FINAL REPORT
for
Research Grant
NAG 9-851
LYNDON B. JOHNSON SPACE CENTER

PLANT GROWTH AND DEVELOPMENT IN THE ASTROCULTURE™ SPACE-BASED GROWTH UNIT - GROUND BASED EXPERIMENTS

R.J. BULA
WISCONSIN CENTER FOR SPACE AUTOMATION AND ROBOTICS
UNIVERSITY OF WISCONSIN-MADISON
FEBRUARY 17, 1997

INTRODUCTION

The ASTROCULTURE™ plant growth unit flown as part on the STS-63 mission in February 1995, represented the first time plants were flown in microgravity in a enclosed controlled environment plant growth facility. In addition to control of the major environmental parameters, nutrients were provided to the plants with the ZEOPONICS system developed by NASA Johnson Space Center scientists. Two plant species were included in this space experiment, dwarf wheat (*Triticum aestivum*) and a unique mustard called "Wisconsin Fast Plants" (*Brassica rapa*). Extensive post-flight analyses have been performed on the plant material and it has been concluded that plant growth and development was normal during the period the plants were in the microgravity environment of space. However, adequate plant growth and development control data were not available for direct comparisons of plant responses to the microgravity environment with those of plants grown at 1g. Such data would allow for a more complete interpretation of the extent that microgravity affects plant growth and development.

OBJECTIVES

The objective of the experiments was to provide ground-based plant growth and development data to serve as control information for comparison with post-flight data collected on the plant material recovered from the ASTROCULTURE™ flight unit following the STS-63 mission.

EXPERIMENTAL PROCEDURES

The experiments involved providing plant material for analyses following three growth periods at 1 g conditions. The first was a growth period that duplicated the growth period of the STS-63 mission and at the experiment defined environmental conditions. The second growth period involved the growth period of the STS-63 mission but at the environmental conditions recorded during the STS-63 mission. The third growth period involved growing the plants at the experiment defined conditions and terminating this growth period at the time period equivalent to the time STS-63 was launched. This last growth period would provide an assessment of the status of the plants at time of launch.

For the first growth period (to provide ground control plant material), seeds of the Wisconsin Fast plants were planted in the root module of the ASTROCULTURE™ flight unit that translated into a growth period of 5, 12, 20, and 25 days prior to what was

considered to be the time the flight unit was turned over for installation into the orbiter. This planting sequence provided plants at different stages of maturity during the space flight. Four seeds were planted at five intervals in a row of the root module. After 5 days, the seedlings were thinned to a single plant at each site. The first seeding took place on January 2, 1996 and the other seeding dates at the times defined.

Wheat seeds were planted at 4 days prior to the defined turn over time. Ten seeds were place in each of 2 rows of the root tray. The wheat seeds were planted on January 23, 1996.

A complete sequence of planting, turnover, and harvest dates of this first growth period experiment is provided in Table 1.

Table 1. Schedule of planting and harvest activities of the experiment to determine plant growth and development at 1g conditions for comparison with plant growth and development in microgravity during the STS-63 mission.

30 January, 1996	12:00 Noon	Plant 1 row of Fast Plants, 25 days prior to turnover
4 February	12:00 Noon	Plant 1 row of Fast Plants, 20 days prior to turnover
12 February	12:00 Noon	Plant 1 row of Fast Plants, 12 days prior to turnover
19 February	12:00 Noon	Plant 1 row of Fast Plants, 5 days prior to turnover
20 February	12:00 Noon	Plant 2 rows of wheat, 4 days prior to turnover
24 February	12:00 Noon	Turnover of ASC hardware, Noon, 31 January, 1995
28 February	12:30 AM	Launch of STS-63, 3 February, 1995
6 March 1996	2:00 PM Harvest	Equivalent to return of hardware at end of mission, 11 February, 1995.

The root module with the seeded material was maintained in a controlled environment chamber until turn over time. Environmental conditions of the growth chamber were defined by the experiment as: 200 (±20) $\mu mol\,m^{-2}s^{-1}$ of continuous light (no dark period), 24 (±2) °C temperature of the air in the plant chamber, 65 (± 10) % relative humidity of the air in the plant chamber, and 0.5 kPa water delivery loop pressure. No carbon dioxide control was available in the plant growth chamber during the growth period. In the ASTROCULTURE™ flight unit, atmospheric carbon dioxide concentration was controlled at 500 ppm by addition of pure carbon dioxide when the concentration was below 450 ppm.

