BIG BLUE: High-Altitude UAV Demonstrator of Mars Airplane Technology

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Abstract—BIG BLUE[1,2] (Baseline Inflatable-wing Glider, Balloon-Launched Unmanned Experiment) is a flight experiment envisioned, designed, built, and flown primarily by undergraduate students in the College of Engineering at the University of Kentucky. BIG BLUE was conceived as a demonstration of unique inflatable wing technologies with potential for application for Mars airplanes. On May 3, 2003, BIG BLUE achieved the first-ever deployment and curing of UV hardening inflatable wings and reached an altitude of 27.1km (89,000ft). BIG BLUE II was launched successfully on May 1, 2004 with a second-generation optimized wing design. The wings were deployed and cured to an excellent symmetric flying shape from a flight ready fuselage with an autonomous autopilot, sensor and communication systems. To date, over 100 students have participated directly in the design, fabrication and testing of BIG BLUE, exposing them to the challenge and excitement of aerospace careers. BIG BLUE is supported by the NASA Workforce Development Program which has objectives to attract, motivate, and prepare students for technological careers in support of NASA, its missions, and its research efforts. BIG BLUE provides multidisciplinary experiential learning directed specifically toward entering the aerospace workforce.

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1. INTRODUCTION

BIG BLUE is a high-altitude flight experiment developed, designed, built, flown and evaluated primarily by undergraduate students in the College of Engineering at the University of Kentucky. The acronym BIG BLUE stands for **B**aseline **I**nflatable-wing **G**lider, **B**alloon-**L**aunched **U**nmanned **E**xperiment. BIG BLUE was conceived as a demonstration of unique inflatable wing technologies with potential application to Mars airplanes and other novel high-altitude Unmanned Aerial Vehicle (UAV) applications.

BIG BLUE is supported by the NASA Workforce Development Program, part of the National Space Grant Student Satellite Program of the National Space Grant College and Fellowship Programs. Space Grant students across America are learning about aerospace careers by designing, building, flying and operating a broad range of spacecraft.

BIG BLUE was designed to expose undergraduate students to a state-of-the-art aerospace project, with opportunities to do complex multidisciplinary research and development and to interact as peers with researchers in the aerospace industry at NASA centers and ILC Dover Inc. In essence, students join the aerospace workforce while participating in this project. The experience of designing, developing, testing, launching and evaluating a complex, state-of-the-art system produces graduates with valuable experience -- in systems engineering and working in multidisciplinary teams -- uncommon in engineering curricula. Students with this experience are able to make an immediate contribution upon entering the aerospace workforce or other industries.

Management of BIG BLUE parallels that of a NASA mission program, with students working in multidisciplinary teams led by student technical and management leaders. Through the two years of BIG BLUE, nearly 120 students have participated directly in the design and deployment of the BIG BLUE flight experiment. In addition, many K-12 students have been exposed to the work through various outreach activities.

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The project has four faculty advisors with research specializations in aeronautics, systems engineering and testing, communications, and embedded control. In addition, BIG BLUE offers a variety of extra-curricular opportunities for students. Groups of students visited NASA centers (Wallops, Langley and Ames) to present their work and to meet with NASA researchers involved in related research. Students also made trips to Colorado to meet with Edge of Space Sciences personnel to learn about the high-altitude weather balloon launch process and required interfaces. The BIG BLUE project is being conducted in partnership with ILC Dover, Inc., maker of NASA's space suits and the Mars-lander airbags. Two formal Critical Design Reviews (CDRs) have been held at ILC Dover. BIG BLUE students also participated in low altitude flight tests on the dunes in Kitty Hawk NC shortly after the 100th anniversary of the first flight. In its two years, the BIG BLUE project has exposed dozens of students to the aerospace industry by allowing them to work on a real aerospace project that has produced significant research results, including aviation milestones.

In this paper, the first two years of the BIG BLUE project are presented. Following the technical background on inflatable wing technology, the BIG BLUE project and student experience are described in detail. Other aspects of the project are also presented, including interactions with researchers in the aerospace industry, project management and organization and outreach activities.

