A Low-Cost Control System for a High-Altitude UAV

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Abstract—The BIG BLUE project at the University of Kentucky is a test bed UAV for Mars airplane technology. A major focus of the BIG BLUE effort has been the development of a low-cost and light-weight avionics, control, and communication system to manage the aircraft and correspond with ground stations. BIG BLUE I, launched in May 2003, achieved the first successful deployment of inflatable/rigidizable wings at altitude. BIG BLUE II, launched in May 2004, had a flight-ready fuselage and control system. This paper1,2 describes the BIG BLUE project detailing the design and implementation of the avionics, control, and communication system.

1. INTRODUCTION

BIG BLUE (Baseline Inflatable-wing Glider, Balloon-Launched Unmanned Experiment) is a multi-year project at the University of Kentucky with the purpose of developing a test bed for Mars airplane technology. On May 3, 2003, BIG BLUE I was launched near Fort Collins, Colorado, reached an altitude of approximately 90,000 feet, and achieved the first documented deployment of inflatable/rigidizable wings at altitude. BIG BLUE II expanded the mission goals to include autonomous flight with wings rigidized at altitude and was launched on May 1, 2004. BIG BLUE II reached 66,000 feet and achieved a second successful wing deployment but a premature balloon burst placed the vehicle off of the expected decent path. As a result, autonomous flight was not conducted due to Federal Aviation Administration (FAA) restrictions that prohibit flight without visual contact.

Both generations of BIG BLUE relied on a sophisticated avionics, control, and communication (ACC) system to carry out the mission sequence. The control system was designed for maximum fault-tolerance, using redundancy and fail-safe designs wherever feasible. The ACC design evolved from a single processor in BIG BLUE I to a multi-processor implementation in BIG BLUE II, allowing additional crosschecking and backups for critical functions. The mission profile for both generations required the ACC system to monitor an array of sensors to track and direct the mission progress as well as gather scientific data. Mechanical actuators used in the mission triggered wing inflation, activated a cutter to separate the glider from an ascent package (to initiate autonomous flight), and deployed a recovery parachute. The autopilot functions of the ACC required sensors for airspeed, accelerations, and angular rates as well as interfaces to control surface servos.

Mission requirements for communication between the aircraft and the ground stations planned for an ascent of approximately 20 miles through the troposphere, jet stream, and into the stratosphere. The extreme altitude combined with the distance the vehicle would be carried downrange by ascent and descent through the jet stream required long-range communication systems. The communication channels carried position information, telemetry, and command sequences between the vehicle and the ground stations. Ground stations were developed to display telemetry data and provide an intuitive graphical user interface for the transmission of commands to the vehicle. Multiple ground stations were used to track BIG BLUE I as it moved beyond the horizon. In BIG BLUE II, a mobile station was added for in-flight communication with the aircraft throughout the mission. All telemetry data was stored in non-volatile memory on the vehicle to prevent the loss of information if radio contact was lost. In addition, critical position information from the GPS was transmitted on redundant radio links. Finally, the ACC system was designed to provide autonomous operation and thus ensure mission completion in the case of complete radio link failure.

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Throughout the design and implementation of the ACC, significant efforts were made to minimize its weight. The target altitude of 100,000 feet necessitated a larger balloon as the weight of the vehicle increased. This restriction also limited the amount of energy available, as additional batteries constituted a significant weight penalty. As a result, the ACC design tried to minimize both weight and power consumption. For BIG BLUE II, a constraint requiring that the ACC system be housed within a streamlined composite fuselage was added. Figure 1 shows the BIG BLUE II composite fuselage with the ACC visible through the hatch.

Figure 1 - ACC Mounted Inside Composite Fuselage

The final design and implementation of the ACC system is a successful example of a low-cost and light-weight avionics, control, and communication system for a small UAV, capable of long-range communication and several hours of autonomous operation. In this paper, Section 2 outlines the BIG BLUE project and the mechanical design of the aircraft and systems controlled by the ACC. Sections 3 and 4 present the design and implementation of the ACC as used in BIG BLUE II. Sections 5 and 6 discuss lessons learned and summarize the design and development of the ACC.

