Integrated Development & Operations System

Universal Space Lines LLC (USL) develops technologies to reduce the significant mission development and verification costs associated with current launch systems. The primary objective of our integrated development and operations system (IDOS) is to simultaneously lower the cost and improve the reliability of flight mechanics functions for NASA's 2nd generation reusable launch vehicle (RLV).

The IDOS provides an integrated tool set enabling the user to develop and analyze flight mechanics designs; generate and validate software; and plan and support operational missions.

USL has matured the IDOS concept over the past 8 years through multiple efforts beginning with the DC-X program. Incorporation of an early version of this concept in the successful DC-X program resulted in a reduction in mission development and verification labor-hours of 80% relative to the same functions performed for the Delta launch vehicle.

The IDOS integrates flight mechanics planning, design, and validation tools in a single environment as shown in Figure 1 enabling the IDOS user to perform the following tasks:

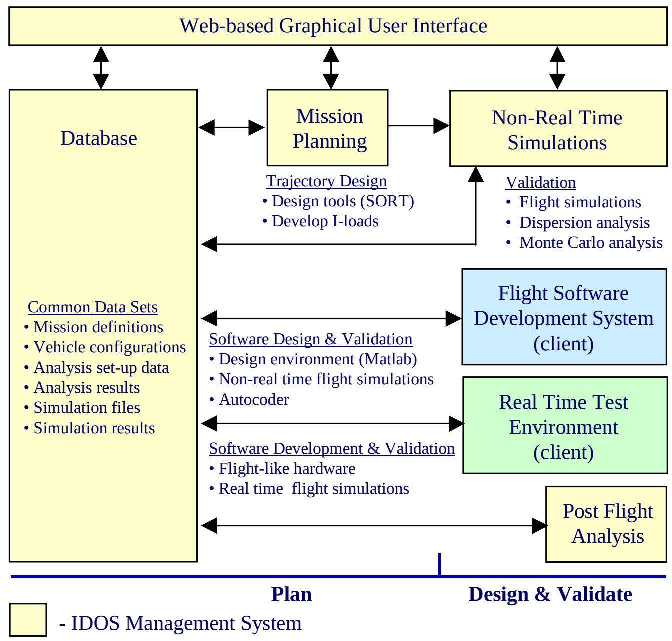
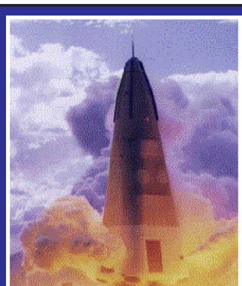


Figure 1 - IDOS integrates flight mechanics tools supporting the entire flight mechanics life cycle

- ❐ Define specific flight vehicle configurations & mission trajectories
- ❐ Perform non-real time flight simulations with either nominal or dispersed parameters
- ❐ Evaluate performance of vehicle configurations
- ❐ Evaluate vehicle performance for different missions
- ❐ Perform Monte Carlo analyses
- ❐ Develop and analyze GN&C algorithms and software
- ❐ Generate source code
- ❐ Verify flight software real-time execution on flight-like hardware
- ❐ Graphically analyze simulation and/or post flight data



The DC-X was a highly focused operations demonstration program in which the majority of our key personnel participated. The DC-X proved the ability to achieve aircraft-like operations for a reusable launch vehicle. It had 12 successful flights between 1993 and 1996 and was initiated by the DoD and continued under NASA-MSFC guidance in 1995. In only 24 months, this highly complex technology demonstration program went from contract award to first flight. The flight mechanics system, software, and mission development system were developed in only 14 months by a team of 12 people and enabled it to successfully perform extremely complex maneuvers.