2. BACKGROUND

Future planetary exploration, including exploration of Mars and Venus, is envisioned using stable unmanned "airplanes" that are designed to deploy and fly in low-density atmospheres. Currently, NASA is working on prototype Mars airplanes, including ARES at Langley and Kitty Hawk (now MARES) at Ames. Although the concept is not new, tests by NASA Ames in 2001 (Figure 1,http://www.nasa.gov/centers/ames/news/releases/2001/01images/marsplane/marsplane.html) confirmed the desired high-altitude flight performance of a 2.4m wingspan rigid glider launched from a balloon at 30.8km (101,000ft). A flight test by NASA Ames in September 2002 resulted with on-board video (http://marsairplane.larc.nasa.gov) that now serves as the vision for the BIG BLUE project. Both the NASA Ames and Langley groups use variations of mechanical unfolding wing designs. Note that the appropriate test analog for "sea-level" atmospheric density on Mars is at 30km (100,000ft) on Earth.

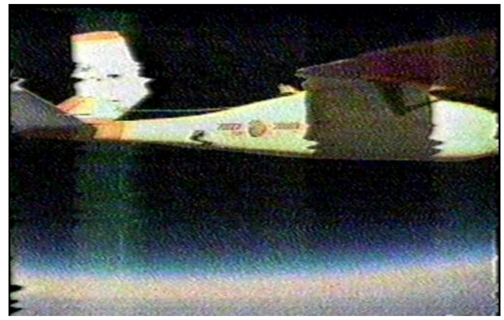

Figure 1 – NASA Ames high altitude test flight, 30.8km (100,000ft)

Concurrently in 2001, research efforts at NASA Dryden (Figure 2) flight tested the deployment of 1.5m semi-span inflatable wing. The benefits of inflatable wings include providing minimal mass and stowed volume, along with the ability to deploy the wings only when needed. The inflatable wings retained their aerodynamic shape and rigidity through a combination of internal air pressure and molded foam. A successful flight at low altitude confirmed the stability during rapid deployment and flight.

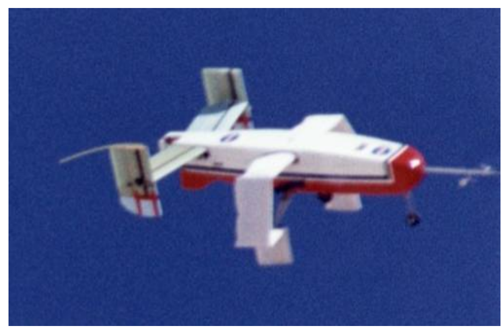

Figure 2 – NASA Dryden inflatable wing research

The BIG BLUE project aims to combine these two technologies to produce a Mars exploration vehicle with inflatable wings. BIG BLUE was originally conceived in July 2002. The illustrated experiment concept (Figure 3) includes three main stages: 1) balloon ascent, 2) deployment of inflatable wings, and 3) descent glide to recovery.

Dual objectives for the inflatable/rigidizable wings included deployment of a proof-of-concept demonstration and flight assessment. Development and execution of BIG BLUE is a complex combination of spacecraft and aircraft concepts and technologies. Consequently, it provided a comprehensive technical experience for all involved. Further, Mars exploration and BIG BLUE are exciting topics that capture the imagination, providing an opportunity to initiate interest in aerospace careers through wider outreach efforts to K-12 students and the general public.

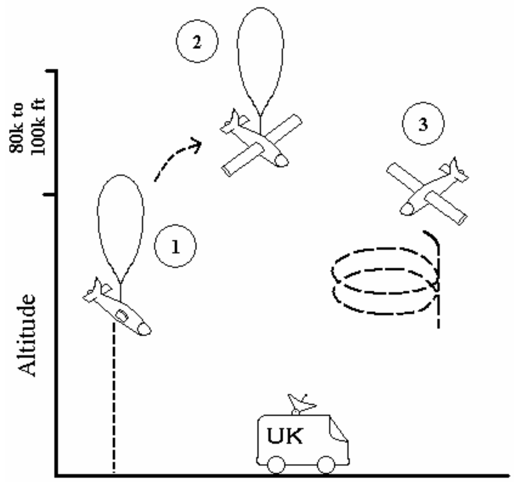

Figure 3 - Flight Concept for BIG BLUE I and II

3. BIG BLUE

3.1 Experiment Overview

The challenging state-of-the-art technical goal of BIG BLUE is to demonstrate the feasibility of inflatable wings for flight in the low-density atmosphere of Mars. To date, the BIG BLUE project has completed two years of development and testing: BIG BLUE I and BIG BLUE II. Two more years are anticipated before BIG BLUE reaches the ultimate goal of a high-altitude test flight of inflatable wings. The development necessarily progresses in phases, each building on the previous year's accomplishments.