2. BACKGROUND

In recent years, Mars exploration has been given considerable attention. The 1997 Mars Global Surveyor and 2001 Mars Odyssey orbiter missions captured images of a large portion of the Martian surface and sent them back to Earth. The 1997 Pathfinder mission and the 2004 Spirit and Opportunity missions have successfully sent back high-resolution images of the landscape they traversed and have greatly enhanced our understanding of the composition of the Martian surface and its history.

Future Mars exploration can benefit from low altitude planes that can survey larger areas more rapidly than rovers and with more acuity than can be achieved through orbiting satellites. The “Mars Airplane” is a concept that is nearing reality [1,2]. A typical fixed wing aircraft is undesirable for this type of mission because of the volume required to transport a fuselage and wings to Mars. The Aerial Regional-scale Environmental Survey of Mars [3] (ARES) aircraft, developed by the NASA Langley Research Center, has demonstrated high-altitude, low air-density flight capabilities and solves the transportation problem with an unfolding rigid wing. Our approach, aiming to minimize packed volume and weight, is an inflatable composite wing impregnated with UV-curable resin. With this method, UV radiation from the sun rigidizes wings that are deployed when pressurized [4].

BIG BLUE

The BIG BLUE project was initiated in January of 2003 with funds from the NASA Workforce Development Program and involves strong partnerships with the aerospace industry and NASA. This program was developed expressly to expose students to aerospace technology and stimulate their interest in such careers. During the past two years of the BIG BLUE project, over 120 students have worked on the design and testing of the two generations: BIG BLUE I and II [5]. During the course of this time, students have visited several NASA facilities, such as NASA Langley, NASA Ames, and NASA Wallops, where they had a chance to present their ideas and receive feedback from NASA engineers. The design for both generations of the aircraft and their accompanying systems were presented by student team leaders during a critical design review to professional engineers working in the aerospace industry. Students also had the chance to travel to Colorado and participate in the mission preparations and launch with Edge of Space Sciences (EOSS), the group that launched both generations of BIG BLUE.

The technical goal of the BIG BLUE flight experiment was to demonstrate feasibility of inflatable/rigidizable wings for flight in the low-density atmosphere of Mars [6]. This environment and high Mach number flight characteristics establish a flight regime in which the aerodynamics are not well understood. Initial stages of wing design focused on the selection of a candidate airfoil with a low Reynolds number to develop into an inflatable/rigidizable wing. Analyses of lift, drag, and pressure profiles were paired with manufacturing considerations to develop the implemented wing design. In addition, wind tunnel tests showed that a rough wing surface enhanced the airfoil characteristics in low Reynolds number regimes and was not detrimental to high Reynolds number regimes [7,8]. The wings, seen in Figure 2, were manufactured by ILC Dover, Inc. of Frederica, Delaware, the project’s primary industrial partner. With experience in highly engineered soft goods and UV sensitive resins, their contributions to the project were essential.
The BIG BLUE I project goal was to develop and verify technologies for inflatable, UV-rigidizable wings and concluded with a successful demonstration flight on May 3, 2003. The test article consisted of the folded wings, inflation system, microprocessor controller, sensors, cameras, global positioning satellite (GPS) receiver, and communications radios. The aircraft was not designed to fly, but rather as an insulated structure for the wing-deployment experiment. The sensor suite aboard this craft allowed the measurement of accelerations, angular rates, various temperatures, atmospheric pressure, and the wing inflation pressure. Photographic records were made with a still camera oriented to capture images of the wings along their spars and an onboard video camera looking forward from the tail. Figure 3 shows a sequence of digital images taken through ascent and decent. The onboard video was the only system that failed during the flight; however, the “look-down” video from EOSS’s balloon package provided live views of the aircraft from liftoff to landing. Two radios provided communications to and from the ground: one dedicated to reporting GPS position and the second for telemetry data and command transmission. A mission control computer was designed and built to manage communications, deploy the wings, and to take still pictures and video.

The goal of BIG BLUE II, the next step in the evolution of the BIG BLUE project, was to develop an aircraft using inflatable wings that could fly. To do this, all the functionality of BIG BLUE I was needed with the addition of an autopilot. Work on BIG BLUE II started in January of 2004 and culminated with a successful launch on May 1 of the same year. A photograph of the aircraft after having completed the mission is shown in Figure 4.

