for development of new remote sensing capabilities relevant to both research and applied science – including disaster response – and represents a significant contribution to continuance and enhancement of the NASA mission to investigate changes on our home planet.

Clearance Analysis of Node 3 Aft CBM to the Stowed FGB Solar Array

Donn Liddle

In early 2011, the ISS Vehicle Configuration Office began considering the relocation of the Permanent Multipurpose Module (PMM) to the aft facing Common Berthing Mechanism (CBM) on Node 3 to open a berthing location for visiting vehicles on the Node 1 nadir CBM. In this position, computer-aided design (CAD) models indicated that the aft end of the PMM would be only a few inches from the stowed Functional Cargo Block (FGB) port solar array (see figure 1).

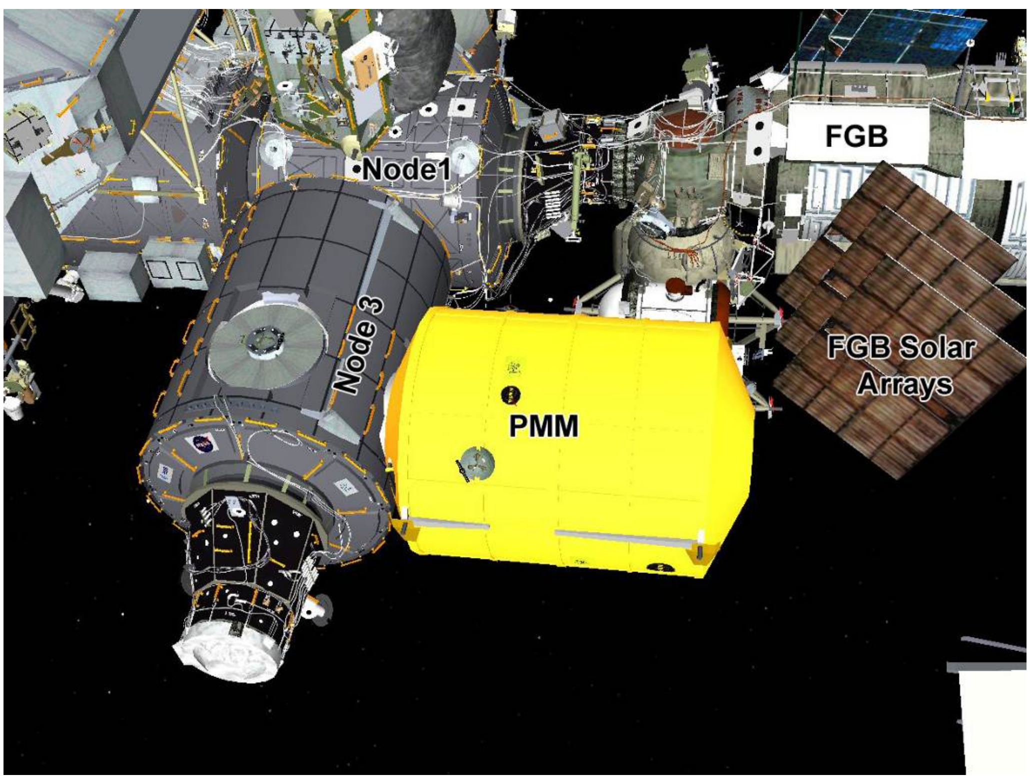

Figure 1.– Proposed relocation site for PMM with minimum clearance to FGB solar arrays.

To validate the CAD model clearance analysis, in the late summer of 2011 the Image Science and Analysis Group (ISAG) was asked to determine the true geometric relationship between the on-orbit aft facing Node 3 CBM and the FGB port solar array (see figure 2).

