CAPABILITIES AND CONSTRAINTS OF NASA'S GROUND-BASED REDUCED GRAVITY FACILITIES

N93-20184

Jack Lekan, Eric S. Neumann, and Raymond G. Sotos
NASA Lewis Research Center
Cleveland, Ohio 44135

Introduction

The ground-based reduced gravity facilities of NASA have been utilized to support numerous investigations addressing various processes and phenomena in several disciplines for the past 30 years. These facilities, which include drop towers, drop tubes, aircraft, and sounding rockets are able to provide a low gravity environment (gravitational levels that range from 10^{-2}g to 10^{-6}g) by creating a free fall or semi-free fall condition where the force of gravity on an experiment is offset by its linear acceleration during the "fall" (drop or parabola). The low gravity condition obtained on the ground is the same as that of an orbiting spacecraft which is in a state of perpetual free fall. Figure 1 summarizes the gravitational levels and associated duration times associated with the full spectrum of reduced gravity facilities including spaced-based facilities. Even though ground-based facilities offer a relatively short experiment time, this available test time has been found to be sufficient to advance the scientific understanding of many phenomena and to provide meaningful hardware tests during the flight experiment development process. Also, since experiments can be quickly repeated in these facilities, multistep phenomena that have longer characteristic times associated with them can sometimes be examined in a step-by-step process. There is a large body of literature which has reported the study results achieved through using reduced-gravity data obtained from the facilities.

Over the past several years these ground-based facilities have grown in their importance, particularly in the vital role they play in the support of research programs sponsored by the Microgravity Science and Applications Division (MSAD) of the NASA Office of Space Science and Applications. These facilities support the development of long duration space flight experiments aboard the Space Shuttles and eventually Space Station Freedom. The resources required to execute space-based experiments require thorough scientific justification and proven technological feasibility. Many of these requirements can be met in ground-based facilities. Drop towers and aircraft are employed to perform precursor tests to define space experiment science requirements and conceptual designs, perform tests for space experiment technology development and verification and to also provide baseline normal and reduced gravity data. The NASA facilities have enhanced the success and value of space experiments to such an extent, that when appropriate, their utilization is a prerequisite prior to flight. The facilities are also utilized for the execution of ground-based science programs. The requirements of these investigations can be fully met in the facilities and thus avoid the need for longer duration flight experiments.

While the value of the NASA ground-based reduced gravity facilities is clear, that value is enhanced by considering the capabilities and characteristics of each facility and selecting the one best suited for a particular series of experiments. This document will focus on the capabilities of the facilities located at the Lewis Research Center (LeRC) in Cleveland, Ohio which include a 2.2 Second Drop Tower, the Zero-Gravity Research Facility, and a model 25 Learjet. The capabilities of the KC-135 aircraft of the Lyndon B. Johnson Space Center (JSC) in Houston, Texas will also be presented.

Background

The initial low gravity test activities at LeRC focused on testing to enable the development of technologies and systems for space power and propulsion. Fundamental studies were performed to gain an understanding of fluids under reduced gravity conditions. These studies allowed NASA to develop on-orbit fluid management and handling functions including storage, conditioning , and transfer with a variety of liquids, gases, and supercritical fluids. Along with addressing the needs of propellant systems, smaller studies were initiated in other areas such as combustion, including fire safety. Through a large number of tests performed in the LeRC facilities in the 1960's and 1970's, including a progression from the Aerobee sounding rocket to an AJ-2 airplane to the 2.2 Second Drop Tower and finally the Zero-Gravity Research Facility, our understanding of many low gravity processes was greatly enhanced. During the late 1970's and early 1980's ground-based reduced gravity research declined. This reduction was due to the fact that the many critical enabling low gravity technologies had been successfully developed and implemented and some experimentation had moved to space as components of the Apollo and Skylab programs.

Reduced gravity or microgravity research (a term synonomosly used with research activities conducted at less than normal earth gravity) was reborn with the new era of the Space Shuttle and plans for the Space Station. NASA's MSAD program developed and grew since a restructuring in 1978. The MSAD program now sponsors over 115 researchers in several disciplines. The large growth in the MSAD program has been paralleled by an explosive growth in the number of programs, testing, and experiment complexity in ground-based facilities.

Facility Descriptions

The 2.2 Second Drop Tower, due to its relatively simple mode of operation and associated low cost, is the most heavily utilized facility as it now routinely supports over 1000 test drops per year. The Drop Tower, while only providing a test time of 2.2 seconds, does represent an easy and timely method of acquiring low gravity data. A schematic of this facility is shown in Figure 2. The components of the Drop Tower include a shop for experiment build-up, integration and testing, several small laboratories for experiment preparation and normal gravity testing, an electronics support area, and an eight story tower in which is contained the drop area.