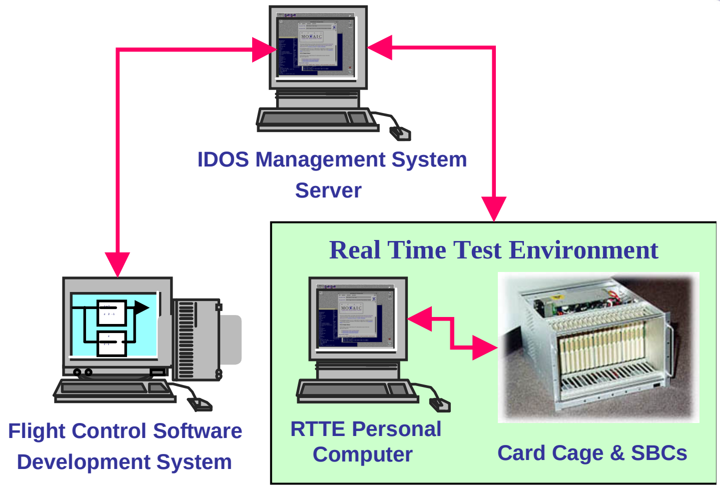


Figure 2 - The three IDOS primary components provide specific flight mechanics functionality

An important part of the IDOS is the introduction of a central, relational database to the flight mechanics process. Historically, as flight mechanics tools were developed to support specific applications, they were created as stand-alone entities, storing their own data in custom files. These files were usually unstructured, flat files that could only be used by the specific computer program for which they were created. While the programs themselves are very useful, the inability to control and conveniently share data between them is a major contributor to the high cost of using them.

By creating a central, modern database management system, the IDOS enables users to create content on request, efficiently search large amounts of data, maintain consistency of data across multiple applications, coordinate updates, control configurations and versions, and reap many other productivity benefits. This system provides for scalable growth; user-friendly, secure Internet access; uses industry-standard hardware and software elements; and can be integrated with current and future operating systems. The IDOS is designed to be modular with well-defined interfaces and functions, enabling additional tools, capabilities, and clients to be added to the system.

The features incorporated in the IDOS to lower mission costs, reduce turnaround time, and increase mission safety are as follows:

- ❒ Integration of tools (process simplification) reduces labor hours and the potential for human error
- ❒ Integration of development, analysis, and operations tools enables fewer people to support all program phases and provides continuity between phases
- ❒ Task automation reduces labor hours and the potential for human error
- ❒ Simple, user-friendly interface reduces labor hours and the cost associated with tool usage
- ❒ Secure, internet based access facilitates independent validation efforts
- ❒ Multiple tool capability enables redundant and independent evaluation of the flight mechanics design
- ❒ Modular design with well defined interfaces provides a scaleable growth capability reducing the time and effort required to implement updates

The IDOS is composed of three primary components, the IDOS management system, the flight control software development system, and the real time test environment as shown in Figure 2.

IDOS Management System

The IDOS management system is the IDOS core component that integrates IDOS functionality by hosting the integrated database used to store critical vehicle and mission data, simulation models, and source code that supports all three IDOS component functions.

The user logs onto the IDOS management system through a standard web browser and is provided a graphical interface enabling the user to perform the following tasks:

- ❒ Define specific vehicle configurations to be used in analyses
- ❒ Define missions to be used in analyses
- ❒ Design trajectories (using specific vehicle and mission definitions)
- ❒ Generate I-loads that tailor the IDOS management system non-real time simulation to the specific vehicle and trajectory design
- ❒ Run non-real time simulated flights of the designed trajectory & vehicle with either “normal” or dispersed parameters
- ❒ Perform Monte Carlo analyses
- ❒ Analyze results (either the specific simulated flight or comparison of one or more simulations)
- ❒ Export database data for usage with other tools
- ❒ Access database elements (presented in either tabular or graphical format).
- ❒ Transfer data to the flight control software development system or real time test environment.

Flight Control Software Development System

The flight control software development system supports the development and maintenance of flight control software. Flight control software functionality includes the guidance, navigation and control algorithms, mission sequencing, and contingency or abort control functionality necessary to provide the flight critical capability of the RLV flight system.

