SUMMARY REPORT:

Findings of the Red Bull Stratos Scientific Summit

California Science Center, Los Angeles, California, USA
January 23, 2013

FOREWORD

Making a supersonic freefall from the edge of space was always my dream.

But I never dreamed how many people would share it.

When I jumped from a capsule 24 miles above Earth on October 14, 2012, millions of people across the globe shared the experience live on the Internet and television. Now, after months of analysis, we're very happy to be able to share another aspect of the adventure with people worldwide: the scientific findings of the Red Bull Stratos team.

The experts who contributed to the mission are extraordinary – the very best of the best in some of the most challenging areas of science, medicine and technology. They safeguarded my life; and in doing so, they broke boundaries in their own fields just as surely as I broke the sound barrier. I'm not sure I'll ever be able to express my gratitude (definitely not in these few words), but I hope that after reading this document you too will appreciate their historic efforts.

From the start, the men and women you'll hear from in these pages, people like our technical project director Art Thompson and the legendary Joe Kittinger, were determined that Red Bull Stratos would be a true scientific flight test program, with the results of our work shared for the benefit of the global community. It's thrilling to know that, after months of analysis, their insights are being released to a world eager for the findings.

I can think of no greater honor for myself – or for this team – than to know that people informed by our mission will use the data to take aerospace safety to the next level; or to spark children's interest in science; or simply as inspiration to pursue their own goals. I look forward to seeing what the realization of *their* dreams holds for all of us.

Felix Baumgartner
February 2013

PREFACE

What was the Red Bull Stratos mission to the edge of space about? For those of us on the mission team, there's never been any question: Red Bull Stratos was (and is) a world-class, multi-stage, scientific flight test program.

Why did I agree to spearhead project development over seven years of planning, including five years of active development and countless challenges and setbacks?

Because that's what a flight test program is. You learn something from every assessment; especially when you encounter problems along the way. You probably learn *more* from the problems and the things that did not work as planned. But if you're persistent and ingenious and collaborative and downright dogged, the results are worth it.

I speak for all of us on the team when I say that the result we're most happy about is Felix Baumgartner's safe touchdown on October 14, 2012. Protecting Felix was always job one. But in figuring out how to get him supersonic and yet get him home unharmed, we hoped that we would also have the opportunity to emphasize the importance of continued progression in aerospace safety and life-support systems, as well as to advocate their very use – hopefully providing some contributions of our own to the existing body of knowledge in aerospace and private space programs.

Red Bull Stratos was a singular chance to assemble an elite team across numerous disciplines for an open collaboration to theorize, investigate, problem-solve and share in creating a truly significant program. Besides the people credited herein, many other additional team members contributed substantially to the project. I am proud to have worked with every one of them, and it's no exaggeration to say that we've become a family.

The preliminary findings documented in this paper were first presented at the Red Bull Stratos Scientific Summit, held in Los Angeles at the California Science Center on January 23, 2013, where the audience was made up of representatives from both government and commercial sides of the aerospace industry. It was gratifying to know that these eminent attendees found our work to be potentially valuable to their own. In fact, over the years many of them had helped to open doors as our ambitious little project sought access to equipment and facilities necessary to make it the true flight test program we envisioned.

There are so many unfinished chapters in the story of Red Bull Stratos. On our own side, the data analysis continues. The information in this report is detailed, but top-line. There are many more layers to examine.

Some of the chapters will be written not by us, but by future programs, as they continue to explore and prove out the protocols and safety systems suggested by our team. And I like to think that at least a few of the chapters in this amazing adventure will be written by some of the millions of people who watched the mission live and came away inspired to see more and understand more. Hopefully, we have inspired many children (the next generation) who dream of space travel to dare to make those dreams a reality. The story could go on for quite a long time.

There are too many people and organizations to thank here, from the experts at David Clark Company who worked so closely with us to produce a full-pressure suit adapted for supersonic freefall, to the ultimate professionals at Beale Air Force Base and the Wyle facility of Brooks City-Base, who hosted our most critical pre-flight tests; and from Red Bull – a true partner in the mission – to my friends and colleagues Joe Kittinger and Felix Baumgartner himself. Together we proved that a human in freefall can break the speed of sound returning from near space, going through a transonic phase and landing safely on the ground. That was a big part of the program, and monitoring the event was a meaningful step in aerospace medicine and physiology.

Red Bull Stratos was a true accomplishment, and it will forever be part of history. It has been my pleasure to be a part of it.

Art Thompson
Red Bull Stratos Technical Project Director
Vice President, Sage Cheshire Aerospace

INTRODUCTION

Red Bull Stratos meant a lot of things to a lot of different people. At a basic level, the program was about one man pushing his limits; but another phenomenal part of the mission was the making of the team that worked together to pull it off. A defining characteristic of this team was their ability to overcome challenges. They proved time and time again what a passionate group of people can accomplish when – with a real desire to put themselves second and the project first – they focus on a singular objective.

As you'll see, the outcomes have been absolutely amazing for everyone involved.

Another defining characteristic of this mission team: They never wanted to keep those outcomes to themselves. A primary goal of the program was to give back. Much as Joe Kittinger's Excelsior III mission in 1960 delivered vital insights into life support systems and the possibilities for space travel, from the outset all of us on the Red Bull Stratos team wanted to share our findings to hopefully play a small part in the next generation of near-space exploration and high-altitude egress. This publication is the beginning of that process.

What you'll read here is only the tip of the iceberg: analysis will continue, and the team is already planning on sharing subsequent learnings in depth through venues such as subject-specific conferences and journals. I hope that in this initial documentation you'll enjoy discovering what the people behind Red Bull Stratos experienced and what they learned.

Andy Walshe, PhD
High Performance Director

TABLE OF CONTENTS

RECORDS, VALIDATION AND TIMINGS
Brian Utley

The records set by Felix Baumgartner and the Red Bull Stratos mission were not merely an end in themselves. Rather, they were the outcome of a pioneering flight test program that went well beyond known limits to explore the possibilities for, and effects of, supersonic freefall from the edge of space.

This paper summarizes information presented by Mr. Brian Utley, Official Observer for the Contest and Records Board of the United States' National Aeronautic Association (NAA). On behalf of the NAA and the Fédération Aéronautique Internationale (FAI, the governing body for air sports worldwide), Utley collaborated with the Red Bull Stratos program for three and a half years to assure accurate documentation and verification of the mission's accomplishments.

RECORD CLAIMS: OCTOBER 14, 2012
Three records have been submitted for verification by the FAI. They are:

Highest Exit Altitude
- 38,969.4 meters / 127,852.4 feet MSL (above mean sea level)

Maximum Vertical Speed without Drogue or Stabilization Device
- 377.1 meters per second
- 1,357.6 kilometers per hour
- 843.6 miles per hour
- Mach 1.25

Vertical Distance of Freefall without Drogue or Stabilization Device
(This record measures the distance from the time Baumgartner jumped from the capsule until he pulled his parachute deployment cord.)
- 36,402.6 meters, 119,431.1 feet

(N.B.: Official FAI records are measured in meters or kilometers. Figures above have additionally been translated into imperial measurements for convenience.)

Utley pointed out that Baumgartner's altitude was especially remarkable because it was a "quantum leap" over the previously known highest exit altitude, Joe Kittinger's 1960 jump from 31,333 meters / 102,800 feet: a 24 percent increase in altitude.

Unofficial Record Categories

Baumgartner broke additional records that, while not fitting established FAI categories, are nonetheless notable:

- First person to break the speed of sound in freefall, without the protection of or propulsion of a vehicle
- Highest untethered altitude outside a vehicle
- Largest balloon ever flown with a human aboard: 29.47 million cubic feet
- Highest manned balloon ascent: 39,068.5 meters / 128,177.5 feet
- Fastest overland speed of manned balloon: 135.7 miles per hour / 117.9 knots

(Utley clarified that Baumgartner's balloon was on a slow downward trajectory from its peak altitude at the moment when Baumgartner jumped.)

CHALLENGES

As Utley explained, world record attempts are challenging events that push the limits of performance. Minimum requirements are defined by the FAI, and measurement and verification must also satisfy the FAI's stringent requirements.

"By definition, world records push the state of the art; we're pushing the limits," he said. "We are stressing not only the aircraft and the human being but also stressing the measurement processes. How do we measure performance as we go faster and farther? Whatever tools we use must satisfy the requirements for that particular record."

In all such verification efforts, a "chain of custody" must be identified and adhered to in order to ensure that certification is accomplished with absolutely secure data, and of course, not compromising personal safety for the participant(s) is paramount.

"There are two classes of record breaking attempts. Most record attempts seek to improve an existing record by exceeding a minimum threshold. But for attempts such as the Red Bull Stratos program, you must be involved very early in the game in order to have the ability to measure the desired results," Utley noted. "For such projects, from beginning to end there is a very complex development process."

Red Bull Stratos Documentation

The Red Bull Stratos program presented particular concerns for accurate data capture and verification. It was clear that GPS-based tracking would provide the best solution, but it would require using GPS in a much more challenging environment than previously practiced, such as: a space-based vs. terrestrial environment, challenges to global positioning system (GPS) accuracy and performance, using a human platform (Felix Baumgartner) and the unknowns of the sonic shock wave impact.

In the past decade, GPS tracking has become a new and indispensable tool for records verification. Citing as examples GPS-verified global circumnavigations by Burt Rutan's *Voyager* and Steve Fossett, as well as the suborbital flight of *Spaceship 1*, Utley stated, "GPS has become an absolutely integral part of our record-keeping toolkit and has allowed us to verify records that would not have been possible."

But for Department of Defense security reasons, GPS systems are seldom available for public use above 60,000 feet; and there were also questions with regard to whether GPS data would be reliable in penetrating the sound barrier, or if Baumgartner's rapid orientation change in potential tumbling or spinning at high speed would affect the ability of the GPS system to maintain lock on the satellite constellation.

As with every other aspect of the program, redundancy was instituted as a safeguard: Baumgartner wore multiple GPS systems. In the final outcome, the primary system dedicated to records capture, which employed an antenna affixed to the back of Baumgartner's helmet, functioned well and provided the necessary data for record validation.

Baumgartner underwent two progressively high stratospheric test jumps before the final mission on October 14, 2012. Utley feels that critical to understanding and overcoming the challenges in accurate measurement was the decision to treat each manned test flight as an official record attempt in order to validate the total verification process, both evaluating the efficacy of the data capture equipment and exercising the complex records verification process. "In every test we learned something; and because of that we improved our process," Utley stated. New to record validation by GPS were the following:

- Use of GPS for establishing altitude records
- Use of GPS for determining vertical velocity
- Use of GPS for determining maximum (instantaneous) vertical velocity
- Use of GPS as on-person equipment

Manned Flight 1, on March 15, 2012, enabled Baumgartner to claim the maximum vertical speed record (586.92 kmh / 364.69 mph), an entirely new category in FAI parachuting records created especially to accommodate the groundbreaking nature of the program.

In Manned Flight 2, on July 25, 2012, Baumgartner claimed new FAI records not only for maximum vertical speed (869.3 kmh / 540.2 mph), but for highest exit altitude (29,610 meters / 97,145.7 feet) and longest freefall distance (25,674 meters / 84,232 feet), thus testing and confirming the data capture process for the claims to be made in the final October jump. The existing record for freefall distance was 24,500 meters / 80,360 feet, held by E. Andreev of the USSR and set in 1962.

(The record for Manned Flight 1 was thoroughly vetted by the FAI and approval was officially announced on July 26, 2012. At the time of publication of this document, the records claimed in Manned Flight 2 and the final October 14 flight are pending final ratification.)

Although the first two test jumps were undeniably beneficial to the records verification process, their results posed questions for the final jump. The amount of speed gain from the first jump to the second jump and the absolute speed on the second jump were less than expected and not enough to make it clear that Baumgartner would be able to exceed the speed of sound from the final jump's stated target altitude of 36,576 meters / 120,000 feet. The information was vital to the team's considerations as they planned the final ascent. "The numbers were not as strong as we had hoped, and there was uncertainty as to whether he would break the sound barrier. We knew we had to get the balloon as high as possible," Utley said. The mission's end results speak for themselves.

As Utley commended the Red Bull Stratos program in ultimately meeting the requirements of the verification process, he summarized key aspects of that success as a project that had:

- Clearly defined objectives
- A multi-disciplined development and leadership program
- Deep industry experience among the team members
- A well-defined test plan "road map" and milestones
- A flight test program
- An integrated record validation process
- Adequate funding

TIMINGS

Utley's examination of the data indicates:

Baumgartner reached Mach 1 when he was 34 seconds into his freefall. The speed of sound is dependent upon temperature, and in the prevailing conditions Baumgartner reached Mach 1 at an altitude of 33,446 meters / 109,731 feet MSL.

Baumgartner continued to accelerate, reaching his maximum vertical speed of Mach 1.25 at an altitude of 27,833 meters / 91,316 feet MSL, when he was 50 seconds into his freefall.

