Chapter 1

KC-135 Flights for Life Science Activities

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**ABSTRACT**

The KC-135 Reduced Gravity Facility at the Johnson Space Center is a useful support facility for conducting brief zero gravity life science experiments, as well as for validating hardware designs and experimental protocols for more extensive shuttle-based experiments. This paper discusses the zero gravity capabilities of the aircraft, preparations for and conduct of the flight tests, and the procedures for requesting a flight. Several Ames Research Center experiments and procedure demonstrations are described. Finally, a crew perspective is presented that discusses the similarity of the KC-135-induced microgravity environment with that actually experienced in space.

**INTRODUCTION**

The Reduced Gravity Program is located at Johnson Space Center (JSC) in Houston, Texas. The program has offered a simulated weightless environment for investigating physiological responses and hardware performance in a microgravity environment since 1959. This microgravity environment is achieved by utilizing a modified United States Air Force (USAF) Boeing KC-135A turbojet aircraft which is flown in a parabolic flight path creating 20 to 25 seconds of zero gravity. Different fractional g levels and durations can be accommodated depending upon the requirements of the specific test. Typical durations for various maneuvers are as follows:

- Negative g (to -0.1 g max) 15 sec.
- Zero g (0 g) 23 sec.
- Lunar g (1/6 g) 30 sec.
- Martian g (1/3 g) 40 sec.

To achieve microgravity, the aircraft is flown in a parabolic flight path. The plane must fly through a period of 2 g, climbing from approximately 24,000 feet to 32,000 feet. At 32,000 feet, it reaches the peak of the parabola and immediately enters its descent to 24,000 feet and the beginning of the next parabola. The "simulated" microgravity environment is achieved at the peak of each parabola (Figure 1). These maneuvers may be flown consecutively, roller-coaster fashion, or separated by enough time to alter the test set-up. A typical flight consists of 40 parabolic maneuvers with 5-10 parabolas in a row followed by a few minutes of 1 g, followed by another set of parabolas, and so on, based on user requirements. Changes to the normal mission can be made to ensure more efficient testing operations.

**KC-135 CHARACTERISTICS**

The Boeing KC-135A is a four-engine, swept-wing aircraft similar to the Boeing 707. KC-135's are primarily operated by the USAF as tankers; however, this particular KC-135A, NASA 930, has undergone extensive modifications by NASA to support the Reduced Gravity Program. The NASA 930 has been owned and operated by JSC since 1973 and has flown over 40,000 parabolas.
Figure 1. Parabolic Profile (from JSC KC-135 Users Manual, Appendix E, p. E-1).

Figure 2. KC-135 internal layout diagram (from JSC KC-135 Users Manual, Appendix A, p. A-1).
The testing area within the aircraft is 20 meters in length, 3.3m wide and 2.3m high, and can carry a maximum load of 90 kg per 0.09 m². The cargo hatch, through which equipment is loaded, is 1.8m high by 3 m wide. The aircraft is equipped with 23 seats aft of the test section (Figure 2). The interior walls of the cargo compartment are covered with foam padding for the protection of personnel and equipment.

Cabin pressure is maintained between sea level (14.7 psia) and 5,000 feet (12.2 psia) during the parabolic maneuvers. Loss of cabin pressure could result in a pressure as low as 3.5 psia, a factor that must be considered in the design of the test equipment. Normally, cabin temperature varies from 10° to 27° C in flight. The temperature in the cabin is not controlled while the airplane is on the ground. If necessary, a portable ground air conditioner is available during preflight operations.

A cryogenic storage and supply system is available to provide a source of breathing air or nitrogen. High pressure bottle racks for a limited supply of inert gases are available. Plumbing is available to allow manual or automatic venting of liquids and/or gases overboard in flight. The following electrical power is available in the test section of the aircraft:

- 28 volt DC, 80 amps
- 110 volt AC, 400 Hz, three phase, 50 amps per phase (from each of two sources)
- 110 volt AC, 60 Hz, single phase, 20 amps.

Momentary interruptions of electrical power may occur during flight. Although infrequent, these interruptions may disrupt certain sensitive instruments, so test equipment should incorporate protection devices to prevent any loss of data.

