

## 2.5 Microgravity Effects on Plant Boundary Layers

### **FLIGHT DATES:**

June 29 – July 2, 2004

### **PRINCIPAL INVESTIGATOR:**

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### **CO-INVESTIGATOR:**

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## **INTRODUCTION:**

The goal of these series of experiment was to determine the effects of microgravity conditions on the developmental boundary layers in roots and leaves and to determine the effects of air flow on boundary layer development. It is hypothesized that microgravity induces larger boundary layers around plant organs because of the absence of buoyancy-driven convection. These larger boundary layers may affect normal metabolic function because they may reduce the fluxes of heat and metabolically active gases (e.g., oxygen, water vapor, and carbon dioxide). These experiments are to test whether there is a change in boundary layer associated with microgravity, quantify the change if it exists, and determine influence of air velocity on boundary layer thickness under different gravity conditions.

## **METHODS AND MATERIALS:**

### **Experiment Description**

The following experiments were performed as part of the Microgravity Effects on Plant Boundary Layers project on the KC-135:

Rates of temperature change in microgravity from wet and dry wicks at various wind speeds were measured.

Rates of temperature change in microgravity from monocot (wheat) and dicot (radish) plant leaves with and without forced convection were measured.

Oxygen consumption rates in stagnant and stirred water containers in microgravity were measured. These rates were compared to O<sub>2</sub> consumption rates in a moist substrate in microgravity

The results from this experiment provided insight into how microgravity-induced changes in boundary layers affect mass and heat transport from bulk air to plant organs (leaves and roots). Similar experiments have flown twice aboard the KC-135 aircraft, first as a part of the ISS PESTO experiment in 2000, and again as a Fluid Physics-Plant Growth Experiment on a combined flight of Advanced Life Sciences and Fundamental Biology experiments in early 2004.

### **Hardware Description**

Oscar Monje, Ph.D., was the technical lead for these experiments and designed the payload hardware package and has been responsible for post-flight analysis of data.

The experiment hardware consists of an aluminum base plate with a small rack that contains the plant chambers, fan, accelerometer, data logger, light and video equipment. The base plate was bolted to the floor prior to take-off and has the accelerometer, data logger, fan, and light attached. The video equipment and plant chambers were set up upon reaching level flight and were re-stowed prior to landing. All tools were located in a tool kit contained in the Reduced Gravity Program Offices' yellow container during takeoff, parabolas and landing. Access to the tool kit was not required during parabolas. Operators used straps for restraint during the parabolas.



**Figure 6. The experimental configuration on the aluminum base plate.**

The aluminum base plate provides structural support for crash loading and has flown numerous times aboard the KC-135. Figure 1 shows the experiment configuration on the aluminum base plate.

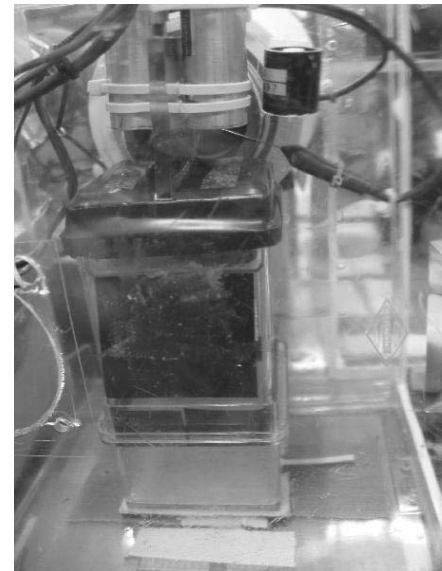
## **RESULTS**

### **Experiment One: Microgravity effects on boundary layer development on wet/dry filter paper.**

#### **Objective**

Changes in boundary layer resistance will affect heat and mass transfer rates of surfaces to air flowing above them.

Quantifying heating rates of these cellulose surfaces (filter paper) in differential g's (1g, 0g, 2g) allows the hypothesis that boundary layers increase under microgravity conditions. The effects on boundary layer development were determined. Infrared thermometers measured the effects of changing gravity conditions (1g, 0g, 2g) on filter paper temperature at different levels of forced convection (wind tunnel) during the KC-135 parabolic flight. These measurements will allow the effects of gravitational forces to be quantified, and to establish whether gravity alters the impact of air velocity on boundary layer disruption.



#### **Data collection**

The g force was measured with an accelerometer, the air-flow with an anemometer, air temperature with thermocouples, and filter paper temperature with infrared thermometers.

#### **Observations**

The experimental hardware performed well during the parabolic flights. Temperature difference ( $T_{\text{surface}} - T_{\text{air}}$ ) data was recorded during the 0g, 1g, and 2g at 0, 0.2, 0.4, 0.6, 0.8, and 1.0 m/s wind

speeds. The convective heat transfer for the dry surface increased as wind speed increased. However, for a wet surface the convective heat transfer increased only until the wind speed reached 0.4 m/s. At wind speed greater than 0.4 m/s, the convection decreases, probably because less heat was transferred through convection, but rather through evaporation.

