Functional Cargo Block Structural Life Extension

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The Functional Cargo Block—usually referred to by the Russian acronym FGB—was the first module of the International Space Station (ISS) to be launched. This event took place on November 20, 1998 (figure 1).

Fig. 1. *The Functional Cargo Block on orbit.*

The certified life of the FGB was originally 15 years, meaning it would reach the end of its certified life by the end of 2013. The original life expectancy for the ISS was 2016. This 3-year discrepancy drove the FGB life extension effort that began in 2004.

The ISS is truly an international collaboration involving many international partners. Two major contributors are the United States and Russia. The design and certification philosophies between these two partners, however, were not necessarily the same. To work together successfully, the partners developed an agreement stating that certification of the U.S. elements would be performed using U.S. standards, and certification of the Russian elements would be performed using Russian standards. In light of the United States' responsibility for overall ISS integration, both partners worked jointly to evaluate—not certify—Russian elements against U.S. standards. This evaluation approach was used for the FGB life extension effort.

The structural life of the FGB was certified using a dedicated fatigue test article. Three highly loaded interfaces were identified for testing. These locations were the forward end where the FGB attached to the pressurized mating adapter and the U.S. segment, the aft end where it attached to the service module, and at one of the two solar array attachment points. Engineers developed a design load spectra at each of these interfaces, which would envelop the actual load spectra to which the interfaces would be exposed. These spectra were then applied at each of the three interfaces one at a time with each set of three spectra representing a 15-year life. Since the Russians required a scatter factor of 8 on life, this procedure was repeated seven more times (figure 2).

Fig. 2. *The Functional Cargo Block.*

The United States evaluates life with a different approach, and generally does an analytic determination of life. That is, the United States uses fatigue analysis, and for critical locations, a fracture mechanics analysis.

Several pieces of data were necessary to perform the fracture mechanics analysis—data not immediately available for the FGB. These data included: fracture mechanics properties of the Russian materials, and non-destructive evaluation (NDE) flaw detectability of the Russian NDE techniques.

Samples of several materials were shipped from Russia to Johnson Space Center in Houston, Texas, for testing to obtain the fracture mechanics properties of the Russian materials. Two of these materials were sheets of Russian Aluminum AMg6-H and AMg6-M. These materials are commonly used by the Russians, as the FGB shell was fabricated using AMg6-H. Several technical interchange meetings were held in Houston and in Moscow to determine the materials' NDE flaw detectability. Russian

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continued

techniques were used on standard NDE specimens. It was determined that the Russian techniques had almost identical results to the U.S. methods.

With these data, the U.S. and Russian team performed further analysis as part of the additional evaluation for the integration task. There were two areas of evaluation, the first of which was robustness of the design. Using fracture mechanics techniques, the team demonstrated that the FGB was a leak-before-burst design, meaning if a crack-like flaw occurred in the structure, the module would not rupture but would, at worst, leak. The second area of evaluation involved performing spot checks of some critical areas using fracture mechanics techniques.

Life Extension

Life extension for the FGB (and for the ISS) can be a difficult task. Since the hardware is on orbit, it can't be structurally modified to give it additional life, or be re-inspected to demonstrate additional life. Because of the difficult nature of life extension, the FGB certification included U.S. methods along with the Russian methods.

Fatigue Test Article

While the FGB was not accessible during the life extension activities, the Russian partners retained their fatigue test article to allow for additional test cycles. Additional fatigue testing was done using the design spectrum at the forward and aft interfaces, which were run to a 2028 equivalent time frame. The solar array attachments were not included in this assessment because the FGB solar arrays were refolded due to an interference with the main radiators on the U.S. segment after the solar arrays were deployed (figure 3).

Updated Spectra

Fracture mechanics methods can be more conservative than fatigue analysis or tests, therefore it was unlikely that a fracture mechanics method would demonstrate life for all components of the FGB to 2028 using existing analysis with the existing design spectrum. However, since the ISS has been in operation for the past 10 years, access to actual loads data to which the FGB has been exposed is available.

Fig. 3. *The Functional Cargo Block with solar arrays folded.*

As such, a new spectrum was developed using the history to date and new predicted spectra to 2028.

Analysis Updates

In some cases, simply modifying the loads spectra was not sufficient to demonstrate adequate life. In these cases, it was also necessary to refine the stress analysis that determined the stresses used in the fracture analysis.

Weld Fracture Data

The FGB structural shell consists of a number of machined segments that were welded together. During its initial evaluation, the material testing done to obtain fracture mechanics properties did not include welded materials. To adequately perform life analysis on the welds, these data were needed. To this end, the Russians produced weld samples for use in developing these properties. Given the FGB's original construction was 15 years ago, advances in welding process in the intervening years raised concerns. Several weld sections were cut out of the fatigue test article to account for this. These sections, along with samples that the Russians produced, were tested at Johnson Space Center to determine the fracture properties of the as welded material. These data were, in turn, forwarded to the Russians for use in their fracture assessment of the FGB.

Conclusion

Extending the life of an on-orbit vehicle can be challenging, and the FGB was no exception; however, life predictions for the FGB were increased by gathering additional data and removing conservatism from analysis. Although this work is not complete, all indications are that the FGB life certification will be extended to 2028.