Due to unavoidable wind gusts and other factors, the "reduced gravity" will be closer to zero gravity on some parabolas than others. The aircraft provides an accelerometer system to provide the experimenter with a LED digital display of the g level in tenths of a g. Two of these monitors, which include a parabola counter, are located on the front and aft bulkheads for easy viewing from anywhere in the test area. Alternatively, an investigator can provide his or her own accelerometer if a precise record of the g jitter is required, since it varies with location inside the aircraft.

Photographic lights are installed in the aircraft test section. These are sufficient to support photography of most open tests. Additional lighting equipment is available to support enclosed tests or special photography. In addition, NASA JSC will provide photographers; VHS, SVHS, and MII video; 16-mm movies; 35-mm slides; 70-mm negatives; and 8" x 10" color prints and a VHS video, or video master if required.

One of the best features of the KC-135A for low gravity experiments is that it can be used very much like any other "crowded" laboratory. Many experiment packages look very much like they would in any laboratory except for greater compactness and some judicious padding. The trend is to use portable PCs with hard disks for data acquisition and ordinary consumer-grade camcorders for video data collection.

**FLIGHT PROTOCOL**

**PREFLIGHT AND LOADING OPERATIONS**

Test equipment should be received at JSC Ellington Field in a timely manner to allow for buildup, inspection, and the Test Readiness Review (TRR). Each investigator is responsible for the buildup and checkout of all his or her test equipment. Likewise, all tools and checkout equipment must be provided by the user as the shop facilities at Ellington are limited. The TRR is normally conducted one day before the flight and in addition to the examination of test equipment, procedures and documentation, the TRR may include a simulated ground run where the test developer demonstrates normal and contingency inflight procedures.

Loading of all experiments will take place following completion of the TRR. Each investigator must design experiment tie-downs appropriate for the bolt-hole layout of the aircraft test compartment. Loading, securing and set-up of experiment equipment is the responsibility of the investigator. Some assistance in the ground-to-plane loading is provided by JSC.

**FLIGHT PHASE**

During take-off and landing each investigator sits in airline seats in the back of the aircraft. Once the appropriate altitude is reached, the investigators are given approximately 20 minutes to perform typical experiment set-up procedures and get in position prior to the start of the first parabola. Because the first portion of the flight can be very chaotic, it is best to plan initial operations that are short and simple. The start of the first trajectory begins with 2 g pull-up. After 10-15 seconds, there is a sudden release as the aircraft reaches zero g. At this time the aircraft becomes strangely silent, since it too is weightless and...
the only thrust needed is that to overcome drag. After about 25 seconds, during which the aircraft has gone from a 45° nose-up to a 45° nose-down attitude, zero g is abruptly terminated by the pull-out, and its back to 2 g again. After a brief period that feels like 1 g, the roller-coaster ride repeats. The parabola counter is particularly useful for tracking test progress since the notable adverse effects on human performance with this type of "ride" can severely impact the amount of constructive time that is spent on the experiment operations.

LANDING AND POSTFLIGHT OPERATIONS

Immediately after landing, a postflight debriefing is held to review any problems that occurred during the flight and to discuss possible alterations to the test hardware or test procedures. Off-loading of equipment and hardware, which usually requires less time and effort than loading, occurs at the completion of the test phase (typically at the end of the scheduled flight week). Once again, some support is provided, but investigators and their support personnel should expect to do most of the work. The user is also responsible for packing and shipping his or her equipment.

NASA JSC requests that each investigator prepare and submit a brief summary of results and findings within 10 working days of the postflight week. The summaries are used to support future flights utilizing the KC-135 aircraft.

PREPARATION FOR FLIGHT

TEST REQUEST

To conduct a test aboard the KC-135, an investigator must submit a formal written request to the NASA JSC CA/Director of Flight Crew Operations. This request should be submitted as soon as the requirement is firm but no later than six months prior to the desired flight date. The schedule priority is set on a first-come first-served basis. Each test request should contain general information describing the following: a) test objectives; b) desired schedule; c) brief description of the test and associated test equipment; d) special support required or constraints; e) preliminary hazard analysis identifying hazards and controls; and, f) names and addresses of contacts. This initial test request is screened by a representative of the Human Research Policy Procedures Committee (HRPPC) who determines if the planned test will require the involvement of the HRPPC. In general, any test developer using human, animal or biological subjects must submit their protocols to the HRPPC for approval no later than 6 weeks prior to flight.

