

Kedalion: NASA's Adaptable and Agile Hardware/Software Integration and Test Lab

Mark L. Mangieri¹
Jason Vice²

NASA – Johnson Space Center, Houston, Texas, 77058
[e-mail: mark.l.mangieri@nasa.gov](mailto:mark.l.mangieri@nasa.gov)
[e-mail: jvice@odysseysr.com](mailto:jvice@odysseysr.com)

NASA's Kedalion engineering analysis lab at Johnson Space Center is on the forefront of validating and using many contemporary avionics hardware/software development and integration techniques, which represent new paradigms to heritage NASA culture. Kedalion has validated many of the Orion hardware/software engineering techniques borrowed from the adjacent commercial aircraft avionics solution space, with the intention to build upon such techniques to better align with today's aerospace market.

Using agile techniques, commercial products, early rapid prototyping, in-house expertise and tools, and customer collaboration, Kedalion has demonstrated that cost effective contemporary paradigms hold the promise to serve future NASA endeavors within a diverse range of system domains. Kedalion provides a readily adaptable solution for medium/large scale integration projects. The Kedalion lab is currently serving as an in-line resource for the project and the Multipurpose Crew Vehicle (MPCV) program.

Kedalion – NASA's insight and SW analysis augmentation lab

Since Orion's inception, NASA has conducted a risk mitigation strategy by implementing an in-house lab resource for targeted analysis and experimentation of Orion concepts. Largely used for analysis and validation of flight test loads, and GN&C mode team support, Kedalion developed into a significant program resource recognized by Orion program management as an integral part of Orion's overall success.

Integration Synch Points (ISP's) are developed as interim demonstrations of Orion developmental technology at strategic points mutually agreed to by NASA and Lockheed-Martin. These ISP's accomplish both milestones of progress and confidence building, especially in the area of inherently risky program technologies. ISP schedules and capabilities are coordinated with the Kedalion lab for purposes of technology sharing between NASA and LM, as well as validation of ISP content as it is stood up in the Kedalion lab.

¹ *Kedalion Project Manager, Spacecraft Software Engineering Branch, Houston, TX 77058/MS ER6, AIAA Member.*

² *Kedalion Chief Engineer, Odyssey Space Research, LLC, Houston, TX (www.odysseyspace.com), AIAA Member.*
American Institute of Aeronautics and Astronautics

Orion FSW loads will be delivered to the Kedalion lab for validation runs, much like PA-1, to further mitigate risk as the FSW loads are prepared for formal testing on the programs scarce VTB test platforms.

Lab heritage (JAEL, GITF, etc.)

NASA's Kedalion lab is the latest implementation in a rich history of analysis, prototyping and integration facilities. Understanding the complex interactions between spacecraft avionics has always required hands-on engineering analysis and testing. Experience gained on previous NASA programs has shown that the use of an agile analysis and integration facility can greatly benefit a program by allowing for risk mitigation very early in the program development as well as throughout the life cycle of the program.

NASA facilities such as the Shuttle Program's JAEL (JSC Avionics Engineering Lab) and the ISS Program's GITF (GN&C Integration Test Facility) have brought many years of value to those programs by providing more efficient and productive facilities for early integration testing, risk mitigation, avionics burn-in, problem resolution and other critical program tasks best done in an agile process oriented facility. While not always initially implemented as an in-line testing facility, these types of NASA facilities have typically become early in-line testing facilities that allow for pre-formal testing in advance of the more expensive formal V&V facilities.