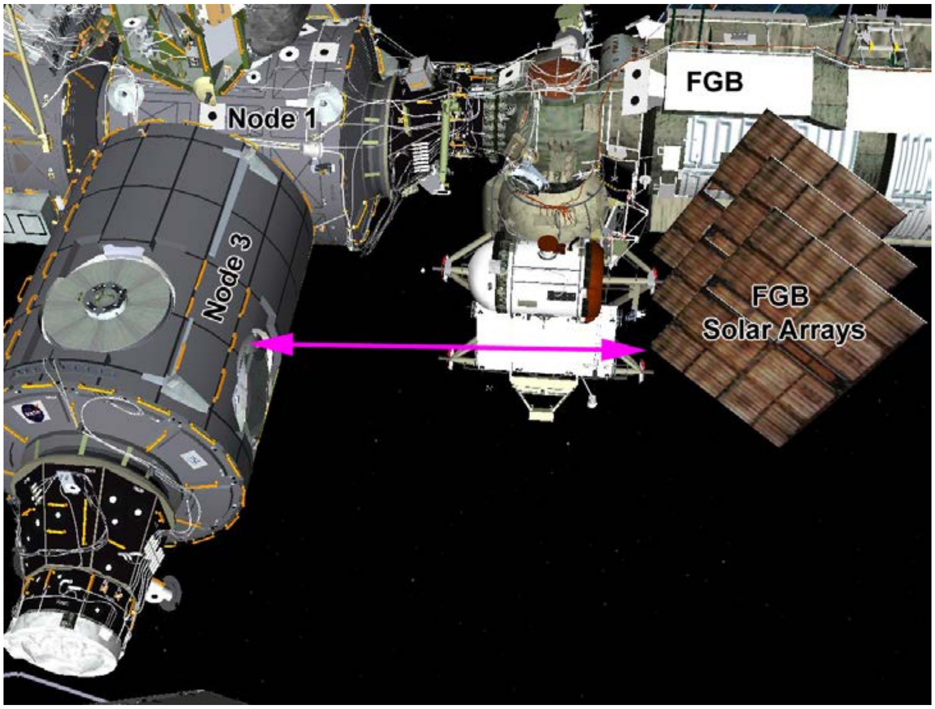

Figure 2.– Photogrammetric analysis of the aft face of Node 3, port side of Node 1, port side of pressurized mating adapter 1 (PMA1), port side of the FGB hemisphere, and port FGB solar arrays to determine the absolute location of the port FGB solar arrays relative to Node 3.

The desired measurements could be computed easily by photogrammetric analysis if current imagery of the ISS hardware were obtained. Beginning in the fall of 2011, ISAG used the Dynamic Onboard Ubiquitous Graphics (DOUG) program to design a way to acquire imagery of the aft face of Node 3, the aft end-cone of Node 1, the port side of pressurized mating adapter 1 (PMA1), and the port side of the FGB out to the tip of the port solar array using cameras on the Space Station Remote Manipulator System (SSRMS). This was complicated by the need to thread the SSRMS under the truss, past Node 3 and the Cupola, and into the space between the aft side of Node 3 and the FGB solar array to acquire more than 100 images from multiple positions.

To minimize the number of SSRMS movements, the Special Purpose Dexterous Manipulator (SPDM) would be attached to the SSRMS. This would make it possible to park the SPDM in one position and acquire multiple images by changing the viewing orientation of the SPDM body cameras using the pan/tilt units on which the cameras are mounted. Using this implementation concept, ISAG identified four SSRMS/SPDM positions from which all of the needed imagery could be acquired. Based on a photogrammetric simulation, it was estimated that the location of the FGB solar array could be measured within an accuracy of about 1 in. in each axis relative to the ISS Analysis Coordinate System (ISSACS).

In October 2011, a proposed image-acquisition plan was drafted by ISAG and released for review. The ISS Robotics flight control team (ROBO) proposed minor changes to SPDM positions 1 and 4 to meet ISS proximity requirements. The updated image acquisition plan and draft chit were presented to and approved by the Systems Working Group (SWG) November 18 and were sent to the Vehicle Configuration Board (VCB) in early December 2011.

Working with ROBO on 3 successive days (February 21, 22, and 23), ISAG collected 161 images of the ISS. Approximately 40 images were collected from each of the four different SSRMS/SPDM positions, with each set mapping the region from the Node 3 end cone, across Node 1, along the forward port side portion of the FGB, and out the port side FGB solar arrays.

