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USC/AIAA STUDENT GET AWAY SPECIAL PROJECT LIQUID DROPLET COLLECTOR EXPERIMENT

by

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ABSTRACT

This experimental payload was developed in order to observe, in a micro-gravity vacuum environment, the characteristics and stability of a thin fluid film flowing across a slightly curved surface. The test apparatus was designed based upon various ground-based thin film investigations, combined with the constraints imposed by the rigors of launch and the space environment. Testing of the fluid test article at atmospheric pressure and in vacuum verified the design provisions employed concerning ultra-low inlet pressure pump construction, as well as confirming expected pressure losses in the system. During the course of hardware development and construction modifications were required; however, the overall payload configuration remained largely unchanged. This will allow for modification and reflight of the apparatus based upon the findings of the initial flight. The specific applications of this experiment include Liquid Droplet Radiator development and various forms of material transport in vacuum.

Eight years ago, the Los Angeles Section of the American Institute of Aeronautics and Astronautics (AIAA) secured the future use of a 200 lb. payload Get Away Special (GAS) container. They intended for this GAS project to provide an opportunity for "hands-on" engineering experience for students through the numerous challenges and tasks involved in a project of this magnitude.

In November 1984, a proposal was submitted to the L.A. AIAA by a group of students under the direction of Dr. E.P. Muntz at the University of Southern California (USC). The acceptance of that proposal set in motion the USC/AIAA Student Get Away Special Project, which will investigate the behavior of thin fluid film flows in the low-earth-orbit environment.

Selection of this project was brought about by several factors, including practical application in various areas, with the most immediate being in the field of Liquid Droplet Radiator (LDR) research. This type of heat rejection device will emit hot fluid droplets (ave. dia., 100 microns) into space, and recapture them after they have lost heat through the process of radiation (Figure 1)[1]. LDR systems are presently being studied for use on future space facilities. These radiators may employ an "auxiliary" fluid film flow on the collection surface in order to augment the capture of droplets which have either solidified, or strayed from their original trajectories, or both. The stability and characteristics of such a fluid flow will be critical LDR systems.

Consulting the ground-based studies conducted by Dr. E.P. Muntz, at USC, and the by Grumman Aerospace Corporation, this fluid mechanics investigation was defined.[2] The primary goal is to observe and evaluate the characteristics of a thin fluid film flowing across a slightly curved surface in a micro-gravity, vacuum environment. It is desired to collect data concerning the stability of this open-channel flow for varying thicknesses. For each of these flow conditions, the pressure loss across the open surface will be recorded.

In addition to the design parameters introduced by the experiment itself, other constraints had to be considered in the payload development.[3] The payload is limited in size by the container in which it will be housed onboard the shuttle. The entire payload structure must be suspended from the Experiment Mounting Plate, stipulating, to a large degree, the orientation and placement of payload elements. Furthermore, this experimental package must withstand the rigors of launch. Control of the payload presented another design obstacle since the experiment must be largely autonomous. Additionally, thorough studies must be made in order to assure that no credible possibility of failure existed which might result in a dangerous situation, either on the ground or in space.

With the above concepts in mind, a plexiglass prototype was constructed. Experimentation yielded information concerning the physical characteristics of thin film flow in gravity. There was excellent correlation with the findings of the Grumman Aerospace Corporation, upon which the prototype was based.[4] The ability to discern fluid depth changes ("waves") was realized to be an important aspect of the on-orbit data collection process.

As the prototype testing progressed, the hardware design evolved. New observations continued to indicate necessary modifications and safety concerns, as well as defining which data were pertinent. Ideas and suggestions from other GAS users furthered this design refinement. A high school group in Camden, New Jersey, and individuals at Utah State University (USU) provided insights concerning payload construction and the various payload-descriptive documents required by NASA.

Dr. Rex Megill of USU was of great assistance by supplying copies of a Payload Accommodations Requirements (PAR) report and a Safety Data Package (SDP) prepared at USU. These facilitated a better understanding of the purposes and requirements of these documents. Especially for individuals having little or no previous experience in the writing of this type of report, such reports are indispensable. The use of a word processor is also highly recommended as it speeds revisions.

The GAS program has received

special interest and attention at USU, and as a result, a microprocessor controller was built for use in USU payloads. This device, tailored to the needs of small, autonomous systems such as this, is programmable, samples and stores both analog and digital data, and can control up to eight payload components. One of these USU controllers was purchased for use in this project.

