Self-Examination

Shuttle's new autonomous inspection capability will provide hard data for damage assessment

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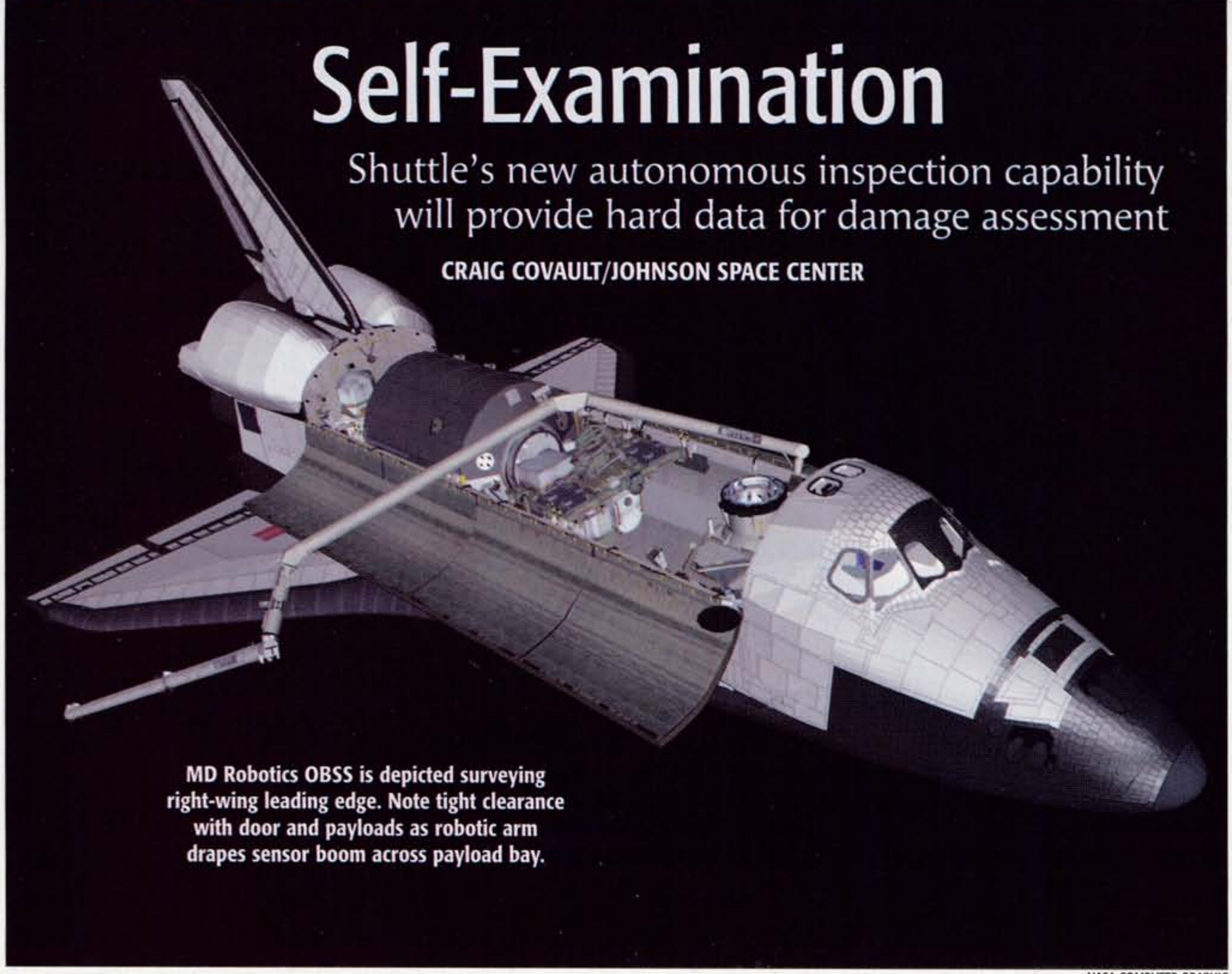

MD Robotics OBSS is depicted surveying right-wing leading edge. Note tight clearance with door and payloads as robotic arm drapes sensor boom across payload bay.

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The operation of the new U.S./Canadian Orbiter Boom Sensor System (OBSS) by the STS-114 Discovery's crew "will be the most complicated space robotics job of the shuttle program," says Paul Hill, lead flight director.