### **Conclusion**

The boundary layer, as measured by temperature difference, was greater under 0g conditions than either 1g or 2g conditions. The effects of increasing air velocity on boundary layer were less in microgravity than 1g for both wet and dry surfaces. These data are consistent with the hypothesis that boundary layers in microgravity are greater than they are under 1g. The effects of microgravity on boundary layer increases could be mitigated by increasing air velocity to 0.4 m/s over the surface.

### **Experiment Two: Effects of microgravity on boundary layer development of monocot and dicot leaves.**

#### **Objective**

Changes in boundary layer resistance surrounding plant organs will affect leaf transpiration and the resulting evaporative cooling of the leaf surface. Measuring the heating rates of plant canopies under differential g conditions (1g, 0g, and 2g) should allow changes in boundary layer resistance to be estimated. Hypothesized increases in boundary layer resistance under reduced gravity conditions should disappear as air velocities increase. These assumptions were tested by measuring changes in leaf temperature at different levels of forced convection (wind speed) and thermal load (light intensity) during parabolic flights on wheat (monocot) and radish (dicot) leaves.



#### **Data collection**

The g force was measured with an accelerometer, the air-flow with an anemometer, air temperature with thermocouples, and canopy temperature with infrared thermometers. Canopy temperature difference ( $T_{\text{surface}} - T_{\text{air}}$ ) data was recorded during the 0g and 1g at various wind speeds over wheat and radish canopies. Light levels were measured with a light meter.

#### **Observations**

The experimental hardware performed well during the parabolic flights. Preliminary results indicate that it took about 3-4 parabolas for canopy temperature to reach equilibrium following a change in light level at constant wind speed. Generally, the plant canopies became hotter as the wind speed flowing above the leaves was reduced. The ground study was conducted in an environment (air temperature and relative humidity) simulating those in the plane using the

Orbital Environment Simulator chamber at KSC. Data analysis comparing the 0g and 1g data is underway.

### **Experiment 3: Determine the effects of microgravity on boundary layer development in rooting media.**

#### **Objective**

Changes in boundary layer resistance may affect the supply and removal of metabolic gases (O<sub>2</sub>, CO<sub>2</sub>) to roots. It is hypothesized that a larger boundary layer in microgravity results in hypoxia in the root zone, which can become limiting to plant growth. If the boundary layer increases during microgravity, then the rate of O<sub>2</sub> diffusion to the O<sub>2</sub> sensor should decrease. To test this hypothesis, O<sub>2</sub> concentrations in 1 mm glass bead media were measured during parabolic flight with and without forced convection above the root zone. It was hypothesized that forced air would reduce the boundary layer, and increase rate of diffusion, and that this change would be proportional to distance from the surface.



#### **Data collection**

The g force was measured with an accelerometer, the air-flow with an anemometer, and air temperature with thermocouples. Oxygen concentration was measured using two different types of sensors: galvanic oxygen sensors and Root Oxygen Bioavailability (ROB) sensors embedded in 1 mm glass beads.

#### **Observations**

The experimental hardware generally performed well during the parabolic flights. Unfortunately the ROB sensor output was outside the range of the data logger and valid data was not obtained. The galvanic O<sub>2</sub> sensors performed well. It was observed that it required 5-6 parabolas for the galvanic sensors to equilibrate following a change in wind speed. The Galvanic sensors indicated that the aeration in the root zone decreases only slightly (~0.3%), however, their output appears to be influenced by the atmospheric pressure changes in the plane, and changes in cabin air temperature. The methods for correcting for these changes are being formulated. The Galvanic sensors also appear to respond to air movement near the air intake of the sensors and dead air volume may confound data analysis.

#### **Conclusion**

The temperature and pressure dependence, as well as the response to air currents near the intake of the galvanic sensors needs to be better characterized in order to interpret the behavior of these sensors in 0g. Once the sensor performance is characterized then they can be used to test the hypothesis that boundary layers are increasing in the root zone.

#### **Fractional g testing**

During the 4<sup>th</sup> day of the campaign, a request for two 0.16 (lunar) and 0.33 (mars) g parabolas to be performed was approved and fractional g data for Experiments 2 and 3 was obtained.

During these parabolas, the data suggests that the differential g forces result in a proportional effect on boundary layer development around the leaf and in the root zone. However, these data are very preliminary, and interpretation difficult due to lack of O<sub>2</sub> sensor stability after only 2 parabolas. However, these results are intriguing and proposed for future parabolic flight testing will be proposed under fractional g conditions.

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**PHOTOGRAPHS:**

JSC2004E27361  
JSC2004E282118 to JSC2004E28120  
JSC2004E28256 to JSC2004E28257  
JSC2004E28298 to JSC2004E28299  
JSC2004E282416  
JSC2004E28423  
JSC2004E2845

**VIDEO:**

- Zero-g June 29 – July 2, 2004, Reference Master: 718394

Videos available from Imagery and Publications Office (GS4), NASA/JSC.

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