From this imagery, the best 80 images were selected for use in the analysis. The images were radiometrically enhanced to improve color and contrast and loaded into the FotoG analysis software along with the camera parameters and control data, which consisted of the coordinates for 54 handrail attachment bolts on the aft face of Node 3, in the ISSACS coordinate system.

The results of this analysis produced the measured coordinates of 116 points distributed across the face of the FGB solar array panels (see figure 3) along with propagated uncertainty estimates in each coordinate axis. These results were sent to the ISS Vehicle Configuration Office, which sent them to the Configuration Analysis Modeling and Mass Properties (CAMMP) team for comparison with the Russian-provided CAD model for the retracted FGB solar arrays.

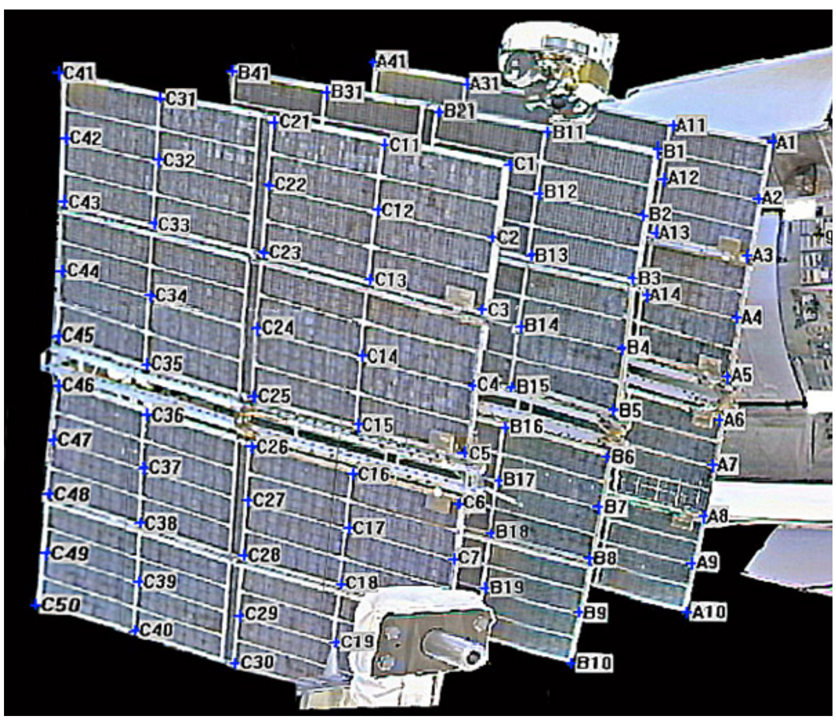

Figure 3.– Points measured on the port FGB solar array in the ISSACS coordinate system defined by Node 3

The CAMMP analysis unexpectedly showed that the measured location of the port FGB solar array was up to 41-in. further outboard than the design and was slightly twisted about its rotational axis (as shown in figures 4 and 5).

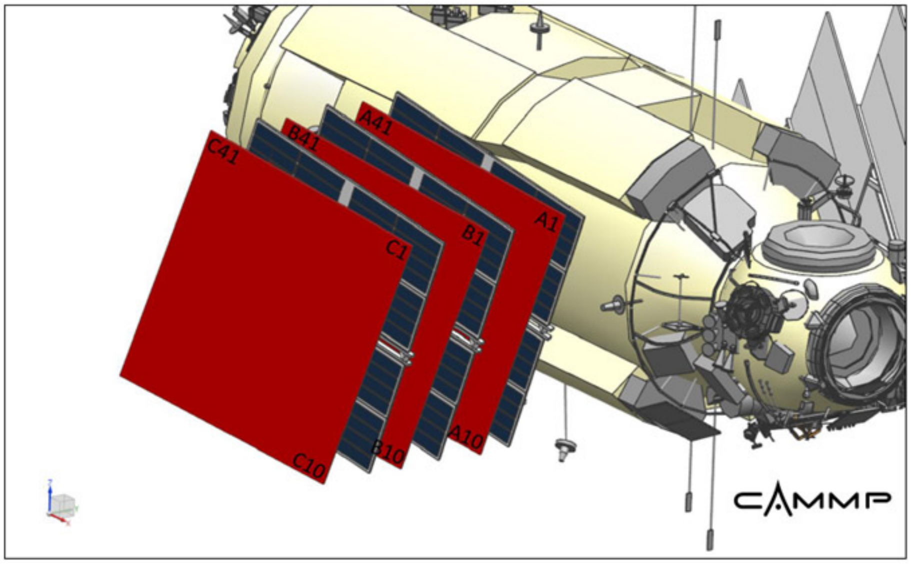

Figure 4.– Delta configuration between the measured coordinates of the port solar array (shown in red) relative to the CAD design models (shown in blue).

