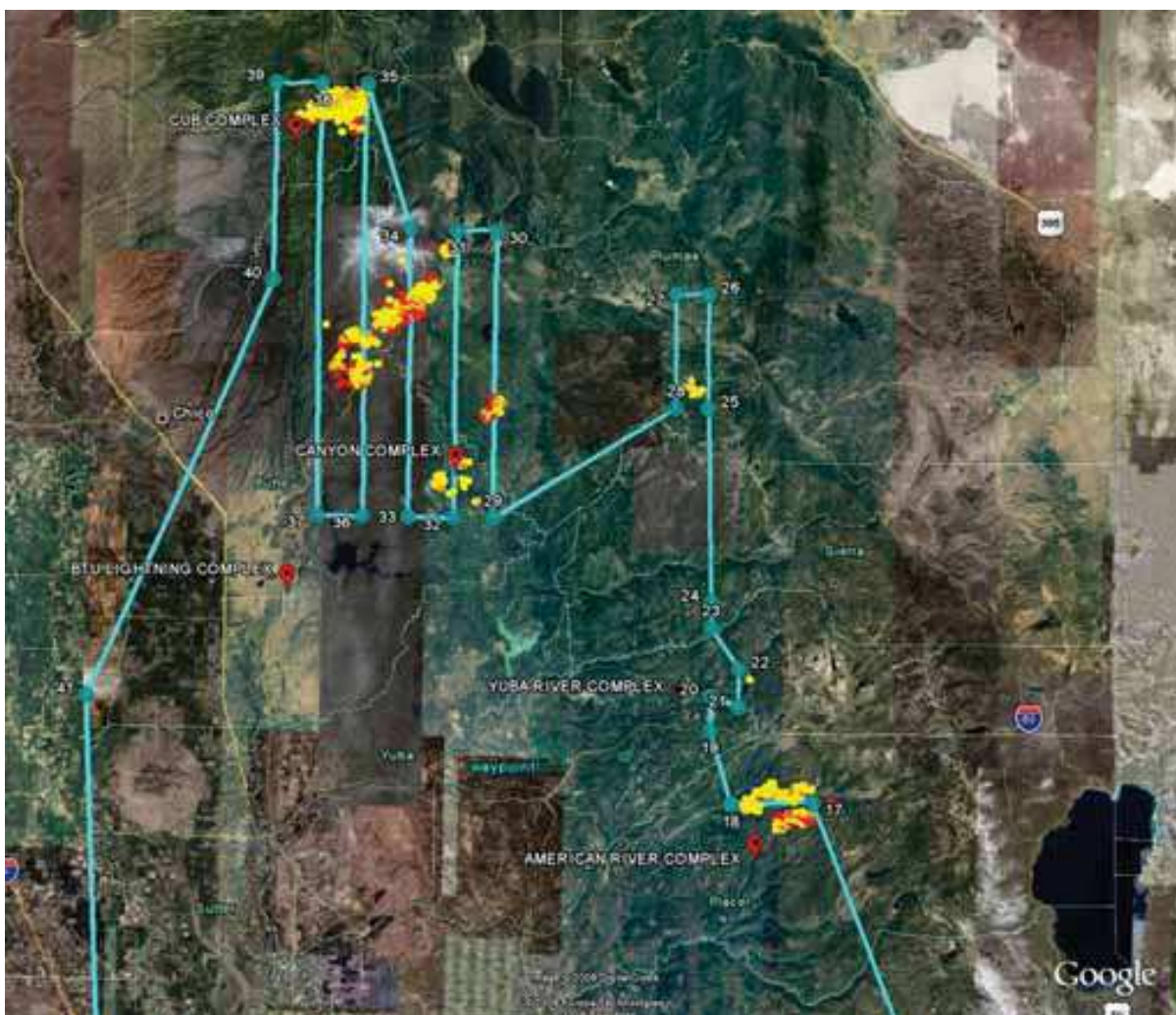


Fig 7. Detailed mission plan indicating sensor data collection flight line locations for an *Ikhana* UAS fire mission. The teal lines represent the flight line plan for regular-spaced flight segments over a complex of fires in Northern California, 8 July 2008. The yellow, orange and red dots represent near-real-time MODIS satellite hot-spot detects, which allow the *Ikhana* sensor team to design flight profiles over the most currently active fire areas for detailed imaging.