At 36 hours before the scheduled launch time, the rooting module with the plants was removed from the controlled environment plant chamber and installed in the ASTROCULTURE™ flight unit. The plants were then grown in the ASTROCULTURE™ flight unit for a time period equivalent to the time the shuttle was on the launch pad, duration of the mission, and the time from landing of the orbiter to the recovery of the flight unit. The launch of STS-63 was delayed 24 hours and this resulted in the plants being in the orbiter for a period of 60 hours prior to being launched into space.

The second experiment included the plant material described for the first experiment and grown in the controlled plant environment chamber under the environmental conditions described for the first experiment. Following installation of the root module in the ASTROCULTURE™ flight unit, the light intensity, air temperature, relative humidity of the air, carbon dioxide concentration, and water delivery loop pressure of the plant chamber in the ASTROCULTURE™ flight unit were controlled at levels that simulated the conditions as recorded during the STS-63 mission rather than at the experiment defined levels. The light levels in the plant chamber recorded during the STS-63 mission are shown in Fig. 1. The air temperatures in the plant chamber recorded during the STS-63 mission are shown in Fig. 2. The percent relative humidity of the air in the plant chamber recorded during the STS-63 mission is shown in Fig. 3. The concentration of carbon dioxide in the plant chamber air during the STS-63 mission is shown in Fig. 4. The water delivery loop pressure of the plant chamber during the STS-63 mission is shown in Fig. 5.

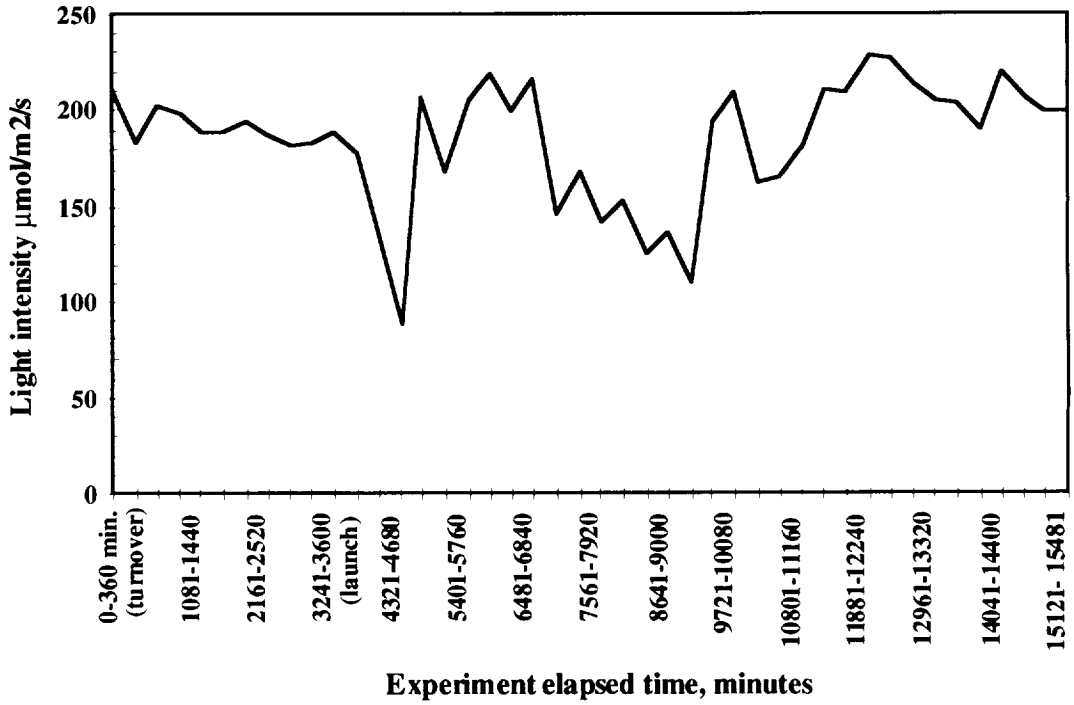

Figure 1. Light intensity in the plant chamber of the ASTROCULTURE™ flight unit during the STS-63 mission.