Since experiment packages are dropped under normal atmospheric conditions, air drag on the package is minimized by enclosing it in a drag shield which has a high rate of weight to frontal area and a low drag coefficient. The drag shield/experiment assembly is hoisted to the top of the drop area where the necessary electrical connections are made. The entire package is then suspended by a highly stressed music wire which is attached to the release system. A drop is initiated by the pressurization of an air cylinder which drives a hard steel knife against the wire which is backed by an anvil. The resulting notch causes the wire to fail and the drag shield and experiment package are smoothly released into free fall. Accelerations of approximately 10^{-5} g are obtained as the experiment falls freely a distance of 20 centimeters within the drag shield while the whole assembly falls from a height of 27 m. The only external force acting on the freely falling experiment is the air drag associated with the relative motion of the experiment within the enclosure of the drag shield. A drop is terminated when the drag shield assembly impacts a 2.1 m deep rectangular container that is filled with sand. The sand is aerated prior to a drop to help reduce deceleration levels. The deceleration rate is controlled by selectively varying the tips of three 1.9 m long aluminum spikes that are mounted on the bottom of the drag shield. At the time of impact of the spikes with the sand, the experiment package has traversed the available vertical distance within the drag shield and is resting on the floor of the drag shield. The deceleration levels at impact vary from approximately 40 to 100 g's for several milliseconds. Precautions taken during design, coupled with various cushioning foams permit the utilization of many off-the-shelf electronic items including video cameras, low-power lasers, light bulbs, and data acquisition and control systems. For sensitive hardware such as optical diagnostics which require decelerations of no more than 40 g's, a shock absorption system has been successfully employed to meet these requirements.

A large variety of experiment packages or "drop rigs" with differing capabilities have been tested in the Drop Tower. Hardware provided by investigators is integrated into a rectangular aluminum frame to form the experiment package. Experiment hardware weight is limited to 140 kg. The frame or drop bus has varied over the years according to the experiment needs. The current "standard" frame is 81cm high, 91cm long , and 40 cm deep. Standard frames need not be utilized however. Examples of two experiment packages are shown in Figures 3 and 4. The Laser Diagnostics rig (Figure 3) represents the most recent and sophisticated experiment package. For the purpose of clearly showing the experimental hardware, the supporting framework was removed. Figure 4 shows a rig utilized for premixed gas combustion. The rig is in the partially assembled drag shield undergoing final preparations prior to a drop test.

Experiment power is provided by onboard battery packs which are generally 28 VDC. A 110 VAC power cord has been dropped along with the package for two experiments. Data is acquired by high-speed motion picture cameras supplied by NASA with framing rates up to 1000 frames per second and also by a variety of video cameras. The video signal can be recorded onboard or transmitted to a remote recorder via a fiber optic cable that can be dropped with the experiment. Onboard data acquisition and control systems are also employed to record data supplied by instrumentation such as thermocouples, pressure transducers, and flow meters. The data acquisition and control system is supplied by NASA in many instances. Table 1 summarizes the characteristics of the Drop Tower operations.

The Zero Gravity Research Facility when compared to the Drop Tower represents an expansion in research capabilities and and in some instances experiment sophistication. Microgravity test time is increased to 5.18 seconds while experiment size and weight can be increased considerably and new experiment features are added. A schematic diagram of the facility is shown in Figure 5. The above-grade portion of this unique facility, which is a registered U.S. national landmark, consists of mechanical and electronics shop areas for experimental build-up, integration, and testing , a class 10000 clean room, shop offices, a control room for drop operations, and the attendant mechanical and electrical systems. A test chamber shaft, deceleration system, and support systems comprise the below-grade portion of the facility.

The shaft component of the facility, which extends 155 m below-grade elevation, consists of a .45 m thick unreinforced concrete casing with an inside diameter of 8.7 m in which is housed a 6.1 m diameter steel walled vacuum chamber which is 145 m deep. Unlike the Drop Tower, aerodynamic drag on the free-falling experiment vehicle is reduced to less than 10^{-5} g's by evacuating the vacuum chamber to a pressure of 10^{-2} torr. A multiple staged vacuum pumping system is capable of evacuating the chamber to the desired drop pressure in one hour. After an experiment has been prepared, the experiment vehicle is enclosed in a protective cover. The experiment vehicle is then suspended by its support shaft from a hinged-plate release mechanism at the top of the vacuum chamber. An umbilical cable is attached to the support shaft to maintain monitoring and control of the experiment during the pump down process. The umbilical is remotely pulled one-half second prior to release. The experiment vehicle is released by hydraulically shearing a bolt that is holding the hinged plate in a closed position. No measurable disturbances are imparted to the experiment by the release procedure. 5.18 seconds of reduced gravity are obtained by allowing the experiment vehicle to free fall in a vacuum through a distance of 132 m. After the experiment vehicle traverses the 132 m distance, it is decelerated in a 3.6 m diameter, 6.1 m deep container which is filled with small pellets of expanded polystyrene. An average deceleration rate of 35 g's is controlled by the flow of the pellets through the annular area between the experiment vehicle and the container wall. Peak deceleration loads reach 65 g's for several milliseconds.

The experiment vehicle, or drop bus, serves as the load bearing carrier structure for the experiment and protects the research equipment mounted within from the deceleration shock loads. The experiment vehicle also provides services such as power and programmable controllers. The primary vehicle configuration currently used is cylindrical (with a conical tip). The vehicle, which is shown in Figure 6 outfitted with the Solid Surface Combustion Experiment engineering model, has an overall height of 3.4 m and gross weight of 1135 kg. The test section of another vehicle equipped with a general purpose combustion chamber is shown in Figure 7. This test section, which facilitates the mounting of experiment hardware, is 1 m in diameter and 1 m in height. Experiments with hardware weight up to 455 kg can be accommodated in the vehicle. As in the Drop Tower, data from experiments is acquired using high speed motion picture cameras with framing rates of up to 1,000 frames/second, video cameras (with onboard video recorders) and data acquisition systems which are utilized to record data such as temperature, pressure, and flow rates. Onboard battery packs supply the necessary power after the experiment is dropped. The key features of the Zero-Gravity Research Facility are summarized in Table 2.

