# Space farming

## A biomass production system sends botanical research out of this world.

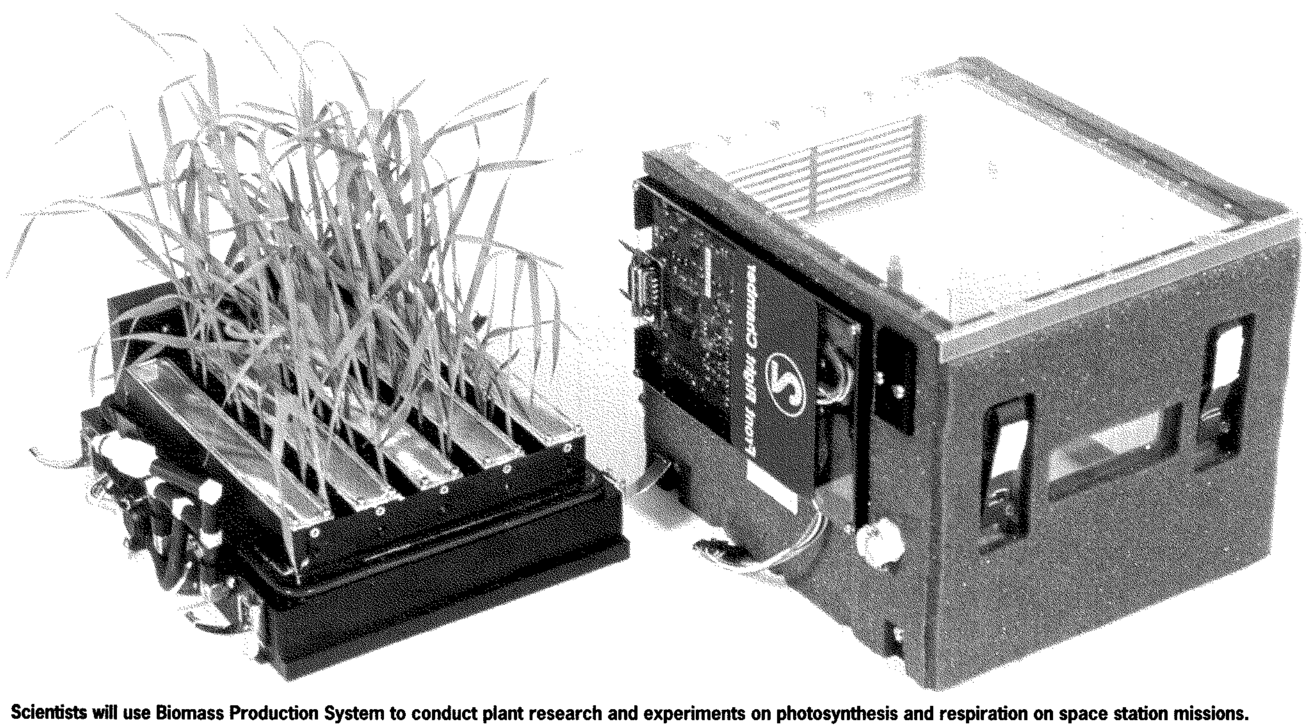
SCIENCE FICTION NOVELISTS have been writing about inhabiting space since before space travel was even possible. Now, however, orbiting laboratories such as the International Space Station can provide unique environments for developing new medicines, industrial materials, and communications technology. They also may serve as stepping stones for more ambitious colonization projects, which will require humans to be self-sustaining on distant planets.

One of the foremost skills colonists will need is the ability to grow their own food. To that end, NASA is currently investing in research technology for on-orbit plant growth that could eventually facilitate longer missions on the space station or even permanent habitation of space.

Orbital Technologies Corp., or Orbitec, is a Madison, Wis., research and development firm that is providing NASA with the advanced tools needed to grow plants in space and the finite element analysis know-how to make sure these tools can be safely transported. Astronauts will use the company's new Biomass Production System to conduct biotechnology plant research and metabolic experiments on photosynthesis, respiration, and transpiration on the middeck of the NASA Space Shuttle and rack facilities on the space station as well.

