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Development of the Boeing Rocketdyne Propulsion and Power RS-68 Rocket Engine for the Delta IV

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This article was originally published in the Summer of 2004 issue of ADI's AD-LIB newsletter. With recent resurgence of interest in rocket propulsion technology, we've decided to republish this outstanding article into ADI's technical library.

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Article Title: The Use of ADI SIMsystem for the RS-68 Rocket Engine Controls Development

Foreword
By Scott James

The next decade is shaping up to be an exciting time for space technology development. As the United States begins to embark on concerted push back into space and on to Mars, exciting projects such as the Mars Reconnaissance Orbiter (MRO) and the Crew Exploration Vehicle (CEV) raise the topic of propulsion.

The CEV is planned to replace the shuttle, return astronauts to the moon, and eventually to Mars. NASA's first formal request for proposal for CEV propulsion requires a rocket able to propel 44,000 lbs. This proposal has resulted in many discussions of new propulsion technologies and projects. Most of the proposed new technologies exist only on paper. However, Boeing Rocketdyne's Delta IV Heavy, demonstrated with a spectacular show at Cape Canaveral December 2004, would satisfy NASA's requirements with proven technology. One of the impressive features of the Delta IV Heavy is that it, by design, sets itself on fire during its ignition sequence and is engulfed in a cloud of burning hydrogen during lift-off. In order to support CEV exploration missions the Delta IV Heavy would need to undergo monitoring and destruction upgrades.

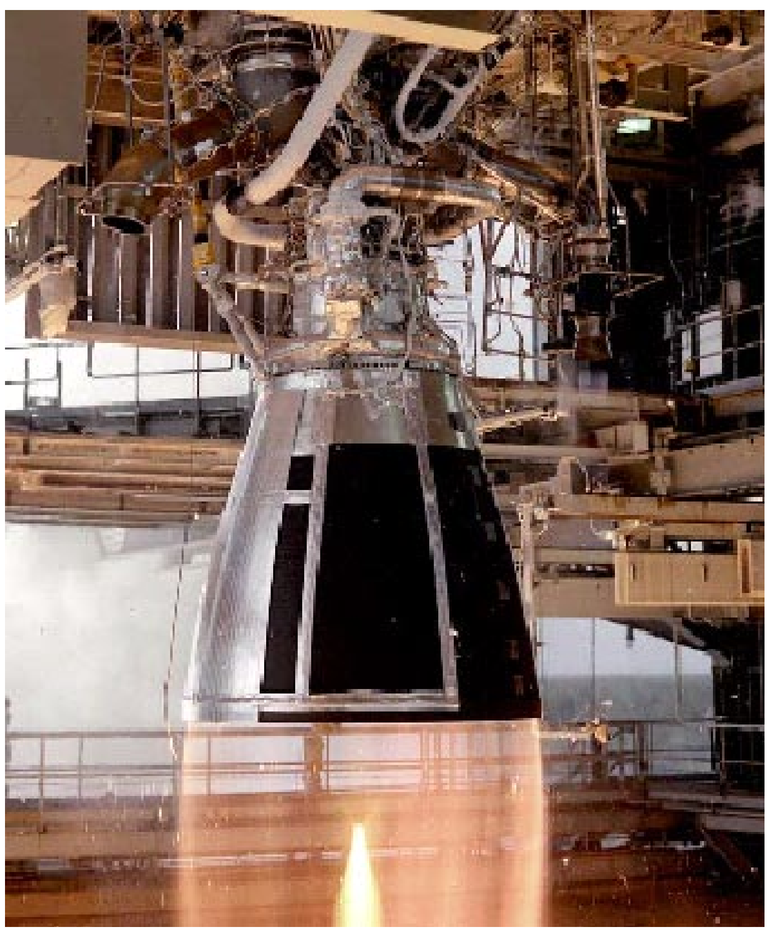
The Delta IV Heavy uses three of the RS-68 engines that are the topic of the article to follow. To date the RS-68 engines have a 100% safety record and look as though they will have a long and illustrious life.

Kentaro Kajino's fascinating article provides insight into the development of the RS-68 rocket engine and illustrates how space programs apply ADI's open architecture real-time simulation technology to reduce risk and meet tight deadlines on the most challenging of projects.