The primary element of the flight control software development system is the Matlab/Simulink graphical design environment, a commercial design tool that supports GN&C design and analysis. Flight control software functional requirements are evaluated in non-real time against a six-degree of freedom (6DOF) vehicle/environment model in the Simulink environment as shown in Figure 3. This is the first step in the design validation process. The flight simulation output data is used as the “truth model” to compare subsequent simulation results against. Linear and non-linear, time domain analysis is also supported. The data to populate the development environment (e.g. flight control software/6DOF model files and I-loads) are obtained from IDOS management system via its web browser interface.

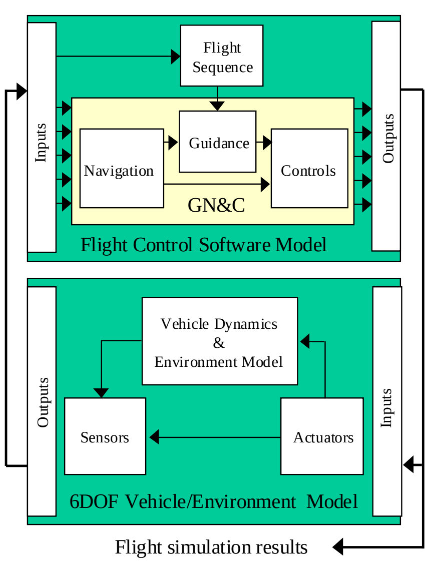


Figure 3 - The IDOS flight simulation executes in all three IDOS components

An enabling development tool used exclusively in this environment is the Matlab/Real Time Workshop automated source code generation (autocoding) tool. The process of autocoding is analogous to the use of a high-order language compiler to “convert” high order source code into a machine specific language (assembly code) that is then converted to its binary equivalent (executable code) that a processor can recognize and act on. Autocoding supports an additional level of abstraction that enables the user to develop, analyze, and generate source code within a single environment reducing translation errors and test time.

The flight control software / 6DOF vehicle/environment model is autocoded and used to perform IDOS management system non-real time simulations and executed in the real time test environment providing further validation of the flight control software design.

Real Time Test Environment

The purpose of the real time test environment is to provide a stable hardware and tool environment to test and debug the flight control software, identify any hardware execution issues of the software, and establish resource utilization metrics (i.e. throughput and memory usage) of the software. The flight control software is executed against the 6DOF vehicle / environment model in real time on flight-like hardware.

The real time test environment is composed of two primary elements, the target hardware (the single board computers and card cage) and a personal computer that hosts the commercial software development tools and provides the means to interface to the IDOS management system. The target hardware consists of two single board computers, one to host the flight control software and the other to host the 6DOF vehicle / environment model, and a card cage to hold the single board computers and enable intra-board communications. The software development tool (Wind River Systems Tornado) provides the capability to compile and link flight control software and 6DOF vehicle / environment software with the VxWorks real time operating system for execution on the target hardware and provides software execution test and debug tools.

IDOS Development Approach

USL is developing the IDOS under contract to NASA as part of the Space Launch Initiative NRA 8-30 program. The IDOS represents the next logical step in addressing flight mechanics productivity. As shown in Figure 4, the IDOS concept is the product of several successful USL programs.

The IDOS provides NASA with an integrated RLV flight mechanics development environment capable of being used to model 2nd generation reusable launch vehicles (RLVs) for mission validation, training, and post flight analysis. The intended users include NASA flight mechanics designers, systems engineers, mission planners, system operators, and 2nd generation RLV program architecture providers.

The IDOS is being developed in multiple design cycles intended to provide user feedback into the design. During development, IDOS access is provided to users through the browser interface. The NRA 8-30 base period (June/01 through March/02) IDOS design is focused on providing comprehensive functionality at various levels of detail. The objective for IDOS development during this phase is to demonstrate the potential to reduce cost, produce the building blocks for future development, and establish coordination with 2nd generation RLV architecture and test vehicle efforts.

