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Activity-Based Simulation of Future Launch Vehicle Ground Operations

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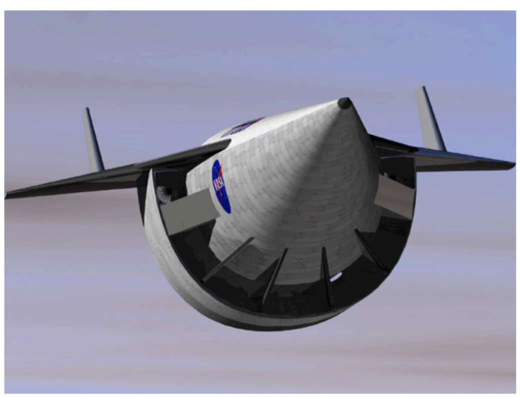
EXECUTIVE SUMMARY

- Environment: Success of future reusable space access vehicles is largely dependent on their operability

- Objective: Develop advanced simulation capability to inform decisions makers of the impact of technical (e.g. TPS type, propulsion system) and programmatic decisions on operability and affordability metrics

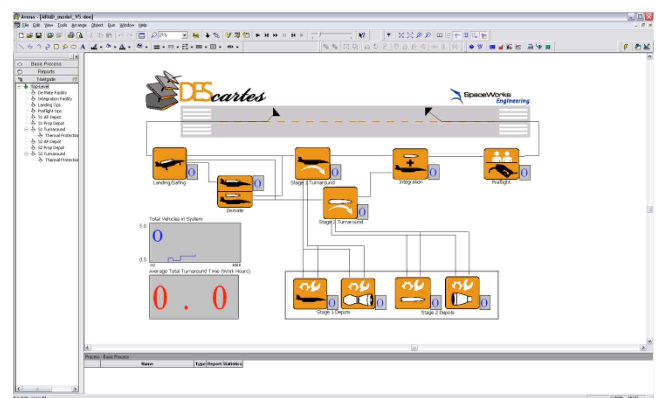
- Process: Discrete-event simulation (DES) using Arena® software
    - Simulate activities that determine turnaround time and recurring operations costs (Phase I)
    - Simulate activities that determine vehicle development and acquisition cost (Phase II)
    - Inputs for such an analysis model include mission profile, campaign, test plan, launch/landing sites, vehicle configuration, mass properties, propellant load, takeoff/landing requirements, operational philosophy, subsystem technologies, etc.