Armed with a more complete understanding of fluid flow behavior, suggestions from other GAS users, and a knowledge of the guidelines stipulated by NASA, a final configuration for the test article, Niagara, emerged. While the general design is similar to the prototype, it is more compact, functional, and spaceworthy. A cross-sectional view of Niagara is shown in Figure 2.

Following the fabrication and assembly of Niagara, extensive testing took place, in both atmospheric pressure and vacuum. While the gear pump performed satisfactorily in the atmosphere, it tended to ingest air, causing turbulent, aerated flow. Such behavior did not occur in vacuum tests, where the test article developed smooth flow. Pressure recovered by the diffuser was on the order of ten percent of the supply (emitter chamber) pressure. This corresponded to the anticipated pump inlet pressure of one centimeter of water, verifying the design of the ultra-low inlet pressure gear pump. Niagara was also tested on a shaker table, and exhibited no damage nor any natural frequencies within the range of vibrations experienced by the shuttle system.

Given that the payload data will be stored in the USU controller, transducers were selected that were compatible with its logic-level inputs. The first parameter investigated was temperature. This measurement is important because of the variation of viscosity of the working fluid, Dow Corning DC-704 diffusion pump oil, with temperature. If the experiment is initiated while below 18 degrees Celsius, frictional losses may be severe enough to prevent proper pumping. Fluid temperature will also be monitored during test article operation in order to help determine the cause of flow variations. The pump motor temperature will be checked periodically as a safety measure.

The three temperatures (fluid reservoir, Niagara, pump motor) will be measured by thermistors. These devices were chosen because of their quick response, simple operation and output. A known voltage will be applied to each and the resulting lower potential recorded in the Erasable Programmable Read-Only Memories (EPROMs) of the controller. This sampling will occur every three seconds during the payload operation.

Unlike the thermistors, which will operate prior to the opening of the reservoir, the two pressure transducers will be energized once DC-704 is flowing within Niagara. One pressure measurement is taken in the emitter stagnation chamber, and the other between the diffuser and the pump (see Figure 2).Piezoelectric pressure transducers were selected based on their sensitivity to small fluctuations and compatibility with both the working fluid and a vacuum environment. As with the thermistors, these devices output a fraction of their supply voltage.

Due to the fact that small accelerations are expected during the payload operation, a three-axis accelerometer package is included. Any perturbations above a threshold level will