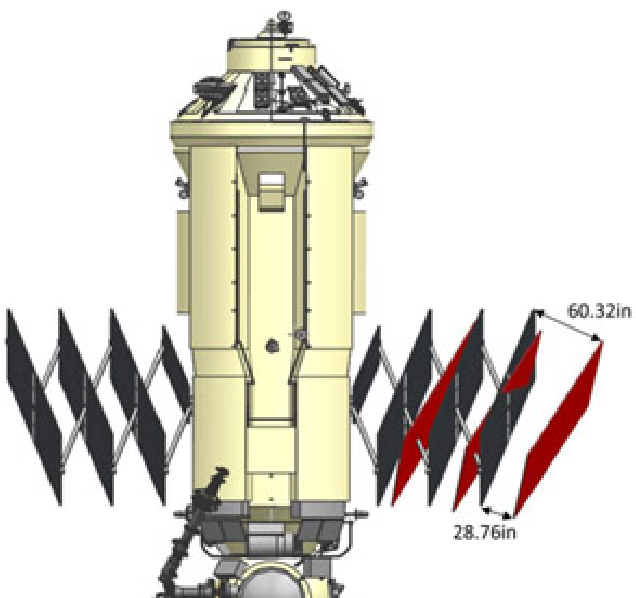

Figure 5.– Delta configuration between the measured coordinates of the port solar array (shown in red) relative to the CAD design models (shown in gray).

The unexpected comparison results produced some initial concern regarding the accuracy of the photogrammetric measurements. To verify the measured results, ISAG personnel conducted a second analysis using just the imagery of the solar arrays in an arbitrary coordinate system defined by the three corner points of the inboard-most panel, with the design distance between points A1 and A10 as the only scale (see figure 6).

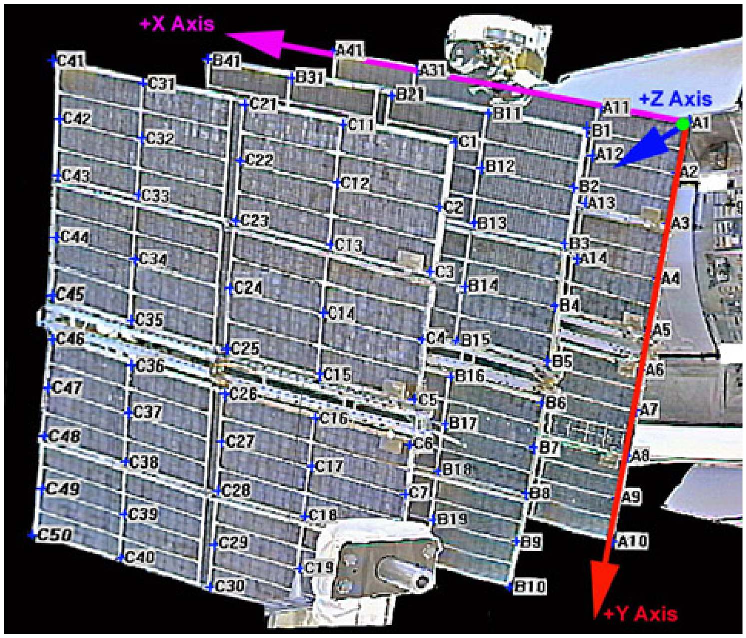

Figure 6.– Control for second analysis.

The new measurements agreed with the original results to within less than 1 in. RMS in each axis, confirming the original solar array measurements.