During mission operations, fire management personnel and the mission management team can make requests to adjust flight parameters to allow for shifting fire locations or target modifications. The modifications can include both flight parameters and sensor configurations (band combinations, changing algorithms, etc). The mission manager notifies the *Ikhana* pilot of “mid-mission” modifications to the flight parameters, who would request such flight modification from the FAA controller via radio. In almost all cases, the requested flight modifications were allowed. Mid-mission sensor configuration modifications are made through the sensor operator, monitoring the system operations.

3.2 Fire Data Products

The AMS-Wildfire sensor data products delivered from the UAS through the satellite telemetry link to the ground include a geo-rectified 3-band color visual product and a vector file of hot-spot-detect “fire” polygons. Imaging smaller fires may only require the collection of a single “segment” of image data (defined earlier as a section of ~1200 lines of scanner data). An investigator can choose any three channels to form an image data set composite as can be seen in Figure 8.

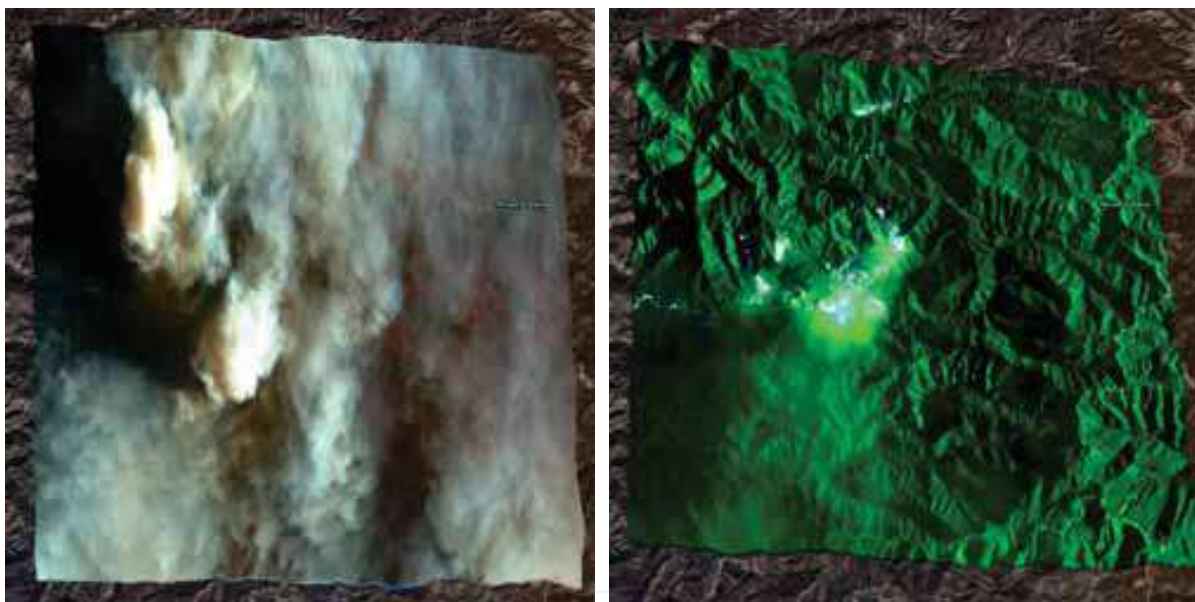


Fig. 8. Image on left represents a single segment image of a geo-rectified three-band composite of AMS-Wildfire visible-band spectral data collected over the Zaca Fire, southern California, 16 August 2007. Fire is obviously not visible in this color composition, but the attenuating smoke clearly is visible and obscures the terrain and fire location. The right-side image is the same region (Zaca Fire), but displays a 3-band color composition that includes both reflected infrared and thermal infrared data. The intense fire locations can be easily seen, even through the dense smoke plume.