During the flight experiment the wings inflated and rigidized successfully. Prior to launch, the FAA granted the...
BIG BLUE clearance to operate the vehicle under conditions meeting the FAA Visual Flight Rules (VFR). The most important of these for the BIG BLUE mission was that a visual inspection for other aircraft in the immediate airspace must be performed by ground observers. This was not possible at 100,000 feet, but was possible as the aircraft and descent parachute neared the ground. Data that the EOSS team had collected from previous launches enabled them to create a reliable empirical model of the predicted flight path based on weather conditions in the days prior to the launch. The mobile ground station was positioned at the predicted touchdown location but a premature balloon burst at 66,000 feet invalidated this estimation. The mobile unit was not able to reach the touchdown location before the aircraft on the descent parachute reached the ground and therefore never met the VFR requirements to allow free flight.

Ascent Configuration and Mechanical Design

EOSS provided the balloon technology used to carry the BIG BLUE glider aloft. The cost of incrementally larger balloons placed weight restrictions on the combined package that was to be lifted. To achieve the target altitude of 100,000 feet, the total weight of the BIG BLUE II payload could not exceed 18 pounds. Figure 6 provides an annotated photograph of the balloon and flight string as it was launched. The balloon carried mission systems for EOSS including a GPS receiver with relay radio, amateur television (ATV) camera and antenna, a balloon release cutter, and descent parachute. To the EOSS string, the BIG BLUE team attached the wing inflation system, aircraft separation system, and the glider. The wings developed by ILC Dover were capable of producing approximately 12 pounds of lift. Since these weighed 5.5 pounds, the airframe and the on-board systems were restricted to a maximum combined weight of 6.5 pounds. To aid in meeting this restriction, the fuselage was made from a composite material to provide the needed strength with minimal weight. The fuselage was 4.5 feet long, 4.25 inches high, and 9 inches at its widest point. The front of the fuselage was broadened into a “pan head” to accommodate the ACC, sensors, radios and batteries. This shifted the center of gravity forward of the center of lift to achieve the desired weight distribution.

Another design decision, aimed at meeting the weight limits imposed by the wings, was to separate the wing inflation system from the airplane into an “ascent package.” This decreased the glider’s flight weight by removing the needed inflation valve and compressed air tank from the air frame. Additionally, this package served as the connection point between the plane and the EOSS flight string. After the wings were inflated and rigidized, the airplane could sever the tether which kept the glider and the inflation system connected. The pressure hoses and electrical cabling between the inflation system and airplane were outfitted with quick-release connectors that separated as the aircraft pulled away.

Before launch, the wings were folded and enclosed in a “UV tight” box that was opened and detached from the glider by the internal pressure of the inflating wings. To avoid a complicated autonomous landing while gliding, the team chose to use a recovery parachute system. This device, mounted in a pod just behind the wings, would allow the craft to descend vertically when its altitude became unsafe for further flight or once it reached the target landing site. Tests showed that the opportunity for parachute entanglement with the glider’s tail was minimized by using a U-tail configuration. The fuselage, wings, recovery parachute pod, U-tail and the lower portion of the inflation system can be seen in Figure 4.

The fuselage housed all of the electronics except for the inflation actuator and an additional battery pack, both of which were housed in the ascent package. The general layout of the electrical components within the fuselage is shown in Figure 7. To carry out mission goals and gather flight data, the on-board systems interfaced with various sensors and actuators which are not shown in this figure. The following were recorded for the purpose of science: pressure inside the wings, UV light intensity, and forces experienced by the glider. Additionally, the air temperatures inside and outside the fuselage, as well as the fabric of the wings, were continually monitored and recorded. Digital still pictures and video were taken to record the wing behavior and document the mission.

![Figure 6 - Flight String for BIG BLUE II Launch](image-url)
The two generations of BIG BLUE have produced significant research results. The inflation at altitude of UV-curable wings and subsequent low altitude flying tests with these wings have shown the feasibility of this approach. In addition, the development of the ACC system has resulted in active research efforts to adapt the ACC design to various UAV platforms and to further advance the fault tolerance of the design [9]. The following sections discuss related work and the details of the ACC design and implementation.