The focus of BIG BLUE I was the development of an experimental UV-curable composite wing design [1, 3], and culminated in – for the first time anywhere - a successful flight experiment demonstrating the successful deployment and cure of inflatable/rigidizable wings. On May 3, 2003, near Fort Collins, Colorado, the inflatable wings were deployed and hardened at an altitude of 15.24km (50,000ft). The experiment reached a peak altitude of 27.3km (89,600ft) before returning to the ground under a parachute. BIG BLUE I included successful tests of other student-designed prototype component systems including the compressed-air wing inflation system, communications systems, imaging, sensors, and microprocessor control (managing the deployment, sensors, communications, and data storage). Onboard GPS was an important requirement for tracking. When the primary GPS provided with the launching balloon failed during the flight, a UK student-written telemetry interface system provided UK ground station operators with location coordinates from the BIG BLUE GPS that were used to report the experiment location to the FAA.

The onboard camera recorded images of the wings after deployment (Figure 4). In the summer of 2003, an extensive post-flight testing and calibration effort was conducted, including post-flight analysis of the flight data and telemetry.

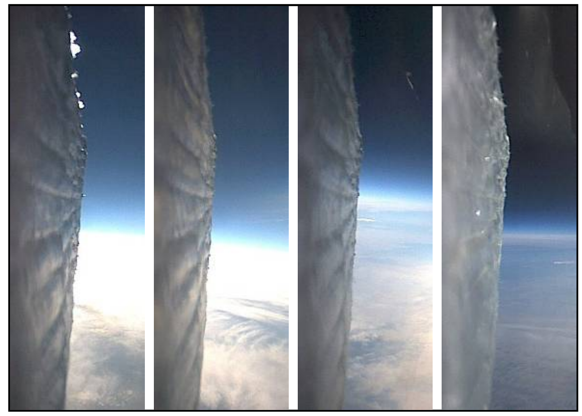

Figure 4 – BIG BLUE I: Images of deployed wing at 17km, 19.2km, 26.2km, and 27.1km (58k, 63k, 86k, and 89,000ft)

In BIG BLUE II, a second generation UV-curable composite wing design was developed to optimize weight and composite strength [2, 4]. BIG BLUE II also included development of a composite fuselage, parachute system, power monitoring system, custom autopilot and second-generation communications and mission control systems. Unlike BIG BLUE I, the vehicle was flight-ready having undergone many hours of low-altitude flight-testing before launch. BIG BLUE II was launched successfully on May 1, 2004; the wings were deployed and cured to a symmetric flying shape (Figure 5).

Figure 5 – BIG BLUE II aircraft and attached inflation system at the recovery site

Due to FAA regulations for UAV testing, autonomous flight was only permitted below an altitude of 0.5-1.0km (1600ft to 3280ft) above ground level and with visual contact of the vehicle. Thus, the vehicle descended from the peak altitude under parachute. However, for BIG BLUE II, a premature rupture of the ascent-system balloon resulted in descent away from the ground spotters and so returned to ground via the parachute. In the summer of 2004, work continued on flight testing of the BIG BLUE II wings. Post flight analysis of the flight data and telemetry was also conducted.

3.2 Student Experience and Technical Development

Most of the students involved each year started the project with enrollment in Spring-term classes without any experience on BIG BLUE. A few student team leaders initiate each year's efforts during the previous Fall term writing the funding proposal and meeting with ILC Dover engineers to report on accomplishments and post-flight analysis results.