Baumgartner's subsequent gradual deceleration took him back to the subsonic level at an altitude of 22,960.7 meters / 75,330.4 feet MSL, when he was 64 seconds into his freefall. (Thus he was supersonic for 30 seconds, a figure Utley found to be "quite remarkable.") Baumgartner went into a flat spin just before he became subsonic and remained in the spin for about 13 seconds, finally stabilizing at 77 seconds into his freefall. *(See Figure 1 for a chart prepared by Utley with timings and a terminal velocity profile.)*

The duration of Baumgartner's freefall was four minutes, twenty seconds. "This was probably one of the more challenging moments of the flight," Utley declared.

"Falling for four minutes and 20 seconds and holding a prone position is a very, very long time."

OTHER NOTABLE FINDINGS

In considering key findings from the mission, Utley identified three observations to be particularly valuable:

- There was no observable sonic barrier.
- GPS performance was excellent during the mission's most critical phase and was not affected by the stratosphere.
- Atmospheric sounding via radiosonde weather balloon was an excellent tool for the prediction and evaluation of performance, including identifying the precise timing for the supersonic phase.

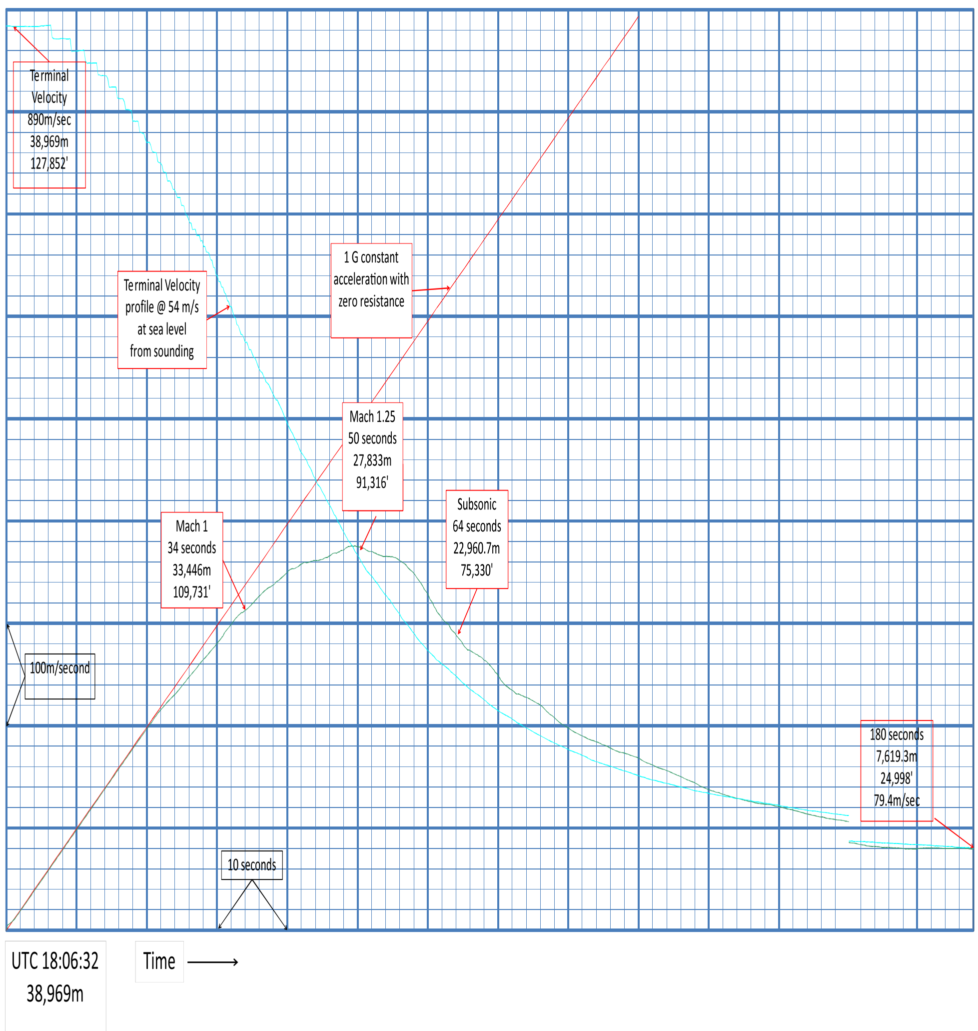
Shortly before Baumgartner's launch, the mission's meteorologist, Don Day, released a radiosonde balloon that took readings of weather data up to an altitude of 130,000 feet (about 39,625 m). These readings not only helped Utley determine the speed of sound in the region that Baumgartner would traverse, but also allowed him to calculate a terminal velocity profile from ground level through 130,000 feet. As Utley discovered, Baumgartner had so much inertia that he blew through calculated terminal velocity to achieve his maximum speed of Mach 1.25. Offering additional comments, Utley noted that with its multi-camera system and webstream broadcast, Red Bull Stratos was the most widely observed world record event ever, providing "incredible detail" and "visibility from beginning to end." He also mentioned that a significant number of people on the ground reported hearing Baumgartner's sonic boom.

In a visual highlight for attendees, Utley played video from the cameras Baumgartner was wearing during his freefall, pointing out that for the early part of the descent (until he was into the supersonic phase) there was no flutter of the space suit fabric, demonstrating that there was almost zero air density at that elevation to restrict his freefall.

Utley said, "Our hats are off to Felix for these records, which present a significant challenge to anyone wishing to displace Felix in the record books."

Fig. 1

Felix Baumgarner Record Jump, October 14, 2012



CAPSULE AND CHEST PACK DEVELOPMENT; MISSION TESTING AND TRAINING

Art Thompson

The capsule that carried Felix Baumgartner to his jump altitude was a self-contained life-support system that served many vital roles, both as a protection for the pilot and as a data collection and communications system.

This paper summarizes information presented by Mr. Art Thompson, technical project director for Red Bull Stratos and vice president of Sage Cheshire Aerospace, Inc., with the assistance of electrical engineer Scott Loftin, capsule engineer Jon Wells and life support engineer Mike Todd (all also of Sage Cheshire Aerospace). Thompson was responsible for assembling the mission team and led not only capsule and chest pack development but program development overall, including data collection/processing and flight test protocols; his presentation reflected the broad scope of his responsibilities.

CAPSULE REQUIREMENT OVERVIEW

Thompson began his presentation by explaining that the Red Bull Stratos program put safety first, with strong focus on developing the best possible life support systems and proceeding through a well-structured, progressively staged flight test program. He credited the work and insights of team members such as Einar Enevoldson, Mike Todd and Joe Kittinger as foundational to the program's buildup and success.

The capsule that carried Felix Baumgartner to the stratosphere was built at the mission's technology hub of Sage Cheshire Aerospace in Lancaster, California. The requirements that the team found it necessary to consider in developing the capsule included:

- Unlike Joe Kittinger's open gondola ascent in 1960's Excelsior III mission, for Baumgartner's longer and higher ascent a pressurized capsule was desired. This would allow him to continue pre-breathing oxygen throughout the ascent in a pressurized state and reduce the risk of decompression sickness (DCS), without the discomfort and exertion of pressurizing his suit before egress.

- The capsule should also protect Baumgartner from extended exposure to the extreme cold of the stratospheric environment. Mission data indicates that although the temperatures traversed by the vessel plunged as low as -95.62 degrees Fahrenheit / -70.9 degrees Celsius, the lowest recorded temperature inside the sealed capsule was 13 degrees Fahrenheit / -10.5 degrees Celsius.
- Capsule materials would need to accommodate expansion and contraction while traversing a wide range of temperatures relatively quickly. Instead of carbon fiber or Kevlar, a conventional fiberglass composite was used for the pressure sphere because its thermal coefficient properties were compatible with those of the acrylic door.
- The capsule door opening would need to be large enough to allow Baumgartner to egress safely despite the bulk of his pressurized suit. The team determined that a 4-foot opening would be sufficient, which in turn determined the 6-foot diameter of the central pressure sphere.
- The capsule door needed to be easy to open for Baumgartner in his cumbersome suit and equipment despite the frigid conditions and near vacuum of the stratospheric environment; and for ease of egress it should impede minimally on available space. Thompson created a hingeless acrylic door system that pressurized easily at launch yet rolled open smoothly and remained unobtrusively locked out of the way at egress.
- The capsule's systems, including life support systems, would need to be redundant (have backups) to ensure optimal safety throughout the mission. As Thompson put it, "Even our backup systems had backup systems."
- Dual communications (from Baumgartner to Mission Control and vice versa) were required throughout the flight.
- Capsule electronics would need to function in the hostile near space environment, even once Baumgartner depressurized the vessel to egress. Thus, because the capsule did not incorporate an elaborate system of air locks, a Space Shuttle–type circuit breaker would not be sufficient. The team invented a solid state circuit breaker that measures the true voltage load across the circuit. Every unit on the capsule had its own circuit breaker so that no one system could compromise the rest, and all circuit breakers could be reset from on board the capsule or from Mission Control.

- Battery systems were a carefully considered element to (a) minimize fire danger in an oxygenated environment, (b) limit unnecessary weight and (c) ensure power for capsule systems throughout a multi-hour mission. All capsule batteries were lithium ion, space-rated units. In total, two sets of three batteries per pack were used in the capsule: one set that powered the camera and video systems, and one set that powered the scientific, operational and life support systems. The battery pack for the cameras was completely separate from the battery pack that powered scientific/operational/life support equipment. All battery systems were designed to have a minimum 25% and 50% margin of battery life remaining after each flight for the camera and life support/science systems respectively. All battery systems had reassuring margins of battery life left when the capsule was recovered.
- A cooling system was required to dissipate the 1,100-watt peak output of heat generated from the camera systems.
- The capsule needed a system that would minimize impact on landing, both because the vessel was intended for reuse during the course of the multi-stage program, and to protect Baumgartner should he find it necessary to return to earth in the capsule rather than jumping. The target was to land with an impact under 12 Gs. Part of this system was a 100-foot-diameter parachute, initially reefed to 17 feet (*described in detail later in this document: see paper entitled "Weather, Balloon and Reefed Parachute System"*). This mission proved out the efficiency of a reefed system in a high-altitude environment. The other key impact-minimization component was a replaceable crush pad system at the bottom of the capsule. The overall capsule recovery system functioned so well that typical landing shocks ranged from 4.5 to 8 Gs.

The same capsule was used on all three of Baumgartner's stratospheric flights. On the program's July 25, 2012 mission, the speed of capsule landing was an unexpected 38 mph / 61 kmh. Despite the relatively high impact, the pressure sphere remained intact, and all power and battery systems were still operating upon recovery. The team returned the capsule from the New Mexico test site to Sage Cheshire Aerospace, where tests revealed that the capsule's pressure systems, life support and electronics were completely in tolerance and fully functional. Nonetheless, with Baumgartner's safety on the line, the Sage Cheshire team completely stripped the capsule down (even removing the fire-retardant paint) to re-verify every component and changed out the LOX (liquid oxygen) and

LN2 (liquid nitrogen) dewars and all battery components as a safeguard. The exterior shell was replaced with an interchangeable backup shell.

CAPSULE ERGONOMICS

The team determined to make the pressurized core of the capsule in a spherical shape due to a sphere's ability to withstand pressure. To initially verify the conceptual design, the team created a plywood mockup at Sage Cheshire Aerospace, which enabled them to assess minimum size requirements for egress in a pressurized suit, as well as to determine optimal layout of electronics and life support for flight operation in the pressurized suit. Baumgartner himself was the subject of some of these assessments.

Computer modeling enabled the team to formulate the capsule design, assess weight and balance, and conduct thermal and stress analyses with required absorption of flight loads for reuse of capsule components including CFD (computer fluid dynamics) analysis.

MODULAR DESIGN

The modular design of the capsule can be broken down into:

- The internal pressure sphere, with an integrated bezel ring and door assembly
- A load frame and door panel
- Exterior capsule skins
- A crush pad assembly
- Battery packs in insulated containers (two independent packs, each containing three sets of space-rated batteries)
- Solid state circuit breaker modules and an electronics bus bar assembly in the instrument panel and upper keg assembly
- LOX and LN2 systems along with GOX systems
- Cooling system to dissipate heat generated from the camera systems

BACKUP SYSTEMS AND REDUNDANCY

To reduce potential delays in the flight test program, spare capsule components were prefabricated or obtained, including:

- Pressure spheres
- Exterior shells
- Load frames
- Floor panels
- Crush pads
- Batteries and electronics
- Life support

"The key was redundancy and safety in everything we designed," Thompson stated.

LIFE-SUPPORT SYSTEMS

The capsule's life-support systems included:

- Two 10-liter liquid oxygen (LOX) dewars
- One 22-cubic-foot emergency gaseous oxygen (GOX) bottle
- One 25-liter liquid nitrogen (LN2) dewar
- A carbon dioxide/water scrubber
- Glove and foot heaters
- Space-rated battery systems
- Two 11.5-cubic-foot bailout GOX bottles on the parachute pack

Thompson noted that among the mission's redundant systems, there was over 10 hours of breathable oxygen on board the capsule.