The Lewis Research Center operates a specially modified Learjet model 25 in support of microgravity programs. The aircraft can obtain 18 to 22 seconds of low gravity by flying a parabolic (Keplerian) trajectory. The aircraft accomplishes this with a rapid climb to a 50 to 55 degree angle (pull up), then slows as it traces a parabola (pushover), and then descends at a 30 degree angle (pull out). It is during the pushover that gravity levels on the order of 10^{-2} are obtained. During the pull up and pull out the aircraft experiences brief periods of increased g, ranging from 2.5 - 3 g. The Learjet can also provide intermediate levels of 1/20 to 3/4 of earth gravity. Although the reduced gravity levels obtained aboard the aircraft are not as low as those obtained in drop towers, the aircraft offers the advantages of increased low gravity duration, real time monitoring and reconfiguration of the experiment in low gravity by an onboard operator, and a very minimal high gravity recovery.

The Learjet has 185 cm of cabin length available for experiment mounting and researcher seating. As many as three researchers can be accommodated. Due to the limited cabin volume, experiments must be attached to the aircraft, and generally only one experiment is installed at a time (Figure 8). Experiments are typically mounted in standard racks which were developed specifically for Learjet experiments. These racks have a usable volume 72 cm high, by 60 cm wide, by 52 cm deep. Each rack is limited to a total weight of 85.2 kg. Two racks can easily be accommodated in the aircraft. Experiment specific racks can be designed when the standard racks are not adequate. For example, a special rack was developed to mount a Get Away Special Canister in the Learjet. All hardware mounted in the aircraft must be designed to withstand the following loads, when applied one at a time: 9.0 g forward, 7.0 g downward, 2.0 g up, 1.5 g aft, 1.5 g side.

Accelerations aboard the Learjet are measured by three servo-accelerometers which are oriented along the pitch, lateral, and longitudinal axes of the aircraft. The inherent accuracy of the accelerometer system is +/- 0.005 g's, but the lowest accelerations achievable during a trajectory are somewhat higher due to air turbulence and other flight control factors. Output from the accelerometers is sent to the cockpit displays for use by the pilots for control of the trajectory. The analog outputs are also stored on a strip chart recorder aboard the aircraft, and can be supplied to experimenters for storage on their data systems.

The Learjet can complete a maximum of six trajectories before landing if minimum accelerations are obtained. Typical flight time for a six trajectory flight is approximately 1.5 hours. One to two flights are generally conducted per day. Because experiments aboard the aircraft do not experience the high g recovery periods associated with drop towers, virtually any ground-based laboratory equipment can be supported aboard the Learjet. Three sources of electrical power are available to researchers: 28 VDC, 80 amps maximum; 115 VAC 60 Hz, 7.5 amps maximum; and 115 VAC 400 Hz, 18.3 amps maximum. Table 3 summarizes the pertinent characteristics of the Learjet.

The Johnson Space Center operates a Boeing KC-135A aircraft in support of low gravity research. The aircraft is a four engine jet transport similar to the Boeing 707. The aircraft achieves low gravity by flying a parabolic (Keplerian) trajectory similar to the one described for the Learjet. Up to 23 seconds of reduced gravity conditions can be obtained during each trajectory. The gravity level experienced by an experiment fixed to the aircraft floor is approximately 10^{-2} g's. Due to the larger cabin space available, experiments flown aboard the KC-135 can also be free-floated during a trajectory. Free-floating enables an experiment to experience a gravity level on the order of 10^{-3} g's to 10^{-4} g's . However, depending on the experiment size, free-float packages usually impact the aircraft walls or ceiling before the end of the trajectory, shortening the low gravity time to 5 to 8 seconds. The KC-135 is also capable of flying partial gravity trajectories. Typically, about 40 trajectories are completed per flight. Flights generally are 2 to 3 hours in duration and one flight is conducted per day. The KC-135 has a much larger volume than the Learjet. The aircraft has a usable cabin length of 18.28 m and a width of 3.25 m. Experiment size is limited by the cargo door of the aircraft which measures 1.90 m high by 2.99 m wide. Experiment weight is limited by the aircraft's maximum floor loading of 976.5 kg/m^2.

Experiment hardware must be designed to withstand the following emergency loading condition: 9 g's forward load, 3 g's aft, 2 g's lateral, 2 g's up, and 6 g's down. Because of the aircraft's large volume it is common to have numerous experiments, both fixed and free floating integrated for the same flight (see Figures 9 and 10). The KC-135 has 3 types of electrical power available to experimenters: 28 VDC, 80 amps; 110 VAC, 60 HZ, 20 amps; and 110 VAC, 400 HZ, 3 phase, 50 amps per phase. The aircraft is also equipped with bottle racks to carry standard K-bottles of inert gases, as well as an overboard vent system to allow for manual or automatic venting of liquids or gases in flight.

Like the Learjet the KC-135 can support a wide range of instrumentation and data systems. Gravity level data in the z-axis (vertical) only is measured during the trajectories and is available for input into research data systems. JSC can also provide photographic equipment and personnel, to support the needs of flight researchers. Further information and documentation regarding KC-135 operation can be found in the "JSC Reduced Gravity Program User's Guide" (JSC-22803).