To qualify the biomass system for spaceflight, Orbitec used linear static and dynamic stress analysis software from Pittsburgh-based Algor Inc. to prove that the unit could withstand extreme dynamic loading during liftoff and landing. Orbitec had to meet NASA's stringent safety and engineering requirements and optimize the design without resorting to costly, time-intensive prototyping.

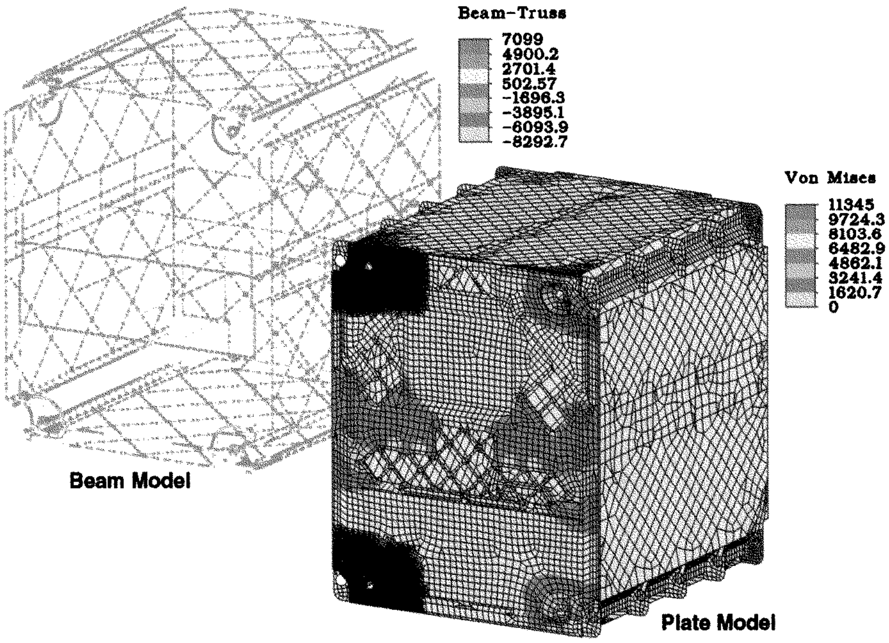
"Orbitec studied plant growth systems flown on previous Space Shuttle missions and consulted with NASA engineers and the science community to develop the Biomass Production System," explained Jeffery Iverson, a lead design engineer on the biomass project. "Our goal was to



**Scientists will use Biomass Production System to conduct plant research and experiments on photosynthesis and respiration on space station missions.**

create a unit that services current research needs as well as enables future technology upgrades. The new system is the result of a large team of talented engineers, scientists, and technicians at both Orbitec and NASA."

Orbitec's design features a double-locker enclosure, which more effectively optimizes the available volume over previous payloads. The double-locker design is twice the height of a single locker, enabling scientists to conduct more extensive and flexible experimentation with the possibility of one large, two tall, two wide, or four small chambers. The new unit's enclosure slides open so that the astronauts have access to the inner chambers through all phases of operation. By allowing astronauts to access the plants, they can capture the results of microgravity studies by freezing the plants on orbit. This is an improvement over previous plant growth systems, which are closed for the length of the mission and can taint the findings of the experiment by exposing the plants to normal gravity conditions once the shuttle lands.




**Beam and plate elements were combined into the FEA model to simulate structural rigidity of the enclosure. Here, the Algor linear static stress analysis results for the beam structure and plate enclosure are shown separately.**

The box-shaped biomass system features independent controls of temperature, humidity, lighting, and carbon dioxide levels; an active nutrient delivery system; and sealed chambers for gas exchange measurements. In addition, the unit includes an advanced control system including diagnostics and event recording, a high-resolution color front panel display, and real-time video output.