A complete sequence of planting, turnover, and harvest dates of this second growth period experiment is provided in Table 2.

The third experiment included the plant material described for the first experiment and grown in the controlled plant environment chamber under the environmental conditions described for the first experiment. Rather than installing the root module with the plants into the ASTROCULTURE™ flight unit, the root module was left in the controlled environment plant chamber for an additional 60 hours and then harvested. These plants represented the condition of the plants at the time the STS-63 mission was launched, which was delayed for 24 hours and the plants were in a 1 g environment while on the launch pad in the orbiter.

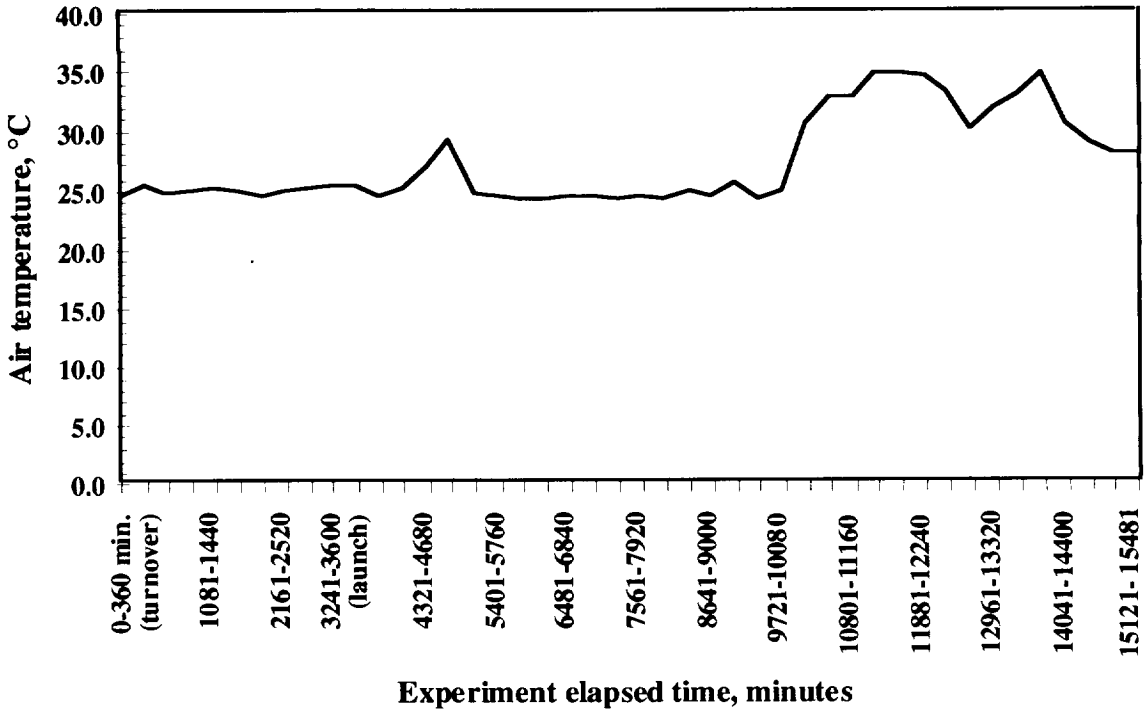

Figure 2. Air temperature in the plant chamber of the ASTROCULTURE™ flight unit during the STS-63 mission.

