MICROGRAVITY IGNITION EXPERIMENT

Worcester Polytechnic Institute
Mechanical Engineering Department
Worcester, Massachusetts

Professor Vahid Motevalli
William Elliott, Teaching Assistant
Keith Garrant, Ryan Marcotte

Abstract

The purpose of this project is to develop a flight-ready apparatus of the microgravity ignition experiment for the GASCAN II program. The microgravity ignition experiment is designed to study how a microgravity environment affects the time to ignition of a sample of α-cellulose paper. A microgravity environment will result in a decrease in the heat transferred from the sample due to a lack of convection currents, which would decrease time to ignition. A lack of convection currents would also cause the oxygen supply at the sample not to be renewed, which could delay or even prevent ignition. When this experiment is conducted aboard GASCAN II, the dominant result of the lack of ignition will be determined. The experiment consists of four canisters containing four thermocouples and a sensor to detect ignition of the paper sample. This year the interior of the canister was redesigned and a mathematical model of the heat transfer around the sample was developed. This heat transfer model predicts an ignition time of approximately 5.5 seconds if the decrease of heat loss from the sample is the dominant factor of the lack of convection currents.

Introduction

One of the most important issues for long-term space occupation, such as in a space station, is fire safety. The very low gravity condition in space can drastically affect the phenomena of combustion and fire. In order to maintain fire safety, the initiation of the combustion phenomenon, ignition, must be understood. While ignition has been studied, the effect of a microgravity environment on the ignition process is not completely understood. The purpose of this project is to determine how the microgravity environment affects ignition time.

A major factor in the ignition process is heat transfer. As a fuel source is heated, products are released due to molecular breakdown of the sample. This process is referred to as pyrolysis. These products mix with the surrounding air and, when a sufficient amount of heat has been transferred to the sample, make ignition possible.

There are three ways in which heat is transferred into or away from an object. These are radiation, conduction, and convection. Heat may be transmitted by the emission and absorption of radiation. In addition to heat transfer due to radiation, there is heat transfer due to the contact of two objects of different temperatures. This is referred to as conductive heat transfer. Finally, heat may be transferred by convection currents in the air.

Convection currents result from buoyancy forces caused by earth's gravity. When a substance is hotter than the surrounding air, the temperature of the air near the surface of the substance increases because of the transfer of heat. Convection currents force the less dense heated air to rise away from the hot substance and the cooler, more dense air to sink to the surface of the substance, as shown in Figure 1.
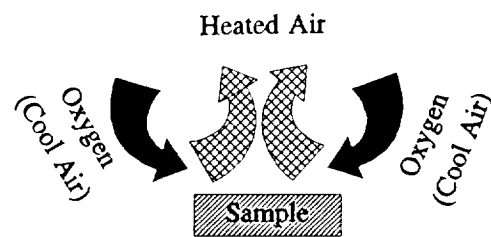

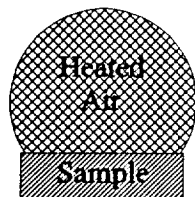Fig. 1 Convection currents on Earth

Oxygen (Cool Air)

Fig. 2 Lack of convection in microgravity

Due to the lack of gravity in a microgravity environment, convection currents are not present. This lack of convection currents causes a cloud of heated air and pyrolysis products to form around the object, as shown in Figure 2. This will cause a reduction in the heat transferred away from the object, increasing the object's temperature, therefore decreasing the time to ignition. The absence of convection currents also prevents the cooler, oxygen rich air from sinking towards the object. It is possible that the lack of this oxygen may stop ignition from occurring at all. The purpose of this experiment is to determine how these conflicting processes affect the time to ignition by collecting and comparing data regarding ignition in microgravity and on Earth, and analyzing the results.[1]

Previous Projects

The microgravity ignition experiment is a continuing project. The first Major Qualifying Project (MQP) on this project was completed in 1986. This project determined the purpose of the experiment and resulted in construction of a prototype. In addition, various types of sensors were investigated for the measurement of flux, temperature, and ignition.[2]

Later groups considered many different substances for the test sample. Eventually, National Bureau of Standards α-cellulose (paper) was selected for its relative consistency. This was chosen because the properties of the paper are relatively constant, and the heat required to ignite the paper is not excessive.[3]

The initial combustion chamber was redesigned by the 1990 MQP group. The 1991 MQP group investigated the reliability of the equipment for the experiment. They discovered that the moisture content of the α-cellulose paper affected the time to ignition. A procedure for drying the test sample was then developed. In addition to this and their development of the alignment apparatus and procedure, low temperature testing of the perimental components was conducted.[3,4] Modifications in the chamber have been made by this year's team.