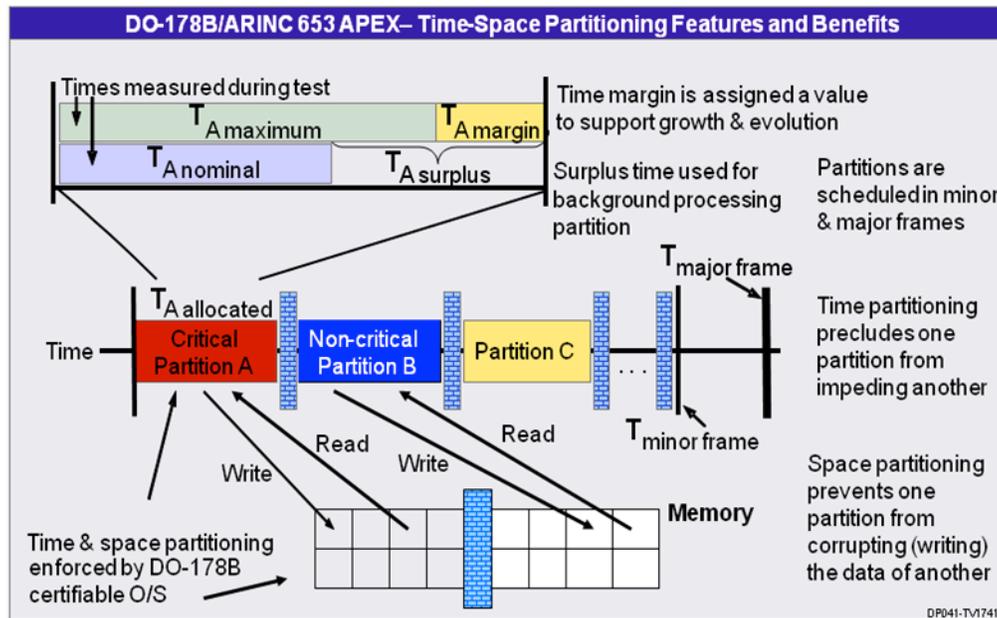
Kedalion was born from this heritage of less formal integration and test facilities. In fact, the Kedalion facility is housed in the same room as GITF was for many years and even uses some of the same facility assets as were used by GITF.

Kedalion's purpose/mission

The Kedalion lab's fundamental mission is to provide a facility for risk mitigation throughout the life cycle of a space vehicle's development and operation. To achieve success the lab is oriented toward hands-on engineering analysis that allows NASA engineers to achieve a deeper understanding of the avionics software and hardware than could be achieved by only reviewing documentation. It is not, however, a formal oversight or verification facility but rather a flexible facility that welcomes collaboration with the vehicle contractors as well as personnel from other facilities to establish the best possible solutions to design issues, operational constraints and problem resolution as early in the life cycle of a vehicle as possible. It is this approach that allows NASA to blend years of experience on past programs with new ideas from industry and from within NASA to produce solutions that can guide a vehicle's development toward ultimate success.

Orion Avionics Instantiation: Integrated Modular Avionics (IMA)

IMA represents a real-time computer network airborne system. This network consists of a number of computing modules capable of supporting numerous applications of differing criticality levels, isolated from one another in partitions supported by the underlying operating system. IMA provides for an alternative Hardware/Software (HW/SW) development and testing paradigm.