Orbitec's project to design and build the biomass system began with Phase I and Phase II contracts from NASA Kennedy Space Center through the Small Business Innovation Research Program, which was created by Congress to help small businesses participate more actively in federal research and development. Today, the project is funded as a Phase III contract through NASA Ames Research Center. According to Iverson, the company relied heavily on FEA to meet the design requirements.

"The use of FEA software was important because physical prototyping was not an option with the limited time and resources available," said Iverson. "The NASA requirements for high strength in combination with our needs for low weight, maximum volume, and a short design time forced us to turn to FEA."

Iverson's FEA studies focused on four fully constrained attachment points at the corners of the biomass system because these areas would experience the greatest loads during liftoff and landing. The location of the proposed biomass system in the shuttle was a major design concern, according to Iverson. "The system will be bolted directly to an internal shuttle wall above the astronauts during liftoff, making the structural analysis a critical safety requirement," explained Iverson.

Iverson was also concerned about four latches on the front panel that secure the sliding portion of the enclosure. These four points bear the weight of the unit when the enclosure is latched shut.

With these considerations in mind, Iverson modeled and analyzed the biomass system enclosure using Algor's linear static and dynamic stress analysis software to ensure that there would be no failure at the attachment points or front panel latches.

## ENGINEERING FOR NASA

Iverson began the biomass system enclosure design by building a solid model using AutoCAD 13. Then he converted the model into more than 200 surfaces so that the edges of the surfaces would align at planned interaction points with beam elements, which were to be added to the FEA model by Algor.

Iverson transferred the model in IGES format to Superdraw III, Algor's single user interface for FEA and precision finite element model-building tool, where he created a surface mesh using both automatic and localized hand-meshing techniques. Iverson generated a surface mesh made of 3-D plate elements. "The geometry consisted of many very thin sections. I chose to use plates instead of 3-D solid bricks or tetrahedra to limit the number of elements in the model," said Iverson. "The ability to mesh multiple surfaces saved a lot of modeling time. This was a huge benefit given the short timeframe."

Iverson first produced a coarse surface mesh and ran preliminary analyses to verify the geometry. Then he produced a finer overall mesh and refined the surface mesh around the attachment points and front panel latches using

*This article was prepared by staff writers in collaboration with outside contributors.*

Algor's Merlin Meshing Technology. This technology features an "open plate" model option that enables engineers to create a consistent mesh, improve the shape of elements, and reduce the overall mesh density for plate/shell models. Iverson also used an automatic surface mesh matching option to align nodes where surfaces meet.

Once Iverson had completed the plate model, he copied the geometry into a new file, and selected lines and nodes that represent the ribs and structural elements of the internal payload. "The sides of the enclosure contain very thin, raised ribs machined directly into the side of the enclosure," Iverson explained. "These ribs provide important structural rigidity to the enclosure. I modeled them separately as beam elements to ensure an accurate representation of the structure without significantly increasing analysis run times."

Iverson deleted the remaining deselected elements and specified the beam cross-sectional properties, which were derived from *Roark's Formulas for Stress and Strain*. He identified different groups for the beam properties than for the plates in the first model to enable easy modification of element properties in the merged plate/beam model.

Using the *Military Specification Handbook 5G*, the materials handbook required by NASA, Iverson specified 7075 aircraft aluminum for the outside enclosure and 15-5 PH stainless steel for the latches. The weight of the payload and enclosure, approximately 125 pounds, as well as varying launch and landing gravitational loadings were applied in 20 different load cases to the combined plate/beam model. According to Iverson, NASA specified the varying combination and distribution of gravitational vectors. Iverson conducted approximately 90 iterations of linear static stress analysis to optimize the design.

"As both designer and analyst, I was in the unique position of looking for ways to add conservancy to the model while staying within the specifications of the design," said Iverson, who did this by adjusting the beam cross-sectional properties and redistributing internal load bearing points. "Situations with separate designers and analysts can lack the communication needed to make quick adjustments to the product according to analysis findings."