ISAG produced a final report for the ISS Vehicle Configuration Office documenting an apparent anomaly in the retracted configuration of the port FGB solar arrays. A copy of the measurement report was translated and sent to the Russian Space Agency. During a Vehicle Integrated Performance and Resources (VIPeR) teleconference September 24, 2012, the Russians acknowledged receipt of a translated copy of the ISAG report. The Russian representative stated that the head of the solar array design team claimed that the measured configuration was impossible unless the structure was physically broken. The Russians acknowledged that they had no expertise in photogrammetry, so the analysis technique employed was a “black box” to them, and they did not know how to use the ISAG results. They asked for a single image in which the overextension of the port solar array could be obviously seen.

On November 10, 2012, during a face-to-face meeting with their Russian counterparts at JSC, ISAG presented nadir-view imagery of the FGB acquired during Space Shuttle rendezvous. Using the known width of the pressurized portion of the FGB as a scale, this analysis clearly showed that the port FGB solar array was extended outboard further than the Russian design for the retracted solar array (see figure 7).

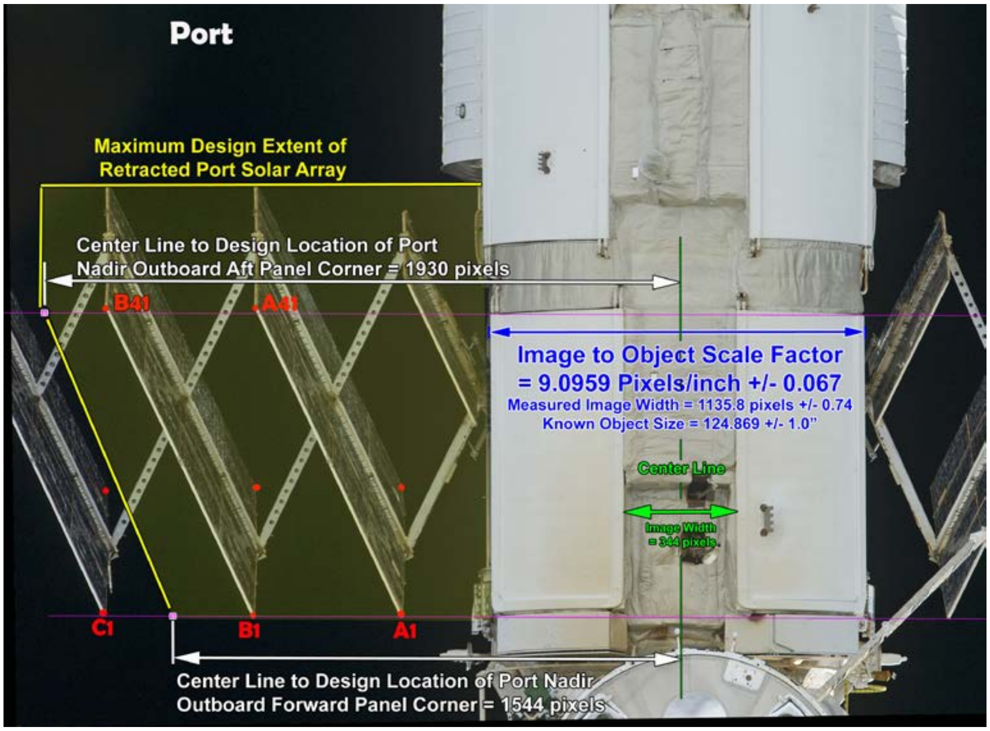

Figure 7.– Single camera measurement of the port FGB solar array.

The same photo contained the image of the starboard FGB solar array. A similar analysis revealed that it also exceeded the designed retraction state (see figure 8).