The capsule contained nearly 90 switches so that Baumgartner could operate not only life-support systems, but cameras, glove and boot heaters, lighting, etc. All systems were individually switched and breakered.

Thompson pointed out that Baumgartner was frequently asked to monitor and report on capsule readings pertaining to life support and other systems throughout the duration of his ascent. This served not only to corroborate readings for Mission

Control, but, just as important, to keep Baumgartner mentally occupied, minimizing his potential for anxiety.

CHEST PACK

The chest pack was a compact assembly of electronics and power supply equipment that Baumgartner wore over his pressure suit. The chest pack contained:

- 3 GPS units
- 2 data loggers
- Inertial measurement unit (IMU)
- Accelerometer
- Mach speed indicator
- Video camera (focused toward Baumgartner's visor)
- Emergency line cutaway knife
- Voice radio – dual communications
- Lithium ion batteries for face plate heating
- Lithium ion batteries for remaining communications and data acquisition
- Connection to capsule power and systems via an umbilical cord

Thompson elaborated that the radio in the chest pack was a 1.5-watt model provided by Riedel Communications that was originally designed for handheld use, chosen because a high-watt radio wouldn't have been appropriate for positioning on Baumgartner's chest. To ensure that the range would be adequate, the communications team (including experts from ATA Aerospace who were an integral part of the mission team) built high-gain antennas that were mounted on the two "JLAIR" ground-based optical tracking systems positioned in the field. The result was that the team was able to conduct dual communication with Baumgartner during the freefall, even when he was at a distance of roughly 65 miles from Mission Control.

MISSION TRAINING

As Red Bull Stratos was a flight test program, Sage Cheshire Aerospace incorporated a multi-stage test schedule that enabled not only Baumgartner, but the entire team, to progressively exercise their operations and procedures, making adjustments and improvements – and refining checklists – as necessary.

These training operations included:

- Egress procedure development and training
- Vertical wind tunnel training in the full-pressure suit
- Bungee jumps to perfect capsule step-off
- Unpressurized skydiving for initial suit familiarization
- Pressurized skydiving for more intensive training

TESTING

Testing was conducted in several phases to exercise and assess all mission-critical components, including:

- Capsule systems
- Chest pack
- Personal parachute and drogue systems
- Drogue activation device
- Life support systems
- Long-range electronics and communication
- Mission Control operations
- Recovery operations
- Balloon launch operations
- Protocols and procedures

Test Phases

Pressure sphere testing

The sphere was designed to withstand six times its normal operating pressure of 8 psi (an altitude equivalent of 16,000 feet) and was fully tested to three times its normal operating pressure.

Vertical wind tunnel testing

Vertical wind tunnel testing was an initial means of testing the full-pressure suit's functionality in skydiving.

Thermal vacuum chamber testing

High-altitude tests in the high-altitude chambers located at the Wyle facilities at Brooks City-Base in San Antonio, Texas allowed: (1) the capsule and electronics to be man-rated, (2) procedural testing and (3) human exposure to low-density altitudes in extreme cold using a controlled environment. Six altitude tests were conducted at the Wyle facility, where altitudes as high as 123,000 feet and temperatures of minus 60 degrees Fahrenheit were attained. Five tests were conducted at the USAF high-altitude chamber facility at Beale Air Force Base in California. On two of these training flights, the chamber was taken to a previously unprecedented altitude of 130,000 feet.

Unmanned capsule testing

Before Baumgartner was ever flown in the capsule, the complete unmanned unit was twice tested to stratospheric altitudes, using the same flight crew and the same Roswell, New Mexico launch site as the final mission on October 14, 2012. Objectives of these unmanned tests included:

- Flight train verification
- C3 (command, control and communication) verification
- Launch procedure development
- Recovery procedure development
- Aerodynamics in freefall
- Predicted flight path confirmation
- Structural integrity verification
- Optical tracking assessment and practice
- Capsule electronics system testing
- Electronics/GPS system testing via a drop pod to verify chest pack systems; the drop pod was weighted to simulate Baumgartner's own center of gravity, weight and balance

MANNED FLIGHT BUILDUP

After completion of the above testing, two progressive high-altitude manned flights were conducted to further test all systems and gather pertinent data, as well as to ensure and practice pre-launch, launch, in-flight, egress and recovery procedures prior to Manned Balloon Flight 3 (October 14).

CONCLUSIONS

- As planned, the mission was conducted as a flight test program.
- The mission's carefully crafted test and training plan provided valuable learnings on their own and ultimately benefited the success of Manned Balloon Flight 3 (the mission on October 14, 2012).
- Notable innovations were made in technology that will benefit future aerospace and private space programs, including development of enhancements for the next generation of space suits, increased knowledge of human physiology and egress safety systems.
- The input, coordination and cooperation of numerous specialist teams contributed strongly to the achievements attained on the Red Bull Stratos program.

PARACHUTE SYSTEM AND FREEFALL
Luke Aikins

To optimize Felix Baumgartner's safety during his unprecedented freefall and throughout the years of testing that led up to it, a unique parachute system was developed.

This paper summarizes information presented by Mr. Luke Aikins, skydiving consultant to the Red Bull Stratos program and one of the designated safety and training advisors for the United States Parachute Association, with the assistance of Mr. Mike Todd of Sage Cheshire Aerospace, the mission's life support engineer. Aikins was a key player in designing the training plan that helped Baumgartner learn to skydive within the confines of a full-pressure suit; personally served as a test subject for evaluating the efficacy of parachute, GPS and face plate systems; and spearheaded development of Baumgartner's personal parachute rig and drogue system.

BACKGROUND

When Aikins joined the Red Bull Stratos program in 2009 (initially as an aerial cinematographer to capture test and training sessions), the mission plan was to modify an existing parachute system. Over the course of assessing the situation, Aikins advised the team that for the singular challenges of skydiving in a full-pressure suit – especially in a stratospheric environment and at supersonic speeds – a unique, purpose-built system would offer optimal safety and best results.

Aikins collaborated with Kelly Farrington, founder of parachute rig manufacturer Velocity Sports Equipment, to develop and produce Baumgartner's custom rig.

UNIQUE ASPECTS OF THE PERSONAL PARACHUTE SYSTEM

Handles

The rig's handle design required extraordinary care because Baumgartner's tactile sense was limited by the pressure suit gloves, and his vision was likewise limited by the helmet. "We couldn't go with military-style D rings or with civilian-style handles either," Aikins noted. In the end, Baumgartner's rig employed four handles with large openings to accommodate his gloved fingers. Each handle was strategically positioned far from the others (one on each shoulder and one on each hip) to limit the potential for confusion.

Oxygen Bottles

The parachute rig accommodated two oxygen bottles, designed by Mike Todd, to function independently so that one would serve as the redundant backup system for the other.

Chest Pack

Baumgartner's chest pack incorporated technology including his power supply for the descent. However, especially with his vision already limited by the helmet, the chest pack made it hard for Baumgartner to look down and see his landing zone. Thus the chest pack was equipped with a release that allowed Baumgartner to move it to the side as he approached the ground.

Reserve Cutaway

Normal skydiving rigs don't have a mechanism to cut away the reserve parachute, a skydiver's last resource in an emergency. But if Baumgartner's reserve chute had inadvertently deployed at high altitude, his landing could have been delayed so much that he'd run out of oxygen. Baumgartner's rig was equipped with a handle that he could use if necessary to cut away the reserve parachute and return to freefall before pulling his main chute at an appropriate altitude – an industry first.

Tracking System

The extreme altitude combined with a potential for high acceleration, tumbling and/or spinning presented a challenge for GPS system accuracy. Baumgartner wore a total of four GPS tracking systems. Three of the GPS systems, collectively used for data recording and record verification, were in his chest pack. Aikins felt the team needed an independent GPS system for the purpose of tracking Baumgartner's position so that the medical and recovery team could reach him as soon as possible. This system, attached to the parachute rig, was tailored to provide accurate readings every 2 seconds, which were transmitted to the recovery team in the field as well as to Mission Control.

Automatic Activation Device: CYPRES

Baumgartner wore a CYPRES automatic activation device (AAD) designed to activate his reserve parachute for landing should he be incapacitated or unconscious – the first ever modified to function despite exposure to a near-space environment, it had a unique arming cable that would allow the CYPRES to be armed upon Baumgartner's exit of the capsule.

Main and Reserve Parachutes

Aikins and the team opted for main and reserve parachutes that, at 270 square feet, were about 100 square feet smaller than typical military parachutes. This was determined to be a canopy size that would get Baumgartner down as quickly as possible in an emergency while offering a relatively gentle, safe landing in the event he should be unconscious or incapacitated.

Altimeter

Baumgartner's altimeter was a challenge because the dial on a typical skydiving altimeter completes a circle once every 13,000 feet – and there was no expectation that he would be able to keep track of the dial's rotations during his long descent. The solution was a digital altimeter with an analog gauge that would read accurately at peak altitude and in the critical area approaching the ground. "As intended, from 60,000 feet down it was exactly accurate," Aikins said.

Drogue system

Like traditional parachute systems, Baumgartner's rig included a main parachute and reserve chute, but it also incorporated a special drogue (small parachute for stabilization) that operated completely independently of the other parachutes in the rig.

A drogue system was needed because the team, and particularly Baumgartner, wanted the descent to be a true freefall, without any stabilization device unless absolutely necessary. As a skydiver, Aikins found that to be an exciting proposition. An unprecedented configuration was devised to incorporate a drogue without using it to deploy a main or reserve parachute (in ordinary rigs, drogue deployment pilots the release of a larger chute). Testing of the system developed for Red Bull Stratos showed that when the drogue did deploy, rather than arresting the spin with a shock, it turned spinning into a gentle turn – a desirable result.

Where to attach the drogue was an important consideration. To keep the center of any potential spin at a high level on Baumgartner's body, which would reduce the chance of a dangerous "red out" condition (in which blood rushes to the head), the team decided to attach the drogue near Baumgartner' shoulders.

DROGUE DEPLOYMENT DEVICE

The team debated whether the drogue should be deployed manually or automatically, and ultimately it was decided that both options would be incorporated. It was Aikins' responsibility to devise a way that the drogue could be manually deployed by Baumgartner or automatically deployed if required for his safety, and to determine parameters of when automatic deployment would be necessary. The solution was a time-based accelerometer, which Technical Project Director Art Thompson dubbed the "G Whiz." Positioned on Baumgartner's right wrist, the accelerometer measured G forces: if 3.5 Gs were sensed for 6 continuous seconds, the drogue would fire automatically.

The team determined that they didn't want the drogue to deploy during the initial portion of the descent because in the thin air and near vacuum of the upper stratosphere, there would be no air resistance to pull the drogue away and prevent it from wrapping around Baumgartner. Thus the system incorporated a time delay, arming about 38 seconds into the descent (38 seconds after its sensor detected 0 Gs for 1.5 seconds).

Once it was armed, the system had two methods of deployment: (1) a manual button on a ring over Baumgartner's glove, which would deploy the drogue if it were held down for 3 seconds (to avoid deployment by brief accidental pressure); and (2) the sensor on Baumgartner's wrist that would automatically deploy the drogue if it sensed 3.5 Gs in any direction for a continuous period of 6 seconds. "Continuous" was key: to allow Baumgartner maximal opportunity to stabilize himself, any drop below 3.5 Gs would restart the 6-second count.

"The most fun was doing all the testing to determine when we wanted that thing to fire," Aikins said candidly in talking about personally undertaking the physical experiments necessary, which included both skydiving "out of control" and using a self-constructed, ground-based turntable. "Benchmarks were when I couldn't draw my hands in due to centrifugal force and when I found that I could no longer spot the horizon."

TRAINING

Aikins noted that the team benefited especially from the input of Col. Joe Kittinger in developing Baumgartner's training plan, which included:

Vertical Wind Tunnel Training

Before he made any parachute jumps in the suit, Baumgartner first became accustomed to the limitations of the garment by training in a vertical wind tunnel.

Exit Training

Baumgartner needed to create as little tumbling momentum as possible in his step-off from the capsule, because in the thin air there would be no wind resistance to halt it via body positioning. Inertia training included fully suited bungee jumps from a crane.

Skydive Training

"It was important to me that Felix didn't just do regular skydives, because we already knew he could do that," Aikins noted. "Jumping from airplanes, I had him falling on his back and rolling over, to get comfortable with the suit and comfortable upside down."

THE FREEFALL

Aikins described Baumgartner's October 14 freefall in terms of how it compared with his own expectations and predictions.

The months and years of training had paid off: Baumgartner's exit was "perfect," even better than Aikins expected, creating virtually no momentum that could result in instability.

The first 30 seconds of the descent were as Aikins had expected, with Baumgartner rotating slowly.

Between 30 and 40 seconds into the freefall, Baumgartner was traveling head low as planned, but he had begun a slight rotation to the right. He reached Mach 1 when he was 34 seconds into the freefall.