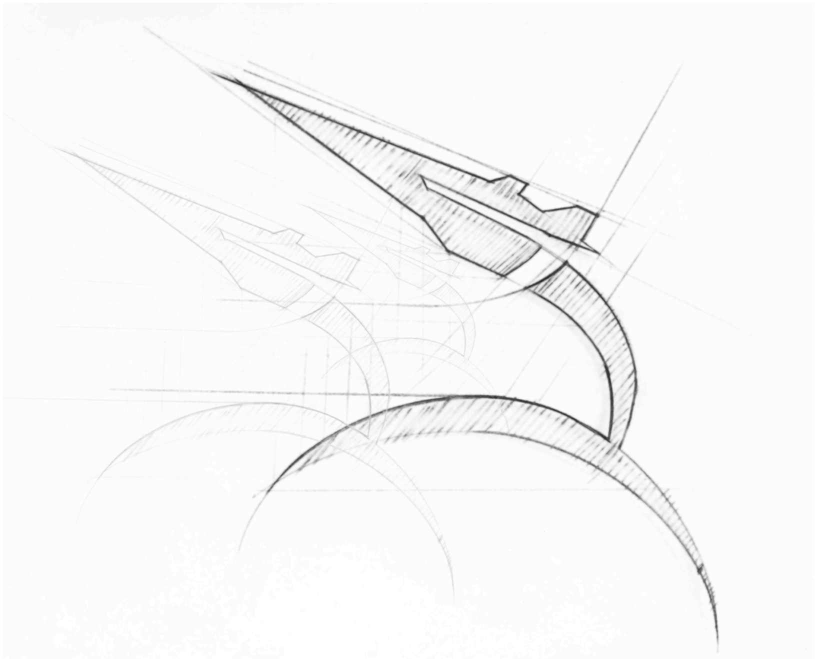
VEHICLE



OPS ACTIVITIES

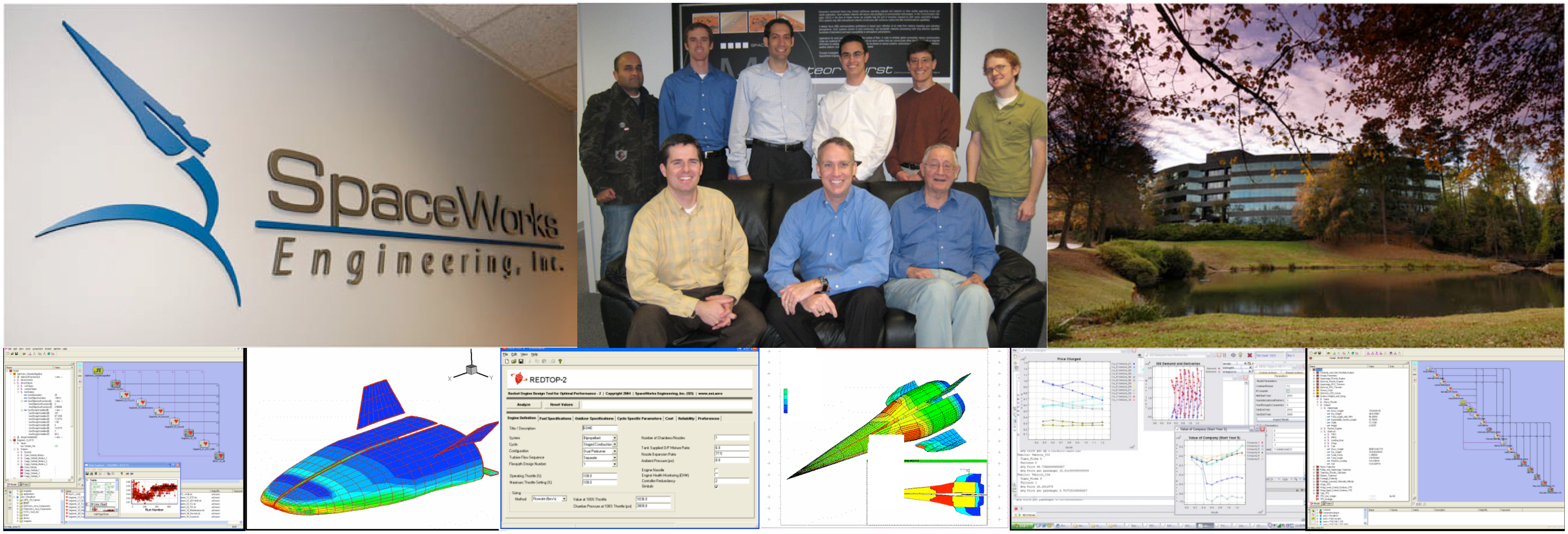
DES MODELING





FIRM OVERVIEW

FIRM

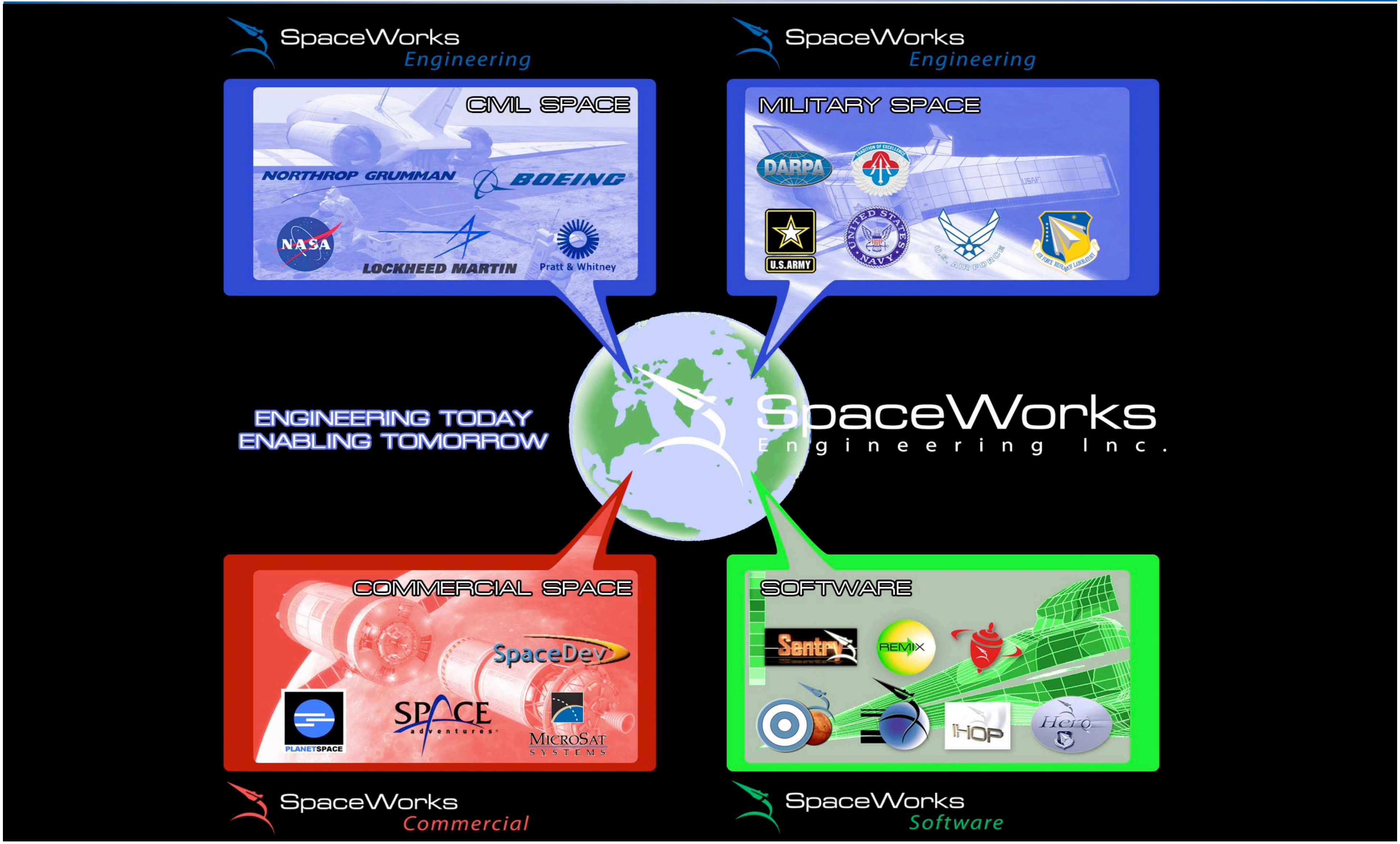


Overview:

SpaceWorks Engineering, Inc. (SEI) is an aerospace engineering consulting and concept analysis firm based in Atlanta, GA USA. Founded in 2000 as a spin-off from the Georgia Institute of Technology, SEI specializes in providing unbiased, independent assessment of advanced space and infrastructure concepts for government and commercial clients. SEI also develops engineering disciplinary analysis tools and software enhancements for collaborative design frameworks. SEI is privately held.