The OBSS is a laser-and-imaging-sensor-equipped 50-ft. extension to the existing 50-ft. arm, increasing the shuttle's reach to 100 ft.

The return-to-flight mission will debut the autonomous robotic self-inspection capability to detect and possibly aid the repair of the type of damage that doomed Columbia and her crew, were it to occur again.

With 3D imaging and laser contour-mapping capability, the OBSS will enable the diagnosis of cracks in reinforced carbon-carbon (RCC) wing and nose areas and thermal protection system (TPS) tiles beyond the view of the standard manipulator arm (see story, p. 46).

Given the major changes to the shuttle external tank, no damage is expected (*AW&ST* Oct. 4, 2004, p. 57). But the OBSS is a direct response to the Columbia Accident Investigation Board's recommendations.

The new boom and a significant amount of its supporting software was developed by MacDonald Dettwiler Space and Advanced Robotics Ltd. (MD Robotics) in Brampton, Ontario, a key contractor in the shuttle program for 25 years. The Canadian Space Agency is also heavily involved in supporting shuttle and International Space Station (ISS) robotics.

MD Robotics also built and supports shuttle's standard Canadarm remote manipulator system (RMS) and the Canadarm2 on the ISS.

Factors in operation of the boom and its sensors include:

- Design: The 50-ft. OBSS is a graphite epoxy boom made up of two 17-ft. sections produced earlier by MD Robotics as backup elements for the current shuttle arms.

The two 15-in.- dia. booms are joined by a middle metal sleeve that, including metal end sections, stretch the OBSS length to 50 ft. Unlike the traditional shuttle arms—with complex, motorized shoulder, elbow and wrist joints—the OBSS has no movable joints other than the pan/tilt mechanisms of its sensor heads.

The OBSS will be launched lying along the shuttle's starboard payload bay sill (the left side facing aft). For inspection operations, the much different and active shuttle arm mounted on the port side of the payload bay (the right side looking aft) will be maneuvered across the bay to grapple a fixture on one end of the OBSS. The two of them together will form the 100-ft.-long inspection arm.

- Complex robotics: During normal shuttle operations, the arm mostly maneuvers objects through auto sequences and various manually-assisted modes. Routinely, moves are made between two distinct points. "This has been like going from Point A to Point B," says Michael Wright, lead STS-114 payload deployment and retrieval officer in Mission Control.