After the first year's experience, several opportunities were added for BIG BLUE II. The following is the general schedule followed for BIG BLUE I and II:

- Oct-Nov: Planning meeting with ILC Dover
- Nov-Dec: Wind-tunnel testing
- Dec: Kick-off for BIG BLUE students pre-registered in senior design and related courses (added for BBII)
- Jan: Pre-term Workshop (BBII)
- Jan: Aerospace Systems short course (BBII)
- Jan-Feb: Visits to NASA centers and Edge of Space Sciences balloon-launch organization
- Feb-early Mar: Internal Critical Design Review (ICDR) with invited faculty and alumni reviewers
- Feb-early Mar: Formal Critical Design Review (CDR) at ILC Dover, Inc.
- Mar: Flight testing at Kitty Hawk, NC (BBII)
- Mar-Apr: System testing and integration
- May: Launch of BIG BLUE flight test in Colorado

The inflatable wings were designed for performance at low Reynolds Numbers (Re) [3] appropriate for flight in a low-density environment. The wings were manufactured at ILC Dover in Delaware, and thus interaction was required between the student designers and wing manufacturers. Initially, five alternate ideal airfoil designs were considered. Analysis of flight characteristics including pressure distributions, lift and drag ranked the candidate airfoils. Selection of the E-398 candidate airfoil as the design resulted from these rankings, in combination with consideration of manufacturability. Wind tunnel testing of the prototype and final wings (Figure 6) demonstrated less flow separation than occurs with a smooth profile wing. Consequently, low-Re flight is possible with inflatable wings and is even better in some flow regimes with these wing geometries. High-speed cameras are used for flow visualization; a laser sheet illuminates the wings in the top image, while the fluid is seeded with particles in the bottom image.

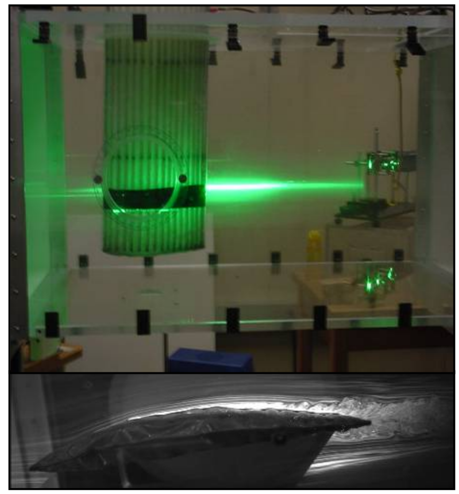

Figure 6 – Wind tunnel testing of the final wing design

Students worked in two main groups; Mechanical and Electrical. In addition to design of the low Reynolds number inflatable wings, students in Mechanical Engineering (ME) designed the UV-curing protocol, performed the system integration and designed and built the inflation systems, composite aircraft structure, tail control surfaces, and wing-monitoring instrumentation. Students majoring in Electrical and Computer Engineering (ECE) designed and built the power, communications, avionics and computer control systems for BIG BLUE II, They were responsible for interfacing with a set of sensors and actuators on the aircraft, managing information flow between the aircraft and the ground stations, and sequencing through the mission profile based on time and sensor readings [7].

All control and avionics for BIG BLUE I were managed by a single computer. While this design worked well for the flight test, it did not offer sufficient redundancy and the lack of modularity made it difficult to maintain. For BIG BLUE II the design advanced to a distributed approach implemented with three processors each assigned to specific tasks with an interconnection network for communication and coordination among the processors. The distributed architecture offered several advantages but these came at the cost of increased system complexity. In addition, because the mission for BIG BLUE II included a free flight segment, sensors, computer control algorithms, and actuators were required to separate the aircraft from the flight string, control the aircraft in a dive and in gliding flight, and finally to deploy a parachute to terminate the flight.

The primary goal in the design of the hardware and software architectures for BIG BLUE II was to enhance the design from BIG BLUE I to support fault tolerance and fault recovery. Several key design decisions were made to allow critical scientific experiments to be carried out and maximum safety to be maintained even in event of failures of processors, the data buses or power sources. The avionics and computer control system for BIG BLUE II consisted of three independent subsystems: mission control, flight control, and parachute/camera control. A central data bus allows the subsystems to communicate with each other through a single shared memory that stores global state variables and mailboxes that the processors use for communication and coordination. Each processor interfaced to a set of sensors and actuators where some sensors were duplicated for redundancy and some actuators could be controlled by more than one processor to allow for fault recovery.

The avionics and control system in BIG BLUE II was built as a single unit shown in Figure 7. The main processor chosen was an 8051 variant from Silicon Labs (previously Cygnal). A development board carrying the microcontroller is at the far right end of the image. A custom-built adapter board daughter card was implemented to carry the flight control, sensor pack, interface circuitry, power monitoring circuitry, EEPROM memory for onboard data storage and actuator interface circuitry, as well as the link to the communications radio. The adapter board was built in a modular fashion with several daughter cards to simplify the development and repair of the system by allowing the replacement of individual modules. Electrical connection is made through ribbon cables shown.