Core Competencies:

- Advanced concept synthesis for launch and in-space transportation systems
- Financial engineering analysis for next-generation aerospace applications and markets
- Technology impact assessment and quantitative technology portfolio optimization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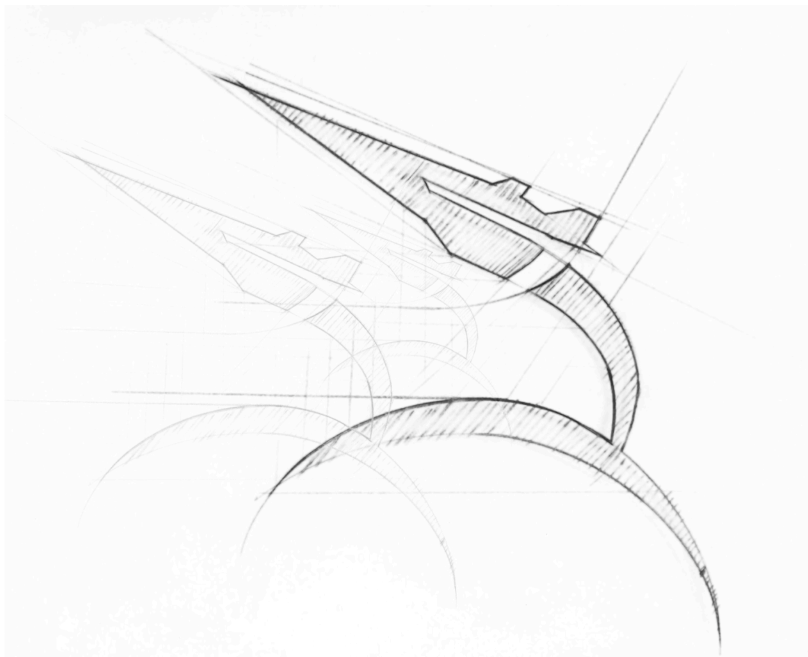
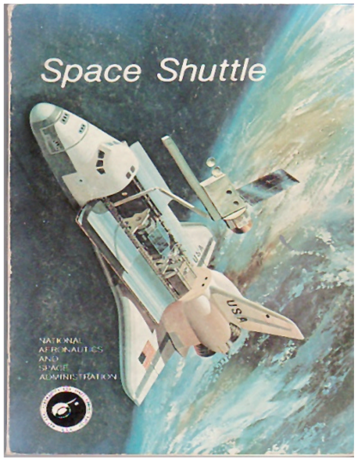
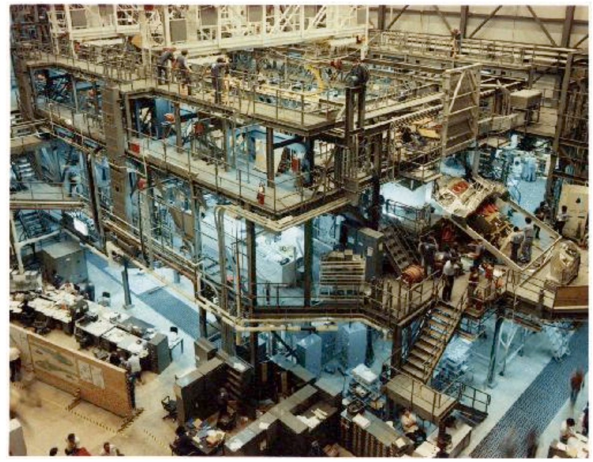
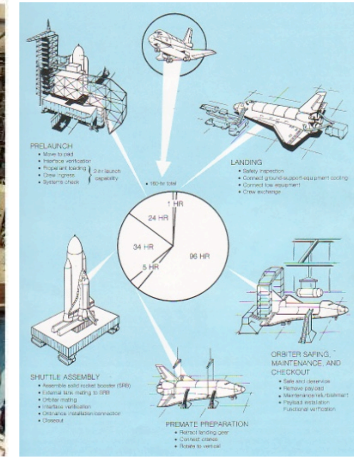