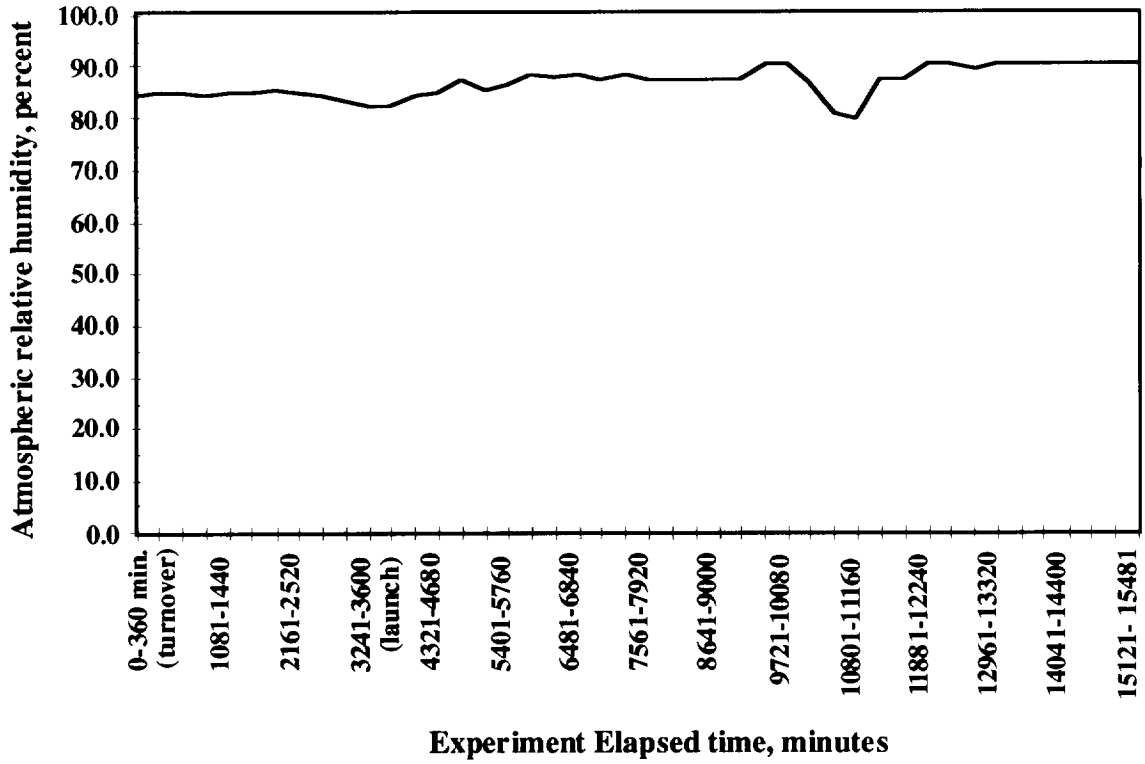

Figure 3. Atmospheric relative humidity in the plant chamber of the ASTROCULTURE™ flight unit during the STS-63 mission.