For most fire events, a multi-segment / multi-flight line fire data collection mission is flown. Since the imagery and vector files are geo-rectified, the mosaics automatically orient and display correctly into any GIS mapping tool or in the W-CDE (GoogleEarth). The fire management personnel can display the images and overlay the hot-spot detection vector

files on the same data sets. This can provide an indication of both the burned and unburned areas surrounding the hot-spot active fire areas (Figure 9).



Fig. 9. AMS-Wildfire sensor near-real-time processed image “segment” mosaic for the Basin Fire Complex, Big Sur, California, collected on 8 July 2008. Data was processed and mosaiced in “real-time” from 5 flight lines of 22 segments of AMS data. The fire hot-spot detection algorithm shape-file information, shown draped in yellow, on the 3-channel composite mosaic (which is draped on the GoogleEarth W-CDE).

W-CDE users can “turn-off” the 3-band image files and display just the vector file hot-spot detections, in order to reduce image clutter and focus on identifying critical small hot-spot locations (Figure 10). By having simple functionality built into the data visualization, the wildfire management teams can make effective use of the UAS sensor-derived data. Additionally, the wildfire managers can make sensor data requests for “alternative” band and data sets to be collected and rendered in near-real-time, allowing true sensor-web-enabled functionality.



Fig. 10. AMS-Wildfire sensor data collected 8 July 2008 over Basin Fire Complex, California. The hot-spot vector file data (yellow polygons) are shown overlain with the recent fire perimeter polygon (teal). All layers draped in GoogleEarth for visualization. The yellow hot-spot fire fronts can be seen extending outside the fire perimeter.

The AMS-Wildfire sensor data can also be visualized in 3-D within the W-CDE. Since all data are geo-rectified, the mosaic imagery and any additional data layers can be draped on the terrain and various visualization perspectives can be rendered. The 3-D visualization capability can be critical for determine rates of fire spread with various terrain slope or aspect conditions (Figure 11).



Fig. 11. Three-dimensional view of AMS-Wildfire sensor imagery collected on 8 July 2008 over Basin Fire Complex, California. This eastward looking view shows the hot-spot fire detects (yellow polygons) overlain on the three-band color composite, which is draped on the GoogleEarth background data base. Note the locations of the fire on the south-facing (sun-intense) slopes at this data collection time.

All of these various W-CDE-enabled capabilities were available to fire management teams during the 2006, 2007 and 2008 western U.S. wildfire season. Additionally, project team members were embedded at fire camps and multi-agency and multi-fire coordination centers to provide W-CDE assistance. In 2008, numerous fire personnel were familiar with the UAS, sensor, and W-CDE capabilities to work seamlessly on data utility for wildfire event management. The additional GIS-enabled web-served data sets (GeoTIFF, etc) were used extensively by the various GIS teams to further map and update fire perimeter information on numerous fires in the U.S. using various image processing and GIS software systems. The 2006-2008 mission series flights, data collections and data utility are highlighted in the following section.

3.3 Western States Fire Mission Flight Summary

The Western States Fire Missions (WSFM) in 2006, 2007, and 2008 demonstrated the integration of the technologies detailed in the previous section. The missions, flown over wildfire events in the western United States served as a test-bed and model for improving disaster data delivery to disaster incident management teams. The 2006-2008 Western States Fire Missions are briefly summarized, to provide context for employment of the integrated tools during operational missions.

3.3.1 2006 Mission Series - The Western States Fire Mission Series began on 24 October 2006, when the AMS-Wildfire instrument on the *Altair* UAS (predecessor to *Ikhana*) collected and delivered near-real-time data over prescribed burns on the eastern flanks of the Sierra Nevada Mountain Range in California, USA. The mission demonstrated long duration UAS and sensor operations and was the first National Airspace System (NAS) operations for the UAS. On 28 October 2006, the Altair supported data collection / delivery over the Esperanza Fire in southern California, USA, providing near-real-time information on fire location and progression to the Incident Command Team. During the 16-hour mission, the AMS-Wildfire scanner system provided multiple image data sets of the fire progression. Data were delivered as GeoTIFF files and served in the fire management camp on the W-CDE through GoogleEarth as well. An integration team was embedded at the fire camp to assist in data management and training. In 2006, approximately 40 hours of UAS / sensor operations occurred over fires.