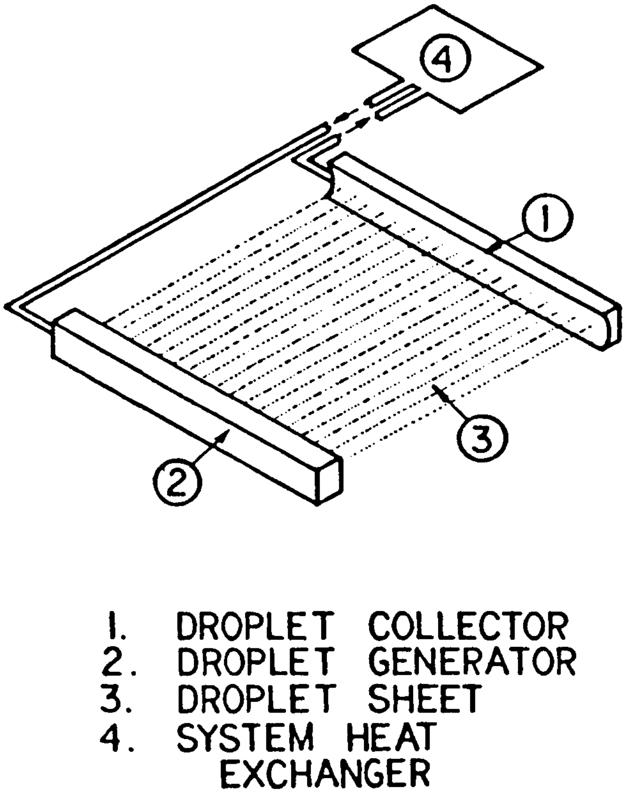


FIGURE 1

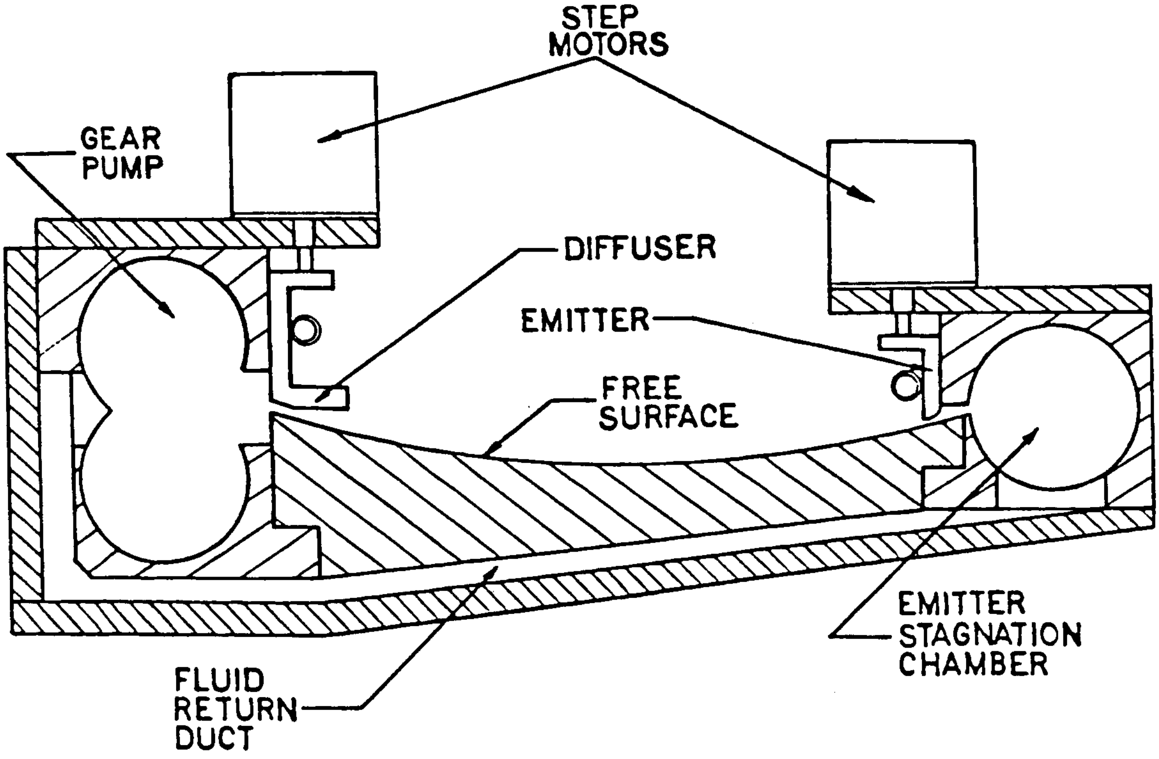


FIGURE 2

cause one or more of three LEDs to glow. This optical indication will be displayed next to the flow surface. This arrangement resulted from a belief that these accelerations will likely be random, short-lived disturbances, and as such, may not be recorded by the discrete sampling cycle of the controller. Furthermore, displaying this data in view of the camera will allow flow perturbations caused by these accelerations to be more easily identified.

The bulk of the results from this experiment will be derived from the recorded visual data. In light of this, the storage of this information received lengthy consideration, with the final decision being made in favor of a video cassette recorder (VCR) system. The most significant factor in this choice was the recording time. While a VCR offers at least 60 minutes, 8mm movie cameras provide three minutes per film cartridge. Another feature of the video camera selected is its ability to operate in low light (7 lux). Because of the length restrictions of the GAS container, the focal length, depth of field, and physical length of the camera were of interest. The camera selected has excellent macro-focus capabilities with depth of field which allows clear focus on Niagara's surface. As mentioned previously, the camera needs to be able to detect the presence of waves on the fluid surface. Analysis suggested that this would not be a problem. This theory was borne out by several tests of Niagara which were videotaped with the flight camera. Definite line were evident where waves occurred in the flow. hydraulic jump occurred in flow. Similar video systems have been successfully used on previous GAS projects, and a vibrational test of the entire payload will verify this system's qualification for flight.

Most of the payload operations, such as turning the video system on, must be accomplished by an independent, internal controller. Activation of this system will be controlled by the shuttle crew via the Autonomous Payload Controller (APC).[6] One relay connects power to the payload, and can return it to a dormant state in the event of an emergency. A second switch initiates the operation of the USU controller.