From the above summary of the description of the NASA low-gravity facilities, it is evident that each facility has its own unique capabilities and limitations regarding the amount of test time, purity of reduced gravity levels, experiment size, operations and researcher interaction. Even though there are limitations, particularly in the amount of available low gravity time, the facilities have enjoyed a high level of effectiveness in meeting the needs of many investigations. The effectiveness of the facilities is evident in a large body of literature which has reported the results achieved using low gravity data obtained from the facilities particularly in the disciplines of combustion and fluids. Also, there have been a number of successful technology developments and successful space flight experiments based on activities executed in the facilities. Specific information regarding facility operations and some experiment hardware will follow.

Facility Operations/Guidelines

Effective utilization of the reduced gravity facilities begins with the selection of the appropriate facility in which to conduct an investigation. Facility selection generally is based on the following guidelines: experiments which are exploratory or require a large number of tests and do not require more than 2.2 seconds of test time should be conducted in the Drop Tower; well-defined experiments that require additional test time and high purity low gravity levels are candidates for the Zero-Gravity Research Facility; experiments which require longer test times and/or can tolerate higher reduced gravity levels and/or require operator interaction or are simply too large for the drop facilities should be considered for testing on the Learjet or KC-135 aircraft. The above represent initial guidelines. Discussions with the respective facility managers and experienced NASA investigators are also required in making a final determination. Note that for all facilities, investigators have the option of providing their own hardware up to a completely assembled experiment, utilizing existing NASA hardware (sometimes in a sharing arrangement) when feasible, or working with their technical monitor and facility operations personnel who will oversee experiment build-up.

The Drop Tower offers the greatest opportunity for "hands-on" investigations as well as the opportunity for the execution of a large test matrix (some hardware has been utilized for hundreds of drops) and easy utilization of investigator-provided hardware. In most instances drop frames are sent to the investigator's institution for experiment assembly. Drop Tower personnel are available for consultation regarding all phases of an experiment, and also for limited hardware integration and assembly. Investigators are ultimately responsible for the testing and maintenance of their hardware. NASA-provided hardware besides the drop frame, can include cameras, certain electronics components, and data acquisition and control systems. A review of Table 1 will serve as guidance for design criteria for the Drop Tower. As mentioned previously, in some cases existing hardware or general purpose drop packages can be used with minor modifications and sharing of that equipment can be arranged.

The Zero Gravity Research Facility operations philosophy is unique particularly when compared to that of the Drop Tower. Except for a few experiments, the design, fabrication, assembly, integration, checkout and test operations are the responsibility of the facility operations personnel. For programs where hardware is furnished, facility personnel are available to consult on the design and buildup of the experiments. Operations personnel also have the responsibility to integrate the experiments into the drop vehicles and conduct the drop tests. Another major characteristic of the Zero Gravity Facility is that there are four experiment vehicles available to support experiments. Due to costs and complexity of the hardware involved, experiment vehicles become multi-user/multipurpose in nature. This situation is very different from the Drop Tower, where, in most cases due to lower costs and complexities, experiment-specific drop frames and experiments can be built-up if needed.

Table 2 summarizes the criteria that should be considered for Zero-Gravity Facility experiments. However, a few of them, due to their importance, are stated here. These design criteria include the following: experiments must be designed to operate in a vacuum environment; experiments should be capable of unattended control for a minimum of one hour after final checkout to allow for experiment vehicle integration into the facility in preparation for the drop test; because of the uniqueness of the facility and potential hazardous conditions to personnel working around the experiment vehicle during facility operations, the experiment must pass a stringent safety review (safety reviews are required for testing in all of the facilities); and because of environmental concerns, limits may be imparted on the types and quantities of fluids or gases available for testing.

Aircraft experiments require a close interface between the investigator and the operations engineering staff to ensure safety, and thus personnel at LeRC are an integral component of this type of testing. For the Learjet, an operations engineer and support staff similar to that of the Zero-Gravity Facility are available to integrate investigator-provided hardware into an experiment package or to have the responsibility for the design, fabrication, assembly, integration and checkout of new hardware. A summary of some of the design constraints can be found in Table 3. In either case, the operations engineer is responsible for the preparation of detailed safety documentation that must meet the approval of the LeRC Airworthiness Review Panel. The investigator will be required to provide certain elements of this documentation. Investigators who plan to fly on the Learjet are required to provide the LeRC Aircraft Operations Office with certification of both a current flight physical (minimum FAA Class III or Air Force Class III) and record of attendance at either a military or FAA passenger/crew physiological training class.

KC-135 experiments can also be supported by LeRC personnel in the same capacity as for Learjet experiments. Even though the KC-135 is operated out of JSC, the Marshall Space Flight Center (MSFC) has the responsibility for coordinating and scheduling flights for experiments sponsored by the MSAD of NASA Headquarters. LeRC personnel are available to assist investigators with the various documentation and contacts (MSFC and JSC) necessary for meeting the requirements for KC-135 flights. Also, LeRC-sponsored KC-135 experiments per JSC guidelines must be reviewed and approved by the LeRC Airworthiness Review Panel. The hardware will also be reviewed by a JSC safety committee for approval prior to flight. The "JSC Reduced Gravity Program User's Guide" provides complete details of experiment design guidelines and requirements for personnel who will be flying on the KC-135.