NRA 8-30 option 1 period (April/02 through May/03) efforts focus on addressing the test vehicles and ensuring that the IDOS structure supports potential 2nd generation RLV architectures. The option 2 period (June/03 through February/05) effort focuses on 2nd generation RLV architectures in more detail, supporting multiple architectures, advanced GN&C, and robust abort capabilities. Upon completion of the option 2 effort,

	DC-X	DC-XA	NASA - Bantam	NASA SBIR	AF SBIR	IDOS
GN&C Design	• Iterative design cycles improves schedule & quality • Design environment with integrated autocoder		• Rapidly implemented closed loop, multi-stage ascent guidance algorithm in advanced autocoding environment	• Focused on advanced GN&C development for SSTO • Advanced entry guidance algorithm development	• Linked design data to database	
GN&C Analysis	• Used both design environment & external tools (some interfaces automated)		• Linked GN&C software I-loads to mission planning tool • Non-real time and real time analysis capability of advanced GN&C software		• Linked tools via database • Multiple tools linked to improve analysis effort	
GN&C Validation	• Flight-like hardware used to "test" software prior to flight hardware high fidelity testing • Automated test & test result data processing		• Implemented X-34 vehicle and guidance parameters and "mimicked" X-34 design reference mission data	• SSTO ascent trajectory validated in trajectory analysis, non-real time and real time execution environments.	• Mission planning software used multiple (3) trajectory optimization tools	
Mission Planning	• Partially automated	• Automated Mission Planner (AMP) prototyped	• First use of automatically linking trajectory optimization tool through mission planner to vehicle GN&C software • Sophisticated mission planning and ground operations GUIs	• Advanced trajectory optimization software linked to AMP software. • AMP derived data drives both non-real and real time simulations without modification	• Linked planning tools to database	
Post-flight Analysis	• Automated post-flight data extraction & cross-plotting with pre-flight test data	• Process refinement through usage to support flight test program		• SSTO non-real and real time analysis data "overlaid" for comparison	• Usage of open source plotting tool linked to database	
Results	• GN&C system & software developed in 14 months (12 people) • 80% reduction in mission planning (compared to Delta) • Flight tests supported by 3 GN&C engineers	• Tool interface automation enabled 2 hour control system margin analysis • Repeatedly demonstrated software change / validation in 4-12 hours	• Environment supported implementation of closed loop ascent guidance algorithm, based on algorithm design document, into flight software in less than 4 weeks, by 1 GN&C engineer	• Mission development system, non-real time software creation, real time software creation, real time test system and advanced entry guidance algorithm all developed in 6 months	• Web based database, multiple trajectory optimization tools, vehicle sizing tool, integrated web based plotting tool, tested and demonstrated to customer in less than 9 months	

Figure 4 - USL has matured the IDOS concept through efforts on previous successful programs

the IDOS is delivered to NASA for use as an analysis tool (e.g. 2nd generation RLV architecture analysis, low cost GN&C development, efficient mission planning and operations, etc.).

IDOS Potential

USL plans to expand the IDOS to address a wide range of launch operations activities and RLV maintenance, including launch processing, flight command and control functions, vehicle health management, post-flight analysis, vehicle refurbishment, etc. The IDOS could be expanded also to streamline and assure greater configuration control of RLV design and development functions.

USL – The Company

Universal Space Lines LLC (USL) is a space services limited liability company providing innovative, cost effective software & avionics solutions for space applications to industry and government. Our team has a history of successful innovation in the aerospace industry, including involvement in the Delta Clipper-X/XA flight and ground system software and avionics design, military aircraft avionics, and satellite tracking network hardware and software. We design and build systems and components critical to low-cost space access. USL's products include flight mechanics design, analysis, and software; launch command and control systems and software; and avionics design and integration for atmospheric and space vehicles.

Contact:

M. D. Talbot, President/CEO
Universal Space Lines LLC
1501 Quail Street, Suite 102
Newport Beach CA 92660
Telephone 949-476-3434
Fax 949-851-9485
Email: talbot@spacelines.com

Matthew G. Maras, Chief Technical Officer
Universal Space Lines LLC
910 15th Street, Suite 1066
Denver CO 80208
Telephone 303- 623-2415
Fax 303-623-2414
Email:
maras@spacelines.com