The Boeing RPP RS-68 Engine

Compared to the Space Shuttle Main Engine, which produces 394,000 lbf of thrust, the RS-68 is a much larger engine, producing at sea level 650,000 lbf.

When the U.S. Air Force selected the Delta IV launch vehicle to become their next generation space launch system, Boeing RPP (Rocketdyne Propulsion and Power) was chosen to build a completely new rocket engine, dubbed the RS-68. The significance of the RS-68 engine is that it is the first brand new first-stage liquid propellant engine produced in the U.S. to fly since the Space Shuttle Main Engine, which has now flown for over 20 years. One of the aims of the Delta IV program is to drastically lower the cost of launching payload, while fulfilling the more traditional requirements for performance and reliability. For the first time in history, cost reduction was made a consideration from the very start of a U.S. made rocket engine program. This had required building cost reduction measures into the design of the engine, as well as the various processes for development, production and operation. HWIL (Hardware-in-the-Loop) testing using ADI's SIMsystem played an important role in meeting these stringent demands for success and lowered cost during the development of the RS-68 engine.



RS-68 engine in hotfire testing

Compared to the Space Shuttle Main Engine (SSME), which produces 394,000 lbf of thrust, the RS-68 is a much larger engine, producing at sea level 650,000 lbf. It uses liquid oxygen and hydrogen for propellants, just like the SSME, but it has a much simpler pressurization system than the SSME to drastically reduce the number of parts. An ECU (Engine Control Unit) controls engine output by regulating propellant flow into the combustion chamber. This finely tuned ECU controls the engine through start, throttle and shutdown operations, some of which are very sensitive, given the extremes of forces and temperatures experienced by the engine. To support the development of this control system, Boeing RPP built a HWIL test setup with ADI's SIMsystem, which took the entire RS-68 control system through its paces well before the real engine was hotfire tested for the first time.

Hardware-in-the-Loop Engine Controller Development

To support the development of this control system, Boeing RPP built a HWIL test setup with ADI's SIMsystem, which took then entire RS-68 control system through its paces well before the real engine was hotfire tested for the first time.

The purpose of HWIL testing was broadly defined as overall risk mitigation and validation of the control system design. To reflect this broad scope, a modular approach was taken in designing the HWIL test setup to ensure flexibility. Thus, the test setup was able to accommodate many unforeseen tasks, which had not been part of the initial plan for HWIL testing. Customers from across the nation within the RS-68 and Delta IV programs came to us to set up any kind of test on the control system they desired. These tests could involve the entire system or just a small part, such as one valve. But most notably, the HWIL simulation could be integrated with a completely separate system, such as the test control and data acquisition system used on the hotfire test stand.

Integrating the HWIL test setup went surprisingly smoothly, thanks to the user-friendliness of ADvantage IDE. It helped tremendously in reducing human error and allowing Boeing RPP to concentrate on the control system issues rather than integration issues. The end product was functionally a "real" RS-68 engine – a simulation which mimics all of the response characteristics

Development ECU breadboard connected to the RTS via the Simulation Interface Box. A flight ECU later replaced the breadboard.

The use of HWIL testing with SIMsystem was instrumental in the RS-68 controls development efforts keeping pace with the aggressive, success oriented style of program management that was adopted be the RS-68 team.

of the actual engine. It behaved as a self-contained, yet highly interactive RS-68 engine, which afforded a very high degree of automation. Input conditions or fault injections could be loaded on the fly, while the simulation went through an unlimited number of test cases. With the use of COSIM Interact and API routines, running simulations, data acquisition and post-processing were completely automated. Thus, once the test cases were defined, no user intervention was needed to produce run data for hundreds of test cases within a day. Even at the height of the development phase all the testing, data reduction and the preparations for peer review required only two full time engineers.

The benefit of using SIMsystem for the HWIL testing of the RS-68 has been tremendous. Aside from the apparent benefits in the form of cost savings and risk reduction, HWIL testing instilled much confidence in the design of the control system that could not be attained in any other way. Developing large scale, mission critical systems such as the RS-68 or the Delta IV vehicle leaves little room for failure, even in much of the development testing, because of potentially large schedule and cost impacts. In this vein I believe the use of HWIL testing with SIMsystem was instrumental in the RS-68 controls development efforts keeping pace with the aggressive, success oriented style of program management that was adopted by the RS-68 team.

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