Baumgartner regained control while traveling at Mach 1.15, between 40 to 45 seconds into his freefall, and his body position began to flatten. He abruptly and aggressively tried to return to the low-drag, head-low position in an attempt to maximize velocity. He overshot the position, so that the relative wind began to hit him on his back rather than from his front. (One consequence of this is that any body movements practiced for expected ascent would need to be reversed to have the intended effect.) At 45 seconds he began a slow left-hand turn.

Baumgartner was in a turn for about 35 seconds that accelerated into a fast spin for a period spanning about 25 seconds into the freefall. At times he was on his back, head low, which made it difficult to see the horizon for reference.

After trying several times to arrest the spin using arm movements, at almost 80 seconds into the descent Baumgartner reverted to the basics of his training and arched as hard as possible, which enabled him to regain control. He continued the freefall in a stable attitude to the predetermined opening altitude of 5,000 feet MSL, where he pulled his main parachute handle.

Aikins had originally predicted that Baumgartner would start to regain control at 30 seconds into the freefall. He assessed that the combination of virtually no drag in the extreme altitude, a lack of body motion and dexterity in the pressurized suit, and the desire to maximize speed to assure supersonic velocity were all contributing factors to the length of time required to stabilize. However, rotations did not reach a dangerously high level of speed/duration. Aikins credits Baumgartner's physical and mental training for helping him to recover from rotation not once but twice in the descent.

CONCLUSIONS

Drogue: Extensive drogue testing and experimentation enabled the team to devise parameters that afforded Baumgartner the opportunity to stabilize without use of the drogue yet have the system available to minimize risk. Although the drogue was not deployed in the record-setting jump, Baumgartner reported that knowing it was available increased his feeling of confidence and security.

Parachute system: The mission's one-of-a-kind system worked flawlessly.

Altimeter: The newly configured altimeter was accurate, and Baumgartner found it easy to read.

Aikins' personal conclusion was that a very experienced jumper would not need a drogue parachute for stabilization when jumping from an altitude similar to Baumgartner's exit of 38,969.4 meters / 127,852.4 feet – but an inexperienced jumper would be in danger without one.

FULL-PRESSURE SUIT AND HELMET
Shane Jacobs, Dan McCarter, Mike Todd

Before Felix Baumgartner's October 14, 2012 jump, Space Shuttle pressure suits were qualified for environmental exposure to a maximum of 100,000 feet. With Felix Baumgartner's jump from 127,852.4 feet / 38,969.4 meters, the Red Bull Stratos mission verified the current state-of-the-art full-pressure suit currently in use to a new altitude, and proved out new design modifications in the process.

This paper summarizes information presented by Dr. Shane Jacobs, design manager for David Clark Company; Mr. Dan McCarter, program manager at the David Clark Company; and Mr. Mike Todd of Sage Cheshire Aerospace, the mission's life support engineer. David Clark Company manufactured all three suits used by Baumgartner for Red Bull Stratos training, testing and mission operations, while Todd maintained the finished suit, worked to ensure its integration and coordination with other mission life support systems and personally dressed Baumgartner for each flight.

OVERVIEW

Jacobs began the presentation by noting that David Clark Company, which has been supporting NASA and the U.S. Air Force for more than 60 years, agreed to collaborate with the private Red Bull Stratos program because, from a suit design perspective, the mission offered an exceptional opportunity to validate equipment and obtain data. "We are constantly trying to improve our equipment, push the envelope and validate our pressure suit designs to higher altitudes and higher speeds," he stated. "We saw this as a great and unique opportunity to prove out our latest state-of-the-art pressure suit."

The mission's use of a pressured capsule, prestigious team of subject matter experts and potential for scientific benefit were key discriminators in securing David Clark Company's participation. Particularly intriguing was the potential opportunity to develop procedures and techniques that could help to recover crews from high altitudes.

Much like Joe Kittinger proved out a standard-issue suit used by U.S. Air Force pilots for his Excelsior III jump in 1960, David Clark Company's state-of-the-art suit currently worn by high-altitude reconnaissance pilots was used as the baseline for Felix Baumgartner's pressure suit: but the stratospheric freefall presented unique requirements.

SUIT DESIGN REQUIREMENTS AND CONSIDERATIONS

A suit for the stratospheric freefall attempt would have to address:

- The need to transition from seated to standing, and to stand upright on the capsule step before jumping
- Baumgartner's objective to attain a streamlined attitude (the "Delta" position) in freefall
- Thermal considerations due to exposure to the hostile stratospheric environment
- Visor fogging mitigation even while rapidly traversing a wide range of temperatures

It was confirmed that a current state-of-the-art suit would be used as the baseline for the Red Bull Stratos design, but because the baseline was designed for use in a seated position (in a cockpit and ejection seat), redesign was required.

Baseline Suit

To achieve their purpose, full-pressure suits are (on the most basic of levels) airtight bags. Although pressure suits have historically been bulky, heavy and made of impermeable materials that trap heat and water vapor, David Clark Company's state-of-the-art suit used as the baseline for the Red Bull Stratos design employs breathable and lightweight materials, making it low-bulk and comfortable, and offering a low thermal burden. Key components of the state-of-the-art baseline suit include:

- A gas container that, while airtight (impermeable to nitrogen and oxygen), is still breathable to let water vapor pass through and reduce the thermal burden
- An integrated vent assembly for cooling

- A link-net restraint that provides comfort when the suit is unpressurized, as well as affording mobility (within the design range) when the suit is pressurized (link-net, exclusive to David Clark Company, is made from high-strength/low-elongation materials that enable the link-net to stretch, but only in specifically designed directions)
- An exterior cover that provides fire protection as well as protection from impingements such as abrasion and puncture

Jacobs described the baseline garment as the lightest-weight pressure suit that could meet the demands of the extreme stratospheric environment Baumgartner faced, and he assessed its breathable gas container as perhaps the biggest advancement in pressure suits over the past 25 years.

The presenters added that, as is customary with these types of suits, aneroid controller hardware was obtained to work with the garment; while the controller was set to various levels during training and testing, Todd set it to maintain a pressure of 3.5 psi (equivalent to 35,000 feet [10,668 meters] in altitude) when the suit was pressurized during the October 14 mission.

Baseline Helmet

Baumgartner's helmet needed to maximize protection from impact yet minimize head-borne weight. The David Clark Company state-of-the-art helmet used as the baseline for the Red Bull Stratos mission includes:

- An integrated visor-fogging mitigation system
- An integrated oxygen delivery system (including redundant regulators) that further aids mitigation of visor fogging and ensures carbon dioxide washout, while minimizing consumable usage
- Phase-change materials in the helmet liner that help to maintain thermal comfort (helping to keep the head cool when it's warm and vice versa)
- A composite shell, which, along with the attenuation liner, provides impact protection while minimizing head-borne mass

Unique Design Specifications

As mentioned above, the baseline state-of-the-art suit is designed in a sitting position, for use by a pilot in a cockpit/ejection seat. (McCarter pointed out that a pilot in a U-2 suit pressurized to 3.5 psi would likely fall over if he/she attempted to stand.)

The Red Bull Stratos suit pattern was modified in the shoulder, elbow, hip and knee areas to enable the mobility Baumgartner required to attain the streamlined Delta position (e.g., shoulders were rolled back and hip position was straightened). The capsule's lap belt enabled Baumgartner to remain seated once the suit was inflated, despite the hip straightening adjustments.

The design of the garment's hold-down (which helps to prevent the helmet from rising off the wearer's shoulders when the suit is inflated) was modified to allow for Baumgartner's transition from a seated to a standing position.

SUIT FITTING AND PRODUCTION

McCarter noted that Baumgartner served as a test subject for the modifications. The pressure suits for most high-altitude pilots are standard issue from one of 12 available sizes, and if Baumgartner had been a military pilot being suited for standard duty, he would have been supplied with one of those standard-size suits. Instead, the Red Bull Stratos suit was custom fit to Baumgartner's anthropometry (a comprehensive body measurement profile), resulting in a smaller (more streamlined) profile than would ordinarily be expected. Gloves were also meticulously fitted, both for ease of Baumgartner's use of capsule instrumentation as well as to enhance his ability to grasp his parachute handles and perform other tasks in the air.

Three suits were fabricated for use in the Red Bull Stratos testing and development program. Each was subjected to a series of acceptance tests prior to use, including leak tests, structural tests and fit checks. The suits were labeled: "S01" for a prototype/training suit, and "S02" and "S03" for the two operational suits.

The S01 prototype suit was used under very rigorous conditions for multiple operational tests. Afterwards, the exterior cover showed some signs of wear, but overall the suit remained in excellent condition. No damage or wear was evident in the gas container or restraint.

Suit S02 was used for some of Baumgartner's vacuum chamber tests, as well as for a stratospheric test jump on March 15, 2012 and the final record-breaking jump on

October 14, 2012. Post-flight inspection showed that the suit is in pristine condition with all systems working as designed. Slight staining is apparent at the knees, which is a result of Baumgartner kneeling in relief upon landing the final mission – a relic of the event that the Red Bull Stratos archivists do not wish to erase.

Suit S03 was used for Baumgartner's stratospheric test jump on July 25, 2012. Although David Clark Company inspection was not yet complete at the time of publication, no anomalies were expected. McCarter confidently stated, "I would wear any one of those suits tomorrow."

SUIT INTEGRATION

Additional modifications were made to Baumgartner's suit and helmet to coordinate them with other mission-critical components/functionality, including:

- GPS system and antennas were integrated
- Boot heaters were integrated, to keep Baumgartner's feet warm during the long capsule ascent
- Camera pockets were added to the legs
- A mirror was added to each glove to aid Baumgartner's ability to observe his parachute lines and other objects peripherally despite the confines of the helmet
- The visor and sunshade were modified so that the sunshade could be used as an additional thermal pane

Todd explained that thanks to the sunshade modification, when the helmet sunshade was lowered over the visor, no air could get between the sunshade and visor, which mitigated heat loss during Baumgartner's freefall phase, which experienced temperatures as low as -95.62 Fahrenheit (-70.9 Celsius).

OPERATIONAL TESTING

The fact that Red Bull Stratos was a flight test program afforded numerous opportunities for operational testing of Baumgartner's suit, including:

- Thermal testing in a cold-soak unit at Sage Cheshire Aerospace
- Vertical wind tunnel tests

- Bungee jumping to perfect capsule step-off
- Skydiving in the unpressurized suit
- Thermal vacuum chamber testing
- Skydiving in the pressurized suit
- Two stratospheric freefall jump missions preceding the final jump on October 14

McCarter noted that for typical U-2 and SR-71 testing, the maximum simulated environment is 70,000 to 80,000 feet (21,336 to 24,384 meters), but the Red Bull Stratos suit was subjected to the unprecedented equivalent of 130,000 feet (39,624 meters) in altitude.

CONCLUSIONS

The David Clark team summarized that all suit systems performed as designed; no anomalies to suit or helmet/visor condition or function were noted during stringent post-flight inspections.

The presenters affirmed that the Red Bull Stratos mission expanded the performance envelope for David Clark Company's aerospace crew protective equipment. They also felt that the mission provided validation of the equipment design and procedures related to extreme altitude by exposing this type of suit to altitudes higher than it had ever experienced, both in an altitude chamber and in the actual atmospheric environment.

Ultimately, Jacobs, McCarter and Todd identified the findings of the Red Bull Stratos mission as having applications to crew survivability and high-altitude bailout for commercial spaceflight and future government vehicles, with the suit evidencing potential to serve as a viable escape method.

MEDICAL ISSUES AND RISK MITIGATION
Jonathan Clark

For Felix Baumgartner's safety, medical teams in Mission Control, in the field and in the air coordinated closely, following specially developed procedures and protocols that had been years in preparation.

This paper summarizes information presented by Dr. Jonathan B. Clark, MD, MPH, who is on faculty at the Department of Neurology and the Center for Space Medicine at Baylor College of Medicine in Houston, Texas. As medical director for Red Bull Stratos, Clark led the medical teams overall and spearheaded planning and development of the mission's medical protocols and procedures.

Clark opened his presentation by describing his experience on the Red Bull Stratos mission: "cutting-edge technology and inspiring minds – the brightest minds I have ever had the honor of working with."