"But with the moving scans required

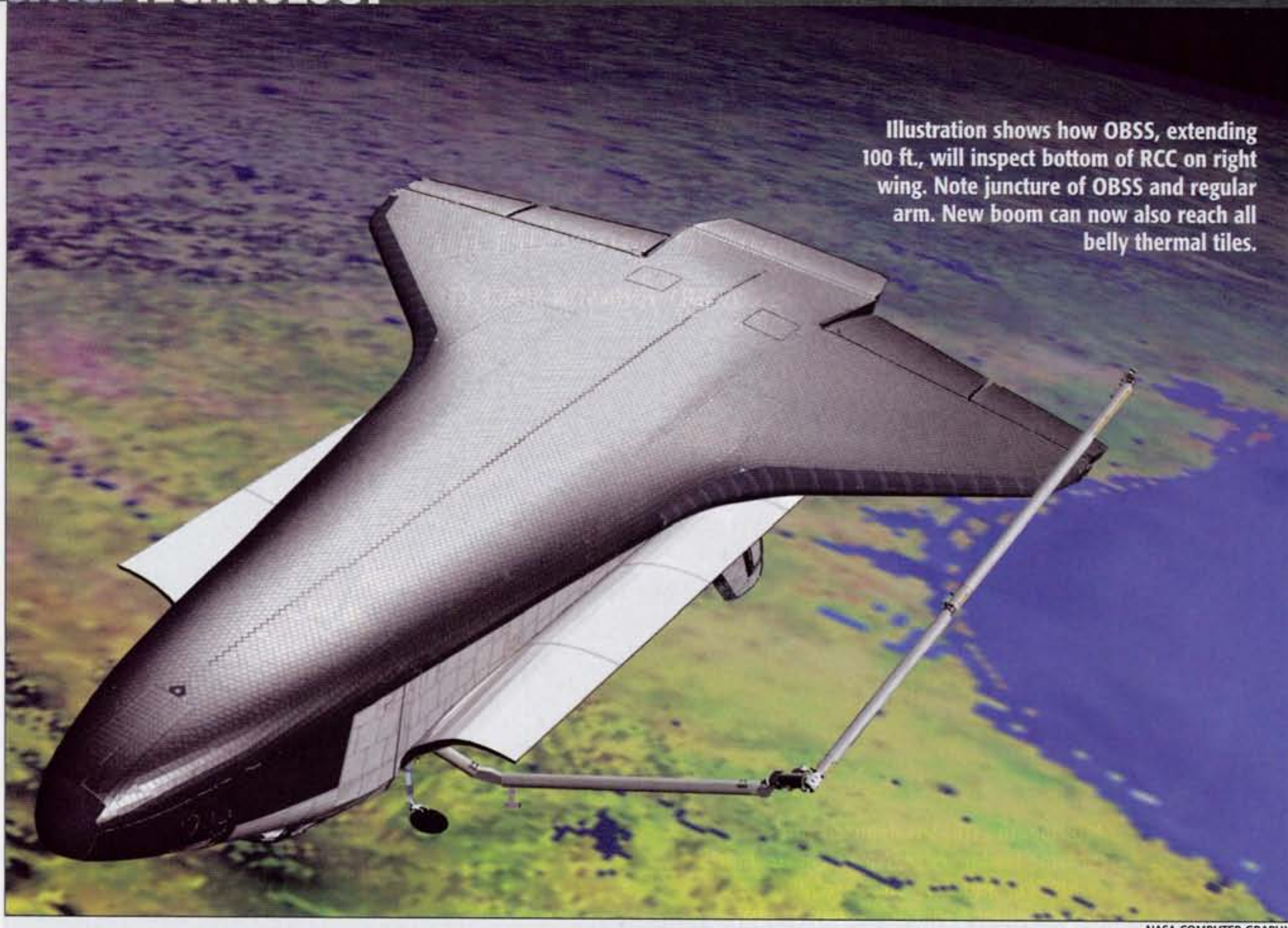

Illustration shows how OBSS, extending 100 ft., will inspect bottom of RCC on right wing. Note juncture of OBSS and regular arm. New boom can now also reach all belly thermal tiles.

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of the OBSS, it will be moving continuously from Point A to Point Z and all the letters of the alphabet in between," he says.

• Safety: The challenge is not just to position the sensors on the end of the boom. The tasks also demand keeping track of where the other joints and sections of the arm are moving in relation to orbiter structure in order to achieve the precise positioning of the sensors on the end.

This means there are continuously changing clearance and positioning concerns for not only the tip of the boom, but all other portions along the overall 100-ft. member.

The end of the boom will often be out of direct sight of the astronaut crew, while other portions of the entire device will be contorting near orbiter structures. Orbiter- and boom-mounted television cameras, as well as computer graphics, will enable the crew and mission control to maintain both the narrow and big picture perspectives needed for safety and scanning accuracy.

Scans on the port side of the orbiter will involve extending the entire contraption across the payload bay, taking care not to hit the mission's cargo, docking system or payload bay doors. (See picture, p. 43.)

"As recently as a year ago there was a lot of concern in the astronaut office and the robotics training community that waving this 100-ft. thing around [no matter how slowly] was going to be a really complicated thing to do," Hill said.

But with lots of training and computer graphics support, "the STS-114 crew is feeling a lot better about it," he said. "Operating it is still something we take very seriously."

For normal arm operations, 2-3 people out of a seven-person shuttle crew are typically involved. But for the OBSS there will be 4-5 astronauts assigned to arm operations, including direct visual and television monitoring, computer graphics monitoring and hand controlling the arm where necessary. This is a major investment of crew time, divided so individual crewmembers can take rest breaks because the workload can be intense.

"I really had my eyes opened in the simulator, seeing what the crew goes through to operate and monitor all this," Hill said.

Each crewmember has specific areas of clearance to watch for at every portion of every scan. Some clearances are as tight as 2 ft., and if a RMS joint motor suddenly begins running at a slower rate, the whole geometry could shift off course—something the crew has simulated.

All the planned scans will be done by auto sequences, with manually-assisted and single-joint mode operations at many points, such as initial arm positioning.