Another aspect of facility utilization involves coordination with NASA personnel. A NASA researcher or scientist is assigned to be a contract technical representative to any LeRC-sponsored investigation in the ground-based facilities. This individual will have the responsibility to provide the sponsored researcher with the necessary guidance regarding facility utilization and also assist in establishing an interface with operations personnel in the various facilities. The activities that will be coordinated with this individual include the following: arrangement of a pre-design meeting with the appropriate operations and design engineers to discuss the investigation, objectives, measurements required, hardware needs, design and procurement responsibilities and the like; maintenance of communications with operations personnel during the design and build-up phase; assistance in the preparation of a Test Request Document (directed to the appropriate operations engineer) which formally defines experiment details and experiment milestones, etc. ; assistance in scheduling tests; and consultation during the testing phase. LeRC mechanical and electronics technicians are available during the testing phase for repairs or modifications that cannot be performed by the investigator. This support may not always be available in a timely manner due to the many investigations that are ongoing.

Experiment Hardware/Investigations

As stated earlier, the NASA ground-based facilities have supported a wide range of investigations over the past thirty years particularly in the fields of combustion and fluids. Table 4 represents a sampling of a few of the recent experiment programs that have been carried out in the facilities. Many of the investigations have utilized more than one facility. A description of some of the hardware will be presented to show what is feasible. Of course these descriptions represent examples of capabilities. Simpler or more complex systems have been or can be engineered depending on the needs of the investigation.

The inventory of operational drop rigs at the Drop Tower has reached twenty-five with several more in the build-up phase. One of those that will soon become available is an updated multipurpose, multi-user combustion rig that will address investigations including solid material flammability, gas-jet diffusion flames, candle flames, and spacecraft fire safety. The test chamber for this rig will have an internal volume of .027 m^3 (.25 m I.D., .53 m length), a working pressure of 4.8 atmospheres, five viewing windows, and several feedthroughs and penetrations for mechanical and electrical hardware connections. The data acquisition capabilities will include accommodations for four thermocouples, one pressure transducer, and movie and video systems. The rig will also have provisions for a laser light sheet and a shock absorption plate system for the mounting of sensitive components.

Since there are fewer experiment vehicles available at the Zero-Gravity Facility, more multipurpose hardware exists, particularly for combustion research. There are three combustion experiment vehicles available. They contain combustion chambers with the following specifications:

1. The general combustion vehicle shown in Figure 7 contains a 113 m^3, 0.4 m internal diameter hemispherical domed cylindrical pressure vessel. The vessel has a centerline length of 0.98 m and a maximum working pressure of 13.6 atmosphere. This chamber has been utilized to support investigations in pool fires, solid materials flammability, spacecraft fire safety, candle flames, etc. This vehicle is adaptable to many investigations.

2. The Gas Jet Diffusion Flame Experiment contains a hemispherical domed cylindrical pressure vessel with an internal volume of 0.087 m^3. The pressure vessel has a 0.41 m internal diameter and a centerline length of .71 m. The maximum working pressure of the vessel is 4 atmospheres. An internal movable thermocouple and gas sampling probe rake is a part of the vessel configuration. This vehicle is currently employed solely for gas-jet diffusion flame research.

3. The convection/combustion vehicle contains a horizontal cylindrical pressure vessel with a centerline length of .91 m and a 0.31 m internal diameter. The maximum working pressure of the

vessel is six atmospheres. Internal to the vessel is a .19 m square fan duct, .61 m long. The fan duct is capable of providing flow velocities of 5 to 50 cm/sec at two atmospheres. A mechanical translation device expands testing into the 0-5 cm/sec velocity range. The convection/combustion vehicle should be adaptable to many investigations also.

All the above experiment vehicles provide high speed movie camera or video photography, programmable controllers, batteries (nominal 28 VDC), a data acquisition system and essential mechanical support systems such as valves and gas charging systems.

A number of combustion and fluids investigations have been conducted aboard the Learjet. Unlike the drop tower facilities, there are currently no dedicated combustion experimental facilities available. This is due to the fact that many of the programs on the Learjet have been development tests for specific shuttle flight hardware. However, a multipurpose combustion experiment known as the Spacecraft Fire Safety Experiment is currently being developed for use on the Learjet and the KC-135. This hardware is being designed for the following investigations:

1. Extinguishment of established fires by addition of extinguishing agents.
2. Extinguishment of established fires by pressure reduction.
3. Measurement of flame spread rate on engineering materials in various oxidizing atmospheres.
4. Measurement of flame spread rate on engineering materials in flowing oxidizer streams.
5. Development and testing of space-based smoke/fire detection systems.
6. Development and testing of combustion diagnostics instrumentation.

The experimental hardware will consist of a domed cylindrical pressure vessel with a centerline length of 74.3 cm and a diameter of 25.4 cm. The maximum working pressure of the chamber will be 3 atmospheres. The maximum oxidizing flow velocities will be 40 cm/s at 1 atmosphere and 20 cm/s at 3 atmospheres. Instrumentation for the chamber will include thermocouples, pressure transducers, video and motion picture cameras, and mass flow controllers. Data acquisition and experiment control will be handled by a personal computer. The combustion chamber will also be equipped with extra ports for additional instrumentation or diagnostics equipment. This apparatus is scheduled for completion in late October, 1992.