MISSION MEDICAL OBJECTIVES

- To assure Baumgartner's health during all mission phases
- To provide medical and safety expertise in planning and implementing procedures, training and integrated testing of support systems
- To provide medical expertise for pre-flight, in-flight and post-flight phases
- To coordinate and assist EMS support at landing sites
- To evaluate physiologic, scientific and medical data

Sharing the stage with Clark were Dr. Rebecca Blue, who was the medical lead for ground-based recovery forces, and Dr. Matt Turney, the lead for airborne recovery. The overall medical roster, encompassing both personnel on site in Roswell and off-site personnel who contributed to planning and development, includes:

Medical Team

- Jonathan Clark, MD, Medical Director
- Matt Turney, MD, Emergency Medicine Physician
- Jennifer Law, MD, Emergency Medicine Physician
- Rebecca Blue, MD, Emergency Medicine Physician
- Sharmi Watkins, MD, Internal Medicine Physician
- Sean Norton, EMS/Technical Rescue Paramedic

Resident Physicians

- Dan Murray, MD (University of Texas Medical Branch)
- James Pattarini, MD (University of Texas Medical Branch)
- Alex Garbino, MD, PhD (Baylor College of Medicine)
- Erik Antonsen, MD, PhD (Harvard / Mass. General Hospital)

Medical Team Technical Consultants

- Andy Walshe, PhD, Red Bull High Performance Director
- Michael Gervais, PhD, Sports Psychologist
- Andy Pilmanis, PhD, Aerospace Physiologist
- Gresham Bayne, MD, Critical Care Consultant
- Shawn Goughnour, Ebullism Ventilator Expert
- Jim Bagian, MD, Safety/Survivability Consultant
- Robert Dunn, MD, Hyperbaric Medicine Consultant
- Jim Sheffield, MD, Hyperbaric Medicine Consultant
- Chris Stokely, PhD, Aerodynamics Reentry Expert
- Jeff Chancellor, Space Weather Radiation Physicist

PRE-MISSION PERFORMANCE OPTIMIZATION

- Strength and conditioning
- Neurobehavioral and psychological enhancement, including brain mapping
- Pressure suit confinement adaptation
- Pre-launch quarantine to ensure optimal health for mission
- Low-residue diet to avoid discomfort in low-pressure environment
- Sleep shift to accommodate launch timeline

MEDICAL PLAN

- Medical/physiologic threat brief
- Oxygen pre-breathe protocol (75 minutes) for decompression sickness risk reduction
- Medical/physiologic monitoring plan
- Launch and recovery medical plan
- Contingency plan
- Medical protocol development against known stratospheric bailout threats
    - Ebullism treatment protocol for exposure to vacuum
    - Medical protocol for flat spin (negative Gz)

PRIMARY THREATS

- Ascent threat (low-altitude abort/ balloon failure)
    - Hard landing with Baumgartner in capsule
- Stratospheric threats (primarily low pressure/vacuum)
    - Ebullism
    - Hypoxia
    - Decompression sickness
- Freefall threats (acceleration forces)
    - Flat spin
    - Shock wave forces, including shock-shock interaction
- Landing injury

Clark explained that in the vacuum of near space and space (above altitudes of about 63,000 feet), liquid water vaporizes. Thus blood spontaneously boils, a condition called ebullism that can lead to serious consequences, most especially in the lungs.

HISTORIC LESSONS LEARNED

To learn from previous events, Clark and his colleagues performed a very thorough historic review of high-altitude programs (and mishaps), including Col. Joe Kittinger's Excelsior program jumps.

- USAF Project Excelsior jumps
  - 120 rpm flat spin (Excelsior I), glove leak (Excelsior III)
- USN StratoLab V balloon flight
  - Landing fatality
- Russian Air Force Volga balloon jump
  - Cracked visor, ebullism fatality
- Project Strato jump (US civilian)
  - Anoxia, delayed fatality
- SR-71/A-12 Aircraft
  - Mach 3+ 78K breakup: three of four crew survive breakup, one fatal neck injury

MEDICAL TREATMENT FOR EBULLISM

Clark stated that based on the pulmonary pathophysiology of ebullism, and the similarity to acute respiratory distress syndrome, critical care experts suggested treatment with high-frequency percussive ventilation. Using liquid oxygen, the percussion ventilator system integral to the Red Bull Stratos ebullism treatment protocol is simple, durable and requires no external power source. The unit, invented by Dr. Forrest Bird, has often been used for very premature infants or burn victims with compromised lungs; incorporation of the ventilator into a field-based environment is one of the innovations of the Red Bull Stratos medical protocols. The entire on-site medical team was trained in use of the device by leading expert Shawn Goughnour.

The protocol is scheduled for publication: Murray DH, Pilmanis AA, Blue RS, Pattarini JM, Law J, Bayne CG, Turney MW, Clark JB. Pathophysiology, prevention, and treatment of ebullism. *Aviation, Space, and Environmental Medicine* 2013; 84(2):89–96.

PHYSIOLOGIC EFFECTS OF THE FLAT SPIN

Objects descending from high altitude have a tendency to spin. Baumgartner trained specifically on stabilization techniques, but the team expected that at least some amount of tumbling or spinning would occur. Medical effects, which can be severe, depend on the center of the spin. Because spin is more tolerable when center of rotation (CR) is at the chest rather than the abdomen, Baumgartner's gear was balanced to give him a relatively high CR. While Baumgartner was also equipped with a specially developed parachute system designed to arrest spinning in the event that he couldn't stabilize his position, the medical team developed a detailed flat spin treatment protocol as a contingency.

CONTINGENCY EVENT MEDICAL SUPPORT

- Establish an EMS plan
- Arrange resources for EMS operations
- Coordinate crew recovery and medical evacuation forces
- Evaluate equipment readiness
- Establish medical contingency protocols and procedures
- Extraction of unresponsive crew from capsule
- Rapid removal of pressure suit in unresponsive crew

EMS STAGING

Clark noted that the medical strategy was "defense in depth":

- Medical director ("Mission Med") in Mission Control Center
- Coordination via Medical Back Room ("Field Med")
- "Air Doc" followed capsule/Baumgartner in helicopter, evaluated Baumgartner at landing zone*
- Two EMS rigs ("Forward/Tail Rig") initially positioned to respond to low-altitude ascent abort (<4000') then deployed to landing zone
    - In each, a physician accompanied the Roswell EMS crew*
- Tactical rescue paramedic with capsule recovery team

- Air ambulance helicopter at Roswell International Air Center on standby for medevac

**Equipped with high-frequency percussive ventilator*

MEDICAL TEAM DEPLOYMENT SITES

Throughout Baumgartner's two stratospheric test jumps (March 2012 and July 2012), medical team deployment sites were based on the balloon track predicted by mission meteorologist Don Day. These field-based medical teams had access to a code that enabled them to watch long-range optics from the mission's ground-based trackers in real time on their mobile devices.

- On the March test, a ground-based medical recovery team was the first to reach Baumgartner.
- On the second jump (July), the airborne (helicopter-based) medical team reached Baumgartner first.
- At the final mission in October, the airborne medical unit and both ground-based teams all converged on the landing zone at the same time – they were on hand promptly upon Baumgartner's touchdown.

CONCLUSIONS

- The mission's multi-stage test plan optimized the medical team's (and the mission's) opportunity for a successful result.
- The Red Bull Stratos program defined some of the operational risks and medical concerns of impending human suborbital space flights, and the program is already producing tangible results.
- Results from Red Bull Stratos may have applications for crew escape from spacecraft.
- A tiered approach to risk management (prevent, mitigate, manage) offers the highest likelihood of success.
- Medical treatment protocols developed for the mission offer application for spacecraft contingency response and high-altitude bailout:
    - Loss of cabin integrity at high altitude – ebullism
    - Flat spin and uncontrolled flight – negative Gz exposure

  - Ground medical treatment protocols for extreme altitude activities
  - Contingency plans based on high-consequence threats
- The Red Bull Stratos mission demonstrated a successful milestone-driven flight test plan with reproducibility, performance optimization and safety as high priorities.

PHYSIOLOGIC MONITORING AND ANALYSIS
Alex Garbino

Physiologic monitoring of Felix Baumgartner throughout the mission extremes of temperature, acceleration and low-pressure/low-oxygen environment was one of the foremost goals of the medical team, both to monitor Baumgartner's condition and to obtain research data.

This paper summarizes information presented by Dr. Alex Garbino, MD, PhD, a resident doctor at Baylor College of Medicine who was invited to join the Red Bull Stratos program by Medical Director Dr. Jonathan Clark. Because he is working on a project related to physiologic data captured during the mission that will be one of the key medical artifacts of the program, for this presentation he represented the efforts and findings of the medical team.

WHY MEASURE?

After opening with words of appreciation for his colleagues on the medical team and the mission team overall, Garbino explained that no physiologic data had ever before been captured from a human in supersonic freefall; thus Red Bull Stratos offered the unique opportunity to ascertain forces, loads and what happens in the body in such an event. Objectives of physiologic monitoring included:

- Monitor Baumgartner for rapid response if necessary.
- Gather data progressively throughout the flight test plan, in order to better understand what might occur on subsequent jumps.
- Collect data about a first-of-its-kind event.
- Conduct analysis if necessary for understanding of any unexpected outcomes.

WHEN TO MEASURE?

Because this was part of a flight test program, the team exercised the physiologic monitoring system on tests leading up to the final mission, including Baumgartner's two preliminary stratospheric flights, to identify and address any anomalies.

HOW TO MEASURE?

The team conducted a rigorous selection process of all devices *on* the market, with key requirements being that the equipment must be appropriate for use in flight and capable of integration in a pressure suit. The latter requirement ruled out most existing systems.

The unit selected was the Hidalgo Equivital™ EQ1, a unit Baumgartner wore under the suit (strapped to his chest) that offered access to:

- Heart rate
- Respiratory rate
- Tri-axial acceleration
- 8+ hours' data collection
- Raw data

The most important factor in the selection decision was access to raw (as opposed to processed) data, which would provide the most information and enable the team to conduct the most precise, accurate analysis.

DATA PROCESSING

The availability of the raw data, while highly desired, offered its own challenges. Each data run generated more than 1 gigabyte of raw data, with more than 40 parameters logged at up to 256 Hz. (Because the unit was worn under the suit, a data run would typically last about 10 hours – spanning the period from Baumgartner's initial pre-flight preparations though the mission itself, recovery operations and post-landing activities.)

More than 100 million data points were obtained on each jump.

Processing Software

With this much data to process, standard computer programs were inadequate, crashing under the demand. The team needed the most powerful data analysis tool they could find. They found a solution in the ROOT (Object-Oriented Data Analysis

Framework) program used by the European Organization for Nuclear Research (CERN) to analyze data from its particle accelerator.

Types of Data Under Analysis

- Tri-axial acceleration
  - What forces were on the body and the strength of those forces
- Respiratory rate
- Heart rate

Particular Challenges of Heart Rate

Garbino explained that the heart rate has proven to be the most challenging physiological information to analyze: The team has access to the raw EKG to examine every parameter, beat by beat. While raw data provides the extremely high resolution desired, in capturing it the recorder can get "confused" if the heart rate is drowned out by physical activity ("noise"). And, as Garbino pointed out, Baumgartner's mission was a far cry from the usual EKG situation, in which readings are taken in a medical facility with the subject prone and remaining still.

Thus using the raw data requires noise reduction to reduce misleading extremes/indicators that were not the result of actual heart activity; otherwise, artificially high readings could be subject to misinterpretation. Another part of the challenge: with readings spanning the full mission, the team has an extraordinarily long data stream to examine (in typical day-to-day situations an EKG strip provides a snapshot of just 10 seconds).

After eliminating noise, the team found that Baumgartner's maximum exertion occurred when he was doing the most physical work: in egress from the capsule. This was something that the team had predicted and Baumgartner had prepared for due to difficulty of movement in the pressurized suit. As he jumped, Baumgartner's heart rate decreased somewhat, increasing again during the spin.

At no time in any of his jumps did Baumgartner's heart rate reach a level of concern or exceed expected parameters for such an endeavor.

Baumgartner's heart and respiratory rate at key milestones:

	Heart Rate (beats per minute)	Respiratory Rate (breaths per minute)
O2 prebreathe	40-100	10-16
Launch	120	17
Ascent	60-100	20-30
Egress from capsule	155-185	20-30
Jump	176	30
Weightless (initial fall)	169	30
Mach 1.25	169	32
Overall freefall	155-175	30-43
Parachute descent	155-180	26-34
Landing	163	33
Recovery flight	100	18

COMPARISON OF BAUMGARTNER'S STRATOSPHERIC JUMPS

	March 15, 2012	July 25, 2012	Oct. 14, 2012
Exit (jump) altitude	21,828.3 m 71,615.2 ft	29,610.0 m 97,145.7 ft	38,969.4 m 127,852.4 ft
Time < 0.1G*	6.1 sec	9.3 sec	25.2 sec
Heart rate	140–180 bpm	115–182 bpm	143–185 bpm
Respiratory rate	22.1–33.8	25.0–39.2	26.0–43.1
Opening shock **Landing shock**	3.21g 4.06g	3.49g 4.11g	3.27g 3.40g

**0.1 G is considered absolute weightlessness*

RISKS AVERTED/MANAGED

Careful planning helped the team to avert number of possible conditions, including:

- Hypoxia
- Ebullism
- Undue temperature exposure
- Decompression sickness

Planning and training also enabled Baumgartner to manage the body's tendency to spin at high altitude.

Spins

Flat spin had been a particular concern to the team from the beginning of mission development. While Baumgartner was ultimately able to use his extensive training and skills to manage the spin he entered during his October 14 freefall, the spin segment of the data did provide a particularly interesting point of analysis for the mission team.

The raw data provided information on all three axes: lateral G, vertical G, and longitudinal G, as well as rotations per minute. Through the period of spinning, the spin axis changed, placing forces on various parts of his body. Analysis indicates that although a force of about 2 Gz (negative G) would have been expected if Baumgartner's spin had been centered at his own physical center (midsection), the actual center of his spin was somewhat higher due to pre-planned placement of his chest pack, thus improving protection for his head.