EQUIPMENT AND PERSONNEL

As part of the preparation for a flight each test conductor, or investigator, must submit a test equipment data package to the Reduced Gravity Office at least four weeks before the scheduled flight date. This documentation must include the test plan, engineering drawings and schematics, structural analysis, electrical load analysis, and an analysis of any identifiable hazards. In certain cases, a signed statement is required from the providing organization certifying that the test developer has met and complied with all applicable safety standards. Copies of the safety certification and the test equipment data package are then distributed to appropriate NASA offices.

All personnel planning to participate in the flight must be certified by possessing a current physical and by completing physiological training within the last three years. This training consists of approximately two days of classes and one altitude chamber 'flight'.

ARC MICROGRAVITY TESTS

Ames Research Center Space Life Sciences Project Office has used the KC-135 to conduct both biological studies, and equipment and procedures verifications. Many of the organisms that have now completed their first space mission or are planned for future shuttle flights were previously flown on the KC-135 to obtain baseline information on behavior in simulated microgravity, as well as to evaluate the animal-machine interfaces and operations. The jellyfish flown on SLS-1 in June 1992 were first flown on the KC-135 in June 1988 to determine how their swimming, pulsing and orienting behavior would be affected in hypogravity. The 2 g condition created by the parabolic maneuvers also provided information on the jellyfish behavioral response to hypergravity as well. The same flight served as a test for the two key pieces of hardware used in the Shuttle Jellyfish Experiment; the Olympus Camcorder and the Specimen Bags that housed the jellyfish and solutions that were to be mixed in flight. Use of the camcorder on the KC-135 documented the jellyfish swimming behavior in reduced gravity within the proposed flight hardware and operation of the specimen bags verified that the solutions could be mixed in microgravity without adversely affecting the organisms. Other organisms flown on this KC-135 flight included frogs to test the SL-J procedures, and rats and pups to test a new facility to house pregnant rodents.
Some purely hardware operation verification tests were also carried out on this flight which included the General Purpose Work Station (GPWS), components of the Research Animal Holding Facility (RAHF), and support hardware for the Gravitational Plant Physiology Facility.

In April 1991 the KC-135 was again employed by Ames to refine the Frog Embryology Experiment procedures for the SL-J mission scheduled for flight in August 1992. In the process of testing the hardware and procedures the investigators observed an interesting and unexpected looping behavior by the tadpoles in response to microgravity.

Many of the rodent dissection techniques planned for SLS-2 were tested on a KC-135 mission in July 1991. In addition to verifying operation of the rat guillotine, the aircraft was used to test the equipment and procedures required to carry out the rodent hematology experiments on SLS-2; specifically, the hematocrit centrifuge and the blood collection and processing protocols. Each of these procedures was performed in a mock-up version of the GPWS.

KC-135 reduced gravity flight tests of animal waste management concepts designed for use in microgravity were conducted in May 1990 by the Biological Flight Research Projects Office at ARC. The experiment evaluated the effectiveness of using an air-curtain to collect waste matter in a reduced gravity environment. Based on the test results of the KC-135 flight tests, the air-curtain, together with the semi-circular waste tray and wire caging arrangement, showed promise as a method of collecting waste matter, as well as keeping the specimen chamber's interior walls cleaner than previous design prototypes. In addition to testing the air-curtain concept, this flight addressed the interaction of liquids with various candidate specimen chamber materials.

'SIMULATED' VERSUS SPACE MICRO-GRAVITY - A Crew Perspective

In preparation for the 1991 SLS-1 flight, the crew flew in the KC-135 multiple times. During this period, one of the authors of this article (Dr. Millie Hughes-Fulford, a Payload Specialist) flew over 300 weightless parabolas. Tasks performed on the KC-135 included filming specimens, handling animals, carrying out several human experiments and working on procedures for the RAHF and Jellyfish Experiment. The following is her assessment of the value of the KC-135 for simulating space microgravity conditions.

*KC-135 flights are educational for working out personal techniques of body movement in weightlessness. The practice is valuable, especially as preparation for the first day of space flight, when time is of the essence in collecting human data during the first 10 orbits. The key concept is you never use your legs in zero gravity, the primary mode of movement is pulling yourself along with gentle hand movements much like swimming. During my KC-135 flights, I learned that working with relatively large or bulky equipment is tricky because of momentum and the need to use one hand in moving from point A to point B.