Previous projects also considered many possible heat sources. An Argus type 44 infrared heat lamp with a gold-plated reflector was chosen for the heat source. The 1991 MQP group designed and fabricated a lamp alignment apparatus. Using this device they developed a procedure for aligning the bulb both horizontally and vertically. This focuses the lamp and allows the point of maximum heat flux to be concentrated on the test sample.[4]

Jeff Goldmeer's master's thesis developed a heat transfer model for a copper plate. This model had problems finding the convection coefficient because of the difficulty in modeling the heat transfer caused by the contact of the copper with the teflon backplate.[5] This model was used as a basis for the heat transfer model of α-cellulose paper.

Experimental Apparatus

Chamber

The experiment consists of four combustion chambers. The combustion chamber is an aluminum cylinder to which four aluminum plates are mounted. Plates one and two mount the infrared heat lamp on the cylinder. Plates three and four are used to position a teflon holder. This holder supports the paper sample and all sensors mounted within the ignition chamber. Plate four also contains ports for a pressure transducer and two purging valves. The chamber is designed to be airtight and contain dry air at slightly higher than atmospheric pressure. Figure 3 shows a diagram of the total configuration of the canister.

different distances from the test sample. This data can be used to approximate the temperature gradient within the canister.
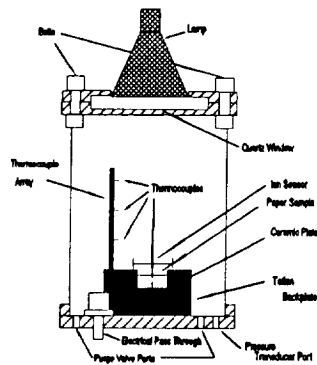
Pressure Transducer The pressure in these three canisters is monitored throughout the experiment with a pressure transducer. The data provided by the pressure transducer can be used to determine the pressure rise caused by the lamp and/or pyrolysis at any point during the experiment. This is useful in more complete thermodynamic analyses. The data can also be used to determine if the seal of the canister was intact at the beginning of the experiment. This is necessary in order to establish that the environment inside the canister contained only the dry air with which it was purged.

Flux Meter One canister will not contain a sample of α-cellulose paper. It will instead contain a gardon gage. This will be used to measure the flux output of a bulb in microgravity. This was done because the flux output of the lamp may be different due to the lack of convection currents within the bulb in microgravity. This canister will not contain an ion sensor, a sample backface thermocouple, a thermocouple array, a pressure transducer, or purge valves.

Purging Apparatus In order to produce repeatable results, it required that a dry environment be maintained within the canister. This is because the paper sample would absorb any moisture present in the air which would affect the time to ignition of that sample. It was decided to provide this dry environment by purging the sealed canister with dry air. This method consists of two valves, one inlet valve and one outlet valve, mounted directly to the bottom aluminum plate. The three canisters which contain the paper sample also contain these valves.

Data Acquisition The data acquisition system developed this year in Marcotte's MQP controls the experiment sequencing. In addition, it stores the results of the experiment in non-volatile EE PROMS. This allows the data to be maintained even when the GASCan batteries are drained. The data acquisition system also contains the preflight diagnostics. All of the electric systems of the experiment can be tested with a personal computer. The chips for the data acquisition system are rated to -25° C.[1]

Fig. 3 Experimental canister

Heat Lamp

The heat lamp is an Argus model 44 infrared heat lamp. It consists of a 250-watt bulb that requires 24 volts to operate. This bulb is mounted within a gold-plated parabolic reflector. The bulb and reflector are separated from the experimental chamber with a circular quartz window.

Instrumentation

Ion Sensor There are currently four types of sensors that are used in the experiment. One of these is an ion sensor. Three of the canisters that contain a paper sample also contain the ion sensor. The ion sensor is used to determine when ignition occurs. It consists of two stainless steel wires that are mounted above the test sample forming an open circuit. When the sample burns, ions that allow a current to pass between the two wires are produced, completing the circuit. When the circuit is completed, a voltage is produced indicating that ignition has occurred.

Thermocouples Another type of sensor used is a thermocouple. The thermocouples are used to measure temperature. Three of the canisters contain four thermocouples in each chamber. One of the thermocouples is used to measure the backface temperature of the sample. The other three are set up in a thermocouple array to determine the temperature at

Sequence of Experiment in Space

The three experiments contained within the GASCan II will be run in a sequence, with microgravity ignition being the first experiment in the progression. The sequence will be started by an astronaut at the beginning of the first sleep period. Running the experiments during the sleep period will provide an environment with the least activity and the lowest acceleration. The astronaut will flip a switch, signaling the power up of the GASCan. Figure 4 illustrates the sequence of the microgravity ignition experiment.