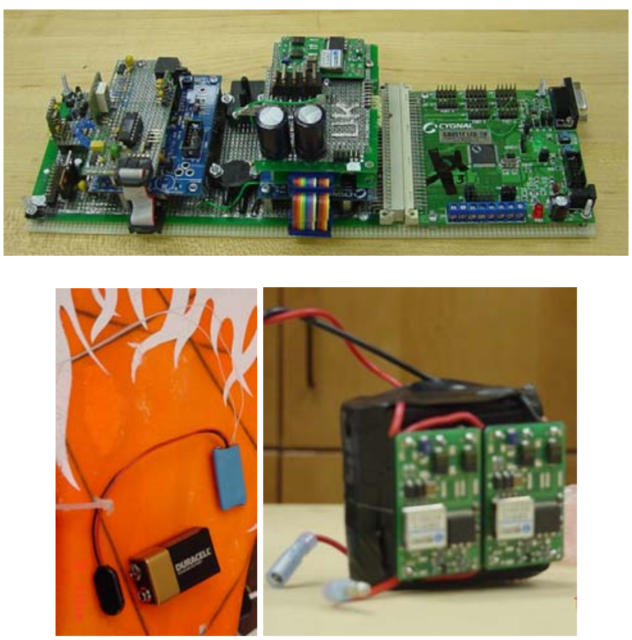

Figure 7- BIG BLUE II avionics and control unit (top), beacon (bottom left) and battery pack (bottom right)

The flight controller is on the left hand side and consists of a small microcontroller card and a daughter card carrying flight subsystem sensors and interfaces to servos. On the right hand side of the adapter board is the parachute control subsystem. It consists of a microcontroller card and two daughter cards. The first carries enable logic for the actuator outputs and the absolute pressure sensor for altitude sensing. The second adapter card carries power MOSFET switches to drive actuators and two capacitors to provide the energy bursts needed to fire ballistic cutters used for cut-to-fly and parachute deployment actuators.

Both BIG BLUE gliders had wireless communications systems on board: telemetry, video and (on BIG BLUE II) a tracking beacon. The telemetry system consisted of two amateur band radios. One radio was used for sensor data and position information. The second radio was dedicated to transmitting position information using an APRS (Automated Position Reporting System) format (see, for example, http://www.aprs.net). Both telemetry systems were transmitting 500mW of radiated power in the 70-cm amateur radio band. The video system transmitted NTSC video from a tail camera in the 33-cm amateur radio band. The ATV (amateur television) system transmitted 1 W of radiated power. A 50mW beacon running of a separate 9V battery was onboard of BIG BLUE II to aid in direction finding and recovery. The tracking beacon transmitted a Morse code signal in the 2-meter amateur radio band and was used as a back-up system for the APRS system. All communications systems used low-gain dipole antennas on board. The onboard power system consisted of redundant 6 V flight packs and power switching circuitry.

Once designed, components were then tested on the bench and during over 150 flights of low altitude flight-testing and using a flight simulation environment developed by the students [9]. This provided students invaluable experience in the preparation, testing and evaluation of designs before the final launch. Flight platforms were developed from the initial easy-to-build designs to the final lightweight design. Figure 8, shows low altitude flight-testing in Fort Collins, Colorado of the inflatable wing aircraft including a flight-equivalent mock-up of the deployed wings.

Figure 8 – Flight-testing of the final design.

Flight-control tests were also conducted over the sand dunes of Kitty Hawk, NC, 100 years after the Wright Brothers.

This was an opportunity to participate in the centennial celebration of flight and engaged students with the history of flight. Students were also impressed with the importance of their contribution to aviation history and to the future of flight. It also provided excellent experience in preparing for and conducting experiments at a remote location. All relevant equipment required for flight testing, building, repairing, and programming the flight vehicle was moved from Lexington KY, to Kitty Hawk, NC for these tests.

Figure 9 – Flight-testing on the dunes of Kitty Hawk, NC

Coordination of the overall system design and integration among the design teams were extremely important for the success of this complex experiment. Thirty-one students and faculty involved in BIG BLUE II returned from winter break before the start of the Spring semester to participate in a Systems Engineering short course. Having learned from the BIG BLUE I experience of separate laboratories during development, laboratory space was shared throughout the BIG BLUE II project. Shared laboratory space supported better systems integration, but also fostered stronger relationships among the subsystem teams.