The major disadvantage of the KC-135 flights is that weightlessness lasts for only 20-25 seconds, followed by a 2 g 'pull out'. Several of my KC-135 flights were in the summer. A routine flight will take the crew out over the Gulf of Mexico for the 40 parabola flight. A minor disadvantage of practicing being weightless on the KC-135 is that many days over the Gulf of Mexico, the air is not uniform, and the 20 second period of weightlessness can be momentarily interrupted by an air pocket, sending the participants and equipment to the floor. The interruptions in 0 g are also a problem when handling large equipment and on very turbulent days can compromise part of the training (and ones stomach)! The majority of the people on the KC-135 that get sick begin during the 2 g periods. Restricting head movements helps in delaying onset or completely abolish experiencing Space Motion Sickness. Many of the experienced KC-135 flyers will lay flat on the floor during the 2 g pull-ups. I have just one other hint for the future crews on KC-135 flights: if you had a rough flight, don't eat too much of that great bar-b-que lunch across from Ellington Field when you return!

*There are many similarities between the KC-135 flight and spaceship flight. The feeling you have when you first reach orbit is exactly the same as on the KC-135; much like the feeling on the first down-run of a roller-coaster. Controlling body movement is very much the same in the KC-135 and on the shuttle in orbit, making the KC-135 parabolic flights an invaluable experience. One thing we never practiced on the KC-135 was getting out of the launch and entry suit in zero gravity, it was difficult to get leverage to take the large and bulky orange suits off in orbit. The other operation I had not practiced was handling many small syringes and needles for long periods in weightlessness. In the KC-135, the periods of 0 g are so short, items do not get lost, in space, anything can float away in a 3 dimensional manner, giving the searcher a much larger area to cover. Some important operations to practice on the KC-135 include the small motions techniques, the securing of small items, and testing container trays for effectiveness in the weightless environment. These tests
are most valuable during development of kits and techniques early in the planning stages of the flight.

"The biggest pleasant surprise in orbit was the fact that some of the bulky equipment was easier to use in space flight than on the ground. These included the RAHF rat cages and the transfer module. In training, these items were difficult to handle and manipulate. In flight, the handling and transfer of the cages were quite simple. The most unpleasant surprise was the length of time it could take to complete a simple operation like a blood draw or blood work up during the mission. Part of the difference is the fact that the crew is aware that the space flight experiments represent a rare opportunity to collect data and many times the crew double check their work for complete accuracy.

"Going into the community and talking about space, I am surprised at the number of people who believe that NASA has a '0 g room' where we can turn off gravity at the flip or a switch. I then find that they have mistaken photos and videos taken on the KC-135 as that '0 g room'. Although it is not perfect since periods of 0 g only last for seconds, the KC-135 is our only source of practice of true weightlessness here on the Earth. The KC-135 flights are a most useful and irreplaceable tool for the space scientist in planning and perfecting scientific techniques."

SUMMARY

The KC-135 aircraft is an extremely useful device to provide relatively inexpensive, albeit brief exposures to reduced gravity conditions. It is particularly suited to carrying out hardware and procedures verification tests where the operations of subsystems and components planned for Shuttle, Biosatellite or Space Station use can be first qualified in microgravity. Specific portions of experiments that are to be carried out by crew members can be tried, tested and refined for conduct in the actual microgravity of space. Due to the qualitative nature of many of the hardware verification tests, the varying fractional gravity environment provided by the KC-135 does not significantly affect the essence of the reported results. This is not true, however, for many biological experiments that require precise, clean levels of zero gravity to interpret results. In these cases, the investigator should provide his or her own instruments to monitor and profile the fractional gravity levels experienced during each parabola.

As a representative environment for the microgravity experienced by a human in space, the KC-135 currently has no equal. No other 'zero g laboratory' exists that can allow scientists to carry out the preparatory work necessary to ensure success once their experiment is in orbit.

REFERENCE


CONTACTS

For information regarding flight opportunities and/or details about how to request a flight, or to answer any other specific questions, contact NASA Johnson Space Center Reduced Gravity Office, Mail Code CC32, Houston, TX 77058. For questions concerning this article, please contact: Greg Schmidt, M/S 240A-3, Moffett Field, CA 94035-1000.