The USU controller has been connected to the various elements of the payload, and code is being developed to sequence the experimental activities. First, the fluid reservoir temperature will be sampled. Based upon this, the flow will either be initiated or delayed for a short time. When the temperature meets or exceeds 18 degrees Celsius, or when a total delay time of three hours has elapsed, the reservoir will be opened and the pump motor energized. Just prior to these operations, the video system and lights will turn on so that the start-up can be recorded. Initial emitter and diffuser heights will be maintained for the first two minutes after the flow begins. Following this, the emitter and diffuser will be raised slightly by step motors. This change in flow thickness will repeat, every two minutes, until a total of five fluid flows have been observed. After data has been recorded for each of the flow conditions, a power-down sequence will return the payload to a latent state. If the pump motor overheats, the controller will turn it off and initiate the power-down sequence.

Even more critical to the success of this experiment are the power supplies. The payload batteries are composed of 15 Gates' rechargeable lead-acid energy cells, which produce potentials of 6, 12, and 24 volts. These cells were selected for use based upon their long storage life, which is sufficient to span the period between payload delivery to NASA and on-orbit operation (typically two months). Gates' cells have been used in both military and NASA projects with favorable results, and also have performed well in past GAS experiments. A combustibility analysis of this payload verified that explosion due to hydrogen production by the batteries is not a credible failure possibility.

The safety verification documents which describe these batteries, as well as the entire payload, developed an effective basis for communication with the NASA Technical Manager (NTM). This exchange of information with the NTM, in the form of documentation and teleconferences expedited the safety procedure. This process was concurrent with the payload design, and was helpful in the development of the final payload configuration.

Several decisions which led to this final design were influenced by a concern for safety. The payload itself is split into two pieces; one-half of the GAS canister will be at one atmosphere of dry nitrogen (Figure 3), while a sealed container will be evacuated prior to launch (Figure 4).

The nitrogen environment provides the proper operating atmosphere for the electronics, in addition to effectively eliminating the potential of fire. The sealed container, housing Niagara and the fluid reservoir, simulates the vacuum of space and provides a secondary barrier against fluid escaping into the Orbiter bay. This sealed container orginally was to be vented and resealed while in orbit, but this was changed in order to eliminate Orbiter contamination hazards. The decision to mount this cylindrical chamber to the Experiment Mounting Plate (Figure 3) was driven by a desire to reduce moments induced in the mounting brackets, as well as to take better advantage of the strength of the stainless steel wall of the vessel.

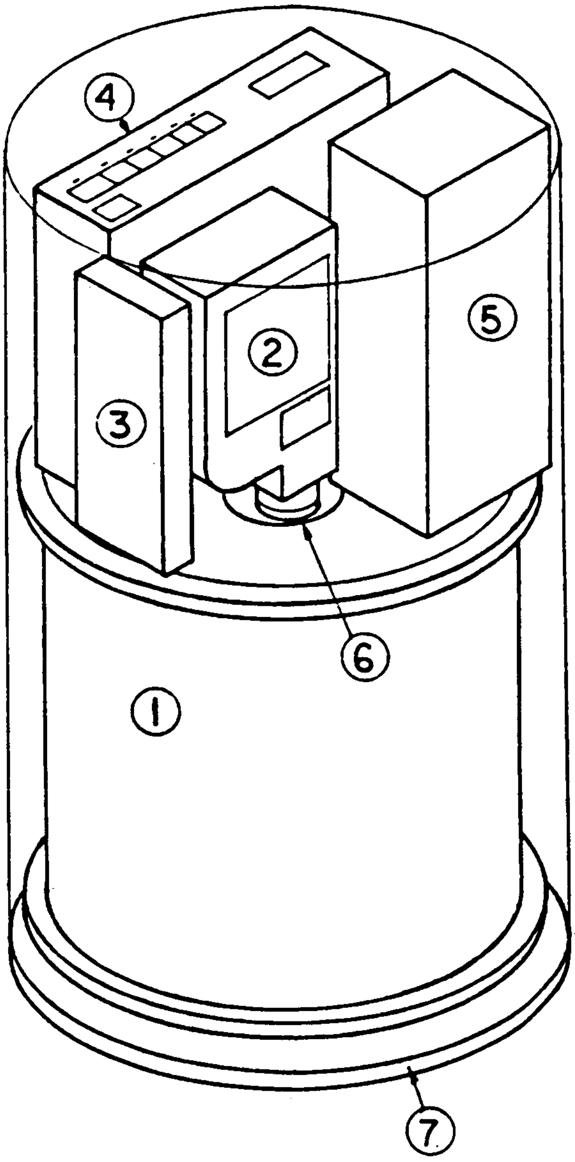
Despite these variations from the original design, the overall payload has remained functionally the same. This will not hinder the future modification and re-use of the payload. Based upon the results of the first flight, such improvements may include a droplet generator, which would allow the investigation of fluid film stability during droplet impingement (capture).