Besides center of gravity, risk in flat spin increases with rotation speed and duration. Analysis also shows that here too, Baumgartner remained in safe parameters: Spin rate never exceeded 60 rotations per minute and exposure to an actual flat spin position lasted roughly 13 seconds at most.

The G forces to Baumgartner's head remained under 2 Gz throughout his spin, well within acceptable risk levels, and the automatic drogue stabilization parachute device on Baumgartner's wrist never experienced the pre-set trigger level of 6 continuous seconds at 3.5 G.

PRELIMINARY CONCLUSIONS

A multi-stage test program enabled the medical team to test out and refine the physiological monitoring process.

The mission team's planning for and management of stratospheric scenarios averted potential conditions including hypoxia, ebullism, undue temperature exposure and decompression sickness, and mitigated the effects of spin.

Baumgartner's spin never exceeded safety margins in rotations per minute/duration, and the high center of gravity provided by the arrangement of his equipment helped to reduce forces to his head.

No unusual G loads were incurred, including at points of parachute deployment and landing.

Valid physiologic monitoring is attainable under extreme acceleration in near space conditions, and under a pressure suit; however, use of raw rather than processed data is essential to rule out "noise" and other possible anomalies that could be misleading.

Garbino and the team will continue to explore and publish conclusions as data analysis continues.

CAMERA AND LONG-RANGE OPTICAL SYSTEMS

Jay Nemeth, Dennis Fisher

Camera and optical systems were essential for monitoring the mission in real time, documenting it for future review and broadcasting images to a global audience. The challenges of providing extensive still and moving image coverage from multiple perspectives in the extremes of the stratosphere proved to be as complex as every other mission component.

This paper summarizes information presented by Mr. Jay Nemeth, founder of FlightLine Films and the mission's director of high-altitude photography, and by Mr. Dennis Fisher, founder of Genesis Applied Imaging, Inc., who contracted with FlightLine to help design and coordinate operation of the "JLAIR" optical tracking units that were used to follow the mission from the ground.

OVERVIEW

From its inception, the Red Bull Stratos program presented an opportunity to build prototype broadcast production technology that could exist on the edge of space, as well as ground-based tracking systems that could follow Felix Baumgartner from ascent through touchdown. The presentation by Nemeth and Fisher provided an overview of the imaging systems developed to respond to those challenges.

As an example, never before had so many high-definition cameras been used aboard an aircraft; the resulting views from inside and outside the capsule enhanced Felix Baumgartner's safety and situational awareness, inspired millions across the globe, and continue to provide research and educational value.

OBJECTIVES AND REQUIREMENTS

Beginning in 2008, FlightLine Films worked with Red Bull Media House and the Red Bull Stratos science team to develop the mission's unprecedented camera and optical systems. Objectives included providing support for:

- Mission control personnel
    - High-quality imaging
    - Monitoring condition of capsule and balloon
    - Monitoring Baumgartner's condition
    - Verifying condition of Baumgartner's parachute on egress from capsule
    - Monitoring conditions on capsule step
    - Providing view of exit attitude
- Baumgartner's situational awareness of capsule, flight train/balloon and terrain
- Medical team and first responders
    - Route video to mobile devices in the field
    - Provide images to correlate to data for analysis
    - Situational awareness for personnel in Mission Control Center
- Records validation
- Print, web and broadcast media

Nemeth pointed out that situational awareness/monitoring was of primary importance to all teams. Medical team members standing by in the field, for example, had access to a code that enabled them to watch long-range optics in real time on their mobile devices. In addition, however, the imaging team strove to produce compelling images of an artistic quality to inspire a global audience.

In a nutshell, the mission's imaging systems encompassed interior and exterior capsule cameras, suit cameras, two ground-based long-range optical tracking units, and a Cineflex-equipped helicopter.

TECHNICAL REQUIREMENTS

- HD video on capsule
  - Progressive (no interlaced images)
  - Minimum 2/3" sensor
  - Space qualified for use in thermal extremes/near vacuum
  - Remote control of shutter speed/integration
  - Remote control of color balance
  - Global shutter
- Digital cinematography
- Digital stills
- HD suit cameras
  - HD progressive (no interlaced images)
  - Internal record
  - Space qualified
  - Adequate battery and record time
  - Pilot operated
- Capsule light source (interior)
  - LED panel
  - Illumination to fill in shadows
  - Dimmable for night use
  - Compatible with video scan rates
  - 5600 K color temperature
- Airborne camera system
- Ground-based long-range optical systems
- Other capabilities beyond cameras, including an imaging station in Mission Control to
  - Power cycle equipment
  - Start recording
  - Turn transmitters on and off
  - Turn LED panel on and off
  - Route cameras to three video transmitters
  - Monitor temperature of the equipment

In regard to the capsule light source, Nemeth explained that in the upper stratosphere there is no blue sky to help fill in shadows – instead, while the daytime sunlight in the stratosphere is strong, the sky is black, which creates high-contrast images. Plus, even within the lower parts of the atmosphere, the lighting needed to be adjustable to accommodate both daytime and nighttime camera usage (launch preparations occurred predominantly well before dawn, while launch and ascent occurred at or after sunrise).

CHALLENGES

Temperature

- Shortened battery life due to cold
- Tape transport malfunctions
- Differential thermal expansion
- Increased viscosity of lubricants
- Equipment can become too cold to turn on
- Equipment can overheat from solar radiation

Pressure levels

- Overheating (no convective cooling in thin air)
- Hard drives malfunctioning
- Outgassing
- Board-level component failure
- Arcing

Condensation

Lighting

Weight and location

- Large amount of equipment
- Limited allowable weight
- Limited space for equipment installation
- Battery and electrical system concerns
- Antenna placement considerations

Signal distribution

CAPSULE IMAGING SOLUTIONS

Nemeth reported that the solutions to these challenges were devised by sourcing existing equipment and then innovating necessary modifications.

In the final configuration, the Red Bull Stratos capsule contained:

- Nine high-definition cameras (seven external and two internal)
- Three 4K (4,000 x 2,000-pixel) digital cinematography cameras (external)
- Three high-resolution digital still cameras (two external and one internal)
- Pressurized electronics "keg" containing more than 125 electronic components and approximately 2.5 miles of wiring
- Monitor for Baumgartner that allowed him to switch camera views for situational awareness

Housings were used to reflect solar heating. Each housing had to hold one atmosphere of dry nitrogen gas, and all were triple-pressure-checked and certified to 45 psi.

To provide the internal capsule lighting, the mission used a custom-designed panel that fit inside the internal pressure sphere (Baumgartner's cockpit). This adjustable panel could provide even very high intensities to fill in shadows in daylight, yet was dimmable for nighttime use. The team found that the solution enabled clear images of Baumgartner's face in varied conditions for visual monitoring by Mission Control.

Nemeth described that because capsule life support systems and other equipment filled the vessel's base area, camera systems were positioned in "the attic" – the narrow cylindrical area above the central pressure sphere. To house this equipment (mostly square components destined for a round space) an ingenious equipment rack, "the cage," was developed. With an appearance similar to a communications satellite, it offered a radial design that efficiently managed space while providing maximal access to components.

This cage in turn was placed inside a pressurized keg that slipped inside the top of the capsule structure. This keg was filled with one atmosphere of nitrogen and was equipped with heat exchangers, as the equipment within it produced a great deal of heat. The space-rated breaker system developed by Sage Cheshire was used to power the equipment, and all camera system breakers were completely separate from those for life support and capsule operations, so that unforeseen camera systems problems could not affect critical functionality. While camera breakers could be operated by Nemeth at his Mission Control panel, Baumgartner also had the ability to cycle them from his position in the capsule.

SUIT IMAGING SOLUTIONS

Baumgartner wore five small high-definition video cameras: two on each thigh and one on his chest pack. The suit cameras were off-the-shelf sport models, with modifications.

TELEMETRY

A telemetry system was devised to allow Nemeth to control the scope of available images in real time as the mission progressed, right from a workstation in the Mission Control Center. This also made him available to confer face-to-face with medical and technical leads in critical monitoring situations.

MISSION CONTROL MONITORS

At the front of the Mission Control center, four 80-inch / 203-centimeter monitors displayed live video of the mission in progress for the clear view of all of the 21 personnel workstations. These four monitors were surrounded by six 47-inch / 119-centimeter monitors that provided additional mission-critical information such as gauge readings for capsule temperature, pressure, etc.

LONG-RANGE OPTICS

Fisher presented the portion of the program on long-range optics. He began by explaining the responsibilities of the long-range optical team:

- Track the balloon/capsule from lift-off to float altitude.
- Track Baumgartner from the capsule to the ground if line-of-sight permitted, also confirming parachute deployment.
- Visually re-acquire the capsule and track its decent, confirming full parachute deployment and landing.

Fisher commented that in some ways the challenge of photographing Baumgartner from a distance of 25 or 30 miles was not unlike assignments he had worked on at the Western Test Range of Vandenberg Air Force Base. However, the Red Bull Stratos program did not possess an existing inventory of long-range optical systems.

The feasibility of leasing third-party tracking assets such as military or NASA resources was considered. As Fisher explained, all options were on the table to ensure the best possible coverage, documentation and situational awareness for Baumgartner's mission. Given the weather dependency of scientific balloon launch – which presents a challenge to precise long-range planning – a flexible schedule would be required, ultimately ruling out third-party options. It was decided to create an in-house system for the mission.

GENESIS OF THE "JLAIR"

Facing a rigorous schedule, the team acquired existing assets that could be modified or repurposed to meet the mission's demands. The result of their efforts was a mobile unit that they dubbed the JLAIR (Joint Launch vehicle and Aircraft Imaging in Real Time), an optical ground tracking camera system with features ranging from infrared to high-definition cameras. Two JLAIR units were created and used for the Red Bull Stratos project.

The JLAIR's primary components include:

- Satellite uplink truck
- Mobile optical tracking system (MOTS)
- Commercial off the shelf equipment including
  - High-definition P2 camera (up to 60 frames per second)
  - 4K (4,000 x 2,000-pixel) camera (up to 120 frames per second in 2K mode)
  - Shortwave infrared camera
  - Digital still camera
  - Computers and electronics

The concept of operation offered by the JLAIR:

- Self-contained
- Mobile (both highways and unimproved roads)
- Can be maintained while deployed
- No single point of failure

Fisher explained that the first step in formulating the design was to develop a calculator that would accept variables relating to the sensor characteristics, optical specifications, wavelength of light, size and distance of the target, and so on, to calculate 29 key performance factors. This was used to answer many "what if" questions about various electro-optical system combinations and guide system configuration.

"Once we had narrowed this down to a few good candidate systems, I got in touch with an associate and asked if he could run a simulation based on one of these systems," Fisher remembered. "While I could calculate the theoretical performance of the system, I didn't have a way to figure in R-naught for various air turbulence conditions."

The result of that simulation and subsequent years of research, planning and development was a JLAIR resource that offers capabilities not previously available to the private space industry or production companies:

- The JLAIR carries a variety of high-power zoom lenses and large telescopes attached to an 8,000-pound motorized pedestal, previously used to track Space Shuttle launches.

- The control room allows technicians to select the best images available and transmit them in real time to Mission Control and/or broadcast viewers.

- JLAIR 1 is the first fully integrated tracking system on one vehicle chassis that includes an optical payload of over 1,000 pounds, an air-conditioned control room, an on-board generator for the tracker and sub-systems, and encoding and satellite transmission of HD video.

- JLAIR 2 shares the same features but employs a traditional trailer-mounted pedestal with separate control truck for mission flexibility.

HELICOPTER CAMERA SYSTEMS

In the air during much of Felix Baumgartner's mission was a tracking helicopter from Airborne Images that was equipped with a Cineflex camera stabilized with a gyro system for precision optics to a sub-pixel level. The helicopter's system allowed tracking of both Baumgartner and the capsule, with display of the resulting image on a moving map that showed the helicopter's own relative position. That moving map image could be displayed to Mission Control to increase situational awareness, and it enabled this tracking helicopter to guide the recovery helicopter to Baumgartner's landing site.

CONCLUSIONS

The imaging systems used for Red Bull Stratos provided extraordinary situational awareness in real time and captured additional still and moving images for post-landing retrieval.

The mission demonstrated world-class long-range optical tracking capability.

The clarity provided by the combination of carefully configured, high-quality cameras and the lighting panel in the capsule proved especially valuable in situations when visual monitoring was critical (as when Baumgartner alerted Mission Control that his visor might be fogging).

Teamwork across the imaging crew was a vital component of success.

Professional and incidental feedback indicates that the high-quality live images and exceptional views had a strong impact on both aerospace professionals and the general public, inspiring a great deal of enthusiasm.

The concept of operation and system design of the cameras and housings were unique to the Red Bull Stratos flight test program and have significantly advanced the state of the art for aerospace remote imaging systems.