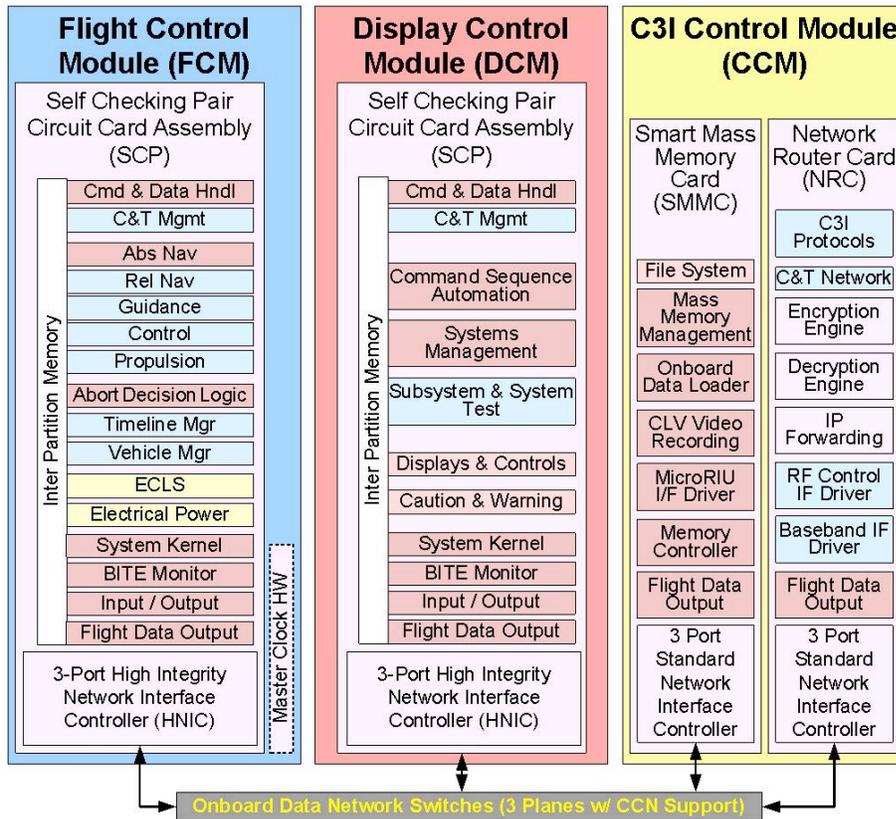
IMA Time & Space Partitioning

Orion's prime contractor, Lockheed Martin, has borrowed from Honeywell's vast experiences in its aircraft avionics heritage. Honeywell's paradigm is an ARINC compliant adaptation of IMA, which Honeywell had successfully deployed on several Boeing and McDonnell Douglas aircraft designs (B737/777/787, MD 10/90). These techniques are mature enough to have been certified as DO-178b compliant by the FAA, and also have the support of major commercial Real-time Operation System (RTOS) vendors with mature products.

While there are significant similarities between aircraft avionics system requirements and space vehicle avionics system design, an augmentation would be required to achieve the Orion avionics system design. Aircraft don't have flight dynamic phases as intense as a space vehicles ascent and decent phases, which require instantaneous reaction with multiple failover scenarios to avert catastrophic failure. Additionally, aircraft don't generally sustain missions as long as typical spacecraft, which could last weeks or months.

Orion's FAA Heritage Avionics Hardware & Software Design

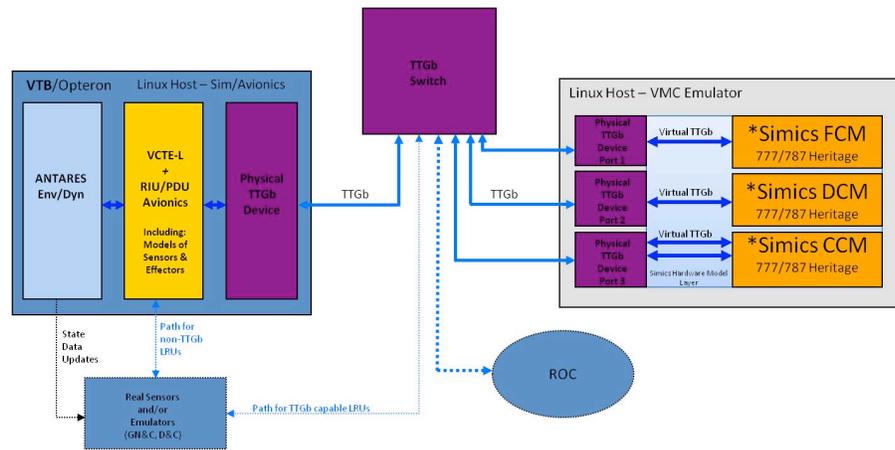
The FAA has successfully used IMA techniques, primarily via Honeywell technology, to independently develop and test partitioned modules of flight SW across vendors at dispersed locations. This paradigm underwent significant analysis by NASA, as it was an unusual form of conducting a SW development program since NASA's earlier Shuttle experience base and culture.



Notional Orion IMA Architecture

Multiple fidelity test platforms – Adapting Early to Unavailable Hardware to Progress FSW Development

The first platform that a SW module is subject to test on the Orion program is the desktop SW development platform that every programmer has access to. This platform includes all of the tools to design and develop SW algorithms, and a suite of simulation tools (SoftSim) capable of executing low fidelity executions of newly developed algorithms. SoftSim is an approach to bring target HW simulation to the developer's desktop SW development platform, based on contemporary advances in simulation technology.



Early Kedalion Test Bed Concept with Simulated Vehicle Management Computer (VMC)

Commercially known as the Honeywell (HI) Valfac Test Bench, the VTB platform was adapted first to successfully support the integration and testing of major SW subsystems on the Orion flight test program. The Orion instantiation of the VTB is a modification of HI's commercial VTB concept to include support for Orion unique interfaces and target HW, including Time Triggered Gigabit Ethernet (TTGbE) and VMC flight computers to support medium fidelity testing and integration.