LeRC-developed KC-135 hardware to date has been quite experiment specific. The Gravitational Influences on Flammability and Flamespread Test System (GIFFTS) is one of those experiments. The sophisticated hardware supports a fundamental investigation into the combustion of thin solid fuels in the presence of very low-speed concurrent airflows that are induced by buoyancy in various levels of inertial acceleration, thereby simulating upward burning combustion behavior over a range of gravity levels. This is the first project to utilize a schlieren system in a reduced-gravity environment. Data obtained from this investigation includes motion picture imaging of the thermal field constituting the flame in order to deduce its size, shape and propagation speed, local temperatures of the fuel in the surrounding gases and three-axis measurements of the local accelerations. The hardware is mounted in two racks and utilizes a gas bottle support rack necessary for the various atmospheric test conditions. One rack can be fixed to the aircraft or free-floated. This rack is equipped with a test chamber with an interior volume of 25 liters, a sample holder, the test specimen, up to 6 type K thermocouples, a Kanthol alloy ignitor wire and an incandescent light bulb. The schlieren optical system which consists of 30 optical elements, a light source, a miniature video camera, and video cassette recorder is also a component of this main rack along with the system control and management computer, three-axis accelerometer, pressure transducer, power supply box and batteries. The support rack, which supports sample changeout and data storage functions, consists of a gas handling subsystem, sample storage, video display and power supply and laptop computer. This experiment has been flown at "normal" parabolic maneuvers in both a fixed and free-float mode, and at 1/6 g (lunar gravity) and 1/3 g (Martian gravity) in only the fixed mode.

Concluding Comments

Over the past 30 years the LeRC reduced gravity facilities have provided data which have significantly advanced the understanding of low gravity processes and phenomena and enabled the development of space-based technology. Research executed under low gravity conditions will continue to grow through the era of space-based research in order to provide critical, economical pre-flight scientific data and technology verification. Experiments are destined to grow in complexity, particularly in the area of diagnostics.

References

1. The Microgravity Combustion Group, Microgravity Combustion Science: Progress, Plans, and Opportunities. NASA TM-105410. 1992.
2. Low-Gravity Fluid Physics: A Program Overview. NASA TM-103215. 1990.
3. JSC Reduced Gravity Program User's Guide. JSC-22803. 1991.

Table 1.
2.2 Second Drop Tower: Characteristics and Capabilities

Operational Parameters

- Low gravity duration : 2.2 seconds (free fall: normal atmosphere with drag shield system)
- Gravitational acceleration : ~ 10^{-5}g
- Deceleration levels : 40 to 100 g's for several milliseconds (< 40 g's with shock absorption system)

Experiment Envelope Summary

- Drop Frame "standard" (aluminum bus for mounting hardware)
  - width (depth): 40cm
  - length: 91cm
  - height: 81 to 102 cm
  - dimensions identified are maximum
  - variations of standard frame are feasible

- Experiment hardware weight: 140 kg (maximum)

Experiment Instrumentation/Data Acquisition Capabilities

- High speed movie cameras
- Video cameras (fiber optic link to recorder)
- Battery packs (110VAC feasible)
- Data acquisition and control system
- Thermocouples
- Pressure transducers
- Flow meters
- Lasers

Mode of Operation

- Engineering support for consultation
- Technical staff to support electronics and mechanical integration and maintenance
- Technician and investigator perform drops
- Twelve drops per day (minimum of two drops per day per investigator)
- Safety review required

Additional Features

- Compressed gas (fuels, oxidant, and diluents) storage, handling, and delivery support available
- Limited community tool supply
- Film motion analyzer

NASA contacts:
Jack Lekan: (216) 433-3459
Mike Johnston: (216) 433-5002

Table 2.
Zero-Gravity Research Facility: Characteristics and Capabilities

Operational Parameters
- Low gravity duration: 5.18 seconds (free fall: evacuated chamber @ 10^{-2} Torr)
- Gravitational Acceleration: $<10^{-5}$ g
- Deceleration levels: up to 65 g's for several milliseconds (mean: 35 g)

Experiment Envelope Summary
- Cylindrical experiment vehicle
  - diameter: 1 m
  - total height: 3.4 m
  - paylod height: 1 m
  - payload weight: up to 455 kg
  - cold gas thrust system available for: 0.003 g to 0.015 g*
- Rectangular Experiment Vehicle*
  - L x W x H: 1.5 m x 0.5 m x 1.5 m
  - payload envelope L x W xH: 0.61 m x 0.40 m x 0.45 m
  - payload weight: up to 69 kg
  - cold gas thrust system available for: 0.003g to 0.037g (positive); 0.013 g to 0.070 g (negative)

Experiment Instrumentation/Data Acquisition Capabilities
- Telemetry: 18 channels of continuous data telemetered from experiment (standard IRIG FM/FM, frequency range: 6 to 10000 cps, and overall system accuracy of 2% to 3%)
- High speed movie cameras
- Video cameras
- Battery packs
- Data acquisition and control system
- Closed-circuit television system
- Thermocouples
- Pressure transducers
- Flow meters
- Lasers

Mode of Operation
- Engineering staff to support design, build-up and testing
- Facility engineering staff perform drops
- One to two drops per day
- Safety review required

Additional Features
- Compressed gas (fuels, oxidant, and diluents) storage, handling, and delivery support available
- Film motion analyzer
- Class 10000 clean room

NASA contact:
Ray Sotos: (216) 433-5485

* These options are not currently in use, but could be made available to satisfy specific requirements.