Nemeth assessed, "This project truly redefined how future aerospace and high-altitude missions are going to be documented. This raises the bar."

WEATHER, BALLOON AND REEFED PARACHUTE SYSTEM
Don Day, Edmund Coca

Red Bull Stratos set a new mark for the largest helium balloon ever launched with a human aboard: 29.47 million cubic feet in capacity. Balloons of such size are rarely launched even for scientific equipment payloads, let alone with a human life on the line, and weather must be near perfect for a safe takeoff. Another important aspect of the mission's safety and success was payload recovery, which pioneered use of a reefed parachute system.

This paper summarizes information presented by Mr. Don Day, Jr., meteorologist and owner of DayWeather, Inc., with Mr. Edmund Coca, Crew Chief for ATA Aerospace High-Altitude Balloon Projects. For every Red Bull Stratos stratospheric flight, manned and unmanned, Day provided the weather information vital not only for launch, but also for plotting trajectories and confirming records; and he stayed in close contact with the Federal Aviation Administration to confirm airspace. Coca was the crew chief responsible for directing launch operations on the flightline, in close collaboration with Day and ATA Aerospace project lead Tracy Gerber in Mission Control.

LAUNCH CHALLENGES AND SOLUTIONS

Plotting weather patterns was critical to the success of the program. Day began by explaining the particular challenges of launching Felix Baumgartner's balloon on October 14, 2012, in comparison to his previous stratospheric test launches on March 15 and July 25 of the same year.

March 15, 2012

Balloon capacity: 1.22 million cubic feet
Balloon height at launch: 357 feet

July 25, 2012

Balloon capacity: 5.3 million cubic feet
Balloon height at launch: 476 feet

October 14, 2012

Balloon capacity: 29.47 million cubic feet
Height at launch: 739 feet

The 29.47 mcf balloon was made from 40 acres of polyethylene, and, including the flight train, at launch it would be twice as tall as a Saturn 5 rocket. To launch with maximum safety, winds needed to be no more than 2 mph from ground level up to 800 feet AGL.

Typically, large balloon launches occur at dawn, when winds are most calm. On October 14, ground conditions were indeed calm at sunrise, but a strong temperature inversion caused increased winds beginning at 685 feet AGL, with winds of 25 mph at 800 feet AGL. Those high-level winds wouldn't have impacted the smaller balloons used for Baumgartner's first two test ascents, but they were a major concern for the integrity of the large balloon needed to take him to over 120,000 feet in the final mission. "If we had released the balloon, it would have been a very dangerous situation for Felix," Day stated.

Day, Coca and the team waited for the inversion to dissipate, which typically occurs relatively early in the morning, post sunrise. However, once an inversion burns off, it's seldom long before thermals build up. Thus Day predicted that the team would have a window of only 15 minutes to safety launch the balloon. The team would need to work in perfect synchronicity: Day likened it to "a football play where everybody blocks exactly the right man and the result is a touchdown." The "touchdown" for the team occurred at 9:28 a.m. Mountain Time, as the balloon launched successfully from the flightline.

Coca shared his own perspective, crediting a long-time working relationship with Day as an important factor in the success of the operation. “This was a very robust balloon in the air, but there are many steps to get it in the air, one of them being handling,” he noted. The balloon team built a catwalk around the wooden balloon container simply to extract the 3,708-pound envelope without damaging its polyethylene film, only 0.0008 inches thick.

Procuring the 180,000 cubic feet of helium necessary to launch the balloon (as well as a backup supply) was a challenge in itself and required significant advance planning, as the United States happened to be experiencing a helium shortage.

Coca also noted the vital importance of using multiple checklists to properly and most efficiently connect and lay out the entire flight train, as well as to optimize balloon inflation up to the point where the balloon is released from its launch arm; at that moment, he said, when the balloon begins to ascend and the crane holding the capsule has to move the vessel under the rising envelope with split-second timing, "It becomes a matter of sheer instinct and real-time judgment calls on the launch director's behalf until the balloon and capsule are released from the crane."

For the Mission Team overall, refining and coordinating checklists over the course of the unmanned and manned test launches helped to improve situational awareness and streamline team functions, a significant factor in being able to launch successfully within the confines of the short weather window on October 14.

Day identified two elements as particularly critical to the success of Baumgartner’s final flight on October 14: use of a radiosonde balloon proprietary to the mission that was launched to take readings up to 130,000 feet above sea level, and an aerostat balloon tethered near the flightline at 800 feet above ground level to provide Day with readings in the critical area at the top of the balloon.

REEFED PARACHUTE SYSTEM

“A lot of people are going to be looking at the Red Bull Stratos reefed parachute system and what we were able to do with it,” said Day. “It was critical to safety and recovery operations.”

Capsule recovery was a vital aspect of the mission. Objectives included landing the capsule safely in good terrain – to protect life and property on the ground; safeguard the camera and data-capture equipment on board; and facilitate the task of recovery crews – and also to get the capsule down quickly, in an effort to provide medical attention as rapidly as possible in case Baumgartner experienced physical difficulties and descended in the vessel.

The solution was a reefed parachute. The system offered two key advantages:

1) Faster descent, especially valuable with a human on board who might need to descend inside for medical attention

2) Significantly greater accuracy than traditional systems in pinpointing accuracy of descent trajectory and drop zone

Typically with high-altitude payloads, a recovery parachute deploys fully as soon as the payload releases from the balloon. The Red Bull Stratos parachute, however, was "reefed"; meaning that restraining fabric around its circumference held the opening to just under 17 feet / 5 meters in diameter for the initial part of the descent, allowing the capsule to fall quickly (up to nearly 350 mph).

At an altitude of about 20,000 feet / 6,096 meters MSL, the reefing was automatically released by a barometric sensor, allowing the canopy to expand to its full 100 feet / 30 meters in diameter so that the capsule would subsequently descend more slowly and with a minimum of swaying.

The descent of the Red Bull Stratos capsule took a total of 20 minutes. Without a reefed parachute, it's estimated that the descent may have required approximately an hour.

An important objective was to have the capsule land within 5 nautical miles of the predicted drop zone. Day and the team found that the reefing reduced drifting distance by one-third, significantly improving predictability for the landing point. "In the October 14 mission, I was able to predict the capsule landing point in New Mexico within about 1.2 miles," Day noted, "but with the 130-mile-per-hour winds, with an unreefed parachute it would have landed somewhere in Texas."

When asked whether he used special or mission-proprietary software to make his predictions, Day responded that he employed a combination of existing software designed for lower-altitude flights and spreadsheets that he built to take into account the mission's high altitudes and parachute reefing. He used a combination of those tools and observed weather data to make his calculations.

EXTREMES OF THE OCTOBER 14 FLIGHT

Some notable figures collected:

Maximum capsule descent rate
30,688.98 feet per minute / 348.74 miles per hour

Maximum temperature (attained at 3,992 feet / 1,217 meters)
67.3 Fahrenheit / 19.6 Celsius)

Minimum temperature (attained at 59,721 feet / 18,203 meters)
-95.62 Fahrenheit / -70.9 Celsius

Maximum humidity (attained at 3,691 feet / 1,125 meters)
53 percent

Maximum overland speed rate of manned balloon/capsule
135.7 miles per hour / 117.9 knots

CONCLUSION

Day and Coca agreed that despite their long experience in the industry, Red Bull Stratos was the most challenging balloon launch project in which they had ever participated. They assessed that as a result of the mission's findings and achievements, the Red Bull Stratos program will set a new standard in stratospheric lighter than air flights and payload recovery.

EPILOGUE

The public perception of Felix Baumgartner's parachute jump of October 14, 2012 – an audacious balloon ascent, a supersonic freefall, a triumphant landing – encapsulates the excitement of the event. But it's far too simplistic to encompass the true scope of the accomplishment.

In reality, Red Bull Stratos was conducted as a structured flight test research program. Led by Art Thompson of Sage Cheshire Aerospace, the project had realistic scientific objectives with a secondary objective of establishing records following a jump from a stratospheric balloon.

OBJECTIVES

Basically, the scientific objectives were to man rate a prototype for the next-generation full pressure suit during a jump from high altitudes and to obtain physiologic information of the jumper during the effort by a new-generation physiologic monitoring device.

Fifty-two years prior to Felix's mission, I established the record of 102,800 feet after jumping from a stratospheric balloon. My project, titled Project Excelsior, was conducted by the U.S. Air Force as a flight test program. I was both the project director and the jumper. This project also had scientific objectives, which were to determine how to protect a man in a space-equivalent environment and how to provide a means of escape from high altitudes by astronauts and aviators.

Remember, this was three years before the Space Age commenced; the chief of the Aeromedical Laboratory at Wright Field in Dayton, Ohio – Dr. John Paul Stapp – was a visionary, and he knew that we needed this information to be prepared for the forthcoming Space Age. He is the one who gave me the support and tools that I needed to accomplish the project. From start to finish, Project Excelsior took one and a half years, with my team of 13 engineers (military and civilian) and technicians (also military and civilian). This number does not include the members of the Balloon Branch at Holloman Air Force Base who launched the balloons.

COMPARISONS

Since Felix's jump, I have been questioned about the similarities and differences in the two projects. I feel that an examination will be of value in evaluating Red Bull Stratos and the lessons learned.

Both Project Excelsior and Red Bull Stratos used the time-tested protocol of "walking before you run." In both projects, we did test flights in altitude chambers for the jumpers, capsules and support crew. On both projects, we conducted unmanned balloon flights to test equipment and recovery parachutes. On both projects, we made two manned preliminary parachute jumps before the highest-altitude jumps. There was an abundance of similarities because both were conducted as flight test programs, jumping from high-altitude stratospheric balloons. Safety of the jumpers was the primary goal.

I was a test pilot and a fighter pilot with vast experience in pressure suits, both partial-pressure suits (T-1, MC-1, MC-3, MC-4) and full-pressure suits (X-15 full pressure suit #3, Navy full pressure suit). I had flown extensively in the partial pressure suits in a variety of aircraft including the F-100, F-104 and the B-57. I had over 75 altitude chamber flights testing these pressure suits from 1955 to 1960. My Excelsior III mission was my 33rd parachute jump.

Although he was licensed to fly helicopters, Felix was not a test pilot and had absolutely no experience in any pressure suits. He was a record-setting BASE jumper and skydiver with approximately 2,500 jumps under his belt. When he first donned a full-pressure suit at the David Clark Company in 2008, he did not display any problems with the enclosure of the helmet. And then in September 2010 he suddenly started experiencing a sensation of claustrophobia and refused to don the pressure suit helmet. Felix entered an extensive program led by Red Bull High Performance Director Dr. Andy Walshe and sports psychologist Dr. Mike Gervais. These two experts in their fields designed a regime to expose Felix to how to overcome this problem. Because of Felix's determination and absolute dedication to accomplish his goal, he was reconditioned to accept the confines of the pressure suit helmet.

Both Project Excelsior and Red Bull Stratos accomplished equipment testing and human exposure to low-density altitudes in altitude chambers: Project Excelsior at Wright Patterson AFB in Dayton, Ohio, and Red Bull Stratos at the Wyle altitude facility at Brooks City-Base in San Antonio, Texas.

Three altitude tests were conducted at the Wyle facility, where altitudes as high as 123,000 feet and temperatures of minus 60 degrees Fahrenheit were attained: in October 2010, with Lockheed Chief U-2 Test Pilot Rob Rowe as the subject; in November 2011, with Felix as the subject; and in September 2012, once again with Rob Rowe as the subject. (The September 2012 test flight was to re-certify the Red Bull Stratos capsule following a hard landing on Felix's second stratospheric test flight of July 25, 2012.)

Five pressure suit training flights were made by Felix at the USAF high-altitude chamber facility at Beale Air Force Base in California. On two of these training flights, Felix ascended to an altitude of 130,000 feet. All three of his David Clark full-pressure suits were flight tested during these chamber runs at Beale AFB.

In addition, Felix made more than 50 training jumps from helicopters and conventional skydiving aircraft (some with altitudes over 25,000 feet) wearing the pressure suit, which was frequently inflated to 3 PSI to get Felix used to the lack of mobility in the pressurized suit.

Felix also made a series of bungee-cord jumps in his pressure suit and helmet to practice jumping from a zero velocity platform. In addition, he made a series of flights in a vertical wind tunnel wearing the full-pressure suit and parachute.

Two unmanned balloon test flights were performed at Roswell, New Mexico, to conduct tests on the capsule's reefed recovery parachute and to test the GPS systems for determining altitudes and vertical descent rates. Two manned flights were also conducted prior to the October 14 jump to prepare Felix and to train the balloon launch crew and the flight operations personnel.

Prior to my Excelsior project, a series of 95 percent anthropomorphic dummies were dropped from stratospheric balloons with altitudes above 100,000 feet. Some of these dummies reached spin rates of 200 rpm, which would be fatal to an astronaut or pilot. On my Excelsior I jump, because of a drogue parachute malfunction I reached 120 rpm and was rendered unconscious; I was saved by an automatically activated reserve parachute. On the Excelsior II and III jumps, a small five-foot-diameter drogue parachute was used, which prevented uncontrolled spinning. These drogue parachutes were deployed just prior to reaching terminal velocity.