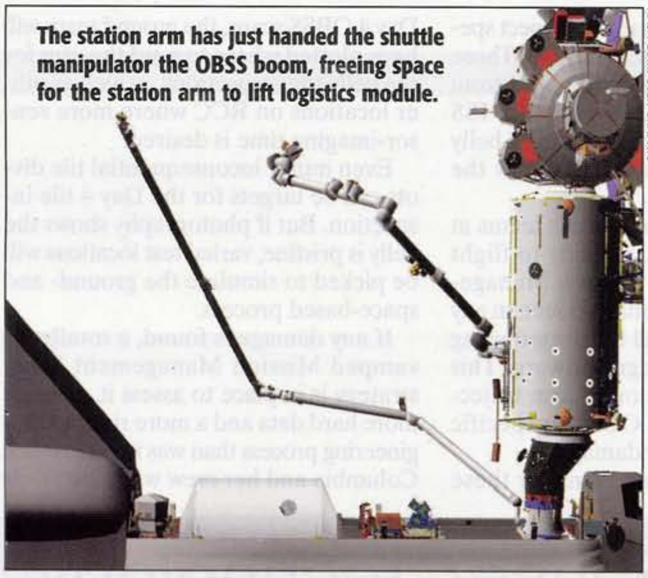
During Discovery's launch there will be 107 ground- and aircraft-based video and camera systems photographing specific parts of the shuttle to document any launch debris.

"But we will not really rely solely on those. The in-orbit inspection with the OBSS will really tell the tale about what we have," says Wayne Hale, deputy shuttle project manager.

In a worst-case scenario, the OBSS data would be key to determining if the damage would warrant implementing the safe-haven option on the ISS or a crew repair (*AW&ST* Apr. 11, p. 54). If necessary, the OBSS can carry an astronaut completely under the belly for an assessment, or direct work.

The OBSS is a direct measure to improve the overall shuttle risk equation and interrupt, in as many places as possible, the formation of any chain of events like that which led to the Columbia accident.

Within 4 hr. of Discovery's liftoff on Flight Day 1, the crew will begin to set up the four laptops needed as an on-



The station arm has just handed the shuttle manipulator the OBSS boom, freeing space for the station arm to lift logistics module.

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board network for inspection and related data-downlink tasks.

They will also do an initial checkout of the active arm to ensure its readiness for handling the OBSS the next day (*AW&ST* Apr. 25, p. 65 and 67).

They will also begin transmitting down the wing leading edge impact sensor data, imagery from the new digital camera in one of the orbiter's tank umbilical wells and crew hand-held camera images of the tank for use in overall debris assessments. Some of these will be pulled from the laptops by Mission Control as the crew sleeps.

Also, shortly after launch, Mission Control will transmit to the orbiter's system management flight computer a software load with the OBSS-scan-maneuver instructions. That has to be sent up from the ground after launch because so much of the orbiter flight computer memory is filled with safety-critical launch ascent/abort and reentry software for launch day.

Support by major robotics and materials-science teams at Johnson and other centers will be an inherent part of OBSS operations early Flight Day 2.

Around dawn of Day 2, U.S. Eastern Time, the crew will first maneuver the shuttle RMS across the payload bay to mate with the OBSS grapple fixture nearest to the end of the boom. This will form both a structural and electrical connection to the OBSS.

The first scans will be done on the RCC of the orbiter starboard or right wing (the left side looking aft).

"These are complex trajectories that need to follow the curve of the wing," Wright said. Using a combination of manually-assisted and auto sequences, the sensor end of the OBSS will be positioned several feet off the bottom side of RCC Panel 22, the panel furthest out on the wing. (See picture, p. 43.)

The standard RCC wing leading edge scans will be done using the OBSS Laser Dynamic Range Imager (LDRI), developed by Sandia National Laboratories. The LDRI can scan large areas with two-dimensional and 3D imagery. The sensor distance from the wing will range from 5-10 ft., depending upon the region being scanned, Hill said.

Starting with the lower portion of the most outboard RCC panel of the starboard wing, OBSS software will command the arm to slowly scan the bottom aft surface of each RCC panel from Panel 22 inward to Panel 1 nearest the wing root. The speed of the scan will range from 3.3 ft./min. up to 12 ft./min. at the point of sensor resolution.

Once done with this initial scan toward the fuselage, the crew will maneuver the end of the OBSS and its sensors to a predetermined arm joint angle pointing a little higher up, but also overlapping the first scan.

