NORTHROP GRUMMAN
Space Technology
Raytheon

THE AEROSPACE CORPORATION

Teaming Early, Teaming Often

Case Study #1. Collaboration Between Raytheon IIS and The Aerospace Corporation in Development of NPOESS Preparatory Project (NPP) Orbit Operations Software

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What's the Big Picture?

- **The NPOESS Preparatory Project (NPP) Orbit Operations (OO) subsystem provides Launch, Early Orbit, and Anomaly (LEOA) maneuver support as well as orbit and attitude maintenance for the NPP and NPOESS satellites. The OO subsystem has multiple functions that include Determine Orbit, Determine Attitude, Determine Orbit & Attitude Events, Identify Station Violations, Evaluate Maneuvers, and Plan Maneuvers. These functions also include the generation of data needed for planning and scheduling of payload activities and ground contacts. Furthermore, the OO subsystem enables analysts to predict, modify and resolve vehicle state/orbit.**
- **The Raytheon Intelligence and Information Systems (IIS) Orbit Operations team, located in Denver, is developing software under subcontract to NGST during build C1.3 to implement 84 subsystem requirements, of which 16 need to be validated by analysis to ensure the Orbit Operations (OO) software meets the stated requirements.**
- **The analysis entails generation of truth models, comparison between OO software outputs and the truth model results, and assessment of any deviations. This task was performed jointly by technical teams from Raytheon IIS and The Aerospace Corporation.**

What's the Problem?

- **16 of 84 OOS requirements needed to be verified "by analysis". This means that it must be determined that the software computes not just an answer, but the "correct" answer. Part of the analysis entails an evaluation of what the "correct" answer is.**
- **A successful, valid verification by analysis entails**
  - **Generation of "independent" data to compare against software results**
  - **Comparison of software results against "independent" data**
  - **Assessment of results and deviations**

  It is best conducted by an organization outside of the software development and test organizations. The more independent the organization, the better.
- **The Raytheon OO team lost two key technical members and didn't have the manpower to do the highly technical analysis work in parallel with the software development efforts in the allotted timeframe for build C1.3.**
- **In the short timeframe it would have been very hard for the Raytheon OO team to hire a qualified person with the needed orbital domain knowledge and expertise to help with the development of the required analysis models.**

Why Collaborate?

- **Raytheon didn't have the resources to perform the analyses in a timely manner.**
- **Aerospace had experience in orbital operations software validation for programs such as Data Systems Modernization (DSM) and Distributed Command and Control System (DCCS).**
- **Aerospace had worked with Raytheon on previous orbit operations software programs, including DCCS and Control Channel Toolkit (CCT), and already had developed independent tools that could be used in analysis verification.**
- **The Raytheon NPOESS OO software is based on reuse code from heritage and existing government programs including CCT and DCCS.**
- **Certain team members from each company had worked together successfully on previous programs, so that MUTUAL CREDIBILITY, RESPECT, AND TRUST had already been established.**
- **The program office also benefits by having an independent organization perform the requirements analysis.**

Who's Involved?