3.3.2 2007 Mission Series - The 2007 mission series were the first flights of the new NASA *Ikhana* UAS, which was delivered in January 2007. The 2007 Western States Fire Mission series began in August following the FAA Certificate of Operation for the *Ikhana*. A total of eight fire data collection missions occurred during the fire season in 2007. The first four missions demonstrated long-duration / range capabilities, with data collection over fires located in eight western states. Mission operations were between 10-22 hours with 2593-5926 kilometers (1400-3200 nautical miles) mission ranges. During those first four flights, a total of 27 fires were flown and imaged with near-real-time geospatial fire data relayed to Incident Command Centers (ICC). To assist in information integration, WRAP team members were embedded at various ICCs.

3.3.2.1 Southern California Firestorm Support Missions – October 2007 - In late October 2007, over eleven major Santa Ana wind-driven fires erupted in the Los Angeles and San Diego areas of Southern California, USA. The NASA *Ikhana* / AMS sensor flew on 24, 25, 26 and 28 October 2007, and provided near-real-time imagery of those eleven complexes to the fire management teams. The FAA facilitated operations through the issuance of an emergency COA for operations in the densely populated area of the fires. Flight endurance each day was between 7-9 hours with ~ 2500 kilometers (1350 nm) mission ranges. Many of the fires were imaged twice a day to provide up-to-date fire progression information. Team members were again embedded in various Incident Command Centers (ICC) and county-level Emergency Operations Centers (EOC). A summary of the 2007 missions is shown in Table 2.

Flight Date	Duration	Fires Flown	Mission Mileage
16 Aug	10 hrs	4	2993 km (1400 nm)
29 Aug	16.1	7	4630 km 2500 nm)
7 Sept	20	12	5926 km (3200 nm)
27 Sept	9.9	4	3333 km (1800 nm)
24 Oct	9	11	2500 km (1350 nm)
25 Oct	8.7	11	2500 km (1350 nm)
26 Oct	7.8	11	2500 km (1350 nm)
28 Oct	7.1	11	2500 km (1350 nm)

Table 2. 2007 Western States Fire Mission Summary.

3.3.3 2008 Mission Series - In late June 2008, lightning ignited hundreds of fires in northern California. When the California Governor (Swartzenegger) declared a State of Emergency, the NASA *Ikhana* and sensor were deployed to support data collection and near-real-time delivery to the embattled fire management teams. The FAA provided an emergency COA-region extension to allow the *Ikhana* unfettered access to the NAS above those fire complexes. Four missions were flown during the mid / late summer in 2008, delivering near-real-time data over 16 wildfire events (Table 3). The missions focused on providing near-real-time fire information to the various ICC and well as to the State Operations Center (SOC), and the Multi-Agency Coordination Center (MACC), where data were integrated into the wildfire management decision process.

Flight Date	Duration	Fires Flown	Mission Mileage
8 July	9.5 hrs	9	2593 km (1400 nm)
19 July	5.0	4	1852 km (1000 nm)
17 Sept	3	1	1482 km (800 nm)
19 Sept	3.5	2	1482 km (800 nm)

Table 3. 2008 Western States Fire Mission Summary.

4. Operational and Integration Challenges

Many of the procedural, operational, and technical challenges were overcome during the Western States Fire Mission series from 2006-2008. Still, it is imperative to highlight those issues, so that substantive efforts towards further improving and enabling the use of UAS and near-real-time sensor collection on emergency-support missions can be realized. Some of the significant operational issues are detailed in the following sub-sections.

4.1 COA Limitations

Over the three fire mission flight years, the FAA issued COAs for the *Ikhana* that ranged in complexity and operational area allowances. In 2008, the *Ikhana* COA allowable mission area was significantly reduced by the FAA. The allowable mission area was limited to flight operations within 50 nm of Restricted Airspace (RA) or a Military Operations Area (MOA). The 50 nm RA / MOA flight operations restriction limited access to airspace and precluded critical data collection over some wildfire events in both 2007 and 2008. The FAA did not provide an explanation for the change in the *Ikhana* COA status. Further refinement to the

COA process and COA allowance are needed. Regulatory guidelines must be established to allow emergency support mission operations in areas of critical need.