3. RELATED WORK

While autopilots and control systems for UAVs have been developed at universities [10,11,12,13,14] and are available commercially [15,16], the unique mission profile for BIG BLUE necessitated a custom design. The target altitude of 100,000 feet required long range communication and sensors appropriate to the extreme altitude. This sections overviews some existing UAV control and communication projects.

West Virginia University designed and constructed the WVU YF-22 aircraft for use in the development of fault detection, isolation, and control reconfiguration schemes as applied to formation flight experiments [10]. Similarly, work on BIG BLUE required the custom design and instrumentation of a controllable aircraft. However, BIG BLUE has been motivated by the requirement to deploy and fly inflatable wings at low atmospheric pressures.

Researchers at the Georgia Institute of Technology have developed a relatively large UAV, the GTMax. This UAV is a helicopter with a total weight of over 200 pounds and a 66 pound payload capacity. The modular avionics architecture developed allows for flexible task-based reconfiguration of the UAV and the large payload capacity enables the execution of multiple tests in a single flight [11,12]. In contrast, BIG BLUE II weighed less than 20 pounds and was a high-altitude glider with a custom made fuselage.

A fixed-wing model airplane-based UAV developed by Cornell University combined off-the-shelf hardware with custom software to implement a cost effective autopilot system. The autopilot is capable of flying GPS coordinates and reacting to wind dynamics [13]. Similar to the BIG BLUE missions, this UAV utilized a live video feed, ground station communication and tracking as well as a fault tolerant implementation that enables autonomous flight in the event of ground communication loss.

BIG BLUE utilized amateur radio transceivers for bi-directional communication with the ground station over the amateur radio frequency bands. In contrast, the University of Colorado, Boulder has developed a wireless network test bed using IEEE 802.11b (WiFi) radio equipment for communication between multiple UAVs over ad-hoc networks [14] allowing high bandwidth within a limited range.

Commercially available UAV autopilots such as MicroPilot’s MP2028g [15] and the PicoloPlus from Cloud Cap Technology, Inc. [16] combine functionality with deployment flexibility. The MicroPilot is much smaller and lighter than the PicoloPlus. However, BIG BLUE mission requirements dictated a small low-power autopilot but did not require as much capability as is available in these systems.

In the design of the BIG BLUE ACC, emphasis was put on a light-weight and low-power implementation to achieve the targeted high-altitude of 100,000 feet and operate for several hours using the on-board batteries. Components were custom built to achieve a compact size and a fail-safe architecture as well as implement special functionality for wing inflation, autonomous flight and long range communication.

4. ACC DESIGN

The management of all aspects of the aircraft and support systems were handled by the ACC and consisted of components both onboard the aircraft and at operator stations on the ground. Figure 8 illustrates the airborne portions of the ACC including power sources in the fuselage and ascent package, the array of controllers, and the communication devices. The ascent package was housed in a separate unit from those systems in the fuselage, as is represented in the figure by a different border. Additionally, digital communication links among the sub-systems are represented with a dashed line and power connections are represented with a solid line.
The composition of the ground stations are shown in Figure 9. The vehicle telemetry data and automated position reporting system (APRS) data strings were transferred through a pair of amateur radio transceivers, each dedicated to one of the two data streams. The telemetry was routed to and from a redundant pair of notebook computers at each ground station. On each of the computer terminals a custom written application allowed operators to easily view the decoded telemetry data as it arrived from the craft, and to send commands to the mission control processor. This setup allowed either of the PCs to handle the ground station requirements if the other PC failed. The ATV signal was received by an independent system that allowed it to be simultaneously viewed and recorded. All of these ground-based systems were designed with mobility in mind and were thus powered from 12 Volt sources. Inverters were required to bring the DC source power to the needed 120 Volts AC power required by some of the sub-systems in the ground station.

A processing architecture that assigned each device a subset of the mission requirements allowed the available resources to be better distributed and tailored to the task set. The functionality of mission sequence tracking, data acquisition, and communication with the ground stations was grouped into a single processing unit dubbed the “Mission Control.” A separate processing unit, the “Flight Control,” was allocated the responsibility of monitoring the flight sensors and performing the functions that are more sensitive to real-time operation. The most safety critical mission requirement was the safe return of the glider to the ground. To keep the firmware responsible for this task isolated and allow easy testing of the supporting hardware, this section of the mission requirement was assigned to a unit called “Chute Control.” The “Camera Driver” is the fourth component of the architecture and was created as a separate unit because of the large bandwidth that image processing and storage required.