## THE NEXT STEP

The resulting design met NASA's requirements for maximum gravitational loading and margin of safety. Using Algor's built-in visualization capabilities, Iverson viewed the stress results using von Mises output for the plate elements and the standard beam-truss output for the beam elements. Iverson used the maximum stress results found in the Algor stress analysis to determine the calculated limit stress value, which was factored into margins of safety calculations for ultimate strength and yield strength.

"NASA looks for positive margins of safety," said Iverson. "A zero margin of safety means that the calculated stress is on the edge of what is acceptable, but still includes the required factor of safety." The minimum margin of safety for the biomass system was 0.6.

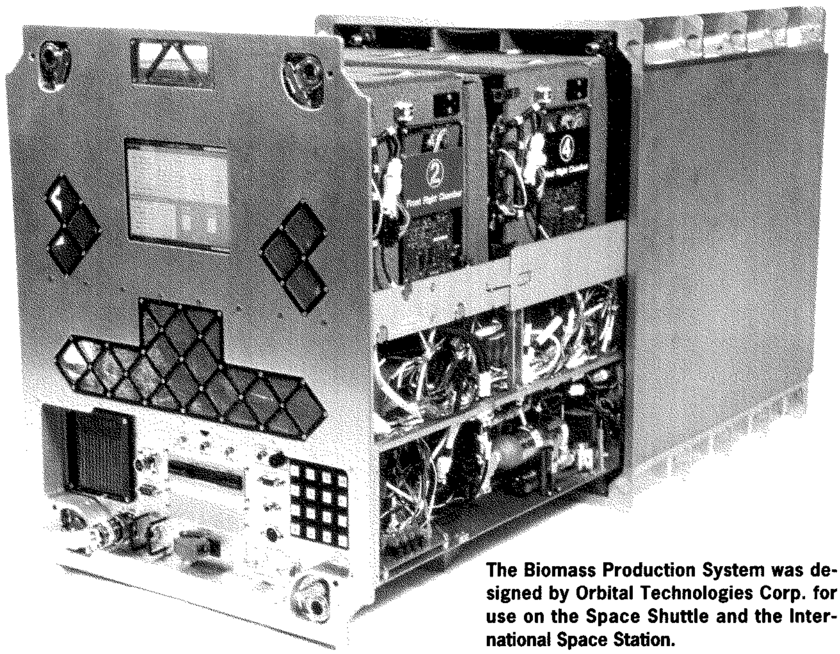
Iverson further tested the design by conducting a brief linear natural frequency stress (modal) analysis to ensure that the natural frequencies of the enclosure would not interfere with the frequencies of the shuttle wall. Iverson noted small deflections in the course of the modal analysis; however, the design met the lowest fundamental frequency requirements for its proposed location in the shuttle, according to Iverson.

"The loading placed on the biomass system is equivalent to 10 to 15 gs. Loads of this magnitude would be virtually impossible to simulate. In addition, the structure will never be loaded to that level in practice," said Iverson. "The benefit of using FEA is to evaluate theoretical loads on an object without physical prototyping." Iverson added that the system has successfully undergone verification vibration testing with lesser gravitational loads, which was used to verify the natural frequency analysis results.

The biomass system is currently in Phase III, the final stage of development and verification for spaceflight. In the summer of 2000, the unit will be subjected to a 24-day science test followed by a long duration mission verification test that will simulate the actual mission operations. This process will prove the hardware integrity and performance of the system.

The system is currently manifested for ISS Utilization Flight (UF-1), scheduled in the spring of 2001. Scientists will use Super Dwarf wheat and a mustard-like plant for their experiments. Both types of vegetation feature short lifecycles, which is ideal for the limited-duration spaceflight missions.

In the future, Orbitec plans to design a larger, next-generation plant research unit for use on long-duration space station missions, according to Iverson. ■



**The Biomass Production System was designed by Orbital Technologies Corp. for use on the Space Shuttle and the International Space Station.**