ACTIVITY BASED SIMULATION BACKGROUND

THE SPACE SHUTTLE EXPERIENCE





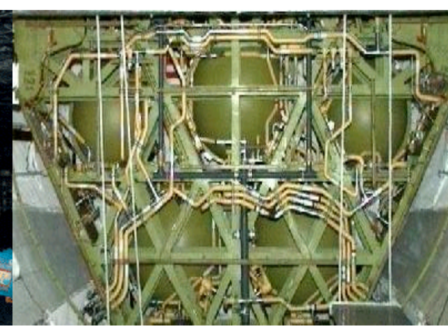


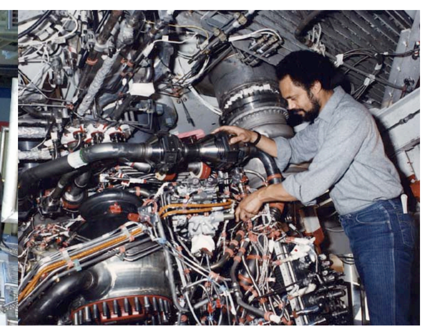
"The Space Shuttle Orbiter is designed for a 2-week ground turnaround, from landing to relaunch. About **160 hours** of actual work will be required."

Source: NASA SP-407, Space Shuttle, ca. 1976; p. 4

Average STS calendar days in Orbiter Processing Facility (OPF) from 1990 to 1997 was **88 days**

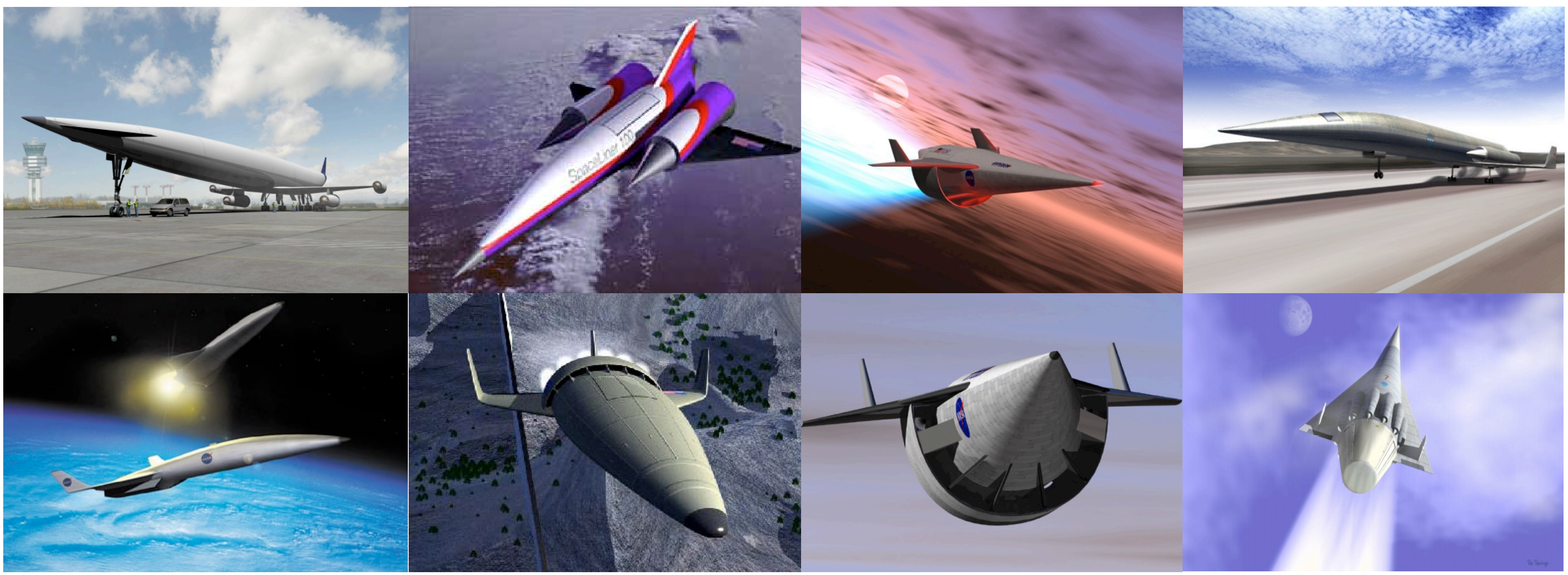
Source: Kennedy Space Center, "Space Transportation Ground Processing Operations Modeling and Analysis: A Review of Tools and Techniques," Edgar Zapata, Systems Engineering Office, NASA KSC, June 2003, p. 6.