After the GASCan itself has been powered up, power will be provided to canister one of microgravity ignition. This is the canister that contains the gardon gage instead of the paper sample. The lamp will be turned on and run for 15 seconds. The software designed by the electrical engineering portion of the team will sample the data for the duration of the run. After 15 seconds the software will turn the lamp of canister one off and pause for 5 seconds before signaling canister two.
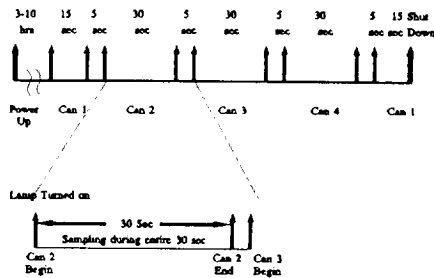

Fig. 4 Experimental sequence

When the software controlling canister two receives its signal, the lamp is turned on, sampling from all the sensors begins, and a timer is started. This continues until the ion sensor detects ignition of the paper sample. At this point, the lamp will be turned off. Sampling of the sensors will continue until the timer, which was started at the beginning of the run, reads 30 seconds. Canister two is then powered down. If ignition is not detected within

30 seconds, the lamp will be turned off and sampling will stop at the 30 second mark. Canisters three and four are run identically to canister two.

Canister one will be run again 5 seconds after the power down of canister four. It will be run following the same procedure that was used during its first run. The data from this run will be compared with the data from the first run to determine if drainage of the batteries has caused any changes in the flux output of the lamp.[6]

Heat Transfer Model

A mathematical model of the heat transfer in the canister for a copper plate was developed in Jeff Goldmeer's master's thesis. This model was redone to take into account some changes in the chamber design and the use of α-cellulose paper. First, the energy balance was considered.

$$E_{stored} = \alpha I - \dot{q}_{cond} - \dot{q}_{conv} - \dot{q}_{rad} \qquad (1)$$

The energy stored by the paper is:

$$E_{stored} = \rho c d \frac{\delta T s}{\delta t} \qquad (2)$$

The heat transfer due to convection is:

$$\dot{q}_{conv} = \bar{h}(Ts - T_\infty) \qquad (3)$$

The heat transfer due to radiation is:

$$\dot{q}_{rad} = \sigma \varepsilon (T_S^4 - T_\infty^4) \qquad (4)$$

The teflon backing was redesigned in order to eliminate conductive heat transfer with the sample, which was a major problem with the Goldmeer model. Because of this, conductive transfer can be ignored. Combining this fact with equations (1), (2), (3), and (4) yields:

$$\rho c d \frac{\delta T s}{\delta t} = \alpha I - \bar{h}(Ts - T_\infty) - \sigma \varepsilon (T_S^4 - T_\infty^4) \quad (5)$$

Finally, solving this equation for h results in:[5]

$$\bar{h} = \frac{\alpha I - \rho c d \frac{\delta Ts}{\delta t} - \sigma \varepsilon \left(T_s^4 - T_\infty^4\right)}{Ts - T_\infty}$$ (6)

In addition the following equation was used for the heat flux from the lamp with I_0 and τ being constants:[7]

$$I = I_0\left[\left(1-e^{\frac{-t}{\tau}}\right)+e^{\frac{-r(tl-rl)}{(d+\tau)}}-e^{\frac{-t}{\tau}}\right]$$ (7)

In order to predict the temperature change of the sample in microgravity, the convection coefficient was set to zero and was solved using Lotus 123. A graph of the results for the sample temperature is shown in Figure 5. Figure 6 displays a graph of the flux output of the lamp and the reradiation loss of the paper.
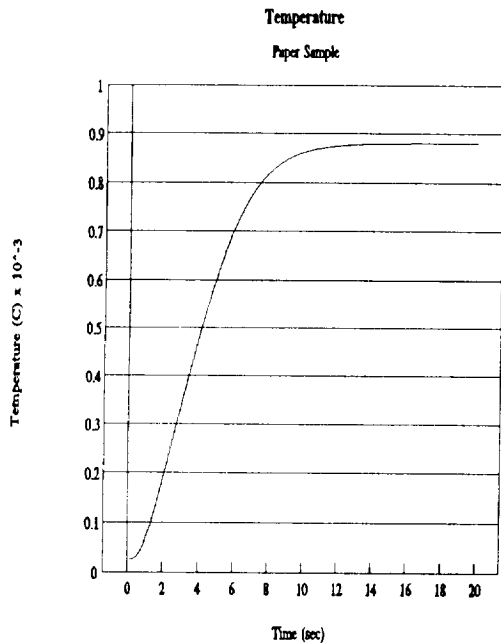
pyrolysis temperature of approximately 625 degrees C at approximately 5.5 seconds. The 1991 team determined that the average time to ignition on earth using the baseplate with conduction was 13 seconds. This predicted decrease in the ignition time is a result of the lack of convection currents and the assumption of zero conduction loss. If the lack of convective heat transfer overpowers the lack of oxygen supply, then this prediction will be accurate. However, this model is not valid if the sample does not ignite because of the oxygen deficiency.

