Advanced Concepts Group (ACG) Overview

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Introduction to SpaceWorks

Advanced Concepts Group (ACG) Introduction

Practice Areas

  - Concept Definition
  - Architecture Design
  - Engineering Disciplinary Analysis
  - Technology Prioritization
  - Probabilistic Analysis
  - Tool Development

Disciplinary Areas

  - Trajectory
  - Propulsion
  - Aerodynamics
  - Aeroheating / Thermal Protection
  - Solid Modeling / Packaging
  - Weight Estimation

Relevant Experience
Introduction to SpaceWorks
Aerospace engineering services and space systems analysis firm founded in 2000
- A responsive and nimble multidisciplinary engineering team focused on independent concept analysis and design, technology assessment, and life cycle analysis at fidelity levels suitable for concept initiation through PDR
- Over a decade of experience supporting advanced design and long range planning activities for customers in private industry, NASA, DoD, DARPA, and entrepreneurial space organizations

Three primary operating divisions: Engineering, Commercial, and Software.

Two partner companies: Generation Orbit Launch Services, Inc. and Terminal Velocity Aerospace, LLC.
Engineering Focus Areas

- Space Launch Systems
- Human Space Exploration
- Robotic Spacecraft and Small Satellites
- Hypersonic Atmospheric Flight
- Emerging Commercial Space Markets
- Revolutionary Aerospace Technologies
Key Customers and Partners

- NASA
- Air Force Research Laboratory
- DARPA
- JPL
- Pratt & Whitney
- United Technologies Company
- United Launch Alliance
- Orbital
- IHI AeroSpace
- National Institute of Aerospace
- UDRI
  University of Dayton Research Institute
- UTS Universal Technology Corporation
- Satrec Initiative
Advanced Concepts Group Introduction
ACG Overview

- The Advanced Concepts Group (ACG) provides conceptual and preliminary analysis and independent technical assessment of advanced space systems.
  
  - The ACG specializes in delivering high value end-to-end analysis packages to our customers engaged in preliminary aerospace vehicle concept development, design space exploration, analysis of technical alternatives, independent concept review, or marketing of new technologies or initiatives.

- Past experience includes conceptual and preliminary level modeling of a broad range of future space transportation and aerospace infrastructure concepts.

- Technical assessments may include analysis of concept weights, ascent and entry trajectories, propulsion, Computer-Aided Design (CAD) drawings, aerodynamics, thermal protection requirements, abort assessments, and subsystem definition and sizing.

- The ACG performs both traditional deterministic and probabilistic analyses to explicitly evaluate system risk through uncertainty in key design variables.
Practice & Disciplinary Areas

Practice Areas

- **Concept Definition** – Concept definition and optimization within multi-disciplinary modeling environment supported by detailed discipline-specific engineering assessments
- **Architecture Design** – Systems integration, optimization, CONOPS definition, and trade studies supporting end-to-end mission analysis and metrics definition
- **Engineering Disciplinary Analysis** – In-depth engineering design and analysis at specific discipline or component level
- **Technology Prioritization** – Providing decision-makers with an understanding of the impacts of technology developments on future designs
- **Probabilistic Analysis** – Mitigating future impacts of design uncertainty through stochastic simulation methods
- **Tool Development** – Together with SpaceWorks’ Software Division, the ACG develops analysis software specialized to the needs of our clients

Disciplinary Areas

- **Trajectory** – POST I / II, OTIS, Copernicus, Bullseye (internal), QuickShot (internal), FlightSight (internal)
- **Propulsion** – ROCETS, CEA, REDTOP-Lite (internal), REDTOP-Pro (internal), RCS-Sizer (internal), Scramjet Propulsion Inlet Designer (SPIder) (internal)
- **Aerodynamics** – APAS, S/HABP, Cart3D, Overflow, MissileDATCOM, CBAero
- **Aeroheating / Thermal Protection** – SHABP, MINIVER, DPLR, Sentry (internal)
- **Solid Modeling / Packaging** – Solid Edge, Vehicle Sketch PAD (VSP), Maya
- **Weight Estimation** – AFWAT, INTROS, LVA, Bender (internal)
Practice Areas
Concept Definition Capabilities

- Concept definition and optimization within multidisciplinary modeling environment supported by detailed discipline-specific engineering assessments.
- Studies are conducted in a collaborative design environment, with interrelated disciplines interacting in a fully coupled manner. Results include converged and optimized system designs including detailed performance assessments and subsystem sizing.