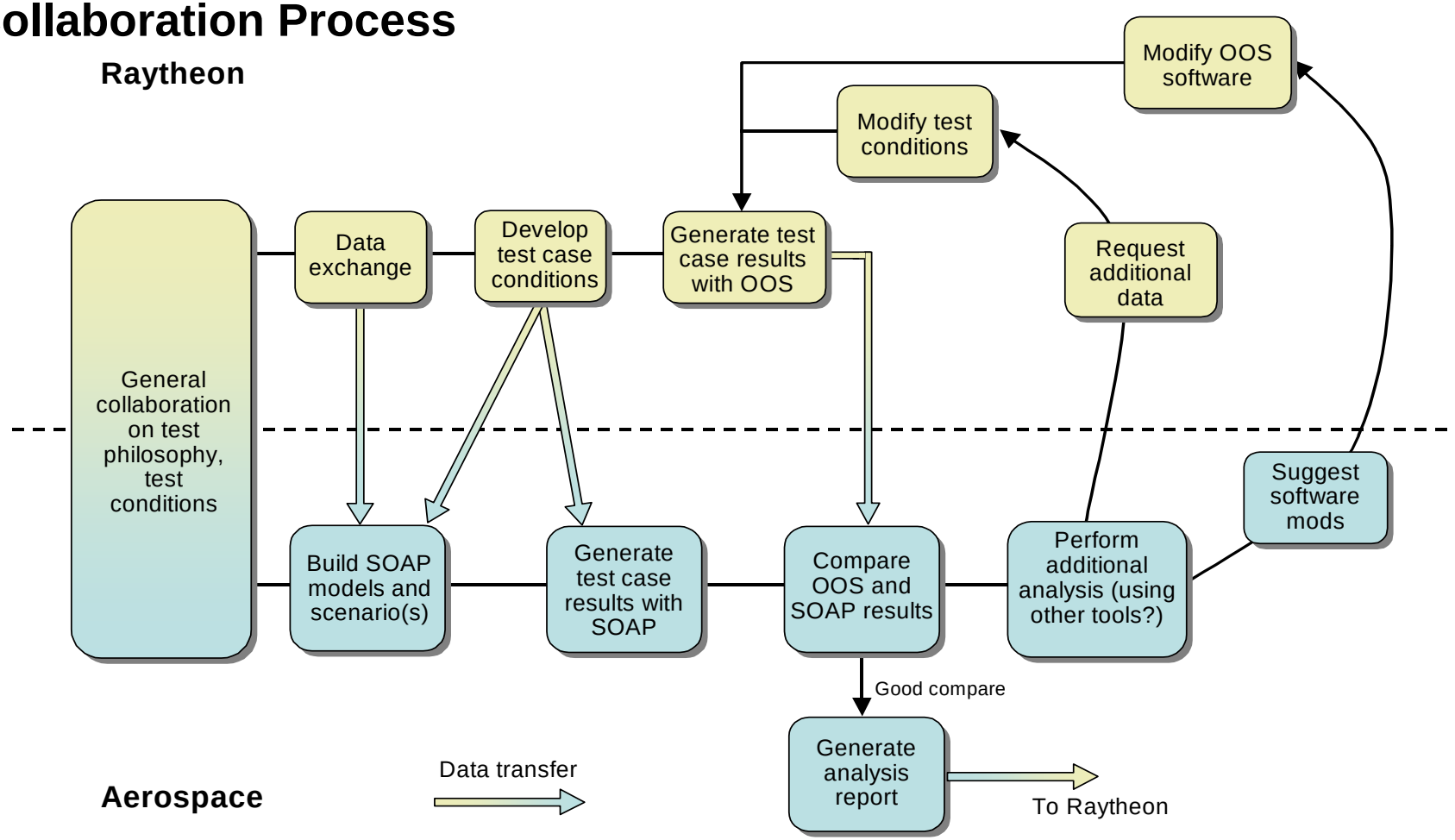
- **Raytheon IIS**
  - **Orbit Operation Team – Denver, CO**
    - **Betsy Dampier – OO Software Technical Lead**
    - **Rob Olson – OO Multi-Disciplined Engineer and Chief Scientist**
    - **Shannon Guidice – OO System Engineer**
    - **Ryan Angell – OO Software Engineer**
    - **Rita Hurst – OO Software Item Lead**
    - **Occasional help from NPOESS System Engineering Organization and Tom Skinner**
- **The Aerospace Corporation**
  - **Silver Spring, MD – NPOESS IPO**
    - **Pete Phillips – commissioned the work and provided the $$$**
  - **El Segundo, CA**
    - **All team members work in the Engineering & Technology Group and are technical specialists in flight mechanics and controls.**
    - **Team members included Roger Metzler, Shawn Iravanchy, Benjamin Mains, David Garza, and Wayne Hallman.**

How Did You Do It?

- **Initial setup**
  - **A joint statement of work was developed that both teams bought into.**
  - **An initial discussion of requirements was held to discuss the requirements to be verified, what they meant, and how each might be accomplished.**
  - **A face-to-face kickoff meeting was held to meet the "other guy" and get the effort started.**
- **Roles of each team during the analysis effort**
  - **The Raytheon team supplied relevant modeling information (ephemerides, sensor locations) and algorithms to the Aerospace analysis team as necessary and provided OO software database parameters, inputs, and outputs needed by Aerospace for validation analysis. Some of this data was generated in parallel with Qualification Testing. Final data for analysis was from Qualification Test Run for Record.**
  - **Aerospace already had well-proven analytical tools suitable to perform the analyses. The main tool used was SOAP (Satellite Orbit Analysis Program). *Mathcad* was used, when necessary, to mimic the OOS algorithms and compute detailed intermediate results.**

How Did You Do It?

Collaboration Process



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How Did You Do It?

- **Products of the collaboration**
  - **Disposition for each requirement included complete analysis case documentation, describing the preparation, data collection, data development, conduct, and analysis of results.**
  - **For each requirement verification, Aerospace generated a report documenting the analysis results, which were used for the final Raytheon analysis reports. The final reports:**
    - **Provide a description of the actual analysis performed, including the identification and justification of the analysis technique(s) employed, and any assumptions or conditions associated with the analysis approach.**
    - **Define reasonable and agreed upon differences in results that will allow the requirements to be validated.**
    - **Provide an analysis results summary, capturing the results of external validation that has been executed to validate the OO software results. This includes indicating the performance level achieved for each requirement and an assessment as to whether the requirement is satisfied.**

How Did You Do It?