FUTURE HYPERSONIC CONCEPTS: QUANTIFYING BENEFITS

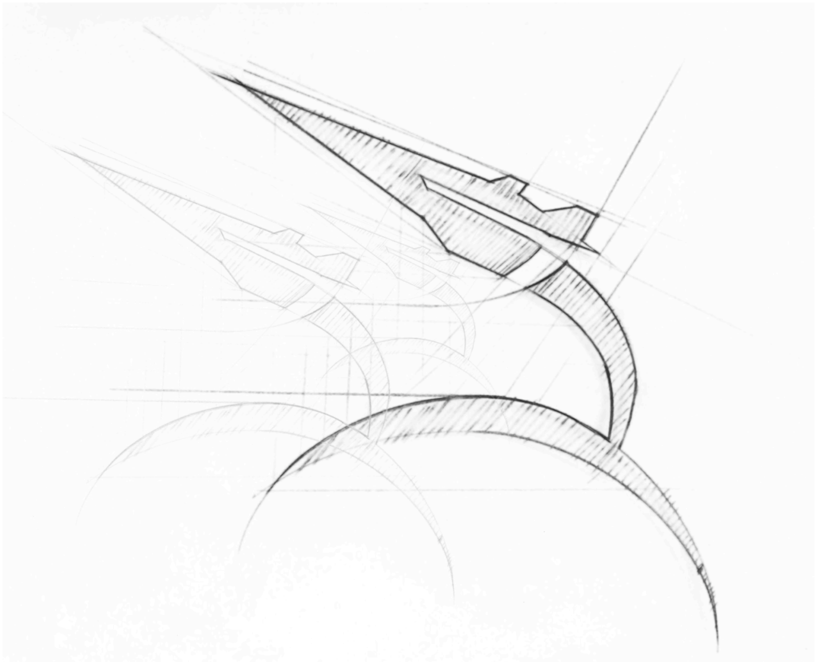
- Future reusable hypersonic vehicles are considered to have potential benefits compared to rocket or solid propulsion systems
- These benefits can arise from reductions in turnaround time, recurring operations costs (labor and materials), and life cycle cost
- Quantifying operability and affordability effects, beyond using historical analogies, has proven difficult for the systems analysis community



MODELING DYNAMIC INTERACTIONS

– The world is complex
– Complex interactions (human to human, human to machine, machine to machine)
– Dynamic events happen -> outcomes change
– Methods such as MS Excel strain to model dynamic complexity

Photo sources: Stephen Eubank, "Social Networks and Epidemics," Basic and Applied Simulation Sciences, Los Alamos National Laboratory, http://blog.q-taro.com/Places%20in%20Tokyo.php