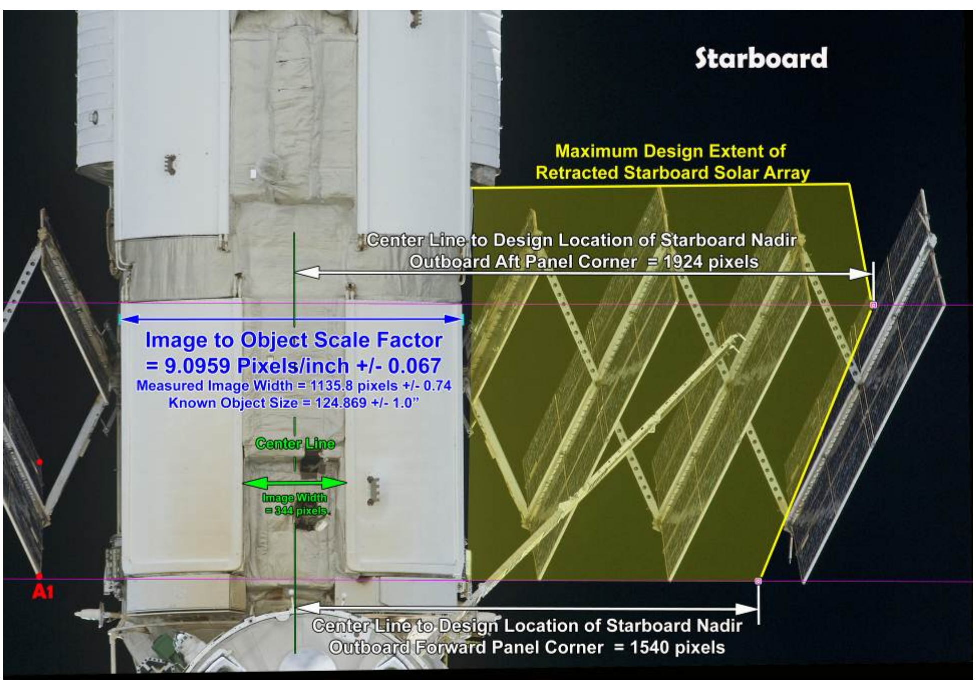

Figure 8.– Single camera measurement of the starboard FGB solar array.

ISAG presented a historical review of the port FGB solar array, showing that the retracted state of the solar array had not detectably changed between October 25, 2007, (28 days after port FGB solar array retraction) and May 18, 2011 (last available nadir image of the FGB). In response, the Russians stated that when the limit switch that controlled the solar array retraction process was tripped and power was removed from the retraction drive motor, the solar array may have rebounded outward by some small amount. They stated that this rebound would have been no more than half a meter, although no documentation or measurements were presented to support this position.

In early January 2013, ISAG located on-orbit recorded video of the port FGB solar array retraction from September 2008. The video shows that when the array reached the point of maximum retraction, it rebounded outboard and oscillated several times before finally stabilizing in a configuration that was significantly less retracted than the minimum point. A similar rebound was seen during the retraction of the starboard FGB solar array. A copy of the port and starboard solar array wing retraction video was provided to the ISS Vehicle Configuration Office and the Structures and Mechanisms Group.

In response to the discovery of the retraction anomaly, the ISS Program Office abandoned efforts to relocate the PMM to the aft Node 3 CBM and has issued a change request to relocate it to the forward Node 3 CBM. The Shuttle Engineering Change Implementation Board (SECIB) has also requested that ISAG perform a photogrammetric analysis of the starboard FGB solar array to document its current configuration.

The image-based measurement techniques employed by ISAG identified and documented a major discrepancy in the as-built configuration of the ISS. Without this capability, any attempt to relocate the PMM to the Aft Node 3 CBM would have resulted in hard contact with the port FGB solar array.

Clearance Analysis of CTC2 (on ELC4) to S-TRRJ HRS Radiator Rotation Envelope

Donn Liddle

In response to the planned retirement of the Space Shuttle Program, International Space Station (ISS) management began stockpiling spare parts on the ISS. Many of the larger orbital replacement units were stored on the Expedite the Processing of Experiments to Space Station (EXPRESS) Logistics Carriers (ELCs) mounted on the end of the S3 and P3 truss segments, immediately outboard of the Thermal Radiator Rotary Joints (TRRJs) and their attached radiators. In an August 2009 computer-aided design (CAD) assessment, it was determined that mounting the Cargo Transport Container (CTC) 2 on the inboard face of ELC4 as planned would create insufficient clearance between the CTC2 and the rotational envelope of the radiators when the TRRJs were rotated to a gamma angle of 35.0 degrees (see figure 1). The true clearance would depend on how