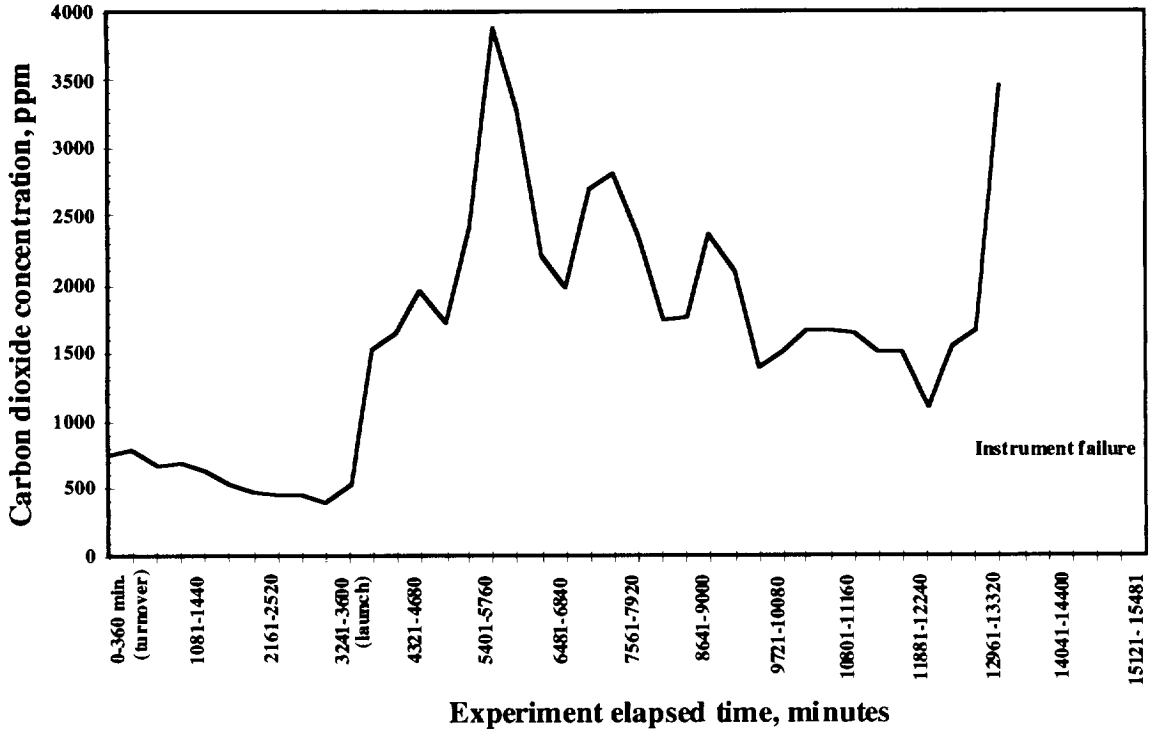

Figure 4. Concentration of carbon dioxide in the air of the plant chamber in the ASTROCULTURE™ flight unit during the STS-63 mission.

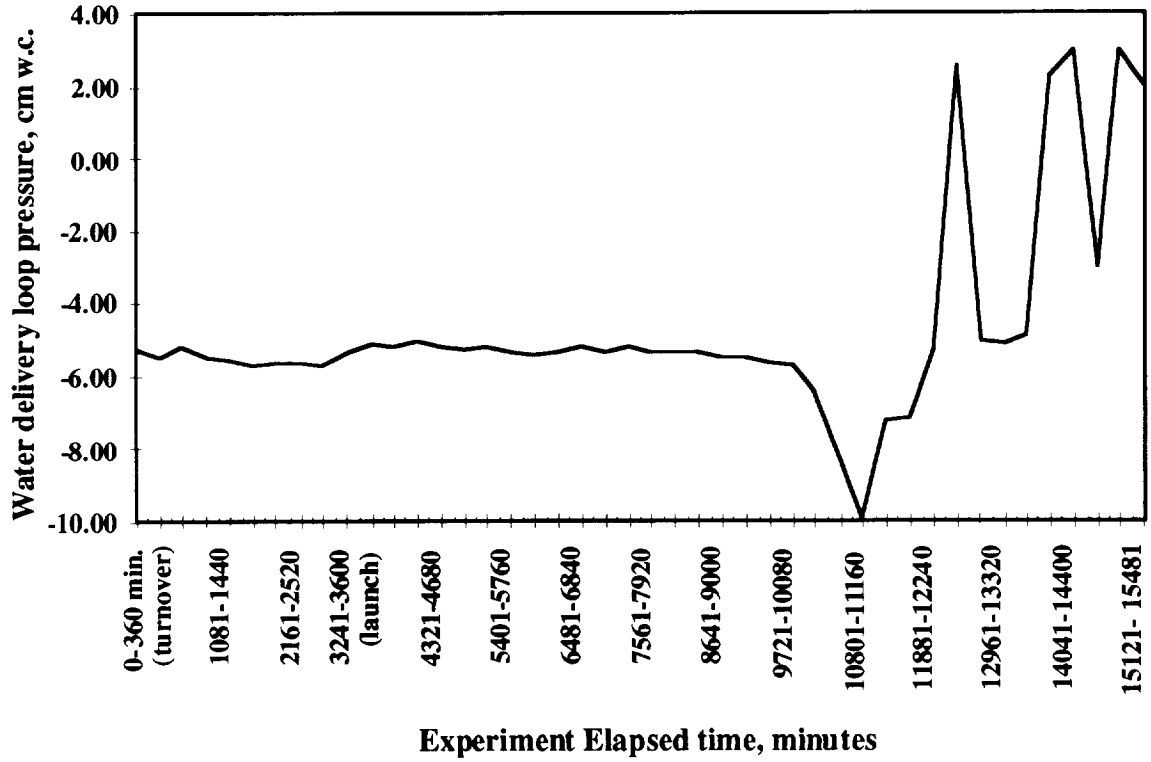

Figure 5. Water delivery loop pressure, cm of water column, of the root module of the plant chambers of the ASTROCULTURE™ flight unit during the STS-63 mission.