Several factors were seen to have an impact upon the evolution of the payload. Major points are summarized below:

Clear definition of the design problem prior to fabrication and acquisition of payload components is essential. The employment of the aforementioned plexiglass prototype provided invaluable insights concerning fluid flows, pump design, characteristic system pressures, and viscosity effects. Similarly, knowledge of the dimensional, material, and safety constraints imposed by NASA allowed the initial paper designs of the payload to be more realistic and appropriate than might have otherwise occurred.

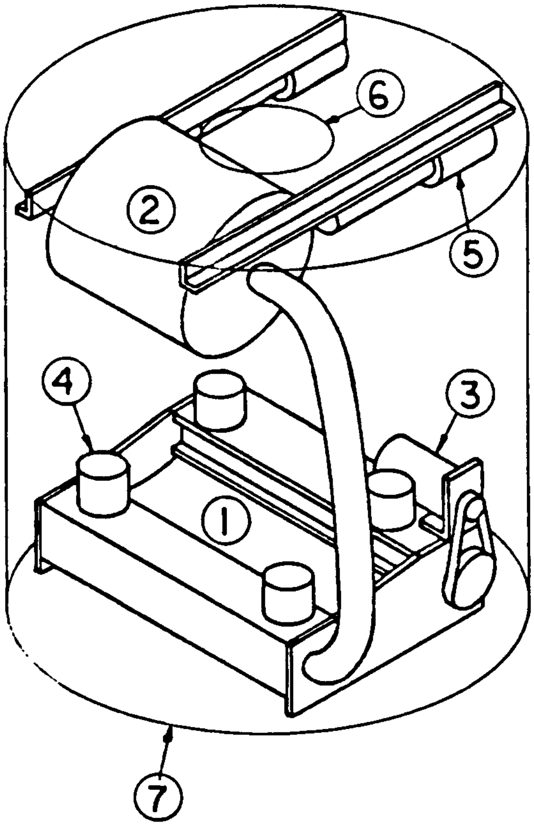
As the design progressed, it became evident that an open-minded, investigative philosophy must be maintained so that insightful discoveries were not overlooked. If the designer becomes enamored with a particular design, such as the original configuration, viable alternatives may be missed due to lack of serious consideration.

FIGURE 3



1. SEALED CONTAINER
2. VIDEO CAMERA
3. CONTROLLER
4. VIDEO RECORDER
5. BATTERIES
6. OPTICAL PORT
7. NASA MOUNTING PLATE

FIGURE 4



1. NIAGARA (TEST ARTICLE)
2. RESERVOIR
3. PUMP MOTOR
4. STEP MOTOR
5. LIGHTS
6. OPTICAL PORT
7. SEALED CONTAINER INTERIOR SURFACE

Overall system safety is an area which often requires unique approaches in addition to common sense. Here, again, consultation and research fostered a more thorough understanding of the design problem. Conferring with other GAS users who have developed and/or flown payloads yielded fresh viewpoints of the safety problems. As previously mentioned, the documentation generated during the design process served as a tool for the discovery of improvements. Inspection by qualified, objective third parties, such as NASA tehnical personnel, also proved to be very enlightening.

In conclusion, the design work, fabrication, and testing described above have resulted in the development of a compact, space-worthy payload for participation in the NASA Get Away Special program. This process was augmented by the advice and assistance of a NASA Technical Manager, other GAS users, research and experimentation, and the preparation of payload documentation. This project has also been quite successful in presenting, at the undergraduate level, an exceptional opportunity wherein theoretical knowledge was supplemented by experimentation and common sense approaches to non-trivial engineering tasks.

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