Table 3.
Learjet: Characteristics and Capabilities

Operational Parameters

- Low gravity duration: 18 to 22 seconds (parabolic trajectory)
- Gravitational acceleration: 10^{-2} g (1/20 to 3/4 normal gravity levels possible)
- Number of trajectories per flight: 6 (maximum at 10^{-2} g)
- Maximum power: 28 VDC, 80 amps
  110 VAC, 60Hz, 7.5 amps
  110 VAC, 400Hz, 18.3 amps

Experiment Envelope Summary

- NASA-provided racks
  - length: 60.9 cm
  - width: 52.7 cm
  - height: 90.8 cm
  - stress limits: weight: 85.27 kg , total moment: 369.23 Nm
- Cabin length: 1.85m

Experiment Instrumentation/Data Acquisition Capabilities

- Three-axis accelerometer system
- LeRC-approved instrumentation provided by the investigator
- High speed movie cameras
- Data acquisition and control system

Mode of Operation

- Engineering staff to support design and integration of hardware
- Flight-qualified investigators conduct in-flight experiments (flight physical and physiological training required)
- Two flights per day are possible
- Safety review required

Additional Features

- LeRC personnel available to fly with payload
- Accommodations for Get Away Special Cannister experiments

NASA contact

Eric Neumann: (216) 433-2608

Table 4.
Examples of Investigations Performed in Ground-Based Facilities

Investigation	**Drop Tower**	**Zero-G Facility**	**Learjet**	**KC-135**
Laminar Gas Jet Diffusion Flames	•	•		•
Droplet Combustion - Pure Fuels at Low and Ambient Pressures	•	•		
Laminar and Turbulent Flames at Microgravity	•			•
Flame Spread over Solids in Quiescent Environments	•	•		
Fundamental Study of Smoldering Combustion in Microgravity	•		•	•
Ignition and Flame Spread over Liquid Fuels	•	•		
Candle Flames in Microgravity	•	•	•	
Interface Dynamics	•			
Vibration Isolation Technology Development			•	
High Pressure Combustion of Binary-Fuel Droplets	•			
Studies of Flame Structure in Microgravity	•			
Combustion of Solid Fuel in Very Low Speed Oxygen Streams	•			•
Flame Spread over Thin Solid Fuels in Quiescent and Slow, Opposed Flow Environments	•	•		
Burke-Schumann Diffusion Flames	•			
Capillary Flow	•			
Multiphase Flow	•		•	•
Experiments in Low-G Fire Suppression and Extinguishment Effectiveness	•		•	
Solidification Phase Change			•	
Cryogen Nitrogen Transfer		•		
Pool Boiling		•		

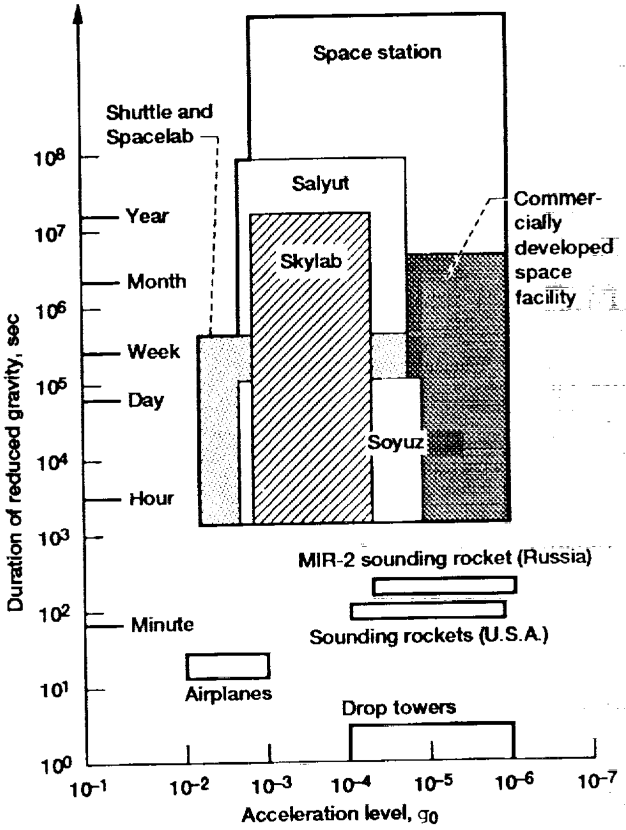

Figure 1.-Characteristic times and acceleration levels of reduced-gravity laboratory facilities.

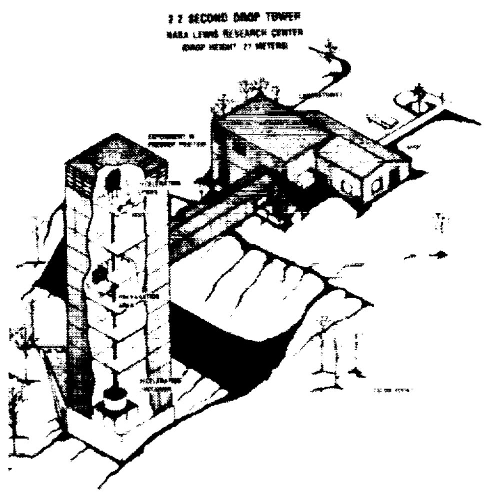

Figure 2.-Cutaway rendering of the LeRC 2.2 Second Drop Tower.