Table 2. Schedule of planting and harvest activities of the experiment to determine plant growth and development under environmental conditions that simulated those that were recorded in the plant chamber of the ASTROCULTURE™ flight unit during the STS-63 mission.

7 November, 1996	8:00 AM	Plant 1 row of Fast Plants, 25 days prior to turnover
12 November	8:00 AM	Plant 1 row of Fast Plants, 20 days prior to turnover
20 November	8:00 AM	Plant 1 row of Fast Plants, 12 days prior to turnover
27 November	8:00 AM	Plant 1 row of Fast Plants, 5 days prior to turnover
28 November	8:00 AM	Plant 2 rows of wheat, 4 days prior to turnover
2 December	8:00 AM	Turnover of ASC hardware, Noon, 31 January, 1995
6 December	12:30 AM	Launch of STS-63, 3 February, 1995
13 December 1996	10:00 AM	Harvest - Equivalent to return of hardware at end of mission, 11 February, 1995.

A complete sequence of planting, turnover, and harvest dates of this second growth period experiment is provided in Table 3.

Table 3. Schedule of planting and harvest activities of the experiment to define the condition of the plants at the time the shuttle was launched since the STS-63 mission launch time was delayed 24 hours.

15 November, 1996	12:30 AM	Plant 1 row of Fast Plants, 25 days prior to turnover
20 November	12:30 AM	Plant 1 row of Fast Plants, 20 days prior to turnover
28 November	12:30 AM	Plant 1 row of Fast Plants, 12 days prior to turnover
5 December	12:30 AM	Plant 1 row of Fast Plants, 5 days prior to turnover
6 December	12:30 AM	Plant 2 rows of wheat, 4 days prior to turnover
10 December	12:30 AM	Turnover of ASC hardware, Noon, 31 January
12 December	12:30 PM	Harvest - Equivalent to launch of STS-63 @ 12:30 AM, 3 February, 1995.

RESULTS

The conduct of the plant growth experiments was delayed in response to scheduling of availability of NASA Johnson Space Center scientists that were responsible for harvesting the plant material and processing it for further analyses. Thus, the first experiment growth period was from January 30, 1996 to March 6, 1996. The second and third plant growth experiments were conducted during the period of November 7, 1996 to December 13, 1996. As was defined in the Grant Statement of Work, harvesting the plants and the

analyses of the plant material was the responsibility of NASA Johnson Space Center personnel. Plant data relative to the plants based on fresh conditions was completed by NASA Johnson Space Center personnel at the University of Wisconsin-Madison at time of harvest. Also, at this site, preservation of the plant material for subsequent analyses was accomplished by NASA Johnson Space Center personnel and shipped to the Johnson Space Center where the analyses were to be performed.

In general, the plants grown under 1 g conditions in these ground-based experiments were similar to the plants grown in a microgravity environment during the STS-63 mission. It may be worthwhile to point out that the environmental conditions in the plant chamber of the ASTROCULTURE™ flight unit deviated from the experiment defined environmental conditions. The mustard or Fast Plants from the ground-based experiment that simulated the environmental condition recorded during the STS-63 mission exhibited more deterioration due to high air temperatures and relative humidity compared to the mustard or Fast Plants grown in microgravity during the STS-63 mission. This may be due to more extensive condensation of the humidity on the plant material under 1 g conditions compared to what may have occurred in microgravity. The wheat plants did not exhibit such deterioration and appeared similar to the plants grown in microgravity, even under the environmental conditions that deviated from the experiment defined set points.

SUMMARY

Three ground-based plant growth experiments were conducted to obtain data for comparing the growth of a mustard called Wisconsin Fast Plants and wheat in microgravity during the STS-63 mission. The three experiments represented a simulation of the experiment conducted during the STS-63 mission with the environmental conditions in the plant chamer in the ASTROCULTURE™ flight unit controlled at the experiment defined level, the same experiment except the environmental conditions in the plant chamber were controlled to reflect the environmental conditions as recorded during the STS-63 mission, and an experiment to define the condition of the plants at the time the STS-63 mission was launched.

The plants were harvested at the scheduled dates and the desired data collected on the fresh plant material. Plant material was also preserved for subsequent analyses. The data describing the plant growth during these experiments are being developed and summarized by Johnson Space Center scientists.