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Stainless steel pressure-stabilized tanks
Common bulkhead tanks
Integrated Vehicle Fluids
Equipment shelf
LH2 tank
LOX tank (with LH2 pass-through)
Avionics
Aft thrust structure
Architecture Design

Architecture Design Capabilities

- Systems integration, optimization, CONOPS definition, and trade studies supporting end-to-end mission analysis
- Architecture studies to near-term human exploration targets including Earth-Moon and Earth-Sun Lagrangian points, the Moon, NEAs, and Mars
- Includes sizing and design of multiple mission elements as well as optimization of entire system
Engineering Disciplinary Analysis Capabilities

- In-depth engineering design and analysis at specific discipline or component level
- Fidelity level of the analysis ranges from initial conceptual design through detailed preliminary design
- Analysis and deliverables customizable to meet study / customer requirements
### Technology Prioritization

#### Technology Prioritization Capabilities

- Providing decision-makers with an understanding of the impacts of technology developments on future designs
- Impact analysis of technologies on individual component / concept figures of merit
- Impact analysis of technologies holistically over an entire architecture or campaign
- Combination of deterministic analysis and probabilistic analysis to give a complete picture of the impacts of technologies
- Expert elicitation methods for qualitative alternative assessment and decision making support
Probabilistic Analysis

Probabilistic Analysis Capabilities

- Mitigating future impacts of design uncertainty through stochastic simulation methods
- Determine how uncertainty in simulation inputs and analysis techniques effect resultant output metrics
- Experienced with probabilistic design and analysis techniques and creating custom software and frameworks tailored to support stochastic analysis
Tool Development

Tool Development Capabilities

- Creation of fully-featured engineering applications including user interface design, installation packages, documentation, and support
- Development of custom analysis tools for specialized modeling and simulation
- Development of add-ons or modules that interface with or integrate into NASA models (such as EXAMINE, NAFCOM, etc.)
Disciplinary Areas
### Trajectory Capabilities

- Ascent trajectories including single and multistage vehicles using rocket and/or airbreathing propulsion, either 3DOF point mass or trimmed simulations
- High speed atmospheric flight including point-to-point missions, skipping trajectories, and hypersonic test article simulations
- Planetary entry trajectories including aerobraking and powered descents
- Launch opportunities and ΔV requirements for deep space missions to NEAs, Mars, and other solar system bodies
- Cis-lunar trajectory options and ΔV requirements including the Earth-Moon Lagrangian points and escape trajectories to other solar system bodies

### Tools, Processes, and Databases

**Industry Standard**
- POST I / II, OTIS, Copernicus

**Internally Developed**
- Bullseye, QuickShot, FlightSight, Earth-Moon Sim, Landing Sim
Propulsion Capabilities

- Liquid rocket engine performance analysis including full power balance calculations and determination of thrust, Isp, weight, geometry, reliability, and cost
- High speed airbreathing propulsion system analysis including scramjets, ramjets, turbine engine, and combined cycle propulsion
- Reaction control / attitude control system design
- Advanced propulsion systems including nuclear thermal rockets, electric propulsion systems, etc.

Tools, Processes, and Databases

Industry Standard
- CEA
- ROCETS

Internally Developed
- REDTOP-Lite
- REDTOP-Pro
- RCS-Sizer
- SPIDer (Scramjet inlet designer)
- Custom NTR propulsion model
- Custom electric propulsion model
Aerodynamics Capabilities

- Aerodynamic configuration design and outer mold line shaping for ground and air-launched launch vehicles, and hypersonic air-breathing systems.
- Engineering-level analysis for rapid sizing and optimization of aerosurfaces based on stability and control requirements, as well as aerodatabase development for trajectory optimization.
- Euler and Reynolds-Averaged Navier-Stokes (RANS) Computational Fluid Dynamics (CFD) methods for complex geometries in internal and external flows.

Tools, Processes, and Databases

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<th>Industry Standard</th>
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| Internally Developed | Aerosurface Sizer |
Aeroheating / Thermal Protection Capabilities

- Engineering-level and CFD methods for aerothermal environment analysis for shaping and optimization of reentry and suppressed trajectories
- Thermal protection system material selection, distribution, sizing, and optimization for reentry and hypersonic vehicles
- 1D, unsteady heat transfer with convection, conduction, and radiation with adiabatic backface
- Recession analysis for ablative materials

Tools, Processes, and Databases

Industry Standard
- S/HABP
- CBAero
- MINIVER
- DPLR

Internally Developed
- Sentry
Solid Modeling / Packaging

Solid Modeling / Packaging Capabilities

- Fully textured 3D models of space launch vehicles, aircraft, propulsive stages, in-space habitats, landers, rovers, and surface structures
- Complete CAD models including detailed internal subsystem and structural elements

Tools, Processes, and Databases

Industry Standard
- Solid Edge
- Autodesk Maya
- Vehicle Sketch PAD
- Google Sketch-Up
- Pixologic Sculptris
Weight Estimation

Weight Estimation Capabilities

- Detailed weight breakdown statements are generated from a variety of resources, including top-down historical data regression as well as bottoms-up component level sizing
- Structural analysis capabilities can be used to increase the estimate fidelity for major structural components

Tools, Processes, and Databases

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<td>TrussSizer</td>
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<td>Internal MERs and References</td>
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Relevant Experience
Reusable Booster System

- SpaceWorks supported the Reusable Booster System (RBS) program as a member of the AFRL team from 2009 through the completion of the Pathfinder Task Order 1 project.