3.3 High-altitude Flight Tests in Colorado

Both BIG BLUE I and BIG BLUE II projects were relocated to Colorado for the culminating flight experiments. Final integration and testing of all systems into the final flight vehicle was conducted in Colorado by student representatives from each sub-system team (Figure 10).

Approximately 25 BIG BLUE II students made the trip to Colorado for the final flight experiment. The vehicle was launched (Figure 11) by students at the launch site, tracked and monitored from the launch site and a down-range remote location (Figure 12).

Figure 10 – BIG BLUE II hotel-room avionics integration center (left) and integration of final systems into the flight vehicle (right)

Figure 11 – Launch of BIG BLUE II

Figure 12- Down-range communications station antennas

The downlink telemetry received at the ground stations was ASCII strings containing base-64 sensor data. A ground station program was written for BIG BLUE I and expanded for BIG BLUE II to decode the information and display it to the mission controllers. The program display is seen in Figure 13, including raw telemetry data in the lower window. The program also allowed the uplink of commands to allow the manual override of the auto sequencing occurring on the aircraft. In addition, the ground software used the current GPS position of the aircraft along with the GPS position of the ground station to compute the azimuth and elevation angles to the aircraft throughout the mission. This information was essential in keeping the ground antennas oriented to maintain the communications links with the aircraft. BIG BLUE was then recovered by a recovery team as seen in Figure 14.

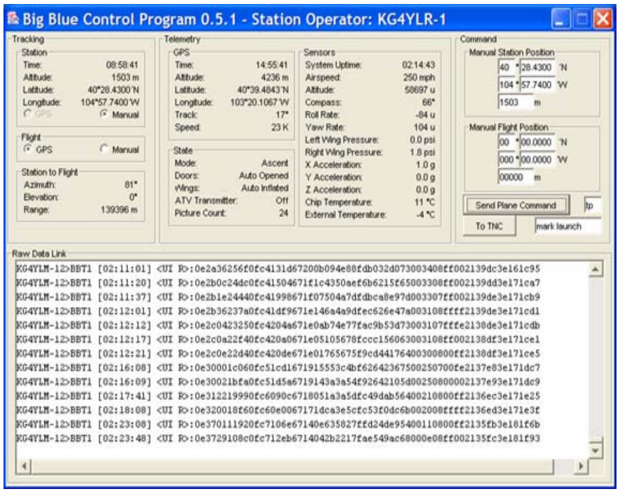

Figure 13- Ground stations software screenshot

Figure 14 – BIG BLUE II recovery on May 1, 2004

4. INTERACTION WITH AEROSPACE INDUSTRY

One of the keys to success of this program has been in the partnership with ILC Dover, Inc. ILC Dover is committed to working with the BIG BLUE program to develop students for the NASA/aerospace workforce by providing insight and design advice based on their prior development efforts in inflated wings and in inflatable/rigidizable spacecraft. ILC Dover provided unique state-of-the-art rigidizable materials and time and materials required for fabrication of the test articles and spares under a subcontract. ILC Dover also contributed engineering time for the development of the inflatable/rigidizable (IR) wings and for the critical design reviews.

Student designs were evaluated by ILC Dover engineers and project managers (Figures 15) during a formal critical design review held at ILC Dover. Students gave presentations on their proposed designs and received feedback from the engineers. Additional discussions during breaks (Figure 16) showed students interacting as peers with ILC engineers.

Additionally, students made trips to three NASA facilities to present the BIG BLUE project and to discuss related technologies. At NASA Ames (Figure 17), the focus was on exploring Mars, but including fuselage design and integration for high-altitude testing. At NASA Langley (Figure 18), BIG BLUE students and faculty learned about large inflated spacecraft and optical measurement techniques. At the Wallops Island Flight Facility (Figure 19), BIG BLUE students learned about high-altitude ballooning.

Figure 15 – Critical design review presentation were for the Director of Engineering, Mars Lander Airbag Project Managers and other engineers at ILC Dover, Inc.