4.2 COA Restrictions for UAS to Remain Clear of GPS Testing / Jamming

The WSFM encountered some mission delays and rescheduling due to GPS testing / jamming exercises at military bases in the vicinity of the WSFM routes. These testing / jamming areas were defined as consisting of an inverted cone centered at the GPS test site, with increasing radius with increasing altitude. When flying at 25,000 ft, *Ikhana* could be affected at a range of up to 300 nm from the testing / jamming origin. Since the *Ikhana* is restricted to a specified flight altitude, no deviation could be made to allow the UAS to avoid those regions during potential missions. When testing / jamming occurred (or was even planned), the *Ikhana* was grounded from operations. This had a detrimental effect on supporting some national emergency mission requests over the northern California wildfires in 2008.

4.3 Access to LOS Communications Frequencies

For flights within approximately 70 nm of *Ikhana's* base of operations (Edwards Air Force Base, California), the UAS is controlled via a direct line-of-sight radio link. Significant DOD UAS operations in the same general area required prioritization of the limited number of attainable frequencies. The *Ikhana* was restricted therefore to secondary priority status which postponed or cancelled mission operations. This became a critical issue when emergency data collection flights were requested to support wildfire teams battling conflagrations. This issue is solvable by negotiating a sharing of frequencies and reprioritization of frequency allocation given national or state-level emergency requests for mission support.

4.4 Unexpected Weather Along Flight Route

The *Ikhana* COA restricted flight from areas of adverse turbulence, convection and icing. During the 72-hour advanced flight planning process, it was difficult to predict weather occurrences or timing along a planned mission route with any certainty. Since the FAA required flight planning route information 72-hours prior to UAS launch, weather forecasts for the day of flight were not meaningful. During one mission in 2007, a significant flight deviation was allowed by FAA flight traffic controllers to avoid several rapidly developing convective cells. This was a major breakthrough for the *Ikhana* team, as we would have had to abort the mission and return to base if not granted the near-real-time deviation. Additionally, flight restrictions and mission aborts occurred due to the "potential" for clouds to be at operations altitude during missions or in the vicinity of the Base of Operations (Edwards AF Base) during planned take-off or landings. If cloud cover was predicted, the mission was cancelled. These weather-related mission issues require further refinement to allow a go- / no-go decision to be made much closer to mission take-off than 72-prior to operations.

4.5 Staffing Requirements

Long-duration flights (>10 hours) for the WSFM required multiple crewmembers for all operational positions due to crew duty day limitations (generally 8-hour duty limits). When missions longer than 12-hours were conducted, multiple shifts were implemented and crew-

duty hours were strictly adhered to. In a few instances, General Atomics Aeronautical Systems Inc. provided supplemental engineering staff and pilots when needed on long-duration missions. Non-standard flight schedules, intermittent sleep schedules, and extended on-call status have the potential to fatigue crew members. These staffing requirements will continue to be a significant issue for long-duration, non-scheduled flights that involve supporting and “chasing” dynamic disaster events, such as wildfires. Therefore, when planning such mission concepts, one must be aware of the additional staffing requirements needed to sustain safe operations.

4.6 Air Traffic Control (ATC) Coordination

The WSFM mission team coordinated airspace access for *Ikhana* flights with the FAA Unmanned Aircraft Program Office (UAPO) and Air Route Traffic Control Centers (ARTCC). Clearly, both NASA and FAA worked together as partners to facilitate the success of such demanding mission profiles and objectives. ARTCC personnel were open-minded and receptive to the prospect of *Ikhana*'s flights through their respective airspace. They communicated concerns and suggested resolutions. Fostering and promoting communication between UAS mission operations personnel and the FAA will continue to be required and a key component to successful operations in the future for any entity (Hall, et al., 2008).

5. Summary

We have demonstrated that various platform, sensor, communications, and geospatial technologies can be integrated to provide near-real-time intelligence to support of disaster management entities. In our work with the U.S. wildfire management agencies, we have developed and demonstrated technologies for providing near-real-time emergency geospatial data delivery, a significant advance over current capabilities.