The VTB platform is conceived as a highly adaptable and reconfigurable rig to support the many variations of tests required by the Orion SW project. The ultimate variation is the highest fidelity SW test platform known as the Super VTB. This test platform includes a dual string set of bus and target processors for testing redundancy and failover scenario's, as well as robust interface capability to access sensors/actuators allowing for initial subsystem vertical integration and test.

Lab architecture/components

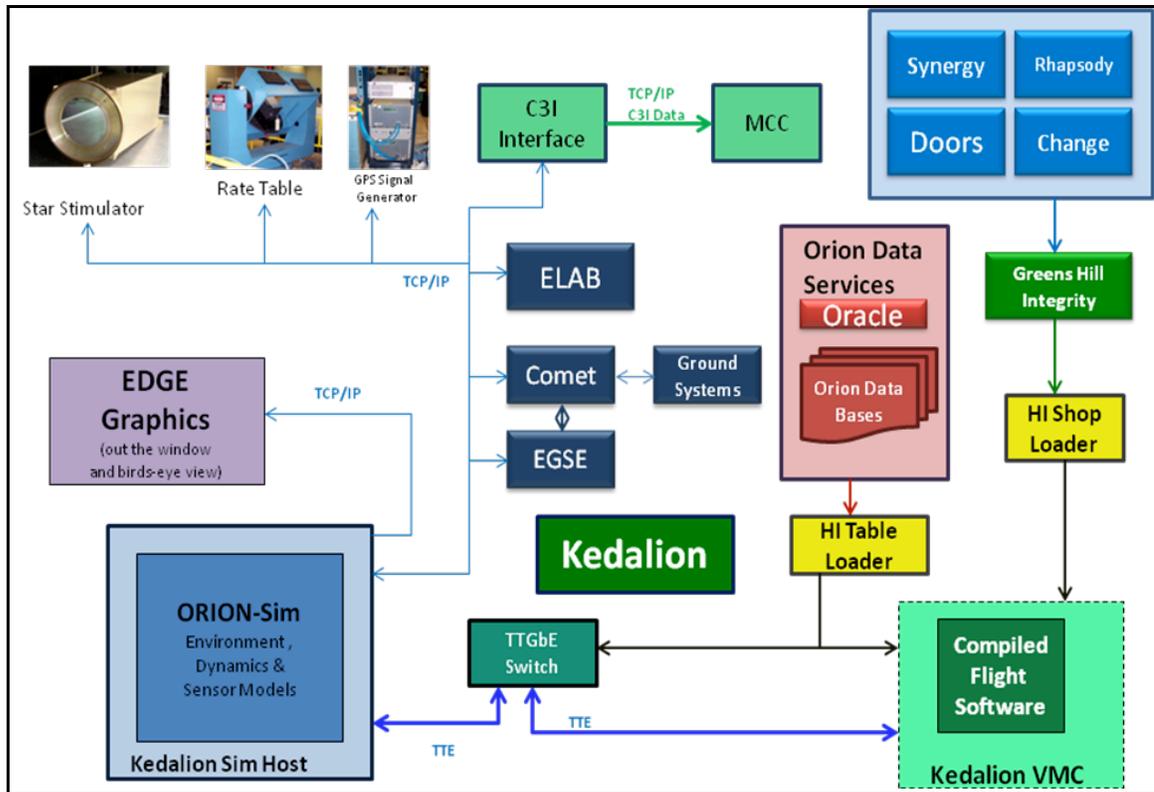
The architecture of the Kedalion lab emphasizes flexibility, modularity and reconfiguration. The lab is populated with a variety of commercial hardware and software as well as some custom items and legacy assets from previous programs.

To establish a robust prototyping and development environment the lab was populated with a rich mix of development workstations that are powered by a variety of commercial computing operating systems including Microsoft Windows, Linux, IRIX and Solaris. By employing modern and legacy operating systems in the development environment engineers are able to maximize the use of modern tools as well as legacy software proven on prior programs.

More capable computing platforms are used to host simulation environments and emulation platforms. Embedded systems running real-time operating systems such as Green Hills Integrity and Windriver's VxWorks are used to establish more robust real-time computing platforms. Non-real-time Linux platforms are also used for simulation and emulation but through careful

software design these systems can be used in integrated configurations with real-time hardware.