All of the real-time and targeted joint angles are displayed as digital numbers on aft cockpit displays as well as in Mission Control.

Once the first scan is completed the crew will initiate an OBSS scan in the opposite direction, from the inboard Panel 1 position outboard to the outermost Panel 22.

In total, the OBSS will make 5 scans of the starboard wing RCC, searching for any defects. The size and location of any defect would be a factor in its perceived threat. The OBSS can see at least 0.25-in. defects and substantially smaller flaws, depending upon survey technique. The wing scan will require at least 90 min. Much higher resolution scanning with the boom's Laser Camera System (LSC) will also be available if anything suspicious is seen.

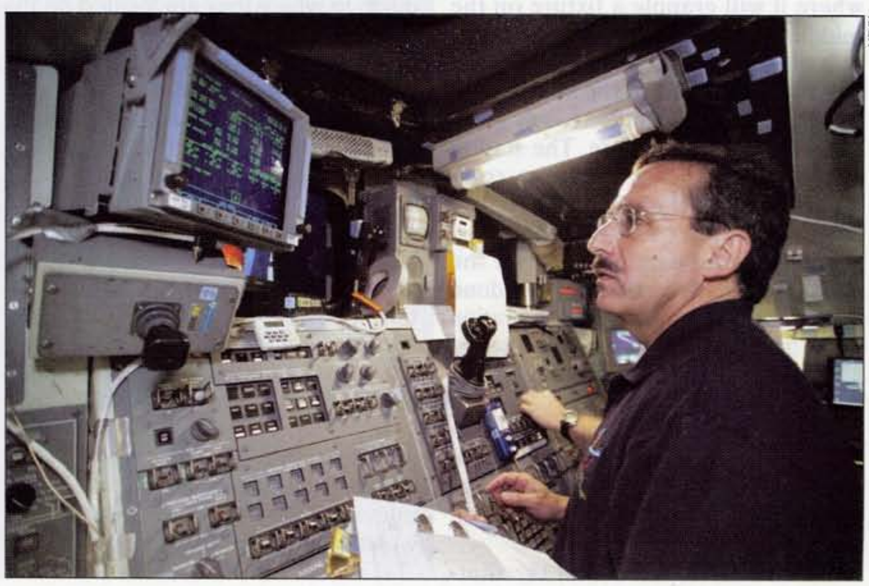
Once an inspection of the starboard wing is completed, the crew will extend the OBSS out over the nose of Discovery to survey the RCC nose cap.

But on the nose they will use the boom's LCS, developed by Neptec, a Canadian company. The LCS scans take longer but provide detailed surface topography through laser ranging. It can also be used on the wings if necessary.

The planned track of the sensor over the nose resembles a zig–zagging road racing course. The scans for the nose are in some ways more complex for sensor operations because the correct sensor angle of incidence must be maintained over the convex nose.

Once the nose is completed, the crew will use the OBSS to survey the port wing just as they surveyed the starboard wing.

Before launch, all of Discovery's RCC panels were thoroughly documented.



NASA

STS-114 astronaut Charles Camarda examines display with robotic-arm joint angles in aft cockpit of shuttle simulator. OBSS operations will involve several crewmembers.

This included tests at the RCC manufacturer, Lockheed Martin Missiles and Fire Control in Grand Prairie, Tex., which continues to use its original RCC facilities at the nearby Vought Aircraft Industries plant.

A practiced and organized ground team of NASA/contractor imaging and materials specialists will look at all the sensor and imagery data from multiple sources. They will combine all that information to begin assessing for any potential defects.

With all the data, new things will be seen and the challenge will be to separate false positives from any real damage.

As the ground team examines data, Discovery will dock with the ISS early on Flight Day 3.

During rendezvous, it will pause 600 ft. below the ISS so the pilots, Mission commander USAF Col. (ret.) Eileen Collins and USAF Lt. Col. James Kelley, flying from the aft cockpit, can maneuver the 100-ton orbiter through a 0.75-deg./sec., 360-deg. nose-up pitch maneuver. This will enable the Expedition 11 crew on the ISS to take high-resolution digital camera images, especially of orbiter belly and wing TPS tiles for use in the launch debris assessments.