- Over this time period SpaceWorks conducted a wide range for activities including but not limited to:
  - Concept design of several sub-X (RBX) demonstration booster systems
  - Detailed rocketback trajectory simulations trade studies
  - Fully operational vision vehicle system designs
  - Pathfinder program systems engineering support including life cycle cost estimates, risk management, requirements definition, program document generation, and support of key meetings and design reviews
  - Member of several Pathfinder IPT’s including aeromechanics / configuration and propulsion
SpaceWorks was awarded a contract to develop reusable, air-dropped hypersonic air-breathing vehicles capable of sustained Mach 6+ cruise, maneuvering, and conclude with a runway landing. Three vehicles were designed for this mission: an inward turning scramjet and a planar scramjet that were externally boosted to cruise speed, and a planar scramjet with integrated rockets for boosting to scramjet takeover.

To design the inward turning inlet, SpaceWorks developed the Scramjet Propulsion Inlet Designer (SPIDer) for parametric shaping of streamline-traced inward turning inlets based on freestream and combustor design conditions.

Customer: AFRL
Duration: 9 months
Date: 2011-2012
Joint Systems Study (JSS)

- SpaceWorks was tasked with the Level 1 (synthesis & sizing) and Level 2 (preliminary design) closure of the reference architecture (all-rocket, two-stage-to-orbit) as part of the NASA/Air Force Joint Systems Study.
- Additionally, SpaceWorks conducted cross checks and Level 2 subsystem design and life cycle assessment work for the rocket-based combined cycle (RBCC) and turbine-based combined cycle (TBCC) systems.
- Analysis tasks included:
  - Design and closure of multiple vehicle designs, serving in both an initial design role and in an independent review mode
  - Conducted detailed design of various vehicle subsystems and disciplinary analysis and incorporated knowledge from higher fidelity simulations into the overall vehicle sizing and closure process

Customer: NASA and USAF
Duration: 3.5 years
Date: 2009-2012
SpaceWorks developed an architecture using common all-chemical cryogenic propulsion stages to achieve future human exploration missions to Earth-Moon Lagrange points, the Moon, NEAs, and Mars.

Key enabling assumptions for the stages included:

- The use of high propellant mass fraction design approaches (i.e. low stage structural mass stages)
- The availability of high performance in-space chemical rocket engines utilizing LOX/LH2 propellants and evolved from the RL-10 expander cycle engine
- The ability to passively manage propellant boil-off for long duration missions through innovative design approaches
SpaceWorks was part of the government team for the NASA/DARPA Horizontal Launch Study. The goal of the study was to analyze near, mid, and far term concepts for air-launch of small, medium, and heavy payloads to orbit. The study culminated in Level-1 design of three mid-term vision vehicle concepts and two near-term demonstration vehicle concepts.

The five concepts developed were designed to separate from the back of a 747, requiring a wing-tail-strongback structure integrated with the rocket stages.

Customer: DARPA and NASA
Duration: 10 months
Date: 2010-2011
SpaceWorks in partnership with the National Institute of Aerospace (NIA) conducted a technology impact assessment study of the NASA Langley TSTO TBCC RALV. The goal of this activity was to assess and prioritize a set of 20 to 30 enhancing technologies based on their impact on the RALV system through key Figures of Merit (FOMs). The impacts of each technology on the RALV design was assessed probabilistically using a fast acting RALV closure module (ROSETTA model) developed by SpaceWorks.
SpaceWorks conducted separate vehicle design studies evaluating the potential impact of two advanced propulsion system concepts under consideration by NASA Langley Research Center:

- The first concept was an expendable multistage rocket vehicle which utilized an advanced Air-Augmented Rocket (AAR) engine. The effect of various rocket thrust augmentation ratios were identified the resulting vehicle design where compared against a traditional expendable rocket concept.
- The second concept leverage Low Energy Nuclear Reactions (LENR), a new form of energy generation being studied at NASA LaRC, to determine how to utilize an LENR-based propulsion system for space access. For this activity, two LENR-based rocket engine propulsion performance models where developed jointly by SpaceWorks and LaRC personnel.