Figure 6 shows Hagdoust's estimate of the warming curve of the lamp. In addition, if the lamp is continuously operated, it is predicted that a steady state condition will be reached at approximately 14 seconds. At this point, the heat flux from the lamp equals the reradiation loss from the sample. This results in the flattening of the curve seen in figure 6.[1]

Results

A baseline experiment was run using the new teflon backplate. Due to problems with the new experiment controller, Labtech Notebook was used to acquire the data.

Temperature

Paper Sample

Fig. 5 Temperature of the paper sample

According to Figure 5, the sample will reach its

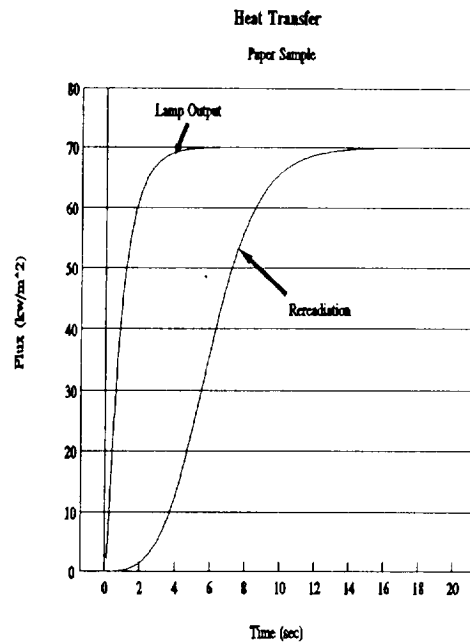**Heat Transfer**

Paper Sample

Fig. 6 Flux output of the lamp and reradiation loss of the paper

Figures 7 - 10 show the results of this experiment. These figures display the changes in temperature that occur within the canister and not the actual temperatures that are felt. The temperatures measured by the thermocouples are close to but slightly less than what was expected. It is possible that this is because the thermocouple junctions are large and that the backface thermocouple was not in contact with the paper. However, the results show the expected trends. Figures 7 - 10 display the results for the thermocouple array from one run. Figure 10 illustrates the results for the backface thermocouple from two separate tests. Both sets of results show the correct trend and show that the results obtained are very repeatable.[1]
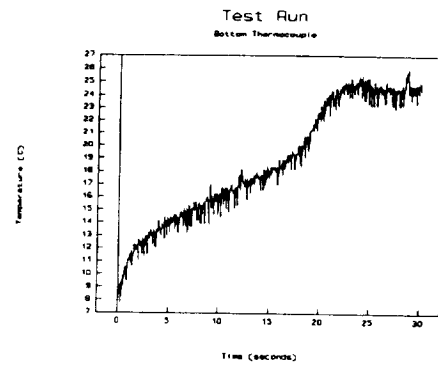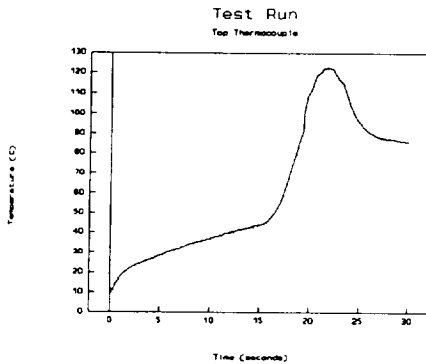
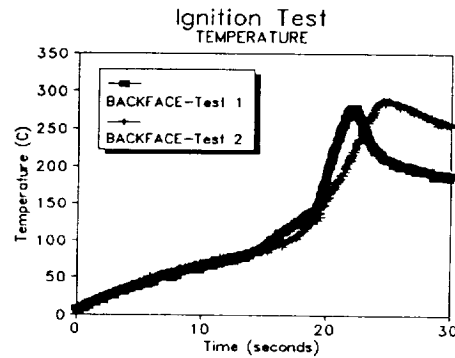Test Run
Bottom Thermocouple

Fig. 9 Bottom thermocouple

Test Run
Top Thermocouple

Fig. 7 Top thermocouple

Test Run
Middle Thermocouple

Fig. 8 Middle thermocouple

Ignition Test
TEMPERATURE

BACKFACE-Test 1
BACKFACE-Test 2

Fig. 10 Backface thermocouple
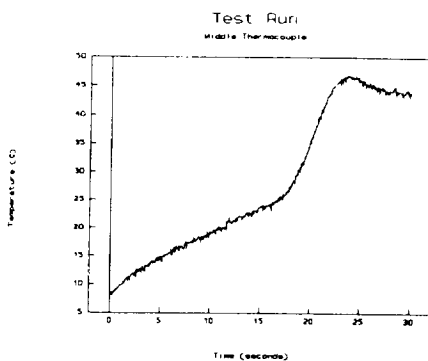
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