To minimize weight, the design placed the inflation valve, sensors monitoring the temperature in the inflation tank and some of the electrical power storage in a remote location. For this reason, digital signal and power lines had to be run between the fuselage and the ascent package to connect the rest of the ACC system to these devices. As the aircraft would be leaving these devices behind after cutting its tether to the ascent package, hardware was needed to ensure that the digital signal and power connections were severed cleanly.
Long range radio communication links were needed to stream commands and telemetry data to and from the craft, track its position, and broadcast TV signals. A terminal node controller (TNC) connected to an amateur radio provided a means for bi-directional transmission of the sensor data stream and the command sequences. Position information was also transmitted by pairing a GPS receiver with a second amateur radio that created standard automated position reporting system (APRS) packets. The onboard analog picture signals were fed into an ATV transmitter for broadcast. To locate the downed aircraft a homing transmitter with an independent power source having enough reserve power for several days of operation was also included in the communications package.

5. IMPLEMENTATION OF THE ACC

The ACC system onboard BIG BLUE II consisted of a mission controller, flight controller, parachute controller, global variable storage area, and a data bus that interconnected those components. This control network monitored and utilized an array of sensors and actuators, a graphical depiction of which is shown in Figure 11. Figure 12 is a photograph of the ACC hardware that was built to implement this design. The mission control processor on the left connects to the extension board on the right. On this board are many of the sensors that the mission control managed, the data bus, the power busses, and connections for the flight control, parachute control, and peripheral sensors and power packs. The flight control processor, along with its sensor card, is stacked on the extension board at the right. In the center of the image, the parachute control processor, as well as its daughter and “granddaughter” card, contains the actuator control circuits. For clarity, the figure does not show the harnesses that linked the ACC with the external sensors, actuators, and flight control surfaces.

**Figure 11 - BIG BLUE II ACC Functional Implementation**

A distributed network was built using the three processors and a common data bus. The Inter-Integrated Circuit (I²C) bus was chosen to serve as the foundation of the network and the global variable storage area was implemented using a 64 Kilobyte non-volatile EEPROM device, the Microchip 24FC512. In the global variable storage area, each networked processor was assigned an array of mailboxes, defined by starting and ending memory locations. Through these mailboxes, data and commands were relayed among the processing units using an atomic read-write protocol.

**Mission Control**

The mission control unit, implemented on a Silicon Laboratories (SiLabs) C8051F120 8-bit microcontroller, coordinated the execution of the mission sequence by utilizing its sensor array and commanding the other processing units in the system. In addition, the mission control collected science data, handled the ground communication, made computations necessary for navigation, and provided an extra layer of safety logic for some actuator signals.

Mission control used the shared memory system to send commands to the flight control and parachute control processors. This command set included the initialization of the flight system, the start of autonomous flight, a request for a change in course heading, use of the still camera, the start and stop of ATV broadcasting, inflation of the wings, the severance of the balloon tether, and the deployment of the parachute.

Scientific data was collected by sensors and stored in nonvolatile flash memory by the mission controller. Analog sensors recorded wing pressure with a Motorola MPX5100 differential pressure sensor, absolute air pressure with an All Sensors 15PSI-A-4V, and UV light intensity with an Electro Optical Components JEC 0.3S. Analog Devices ADXL210 10G-force accelerometers were placed on the lateral, longitudinal and normal axes and a Texas Instruments TMP100 temperature sensor was interfaced through the I²C bus. Mission control processed these sensor readings into telemetry strings and for storage in an Atmel AT45DCB004, 4 Megabyte nonvolatile flash memory card that was interfaced by the mission control’s Serial Peripheral Interface (SPI) bus. This card served as the
“black box” data recorder and collected information throughout the mission.

Location and heading were found with a GPS receiver and compass. The initial GPS choice, the Motorola FS Oncore, was not used because National Marine Electronics Association (NMEA) standard firmware support was not yet available. Instead, the same unit that was used in BIG BLUE I, a Motorola M12 Oncore, was included in the ACC system. A Honeywell HMR3300 magnetic compass was interfaced via the SPI bus.