A variety of data bus configurations are also used to allow integration of a wide range of devices. These data bus types include MIL-STD-1553, commercial Ethernet, Time Triggered Ethernet, various serial interfaces and others as required. The concept of “bus adapters” is also used to allow legacy equipment to be mixed into configurations with more modern data busses.



Current Kedalion Schematic

The overall emphasis of this mixed bag of equipment is to allow all of these diverse lab configuration pieces to be integrated together into any as needed architecture to support prototyping and testing. The same equipment can then be easily and quickly reconfigured to implement some other configuration as required. Computing platforms can be repurposed and data busses can be reconfigured to produce the necessary configurations to support the engineer’s needs.

Software Tool Chain (integrated SW development tool set)

Critical to understanding, designing and analyzing the avionics systems of a space vehicle is an understanding of the software tools used to build the vehicle’s software products. For this purpose, the Kedalion lab has instantiated a modern and fully capable software development environment. While not limited to these tools the core of this development environment was

based on the software tool chain selected by the prime contractor for the Orion program. For this reason, the IBM Rational Tool Suite was implemented as the foundation of the tool chain for the Kedalion lab. In addition, tools such as Mathworks' Matlab/Simulink, National Instruments Labview, Green Hills Multi, Microsoft Visual Studio, DiSTI's GL Studio as well as a variety of commercial software testing tools were added to the development environment to enhance the lab's tool chain.

- **Heavy use of COTS software tools**
 - IBM Rational Tool Suite
 - Mathworks ModelBased Development – Simulink
 - NI Labview
 - Windriver Simics & VxWorks RTOS
 - Green Hills Software – Multi, Integrity RTOS
- **Reuse of common NASA developed tools**
 - Trick Simulation Framework
 - EDGE – Graphics visualization package
- **Multipurpose workstations and servers**
 - Multiple OS environment
 - Linux, Windows, IRIX, Sun
- **Diverse hardware platforms**
 - Orion flight computers
 - Vehicle test bench
 - Multiple I/O interfaces available
 - Emulators and simulators used in place of unavailable hardware
 - Sensor integration platforms
 - Rate Table for inertial sensors
 - Star Field Stimulator for star trackers
 - GPS signal generator for GPS
 - Cockpit prototyping hardware
 - Engineering quality Display Units – low cost
 - Touch screen to virtualize display units
 - Hand controllers
 - “Out the window” views



Diverse Breadth of Hardware and Software Tools

Simulators/Emulators/Hardware/Software

Another key feature of the Kedalion lab is the use of high fidelity simulations to add realism to test configurations. Vehicle avionics components are integrated with complex high fidelity simulations to produce a realistic configuration that can produce the same environmental and dynamic data as would be experienced in actual flight. Interactions with the natural environment and full vehicle dynamics as well as subsystem behaviors are produced through these complex high fidelity simulations.

Many of the models used in these simulations are reused common models and legacy models developed in other programs. This model reuse is enabled by the use of a NASA developed simulation framework known as Trick. The Trick framework is used extensively in the Kedalion lab as the basis of most simulations and emulators. Trick provides an extensive suite of simulation development, execution, monitoring and post execution analysis tools. In addition, it provides a full-featured executive framework that can be configured and built into a variety of

simulation architectures. It provides auto-coding services that allow model developers to focus on their domain expertise rather than on the development of a simulation structure. This combined with the easy reuse and reconfiguration of models allows for very rapid development of complex simulations. Trick also provides simple options for integration with hardware interfaces and, therefore, provides an ideal framework for implementing emulators. If actual hardware elements are too expensive or simply not available an emulation of the device can quickly be developed through the use of Trick.

Lab extensibility – ROC/Optics/AGDL/iPAS/MCC

Since its establishment, the Kedalion lab has experienced steady increases in capability and capacity. The initial implementation of the lab began in the early stages of the Orion program and was largely based on the need to analyze early program options. Software tool selections, development and test methodologies, integration approaches and system architectural investigations all drove the need to implement various capabilities in the lab. These lab building blocks were matured through use and helped to mature the NASA engineering community's understanding of how the Orion vehicle would be developed.