Figure 16 – A BIG BLUE II student in conversation with an engineer from ILC Dover about the power system

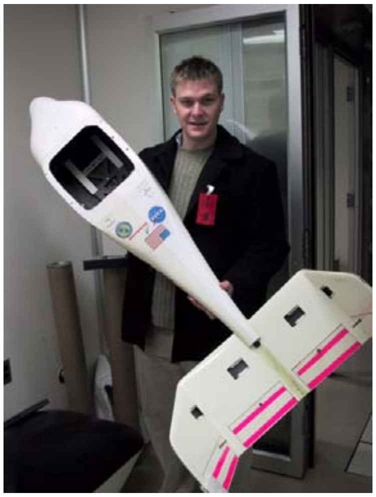

Figure 17 – Andrew Simpson holds the "Kitty Hawk" Mars Airplane fuselage at NASA Ames

Figure 18 – On tour of the Spacecraft Dynamics Branch at NASA Langley Research Center in Hampton, VA

Figure 19 – Students learned about NASA's high-altitude balloons at the Wallops Island Flight Facility

Edge of Space Sciences (EOSS, http://www.eoss.org) is a non-profit organization whose mission is "Promoting Science and Education through Amateur Radio and High Altitude Balloons." EOSS is among the leaders in amateur high-altitude ballooning, providing launch, tracking and recovery services to student groups, among others. The BIG BLUE flight tests were the 66th and 76th EOSS launches, respectively. EOSS members are from various backgrounds, including engineering. BIG BLUE students met with EOSS members on several occasions in addition to launches to discuss the flight test, high-altitude conditions, communications and tracking (Figure 20). An early trip in November 2002 to witness a launch by EOSS helped the BIG BLUE team understand the final test protocol and interface to the launch and tracking systems.

Figure 20- EOSS recovery vehicles with various communication and tracking capabilities lined up at the BIG BLUE I recovery site

Interaction with other organizations also contributed to the success of BIG BLUE. For BIG BLUE I, calculations of expected high-altitude UV-radiation levels were performed by a researcher at the National Oceanographic and Atmospheric Administration (NOAA). Launch-site wind predictions were provided by NOAA researchers for BIG BLUE II. Also, the Bluegrass Soaring Society in Lexington, KY (http://members.aol.com/bgsoaring/) spent time and lent their sailplane expertise for the construction of the BIG BLUE II composite fuselage. BIG BLUE students interacted with many individuals during the course of the project, enhancing their experience on BIG BLUE and contribution to the project's success.

5. ORGANIZATION AND MANAGEMENT

The first year of BIG BLUE, there were three student managers: a business manager, an ECE technical lead and an ME technical lead. The ME technical lead was also the overall student leader for the project, having participated in developing the concept and writing the initial proposal during the summer of 2002. Approximately 40 students of BIG BLUE I were organized into subsystem teams, including wing design, wing deployment, flight control, structural design, avionics and control, communications and power, data acquisition (including instrumentation and wing cure testing), integration, flight watch (website design providing live flight tracking information) and launch/recovery (students traveling to the launch site). Subsystems worked in separate labs and team leaders met frequently for planning and information exchange. This was successful, but changes were made for the second year.

For BIG BLUE II, a single large lab was established, with computers for software development and flight simulation, with lab benches for fabrication and testing of electrical and mechanical hardware and with a conference table for meetings. ME, ECE and CS students worked side-by-side in the lab, learning from each other and resolving integration issues early.

Organization for BBII was a single student leader acting as business and project manager with team leaders for the subsystems. For the avionics and control subsystems, several teams were composed of the same student members. Different students took responsibility for different subsystems, leading for one system and supporting for others. Student lab and flight-test managers were also designated. Two experienced PhD students, one in ME and one in ECE, were important resources for the students as well.

Expenditures for BIG BLUE each year totaled $110k: $30k subcontract for wing fabrication, $20k graduate student stipend and tuition, $20k for travel, $20k for materials, supplies, components and tools needed to fabricate the test article, $10k for undergraduate student pay for the business manager and key personnel (not receiving class credit) and $10k for special equipment such as the thermal-vacuum chamber.

6. OUTREACH

Undergraduate students at the University of Kentucky benefit from immediate involvement in the design and flight of BIG BLUE. However, many other students (K-12, undergraduate and graduate levels) throughout Kentucky are impacted through various activities and outreach efforts including design of a permanent hands-on display at the Kentucky Aviation Museum, participation in "Learn-to-Fly" activities hosted by BIG BLUE students and faculty, development of documentary videos, and K-12 school visits.