- **Interaction was facilitated through**
  - **Team members had free access to each other. There was no "chain of command" that one team had to go through to contact the other.**
  - **Email was utilized extensively to send data, software outputs, and analysis back and forth; and to ask questions.**
  - **The telephone was utilized extensively to ask questions and request additional data.**
  - **The NGST "*Eroom*" application enabled data and documentation to be posted on an intranet that all parties had access to.**
  - **One Aerospace analyst visited Raytheon midway through the effort. This renewed the face-to-face interaction.**
  - **Assuring Aerospace had badge access to the Raytheon Aurora Facility. Aerospace was able to bring computer resources (laptops) into the facility, which facilitated the initial data exchange and analysis.**

How Did You Do It?

- **Programmatics and progress tracking**
  - **Status telecons were held every 2 - 4 weeks, when substantial progress could be reported or when discussions were necessary. Status meetings were not called "just to have a meeting".**
  - **Each telecon included a review of the status of each requirement. A chart was presented showing status of the following items for each requirement.**
    - **SOAP modeling (ready, in progress, complete)**
    - **Analysis (in progress, open issues, complete)**
    - **Report (in progress, complete)**
  - **Each telecon also included discussion of problems and open issues.**
  - **Raytheon status was reported to its management in weekly status reports and at Formal Meetings for build C1.3 (SWIC closeout, TRR, QTRR, PTR, and BTR).**

How Did You Do It?

- **Collaboration timeframe**
  - **Build C1.3 NPOESS OO software and test development milestones:**
    - **6/7/2004: IRR – Integration Readiness Review – End of Code and Unit Test**
    - **8/2/2004: SWIC Closeout – S/W Integration Checkout/Closeout – End of SW Integration and Checkout and SW internal handoff to test**
    - **9/10/2004: TRR – Test Readiness Review – Test Readiness for Formal Dry-Runs**
    - **11/3/2004: QTRR – Qualification Test Readiness Review – Test Readiness for Run For Record**
    - **11/19/2004: PTR – Post Test Review – Formal Completion of Run for Record**
    - **2/16/2005: BTR – Build Turnover Review – Marks the end of the Build C.1.3**
  - **Analysis effort milestones:**
    - **6/4/2004: Statement of work formalized**
    - **6/22/2004: Kick-off meeting**
    - **1/21/2005: Analysis complete**

Did it Work?

- **YES – this was a very successful collaboration effort.**
- **Raytheon was able to concentrate on testing and on-going software development.**
- **The OO software was validated by a COMPLETELY INDEPENDENT Aerospace team, which increased the confidence, of all involved parties, that the software functions analyzed were working correctly.**
- **Necessary code fixes were implemented prior to testing.**
- **Qualification testing was successful and completed almost on schedule and ahead of 3 other SIs (previous build C1.2 was 6 weeks behind schedule)**
- **Most of the analysis was complete prior to formal qualification testing, so there was high confidence, going into formal testing, that the software was functioning properly, and the test results would be satisfactory.**

What Helped?

- **Mutual credibility, respect, and trust existed between certain team members before effort started. This didn't have to be established.**
- **The Raytheon project lead was receptive to Aerospace involvement, so there was no barrier to communication and contact.**
- **The unclassified status of the program and task made collaboration and exchange of data and results much easier than a classified program.**
- **Orbit operations domain knowledge on both teams helped tremendously in resolving problems that arose during the analysis.**
- **Aerospace SOAP was the perfect tool for the job. The necessary analysis and visualization capabilities already existed, and analysts were experienced with its use. No extensive tool development work was required.**
- **Use of an HP Digital Sender facilitated the creation & transmission of analysis reports. The sender scans hardcopy and converts it to PDF. This enabled combination of results of difference applications (*Word*, *Excel*, SOAP, *Mathcad*) into a single PDF document.**

What Didn't?

- **Discussions on algorithms in telecon conversations were highly technical at times and it was sometimes hard for both teams to understand what the person at "the other end" was trying to describe.**
  - **In the future, video-conferencing might help to make this easier.**
  - **Another option might be computer applications enabling "sharing of desktops". Lotus *Sametime* is an example.**
- **It would have helped if the Aerospace team had been involved earlier in the requirement definition and design phases.**
  - **This won't be a problem for any future work, since the collaboration between the two teams has now been established.**

What's Next?

- **Final Raytheon analysis reports have to be completed and submitted to the customer for review.**
- **Similar collaboration will be utilized to verify requirements for future OOS builds (C1.3 ECR related software changes, C1.4, NPOESS software build 2.1).**
- **The Aerospace team continues to support the Raytheon OO team in requirements and design discussions for future builds that will also have to verify requirements by analysis.**