Large-capacity, long-duration, medium-altitude UAS can play a significant role in providing repetitive, lingering operations over disaster events, especially dynamic, evolving events like wildfires. The OTH satellite data telemetry systems on these platforms can be employed to control / command an imaging payload as well as to provide sensor data to ground team members. This telemetry capability allows near-real-time information to be in the hands of Incident Management Teams.

Imaging sensor systems can be designed to collect critical spectral and thermal wavelength information, specifically “tuned” to the phenomenon that is being observed. The use of multispectral data for wildfire observations is necessary to characterize fire locations and movement. The spectral channels defined in this chapter are essential for wildfire observations, and multi-channel capabilities offer clear advantages over single-channel fire detection systems, as we have shown in this chapter. Image processing capabilities, to derive Level II information from sensors, can be automated and included as part of the payload processing package on an UAS platform. Complex algorithms can be integrated into the processing scheme to further reduce those labor / time-consuming, analysis tasks. By integrating sensor / platform IMU and positioning information with terrain DEM data, a fully geo-rectified image product can be developed autonomously on-board an aircraft,

further reducing the critical labor and time requirements for delivery of accurate geospatial information.

The employment of web-enabled GIS tools and systems, such as GoogleEarth, provide a user-friendly “platform” for display of geo-rectified imagery and information. Our goals were to ensure that the information products developed autonomously from the UAS sensor would integrate seamlessly into a multitude of geospatial visualization packages. We achieved that objective by providing autonomously-generated data products in Open Geospatial Consortium (OGC) standard formats. The W-CDE was used extensively as were the access to the various WMS data-formatted holdings.

Following three years of system development and emergency support missions in the western United States, we have demonstrated that current off-the-shelf technologies can be integrated to provide the disaster management community with the data and “intelligence” that they require in near-real-time. We anticipate that the civilian use of UAS will increase dramatically, especially in support of disaster management and disaster relief efforts. The processes and technologies described here for the use of UAS platforms and enabling sensors and technologies should form the foundation for designing future disaster monitoring and observation capabilities. These integrated technologies have obvious cross-cutting application to other disaster events in the United States and the world. As the National Academy of Science has reported, “UAVs provide increased range and flight time and the ability to penetrate environments that might be too hazardous for piloted aircraft. However, issues of cost, reliability, software, and proximity to urban areas have limited the use of UAVs to demonstration missions. For now, conventional aircraft remain more reliable and more cost-effective for Earth sensing, and agencies need to ensure an appropriate balance between these two types of platforms” (Henson 2008).

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Remote Sensing is collecting and interpreting information on targets without being in physical contact with the objects. Aircraft, satellites ...etc are the major platforms for remote sensing observations. Unlike electrical, magnetic and gravity surveys that measure force fields, remote sensing technology is commonly referred to methods that employ electromagnetic energy as radio waves, light and heat as the means of detecting and measuring target characteristics. Geoscience is a study of nature world from the core of the earth, to the depths of oceans and to the outer space. This branch of study can help mitigate volcanic eruptions, floods, landslides ... etc terrible human life disaster and help develop ground water, mineral ores, fossil fuels and construction materials. Also, it studies physical, chemical reactions to understand the distribution of the nature resources. Therefore, the geoscience encompass earth, atmospheric, oceanography, pedology, petrology, mineralogy, hydrology and geology. This book covers latest and futuristic developments in remote sensing novel theory and applications by numerous scholars, researchers and experts. It is organized into 26 excellent chapters which include optical and infrared modeling, microwave scattering propagation, forests and vegetation, soils, ocean temperature, geographic information , object classification, data mining, image processing, passive optical sensor, multispectral and hyperspectral sensing, lidar, radiometer instruments, calibration, active microwave and SAR processing. Last but not the least, this book presented chapters that highlight frontier works in remote sensing information processing. I am very pleased to have leaders in the field to prepare and contribute their most current research and development work. Although no attempt is made to cover every topic in remote sensing and geoscience, these entire 26 remote sensing technology chapters shall give readers a good insight. All topics listed are equal important and significant.

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