A permanent display is being designed and built for the Kentucky Aviation Museum in Lexington, KY. Because Lexington is a tourist destination centrally located in Kentucky, the display will reach students and the general public throughout Kentucky. The permanent display will include a hands-on remote-control airplane that can be flown in a multi-fan wind-tunnel similar to successful displays built elsewhere and a wall-mounted display of artifacts and text describing the BIG BLUE project. Development (separately-funded) of the museum display is being accomplished by a team of undergraduate UK students, led by a business major and including ME and ECE students.

Three students in Communications at Asbury College are also participating in BIG BLUE making a video documentary of the student experience of BIG BLUE II. Over 60 hours of professional-quality video were recorded throughout BIG BLUE II, including interviews with students. Design decisions, technical challenges, fabrication results and flight testing successes and failures typical with the multidisciplinary complexity of state-of-the-art aerospace systems are seen. Editing is currently underway of a 6 to 7-minute documentary of the development and culmination flight of the BIG BLUE II experience.

BIG BLUE students have also participated in several school visits involving K-12 students. For example, on October 20, 2003 over 60 students at Bourbon County High School participated in a BIG BLUE I visit and demonstration. On October 24, 2003, elementary school students at Julius Marks Elementary (Lexington, KY) participated in a visit and demonstration by BIG BLUE II students with an emphasis on flight in science education. Students could see and handle the inflatable/rigidizable wing (Figure 21).

Figure 21 – BIG BLUE students show the inflatable/rigidizable wing at Julius Marks Elementary

7. SUMMARY

BIG BLUE has had a significant impact on the students involved in the project. The goal of the NASA Workforce Development Program is to interest students in careers in the aerospace industry. BIG BLUE was designed to involve undergraduate students in a unique opportunity to experience the excitement of research and development of a complex aerospace system and state-of-the-art technology with interaction as peers with researchers at NASA and aerospace industry contractors (ILC Dover). In essence, BIG BLUE students joined the aerospace workforce while participating in this project.

Notable results of the first year of BIG BLUE include wind-tunnel tests of the inflatable-wing profile that demonstrated less flow separation than occurs with a smooth profile wing. Consequently, low-Re flight is possible with inflatable wings and even better in some flow regimes with these wing geometries. The first year also produced a design and successful fabrication of an inflatable/rigidizable wing for low-Re (low density) flight. To test feasibility on Earth, balloon-launched high-altitude experiments to date include the first-ever demonstration of inflatable/rigidizable wing technology with the successful high altitude deployment of UV-curable wings, with curing on continuing ascent to 27.3km (89,600ft) and descent to recovery (*Space News*, May 19, 2003). Also key to the successful demonstration was development of the electronic mission control and software, low-temp survival and successful data acquisition. The second year of BIG BLUE included the first-ever low-altitude flights of inflatable-rigidizable wings, along with the development of an autonomous flight control.

The experience of designing, developing, testing and actually launching a complex, state-of-the-art system produced graduates with valuable experience working in multidisciplinary teams and systems engineering uncommon in typical engineering curricula. As a result, BIG BLUE students are more likely to receive job offers and are more qualified to make an immediate contribution once hired.

Through the two years of BIG BLUE over 110 students participated directly in the design and deployment of the BIG BLUE flight systems and many more K-12 students were exposed to the work through various outreach activities. Groups of students and faculty visited several NASA facilities to present their work and meet with NASA groups involved in similar research. Trips to meet with Edge of Space Sciences personnel in Colorado, two formal Critical Design Reviews at ILC Dover and low altitude flight tests on the dunes in Kitty Hawk NC just after the 100th anniversary of the first flight also contributed to the student experience and the success of BIG BLUE. Ten Percent of the students who have worked on the BIG BLUE project have continued into an aerospace career (Graduate School, Internships, and Careers).

Currently, efforts are underway to define the goals and budget for BIG BLUE 3. The next step toward the ultimate high-altitude flight test is evaluation of inflatable wing alternatives and advances in autonomous flight control [8]. Ambitious goals for the third year of BIG BLUE will further advance the state-of-the-art in UAVs for Mars exploration and will expose a new group of motivated students to the aerospace industry to give them the excitement and experience of developing a real-world aerospace system.

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