As the lab matured and its capabilities became more stable the opportunity to expand beyond the lab walls became available. One of the strengths of the Kedalion's location is its proximity to other JSC lab facilities. Cooperative efforts and integrated configurations with several other facilities have greatly enhanced the capabilities of the lab. For example, JSC's ROC (Reconfigurable Operational Cockpit) is located a short distance from the Kedalion lab. The ROC is a human-in-the-loop engineering facility with medium fidelity cockpit configurations combined with a dome projection system for accurate out-the-window visualizations. Dedicated data lines have been connected between the ROC and Kedalion, which increases the capabilities of both labs by adding the human-in-the-loop cockpit capabilities to the vehicle avionics configuration. This combination of labs produces a joint configuration that normally would only be found in a more formal and complex iron-bird style lab.

Other facilities and labs have similarly been connected with the Kedalion to produce several cooperative mutually beneficial configurations. A space vehicle optics lab, avionics hardware focused lab and the JSC Mission Control Center have all been connected to the Kedalion lab to augment its capability. Cooperative configurations like these have added value to the program without incurring much additional cost.

Orion VMC Test Benches (VTB's) – Sim Host I/O Pump (SHIOP)

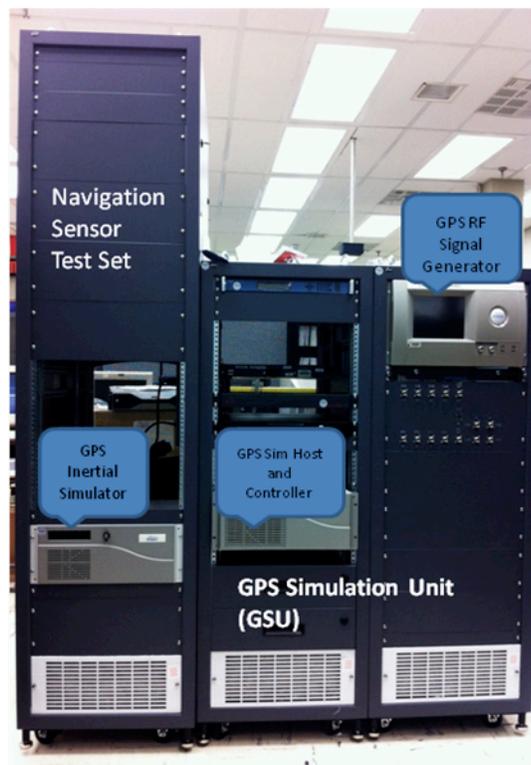
The VTB provides integration capabilities that allow flight software to be executed on actual flight processors while integrated with a full-featured simulation. This allows scenario based testing to be performed where the flight software is executed in a "test like you fly" approach. Since the flight computers for Orion are based on IMA architecture, this type of test

configuration is able to produce the fidelity necessary to reproduce actual flight conditions, as the flight computer would perceive them. The high fidelity simulation combined with a flight data bus capable Input/Output (I/O) pump makes this type of test configuration possible. The simulation feeds the I/O pump with all of the inputs necessary to fully populate the flight data bus. This allows all of the elements of the IMA architecture on the flight computer to interact with the same interfaces as they would in actual flight.

Orion test bed architecture – adding Hardware as it matures

Early versions of Orion hardware are now becoming available to the project. Brass board flight computers have been added to the Kedalion configuration. Flight software has been moved off the simulated or emulated platforms and onto the brass board flight computers. Since the changes to the configuration have happened at the hardware interface points the disruption to the operation of the test configuration was minimal. As additional hardware becomes available it will be added to the configuration in a similar way.

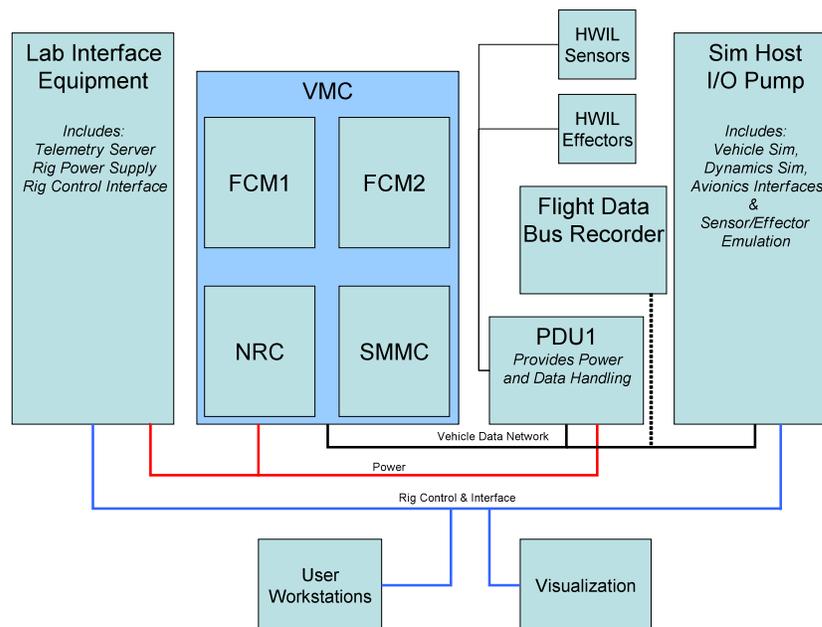
The Kedalion test configuration will continue to be modified and upgraded as the Orion program matures. Hardware and software will be integrated with the other elements as it becomes available in an effort to keep the Kedalion configuration for continued support of program needs.