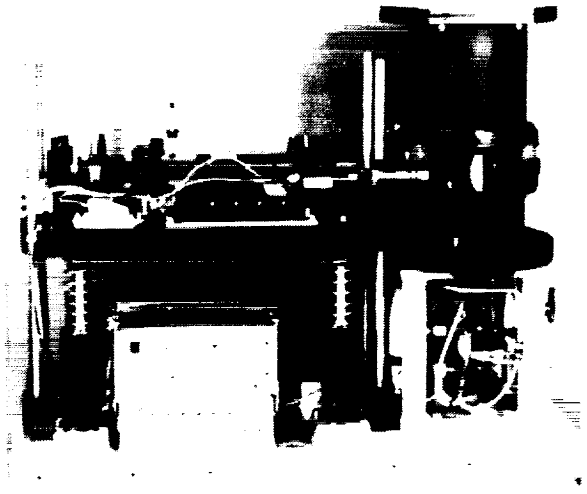

Figure 3.-2.2 Second Drop Tower package (Combustion Diagnostics Laser Rig).

Figure 4.-Drop Tower experiment package drag shield assembly.

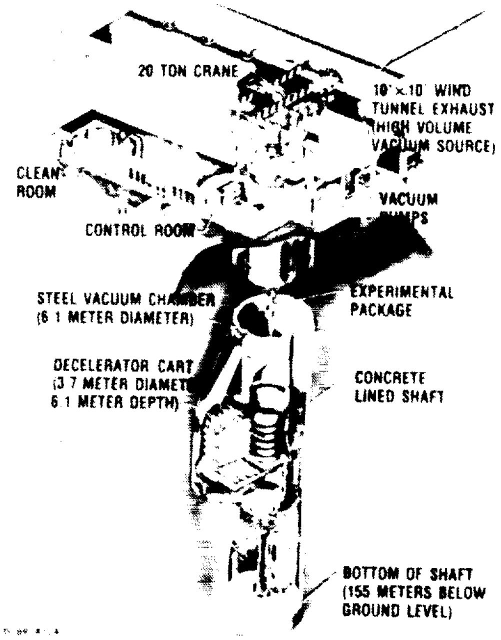

Figure 5.-Cutaway rendering of the LeRC Zero-Gravity Research Facility.

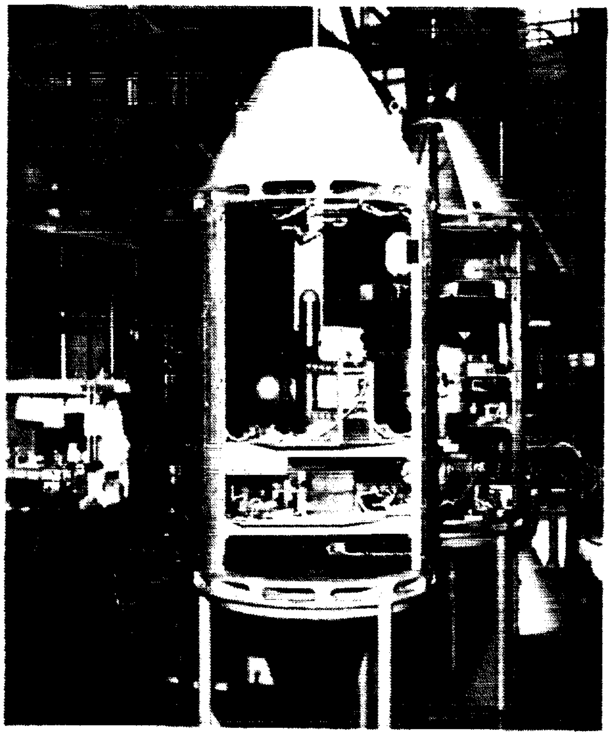

Figure 6.-Cylindrical experiment vehicle utilized in the LeRC Zero-Gravity Research Facility.

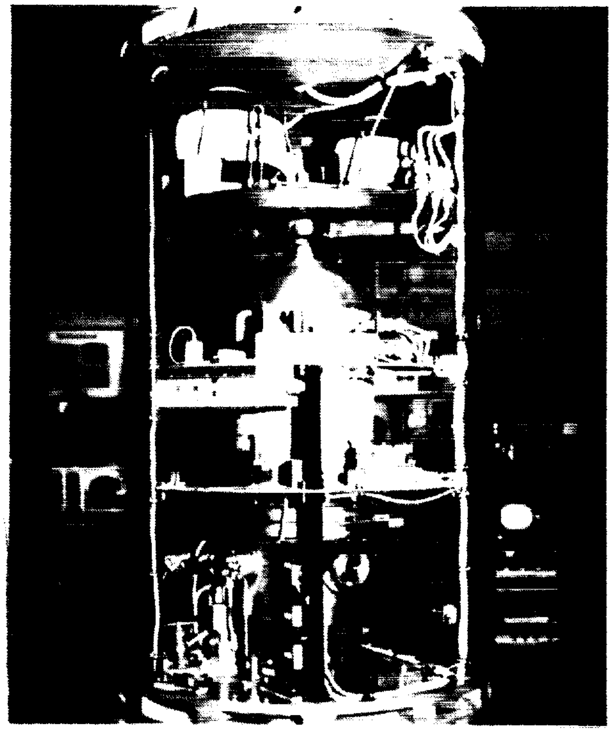

Figure 7.-Test section of cylindrical experiment vehicle outfitted with a multipurpose combustion chamber.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Figure 8.-LeRC Learjet cabin with experiment hardware.

Figure 9.-JSC KC-135 cabin with multiple experiments.

Figure 10.-Free-float experiment aboard the JSC KC-135.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH