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Human and robotic repair of a solar array wing during ISS assembly mission 10A

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Abstract

With the installation of a new module and the relocation of three other modules, including multiple hand-offs from the station arm (SSRMS) to the shuttle arm (SRMS), International Space Station (ISS) assembly mission 10A/STS-120 was anticipated to be one of the most complicated ISS assembly missions ever attempted. The assembly operations became even more complex when a solar array wing (SAW) on the relocated Port-6 (P6) truss segment ripped while being extended. Repairing the torn SAW became the single most important objective for the remainder of STS-120, with future ISS assembly missions threatened by reduced power generation capacity if the SAW could not be repaired. Precise coordination between the space shuttle and ISS robotics teams led to an operational concept that combined the capabilities of the SRMS and SSRMS robotic systems in ways far beyond their original design capacities. Benefits of consistent standards for ISS robotic interfaces have been previously identified, but the advantages of having two such versatile and compatible robotic systems have never been quite so spectacular. This paper describes the role of robotics in the emergency SAW repair and highlights how versatility within space robotics systems can allow operations far beyond the intended design scenarios.

Keywords: Robotic; Repair; ISS; Mission; Assembly; Solar array

1. Introduction

The top priority for International Space Station (ISS) assembly mission 10A, also known as STS-120, was to install the Harmony connecting module to the ISS [1]. The four preceding missions had focused on expanding ISS's power-generating capacity by installing solar arrays and truss segments, so installing Harmony marked a switch from expanding infrastructure to developing the space station's ability to conduct scientific research. Harmony's installation also introduced the possibility of adding international partners pressurized modules; without Harmony, the following three ISS assembly missions could not fly because there would be no available common berthing mechanism (CBM) ports to install their European and Japanese modules.

Harmony was ultimately to be inserted between the shuttle's pressurized mating adapter-2 (PMA-2) and the rest of the ISS. This was impossible to perform while the shuttle was docked to the ISS, so a three stage plan was devised to (1) install Harmony to a temporary location, (2) after the shuttle had undocked, relocate PMA-2 to Harmony, and (3) finally move the combined Harmony/PMA-2 payload to the forward Lab CBM.

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This operational sequence was already more complex than any previous mission, but the nominal flight plan included yet another major payload relocation. The upcoming modules would need additional power, so flight 10A's tasks were expanded to include relocating Port-6 (P6) from its zenith position, where it blocked the rotating starboard and port solar array wings (SAWs) so they couldn't track the sun, to its final port position where it could track the sun along with the other SAWs. The P6 relocation was itself planned to occur over three days, in which the SSRMS would demate P6 and hand it off to the SRMS, the mobile transporter (MT) would translate as far as possible to port, the SRMS would hand P6 back to SSRMS, then finally the SSRMS would install P6 onto the end of the port truss. The entire P6 relocation was scheduled to occur while the shuttle was still docked to the ISS, before PMA-2 could be relocated to Harmony.

Shortly before the launch of 10A, a problem was discovered with the starboard Solar Alpha Rotary Joint (SARJ), so the joint had to be locked and could not track the sun. Locking the starboard SARJ significantly reduced the amount of electricity generated by the starboard solar arrays, making it even more important to achieve full power generation capabilities with the port solar arrays.

During the flight, Harmony was installed to its temporary location according to plan, thus satisfying the mission's top priority, and the crew opened the new module and enjoyed the additional pressurized volume aboard the ISS. The P6 relocation proceeded smoothly through both handoffs and its structural connection to the end of the port truss, and the crew were soon deploying the P6 SAWs in their new location. This marked the last day of a long string of robotics operations, and the robotics support teams were looking forward to nearly a week of relatively quiet operations.

As the second SAW was being deployed, however, the crew suddenly stopped deployment because they noticed that the SAW had torn. Although the damaged SAW was capable of generating electricity, ground controllers were unable to resume sun tracking with the SAW only partially deployed. Physical stresses induced in the SAW while tracking the sun could potentially cause further damage. Because of the existing problem with the starboard SARJ, sun tracking was temporarily disabled for both sets of ISS SAWs. The partially deployed SAW was also much more flexible than a fully deployed SAW and the higher flexibility made ISS attitude control more difficult. Repairing the torn P6 SAW suddenly became the new top priority for flight 10A.

In a previous discussion of lessons learned from shuttle robotics, Hiltz and Ravindran stated that, "it is only when such a capability is not available that its importance is highlighted" [1]. Luckily, during STS-120, the combined ISS and shuttle robotic elements were available and versatile enough to support a last-minute SAW repair.

2. Emergency EVA robotics plan

Crew members typically train for months or years before each mission for extra-vehicular activity (EVA), rehearsing and optimizing each operation for safety and efficient use of time. The P6 SAW ripped on Tuesday October 30, 2007, and the repair was made only four days later on Saturday November 3, 2007. While the EVA and SAW communities devised a method to repair the array, the ISS robotics community planned how to get a crewmember in position to perform the repair.

Within 24 h of the errant SAW deployment, a robotics plan had already solidified. The EVA and robotics plans underwent thorough safety reviews including reviews by the crew onboard. In the four days it took to put a repair plan in place, regular meetings were held around the clock at different levels from the Engineers to the Program Managers. The mission management team met every hour for status updates from every discipline working items needed for the emergency EVA. Test rigs were setup on Space Station models on ground to verify and prove that repair techniques and tools will work safely. For example, the SAW hinge tool specifications had to be defined and refined with the crew and the ground had to verify on ground test rigs that those specifications will work. Also, constraints had to be established to reduce risk to the EVA crewmembers. Once the EVA plans were finalized, it was clear that by orienting the port SARJ at the correct angle, attaching an extended EVA platform to the orbiter boom sensing system (OBSS), locating the SSRMS at its farthest-possible port position and extending the SSRMS so that it was almost completely outstretched, the damaged area was just within reach of a potential EVA crewmember. The SSRMS, OBSS, and an EVA crewmember are shown manoeuvring into position in Fig. 1. The partially deployed and damaged SAW is visible in the center background.

The robotics plan started by placing the SSRMS base as close as possible to the damaged SAW, and manoeuvring the SSRMS into position to be ready to receive the OBSS from the SRMS. Shortly before the EVA started, the OBSS would be handed from the SRMS to the SSRMS and then manoeuvred into a position in which