The signals for wing inflation and parachute deployment were driven by the parachute controller; however, an inhibit signal to prevent premature release from the balloon was generated by mission control.

The communications subsystem radio was interfaced through the second UART on the mission controller. When necessary, portions of the incoming messages were routed by way of the data bus and global variable storage to the other processing units.

Mission control provided many unrelated services to the ACC. The design and final implementation supported all the required functions on a custom built card attached to the mission control processor. The hardware as it was flown can be seen in Figure 13 above.

Flight Control

Implemented on a SiLabs C8051F310, flight control was capable of handling commands from mission control to begin flight mode and change headings and reported back the gliders indicated airspeed. The air data acquired by flight control’s sensor array was used as input to proportional-integral-derivative (PID) control loops. These loops adjusted the two servos embedded in the aircraft’s tail connected to the rudder and elevator.

To stabilize the glider, the flight controller used data collected by an accelerometer, angular rate sensor, and a differential pressure sensor. The 2-axis accelerometer, an Analog Devices ADXL202, a 2G-force version of the same component used by the mission control, was mounted to measure the forces along the normal and longitudinal axes. A solid state gyroscope, the NEC-Tokin CG-L43, was used to measure angular rates. To help correct the temperature sensitivity of these parts, analog averaging circuitry was used to bias the sensor readings. A Motorola MPX5004 differential pressure sensor connected to a pitot-static tube provided an analog voltage proportional to the indicated airspeed. The MPX5004 had an output range of up to 5 Volts, but the flight control processor operated at 3 Volts. To ensure that the processor would not be damaged if a pressure spike did occur, a clipping diode was placed on the sensor’s output.

Because the flight controller needed to be lightweight, simple, and reliable, it was decided that tracking only yaw rates and indicated airspeed would be sufficient to control pitch and heading. Also, because of the sensor output drift caused by the temperature extremes encountered during the mission, over-sampling and averaging was used to enhance the sensor readings. Simulation in X-Plane by Laminar Research and pre-launch verification testing showed that this simple flight control was sufficient [17]. Figure 14 shows X-Plane, a PC simulator, performing hardware-in-the-loop testing. To test the flight controller, X-Plane was set up to send simulated flight data to the flight control processor. After running the flight control algorithm, the response that would normally be sent to the servos aboard the plane was instead returned to the simulator [18].

Parachute Control

The SiLabs C8051F310 based parachute control unit was responsible for inflating the wings, severing the tether to the balloon, deploying the parachute, and controlling the ATV and digital cameras. As implemented, either the mission controller or the parachute controller could independently deploy the parachute. Redundant channels of actuation enhanced the availability of this safety-critical function in the case that one processor failed. To provide redundant altitude information to the parachute controller, a dedicated All Sensors 15PSI-A-4V pressure sensor altimeter was included on this unit. If the aircraft was determined to be descending at a rate greater than 80 feet per second or was
within 3,000 feet of the ground, the parachute was immediately deployed.

A layer of safety logic was implemented to restrict the separation of the glider from the ascent package to when both the mission control and parachute control were capable of handling all failure conditions. As the backup for many potential failures was the parachute, both the parachute controller and the mission controller had to agree that they were capable of deploying it before the tether was cut. To implement this, the actuator logic combined the signals from both processing elements into a single logic state. A layer of Schmitt-triggered hardware was placed between the combinational logic and actuators to protect against false actuation of the fight tether cutter and parachute deployment system due to noise on the logic signals. The safety logic implemented on the processor helped ensure a high level of reliability in this safety-critical subsystem.

The actuators that the chute controller used for the wing inflation solenoid, the Holex 5801-1 ballistic guillotine cutters (used both to cut the balloon tether and to open the parachute pod), as well as the ATV transmitter required high currents to operate. To supply this demand an array of International Rectifier IPS031 power MOSFETS and a bank of capacitors were used.