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<th>Dynamic Pressure (psf)</th>
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<td>175%</td>
<td>1,400</td>
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<td>200%</td>
<td>1,600</td>
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Customer: NASA LaRC
Duration: 6 months
Date: 2009-2010
SpaceWorks developed 4 modules for NASA LaRC’s EXAMINE modeling environment, (1) a nuclear thermal rocket model, (2) an electric propulsion model, (3) a model of the VASIMR propulsion concept, and (4) an updated in-space and surface power generation and storage model.

These models were built in Microsoft Excel and designed to be directly incorporated into EXAMINE using pre-defined templates and layouts.

Customer: NASA LaRC
Duration: 4 months
Date: 2009
Under an Air Force SBIR award, SpaceWorks conducted preliminary research and conceptual level sizing of a new combined cycle space access engine concept: the SCAAT-Engine (Supersonic Core Air Augmented Thrusting)

Key design features of the SCAAT-Engine and operating characteristics that distinguish it from related or historical combined-cycle engine concepts include the following:

- No distinct operating modes and therefore no complex mode transitions from subsonic flight to hypersonic speeds
- Structurally efficient axisymmetric design with high thrust-to-weight ratio that can be wing-mounted
- Capable of generating high thrust and high efficiency at low dynamic pressure (q of 1000 psf or less) to reduce aerodynamic drag, structural loads, aerodynamic heating, and thermal protection requirements.
SpaceWorks supported the Ares project office by probabilistically assessing the payload capability of various candidate Ares V designs and conducting deterministic vehicle sensitivity studies

- Using PHX’s ModelCenter design environment, SpaceWorks built a fast acting Ares V sizing and closure model which incorporated the same tool set used internally by NASA
- The sizing and closure model was coupled with Ares V input design variable uncertainty distributions and a direct Monte Carlo driver to perform the required probabilistic assessments
- Input distributions were developed by SpaceWorks and derived from interviews with relevant Ares V project personnel, project documentation, and augmented with historical data where needed
- Results of this study fed directly into NASA “Level-2” exploration architecture stochastic assessments

**Ares V Probabilistic Analysis and Sensitivities Study**

**Customer:** NASA MSFC  
**Duration:** 2 years  
**Date:** 2008 - 2009
“SuperHero” is the name for a collaborative, automated engineering environment for the analysis of systems and weapons that can be used to support a variety of missions from space-access/entry to global reach/strike

System interface and integration environment utilizes Phoenix Integration’s PHX ModelCenter and Analysis Server products

Provides easy setup and analysis in areas of propulsion, aerodynamics, aeroheating, trajectory simulation, and thermal protection system design using a variety of industry standard tools, SpaceWorks COTS tools, and Hero-specific modules

Capable of multi-fidelity analysis across a range of disciplines
Precursor Mission to Near Earth Asteroid Apophis

- SpaceWorks teamed with SpaceDev to design the Foresight spacecraft as a concept design for a radio tagging mission to Near Earth Asteroid (NEA) Apophis. It was the winning submission for the 2007 Planetary Society Apophis Mission Design Competition.
- Foresight was purpose-designed to meet mission requirements with minimal instruments and complexity. It uses heritage components, instruments, and flight proven technologies throughout to improve simplicity of design and manufacturing, reduce risk, increase reliability.
- It offered a flexible mission schedule with multiple launch windows between 2012 and 2014 and options for extended mission phase after the one-year tracking period.

Customer: Planetary Society Design Competition
Duration: 3 months
Date: 2007
Technology Assessment of Lunar Architecture

- SpaceWorks performed a study to quantify the impacts of ongoing technology development activities on NASA's baseline lunar exploration architecture.
- Sensitivities of various measurable figures of merit (FOM) due to the application of new technologies were analyzed. The architecture model was exercised both deterministically and probabilistically to generate top-level FOMs for architecture masses, mission costs, and top-level reliabilities.
- SpaceWorks selected 18 technology projects upon which to conduct preliminary technology sensitivity assessments, and developed 3 technology portfolios using combinations of these technologies.
Lunar Lander Preparatory Study Support

- SpaceWorks supported the NASA Langley Lunar Lander Preparatory Study and Lunar Architecture Teams during Constellation by performing multi-stage lunar lander sizing and performance analysis.
- Supporting trajectory analysis included descent, terminal landing, ascent, landing site re-designation, and braking stage impact point analysis.
- SpaceWorks also developed an independent lander concept named Dragonfly as an innovative high performance lander using an unpressurized ascent stage and space suits with suit locks for the crew.

Customer: NASA LaRC
Duration: 12 months
Date: 2005-2006
SPACE IS GO

SpaceWorks Enterprises, Inc.