On his October 14 jump, Felix entered a slow clock-wise spin after 27 seconds of freefall and before reaching terminal velocity. After reaching terminal velocity, Felix rotated clockwise three more times before stabilizing and reversing direction to a slow counter-clockwise rotation (approximately 60 rpm). Felix was rotating when he went supersonic. Despite logging 2,500 freefall parachute jumps, one jump from a balloon at nearly 72,000 feet and one jump from a balloon at over 97,000 feet, he was unable to prevent spinning on several occasions during this final jump. Felix's jump corroborated the data that was collected in 1959–60 on Project Excelsior.

In my opinion, Felix's jump demonstrates that a means other than skydiving is needed to prevent spinning during a high-altitude escape from an aircraft or spacecraft. Future exploration to qualify a drogue parachute for extreme altitudes is certainly indicated. Skydiving certainly is not the solution to this problem. If a highly trained jumper with 2,500 jumps is unable to prevent spinning following egress from extreme altitudes, an astronaut, pilot or space tourist could not overcome this spinning probability.

In both programs, the vessels – a pressurized capsule on Project Stratos and an open gondola on Project Excelsior – were suspended below a balloon by an extended recovery parachute. In every manned balloon flight before Red Bull Stratos, including my own, the vessel's recovery parachute was not reefed and opened immediately upon being disconnected from the balloon. During Nick Piantanida's May 1966 attempt to execute a jump from 120,000 feet, he experienced a problem at 57,000 feet on the ascent and was immediately cut loose from the balloon. The parachute opened immediately, and it took 26 minutes for the gondola to land. Of that time, it took 15 minutes for the gondola to descend to 15,000 feet; brain damage occurs after three minutes without oxygen. Nick died nearly four months later from the severe hypoxia he suffered.

If his gondola had been equipped with a reefed parachute like the one we used on the Red Bull Stratos project, he probably could have survived the exposure. Likewise, if the decompression sickness (DCS) protocol that Dr. Jon Clark devised for Red Bull Stratos had been available, perhaps he could have survived.

REEFED CAPSULE PARACHUTE DETAILS

From the beginning of the Red Bull Stratos project, we planned not to use an open parachute for recovery of the capsule. We wanted a system that would provide the capsule a rapid rate of descent to reduce the time of exposure. Freefalling the capsule was not considered, as it was not an aerodynamic shape and could possibly tumble, etc. We decided to use a reefed parachute until 20,000 feet. The altitude of 20,000 feet was selected because there were mountains up to 12,000 feet in the region, and we wanted sufficient altitude to egress in the event that the recovery parachute did not fully deploy at opening altitude. Paul Woodruff of Pioneer Parachutes determined the diameter of the reefed parachute, 17 feet, which expanded to a diameter of 100 feet when fully deployed.

Two unmanned balloon flights were made to flight test the stability of the capsule under the reefed parachute and the opening at 20,000 feet. Both of these unmanned test flights were successful. Unfortunately, on the second manned flight (July 25, 2012) the de-reefing system did not function properly and the capsule was shaken up in sustaining a hard landing beneath the reefed parachute. A new de-reefing system was designed that included redundant de-reefing systems; the system worked as designed on Felix's October 14 mission.

The time from release from the balloon until the recovery parachute de-reefed was 11 minutes, occurring at 21,400 feet with an average descent rate of fall of 9,690 feet per minute. An additional benefit of the reefed parachute is that it greatly reduced the distance traversed from cut-down to landing. This makes this part of the recovery for any type of payloads much safer.

In all of the four Red Bull Stratos flights flown with a reefed parachute, the balloon landed within one mile of the payload, making it much easier for recovery and much safer and more accurate in predicting the landing zone for the payload and balloon.

I highly recommend that all manned and unmanned balloon flights in the future be recovered by using a reefed recovery parachute that will descend the payload to a prescribed altitude where the parachute will de-reef and lower the payload on a fully deployed parachute.

CONCLUSION

The documentaries that have appeared on television about Red Bull Stratos did not have the scope to define the thorough process that the project went through to prepare for Felix's jump. Art Thompson was a superb technical project director and assembled a very professional team to conduct the project. The ATA Aerospace crew from Holloman Air Force Base launched all of the unmanned and manned balloons in a professional manner. Don Day, our meteorologist, did an outstanding job of forecasting the weather. The more than 200 members of the Red Bull Stratos project worked as a team to safely accomplish the goals of the mission. The personnel at David Clark Company, Beale AFB, Wyle, ATA Aerospace, the Air Force Research Laboratory, Col. Don White, the Federal Aviation Administration and the Roswell International Air Center all contributed to the success and safety of the project. The modified David Clark full-pressure suit worked flawlessly. Red Bull was a perfect partner for this historic project, and, finally, Felix Baumgartner made a fantastic jump from near space with "a little bit of help from his friends."

And now you know the rest of the story.

Col. Joe W. Kittinger, Jr., USAF (Ret.)
Red Bull Stratos CapCom (Capsule Communications)

BIOS

LUKE AIKINS

A professional skydiver with a history of tackling unusual aviation challenges, Luke Aikins is one of the designated Safety and Training Advisors for the U.S. Parachute Association. As the skydiving consultant for the Red Bull Stratos team, Aikins was a key player in designing the training plan that helped Baumgartner learn to skydive within the confines of a full-pressure suit; personally served as a test subject for evaluating the efficacy of parachute, GPS and face plate systems; and spearheaded development of Baumgartner's personal parachute rig and drogue system.

FELIX BAUMGARTNER

With a passion for expanding boundaries, especially in the air, Felix Baumgartner devoted seven years of his life to preparing for and executing the jump from the edge of space that on October 14, 2012 made him the first person to break the speed of sound in freefall. Already a world-record-setting skydiver and BASE jumper even before undertaking the Red Bull Stratos mission, the Austrian native is licensed to pilot gas balloons as well as private and commercial helicopters and was also the first person to complete a freefall flight across the English Channel wearing a carbon wing (2003). He is the winner of the Bambi Award (Germany) and FAUST Adventurer of the Year (Japan); has been nominated for TIME's Man of the Year, a World Sports Award (twice), and two categories in the NEA Extreme Sports Awards; and is honored on Vienna's Street of Champions.

JONATHAN CLARK, MD, MPH

One of the most distinguished figures in aerospace medicine, Dr. Jonathan Clark is a six-time Space Shuttle crew surgeon who served in top roles at Johnson Space Center. He currently teaches at Baylor College of Medicine and the University of Texas Medical Branch. In the leadership role of Red Bull Stratos medical director, Clark worked to protect the health of Felix Baumgartner and to establish new safety protocols for future aviators and astronauts. He continues to lead the mission's medical team in analysis of physiologic data and dissemination of the findings for the benefit of the aerospace community.

EDMUND COCA

Ed Coca possesses years of experience in launching high-altitude gas balloons. As crew chief for ATA Aerospace High-Altitude Balloon Projects, Coca was directly responsible for all aspects of Red Bull Stratos balloon launch onsite at Roswell International Air Center: in addition to directing pre-launch, launch and post-launch activities, he personally verified that flight hardware and launch equipment were ready for flight and supervised balloon inflation and capsule release for ascent.

DONALD DAY, JR.

Don Day is a professional meteorologist and owner of DayWeather, Inc., a weather forecasting and consulting firm serving more than 70 radio stations as well as newspapers and business firms. Day specializes in forecasting for gas balloon events and stratospheric airship and balloon flights. For every Red Bull Stratos stratospheric flight, manned and unmanned, Day provided the weather information vital not only for launch and safe flight, but also for plotting trajectories and confirming records; and he stayed in close contact with the Federal Aviation Administration to confirm airspace.

DENNIS FISHER

Dennis Fisher possesses over 40 years of experience as a still photographer, cinematographer and range instrumentation optics engineer/manager, including service as a combat photographer with the 1st Marine Division in Vietnam; worldwide assignments for the Aerospace Audio-Visual Service (AAVS) of Norton AFB and promotion to AAVS chief photographic technologist; and responsibility for the Western Test Range optics at Vandenberg AFB. The founder of Genesis Applied Imaging, Inc., Fisher worked with FlightLine Films to help design the JLAIR optical units that were used to track the Red Bull Stratos mission from the ground.

ALEX GARBINO, MD, PhD

Dr. Alex Garbino is a resident doctor at Baylor College of Medicine whose area of focus is Emergency and Space Medicine. A member of the Red Bull Stratos medical staff, he served as part of Felix Baumgartner's ground recovery team and contributed to the evaluation and use of a physiological monitoring device capable of providing valid data at environmental extremes, as well as conducting detailed analysis and visualizations of the results. Garbino's papers on aerospace medicine topics have been published in leading journals.

SHANE JACOBS

Dr. Shane Jacobs is the Softgoods Design Manager at David Clark Company, where he leads a team in the design, fabrication and testing of new and innovative pressure suits, such as those used for Red Bull Stratos, and other protective equipment associate to high-altitude flight and extra-vehicular activity (EVA). He is currently involved in several space suit research and development projects for NASA, the United States Air Force and a variety of commercial customers. Jacobs holds a PhD in Aerospace Engineering – specifically in space suit design – from the University of Maryland.

JOE KITTINGER

On August 16, 1960, Joe Kittinger made history as he ascended to 102,800 feet / 31,333 meters and jumped to Earth, establishing that it would be possible for humans to survive in space. Following a distinguished United States Air Force career from which he retired as a Colonel, Kittinger set two world ballooning records. He has been awarded a Lifetime Achievement in Aviation trophy from the Smithsonian National Air and Space Museum and is enshrined with highest honor in the National Aviation Hall of Fame, among many other awards and accolades. Kittinger shared his knowledge to help address the challenges of Red Bull Stratos, and as "Capcom" (capsule communications) he was Mission Control's primary radio contact with Felix Baumgartner.

DAN McCARTER

During a distinguished U.S. Air Force career, Daniel R. McCarter served as an aircrew life support specialist and was selected as the USAF Aerospace Physiology/Physiological Support NCO of the Year. Today, McCarter is a program manager for David Clark Company, where he orchestrates support for pilot protective assemblies (PPA), from design through implementation. As the Company program manager for Red Bull Stratos, McCarter's primary role involved coordinating Felix Baumgartner's custom PPA requirements and ensuring that David Clark personnel understood exactly what was required to the smallest detail.

JAY NEMETH

As the Red Bull Stratos director of high-altitude photography, Jay Nemeth personally designed, developed and tested the airborne (capsule and pressure-suit) camera systems for Red Bull Stratos, also leading development of the ground-based tracking units equipped with telescopes. Nemeth has worked as an aerial cinematographer for more than 25 years and is one of only a handful of "zero-G" qualified cameramen. His company, FlightLine Films, provides leading-edge astro cinematography services, offering both advanced technology and outstanding aesthetic results.

ART THOMPSON

Art Thompson possesses more than 30 years of experience in innovating design that has produced such major aerospace milestones as the B-2 "Stealth" bomber. He is co-founder and vice president of Sage Cheshire Aerospace, Inc., which was the hub of technological activity for Red Bull Stratos, and in the leadership role of technical project director he hand picked and assembled the mission's extraordinary team; led capsule and chest pack development in particular and drove engineering program management overall, including data collection and processing and flight test protocols; and liaised with numerous organizations and agencies. He continues to spearhead data analysis.

MIKE TODD

For almost 30 years, Mike Todd worked in Lockheed's High Altitude Life Support and Pressure Suit Division ("Skunk Works"), and he fitted pressure suits for Steve Fossett and Einar Enevoldson's record-breaking Perlan Project. Technical project director Art Thompson brought Todd onto his team at Sage Cheshire Aerospace to serve as the Red Bull Stratos life support engineer. In that critical role, Todd was responsible not only for the pressure suit itself (engineering, system design, coordination, operation, handling, oxygen components, and fitting and field support) but also how it functioned in conjunction with other mission components.

BRIAN G. UTLEY

As the official observer for the Contest and Records Board of the National Aeronautic Association (NAA), Brian Utley is responsible for certifying that all requirements for a world record have been satisfied, including analyzing and verifying data captured during the Red Bull Stratos mission and submitting it for confirmation by the Fédération Aéronautique Internationale. Utley has been instrumental in developing the application of a GPS flight recording system to confirm world records and is also a record-setting glider pilot. He is the recipient of the FAI's Tissandier Diploma for his service to aviation.

ANDY WALSHE, PhD

Dr. Andy Walshe helps people and organizations worldwide to explore human potential. With a PhD in Applied Biomechanics and expertise in neurofeedback performance training, the Australian native is director of high performance for the Red Bull global athlete development program and previously designed the performance program for the U.S. Olympic ski and snowboard teams. As performance manager for Red Bull Stratos, he structured and helped Felix Baumgartner to execute a performance plan encompassing both physical and psychological readiness, and supported the entire mission team.

FOR RED BULL STRATOS UPDATES: www.redbullstratos.com