The digital imaging device that was implemented included its own processing and storage controller, offloading this requirement from the ACC system. For this reason the camera driver was not implemented as was in the design, and the responsibility of the much simpler camera logic control given to the chute controller. A modified Aiptek PenCam SD 1.3 digital camera took 1.3 mega-pixel still pictures as well as 640 by 480 pixel Audio Video Interleave (AVI) compliant video at times of interest in the mission. The camera was outfitted with a wide-angle lens and was mounted at the nose of the fuselage pointing back to the tail. Images and videos were stored on a 128 Megabyte Secure Digital (SD) flash card. As camera operation was not critical for mission success and safety, no redundancy in this sub-system was used. The images in Figure 15 were taken by the camera during the BIG BLUE II mission.

Figure 15 - Onboard Camera In-Flight Image Sequence

Power

Three independent packs of batteries were used to supply energy to the electrical systems and the power load was distributed among these batteries to ensure the demand was met. Lithium batteries were chosen for their energy capacity, light weight, and cost. Two packs, A and B, were used on the glider producing 6 Volts each. Another pack, pack C, was part of the ascent package and produced 9 Volts. For the portion of the mission that the glider was attached to the ascent package, the power was provided by pack C as long as the voltage in C remained higher than that in B. This was accomplished by using an International Rectifier 40L15CT and allowed A and B to be preserved for the critical flight phase at the end of the mission. Both pack A and pack B were available to all three of the microcontrollers through the use of redundant busses, again using 40L15CTs. The only systems which were dedicated to one pack or another were the APRS radio on bus A and the communication radio on bus B. As the ATV required 12 volts, a Powerline Power Patch OBR12DC was used. Figure 16 shows a schematic of the power system. The voltage on busses A, B, and C was monitored using analog to digital converters on the mission controller.

Figure 16 - Distributed Power System

Communications and Ground Stations

The bi-directional communications link and the APRS were implemented with two onboard amateur radios. Kenwood TH-D7A radios were used successfully on BIG BLUE I and were used again in BIG BLUE II. The small locator beacon had its own power supply to ensure long operation after the aircraft had landed and to isolate it from battery failures on the main busses.

Telemetry was transmitted by one of the amateur radios and consisted of the following: GPS location (latitude, longitude, speed, heading, tracking, and number of visible satellites), the ACC state and health (processor flags, processor states, bus voltages, camera and video status, and received commands execution status), flight sensors (absolute pressure, accelerometers, and compass), and science sensors (UV intensity, wing pressure, chip temperature, internal temperature, and external temperature). The radios were only capable of sending 45
characters in one packet, therefore the telemetry string, having almost 100 fields, was encoding using base64 before transmission.

Three ground stations received telemetry and were capable of sending commands to the aircraft. One ground station was set up at the launch site and was duplicated downrange at the approximate landing site. The third ground station, setup within an automobile, was assigned the task of visually sighting the glider on descent and was to serve as the operator in command when the FAA VFR requirements were met. The computers used at the ground stations to record telemetry ran a custom Java application called the BIG BLUE Control Program, shown in Figure 17. The application decoded the base64 telemetry packets, then parsed, logged, and displayed the data. All ground stations had the capability of transmitting commands for manual wing deployment, balloon cut away, parachute deployment, digital picture capture, ATV transmission, and the reset of subsystems through the control application.

![Figure 17 - BIG BLUE Ground Control Program](image)

Overall, the implementation of BIG BLUE II met the goals that it set out to achieve. The use of a distributed architecture helped make the design more modular and allowed redundancy for critical functions. Plans for the ACC systems of BIG BLUE 3 and 4 are set to expand this distributed model for additionally reliability.

6. CONCLUSION

This paper describes the design of an avionics, mission control, and communication system developed for the BIG BLUE project, an ongoing UAV project at the University of Kentucky. It is hoped that a design and implementation that can be applied to a wide range of UAVs with restrictive cost, power, size, and weight requirements was described. The ACC systems that were constructed by students at the University preformed well in two balloon launched missions, successfully deploying wings that inflated and then rigidized at altitude. The ACC design supported an array of sensors and actuators used for the collection of data for both scientific study and to facilitate autonomous flight. The processing was achieved with a distributed network of microcontrollers on a serial bus. In addition, a reliable low-cost communication system was developed using commercially available amateur radio technology. The ACC, as it was designed, will expand to support additional functionality required by future UAV projects at the University.

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BIOGRAPHY

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