*Kedalion built Orion Ground Support Equipment
Will be moved to Lockheed Test Facility*

Integrated Test Lab's (ITL's)

An Integrated Test Lab (ITL) rig configuration is the highest fidelity test platform that Orion flight hardware and software would experience prior to actual testing regimens on the assembled vehicle. In this configuration, many actual vehicle avionics components are connected and loaded with associated flight software (FSW). Appropriate vehicle simulations, environmental/dynamics simulations, actual and/or simulated sensor/actuators, and stimulators provide as close to a “test like you fly” environment as can be assembled within a lab setting.



Simplified Diagram showing the configuration used in the Integrated Test Lab

Extending the Kedalion beyond the Lab

The Kedalion lab has continued to mature and expand over the last several years. The successful integration of hardware and software with steadily increasing levels of fidelity and maturity has demonstrated that the approach of the Kedalion lab can add great value to a project. In the constrained budgetary atmosphere of the aerospace industry the Orion program leadership at both NASA and Lockheed Martin looked for ways to expand the effectiveness of decreasing budgets and limited resources. The Kedalion lab was identified as an ideal means of “filling holes” in the program and augmenting areas that needed additional hardware and resources. For this purpose the mission of the Kedalion lab was altered to expand the scope of the lab to beyond its physical walls. In a way, the Kedalion lab was converted from just a lab to a type of approach or mindset.



*Kedalion built Test Bed with Honeywell Orion Flight Computer Brass Boards
Located in Lockheed Test Facility*

To fulfill the new mission, resources from the Kedalion lab have been diverted to other locations where they have been combined with other program resources and assets to better insure the success of the program. The combining of assets allowed for a more cost effective and timely way of implementing necessary integration and test facilities needed to meet the milestones of the aggressive development, integration and test schedule.

Assets, however, were not the only things diverted to other locations. Personnel from the Kedalion lab were also asked to work in field locations that could include any facility identified appropriate and necessary for reaching program goals. The Kedalion personnel were also asked to collaborate with the prime contractor team performing the Integration Sync Point (ISP) development and integration work. This meant that the Kedalion personnel would not be performing a program oversight role but would be working to “build the vehicle” in a “badge less” environment allowing for enhanced collaboration and cooperation between NASA and contractor personnel.

This new way of fulfilling the Kedalion mission has already shown success as combined government and contractor team has continued to meet milestones of an aggressive schedule. It has allowed the Kedalion personnel to make significant contributions to meeting program objectives and has allowed the flexible, dynamic approach of the Kedalion lab to be broadened beyond the walls of the lab.

Application of the Kedalion Paradigm to Other Programs

The expansion of the Kedalion approach beyond its lab walls has shown that the methods and philosophy used with great success inside the Kedalion lab can be successfully used in other locations. With the potential for the Kedalion lab to be used in other programs besides Orion the possibility exists for the Kedalion “mindset” to be applied as a means to augment programs needing assistance. The resources of the Kedalion lab are limited but with proper planning small “tiger teams” could be formed that could include both NASA and supplier personnel to allow expertise, experience and knowledge to be applied as needed to fill gaps in development, integration and test plans.

Light-weight processes combined with flexible, dynamic approaches that emphasize implementation roles over oversight will be critical as programs look for more cost effective ways of utilizing all assets and resources available to them. The approach used in the Kedalion lab or the Kedalion mindset shows that NASA has produced a means to respond to the challenges of future programs.

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