While docked, the structure of the ISS will prevent Discovery's active arm from reaching across and grappling the OBSS as it did the day before. Likewise, the mission's Raffaello Italian ISS logistics module payload cannot be safely lifted from the bay by the station's arm with the OBSS in its starboard mount.

To solve both clearance issues, the station's own larger manipulator arm will be used about 3 hr. after docking to reach into Discovery's payload bay, where it will grapple a fixture on the middle of the OBSS.

It will then extract the OBSS from the bay and position it so the shuttle arm can move in and simultaneously grapple the OBSS end fixture. The station arm will then release the boom, completing a handoff of the OBSS to the shuttle's arm after a 2-hr. process.

Such a cargo handoff between the shuttle and station arm has been done before in ISS assembly, so the operation won't be as complex as the OBSS scans, although it remains a challenging robotic operation.

That handoff will allow the station arm the next day—Flight Day 4—to reach into the payload bay and extract Raffaello for temporary positioning on the station.

The OBSS, on the end of the shuttle arm, will then be used to inspect specific locations of orbiter belly tile. Those locations will have been targeted from the imagery sent down from the ISS crew photography of the shuttle's belly during the pitch maneuver below the station.

The imaging and materials teams at Johnson will be tied directly to flight controllers and the Mission Management Team. If any damage is seen in any of the imagery, it will be plotted using computer-aided design software. This will allow computation of arm trajectories to vector the OBSS to specific spots to examine for damage.

Before the crew awakens for these Day 4 OBSS scans, the ground team will have plotted where to send the arm for the belly tile inspections, as well as other locations on RCC where more sensor-imaging time is desired.

Even minor inconsequential tile divots can be targets for the Day 4 tile inspection. But if photography shows the belly is pristine, varied test locations will be picked to simulate the ground- and space-based process.

If any damage is found, a totally revamped Mission Management Team strategy is in place to assess it, with far more hard data and a more rigorous engineering process than was in place when Columbia and her crew were lost.

New Sensor Technology

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The three instruments on the Orbiter Boom Sensor System (OBSS) will use a mix of U.S.-and-Canadian-developed laser, television, infrared and 3D imaging technologies.

The sensors are:

• Laser Dynamic Range Imager (LDRI): The laser system was developed by Sandia National Laboratories in Albuquerque, N.M., and integrated by Boeing. It will be the primary sensor used to look at the Reinforced Carbon-Carbon (RCC) wing leading edges. It can also be used on Thermal Protection System (TPS) tile. It will need about 90 min. to scan each wing, on which there are 22 RCC panels, meaning a total of 44 wing panels will be scanned. The significance of any defects discovered will depend on the size and depth of those defects, in addition to where they are located on the leading edge.

The device is composed of an infrared laser illuminator and an infrared camera receiver mounted on a pan-and-tilt system at the end of the OBSS. Data from the LDRI will be sent to the ground for analysis as digital video imagery that can be viewed as either two-dimensional or 3D imagery. It must be downlinked through the orbiter K_u-band antenna.

• Intensified Television Camera (ITVC): The intensified television, also developed by Sandia, is comounted with the laser imager and, together, the two systems are designated SP-1. The laser system provides illumination for the intensified television, but the crew must select whether to collect data in either the infrared camera or intensified television mode for given scans.

• Laser Camera System (LCS): The sensor, developed by Neptec in Ottawa, Canada, can provide detailed 3D surface-topography data about damaged RCC or TPS tile. It is not an imaging camera as such, but rather a laser ranging instrument. The device is a wide-angle, high-speed, high-precision metrology instrument that uses a scanning technique patented by the National Research Council of Canada. The output of this sensor allows a ground-based computer to create a map of minute elevation differences, peaks and valleys and the roughness of defects. It does this by firing a narrow diameter laser beam, whose reflections are picked up by galvanometer-mounted mirrors.

Designated SP-2, the system has an advantage of being able to be used to better characterize damage initially detected by the other two sensors. Its data can also be downlinked more easily than the video stream sent by the other two sensors.

Although it has higher resolution than the other sensors and could be used to examine wing RCC or TPS tile defects, it is currently planned to be the primary sensor for scanning the orbiter's RCC nose cap. It is not the primary sensor for overall wing-panel scans because it would require 1 hr. per panel. Use of it on the wing LCC would take up too much time for the planned Flight Day 2 assessments. But the LCS could be used on any RCC or TPS tile areas of concern on planned Day 4 follow-up surveys.