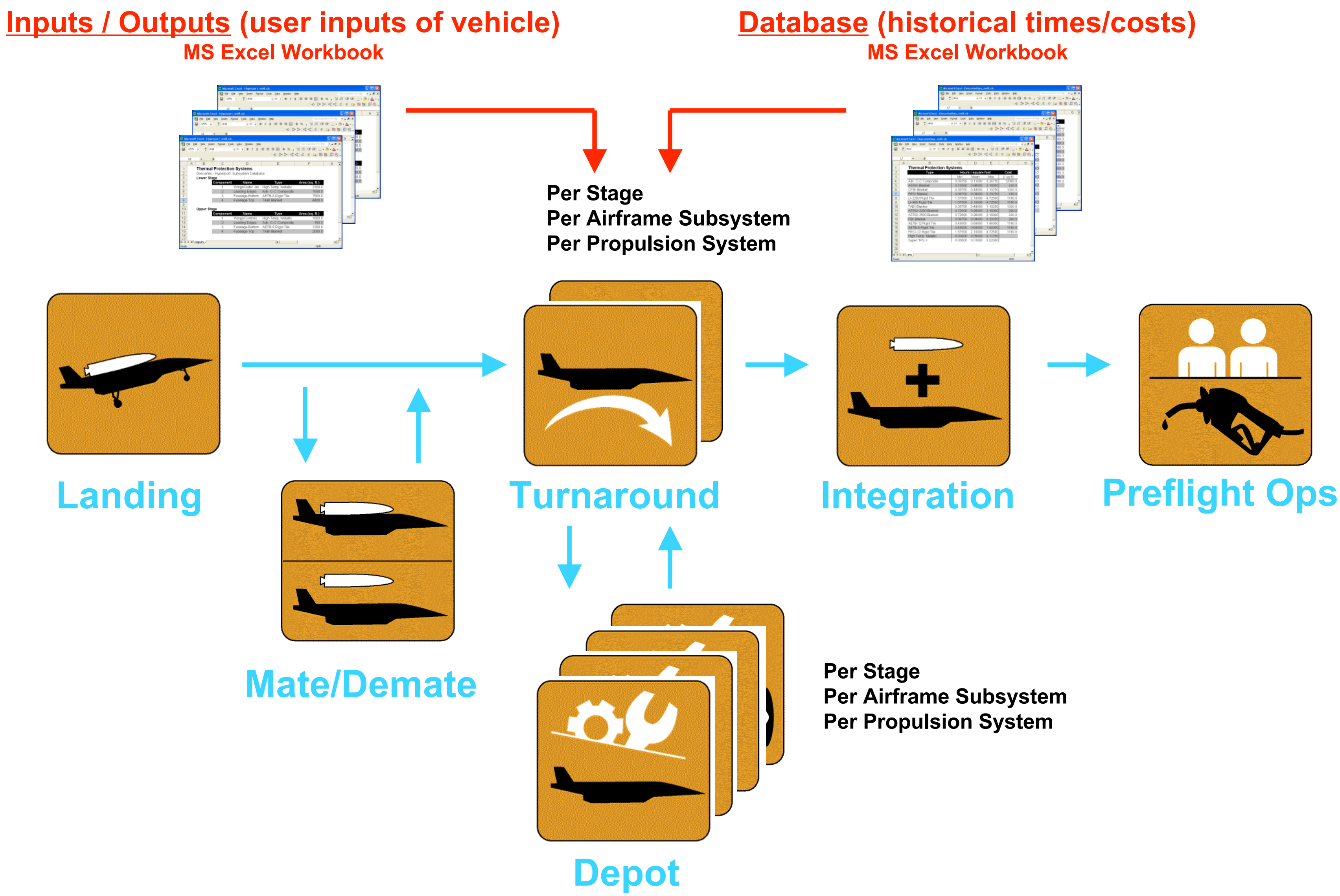
MODELING FRAMEWORK

DESCARTES-HYPERPORT: FEATURES

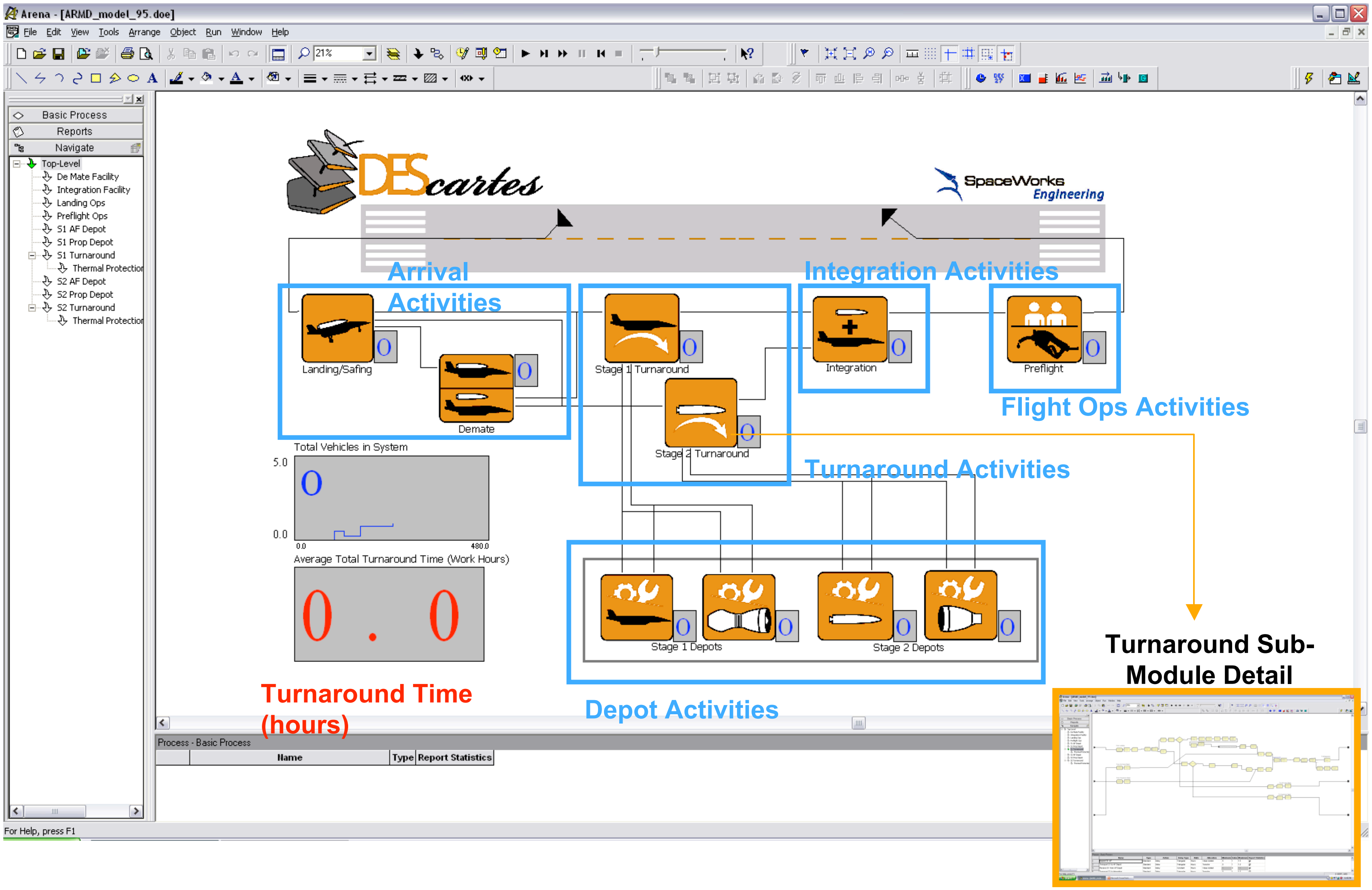
- Descartes: SpaceWorks Engineering's aerospace discrete event simulation modeling framework using Arena® by Rockwell Automation

- Descartes-Hyperport: Implementation of a discrete event simulation model for turnaround time and recurring operations cost analysis of future reusable launch vehicles
  - Consists of large set of submodels and modules within Arena
    - Full Arena animation, with entity and facility icons, basic on-screen statistics
    - Full run control: length, replications, arrival rates
  - User defines various subsystem-level parameters
    - Reference database of historical process times and costs
  - Range of simulation statistics output to MS Excel
    - Entity counters from several checkpoints
    - Turnaround time, broken down by facility
    - Estimate of recurring costs attributed to labor, parts, fuel, etc.

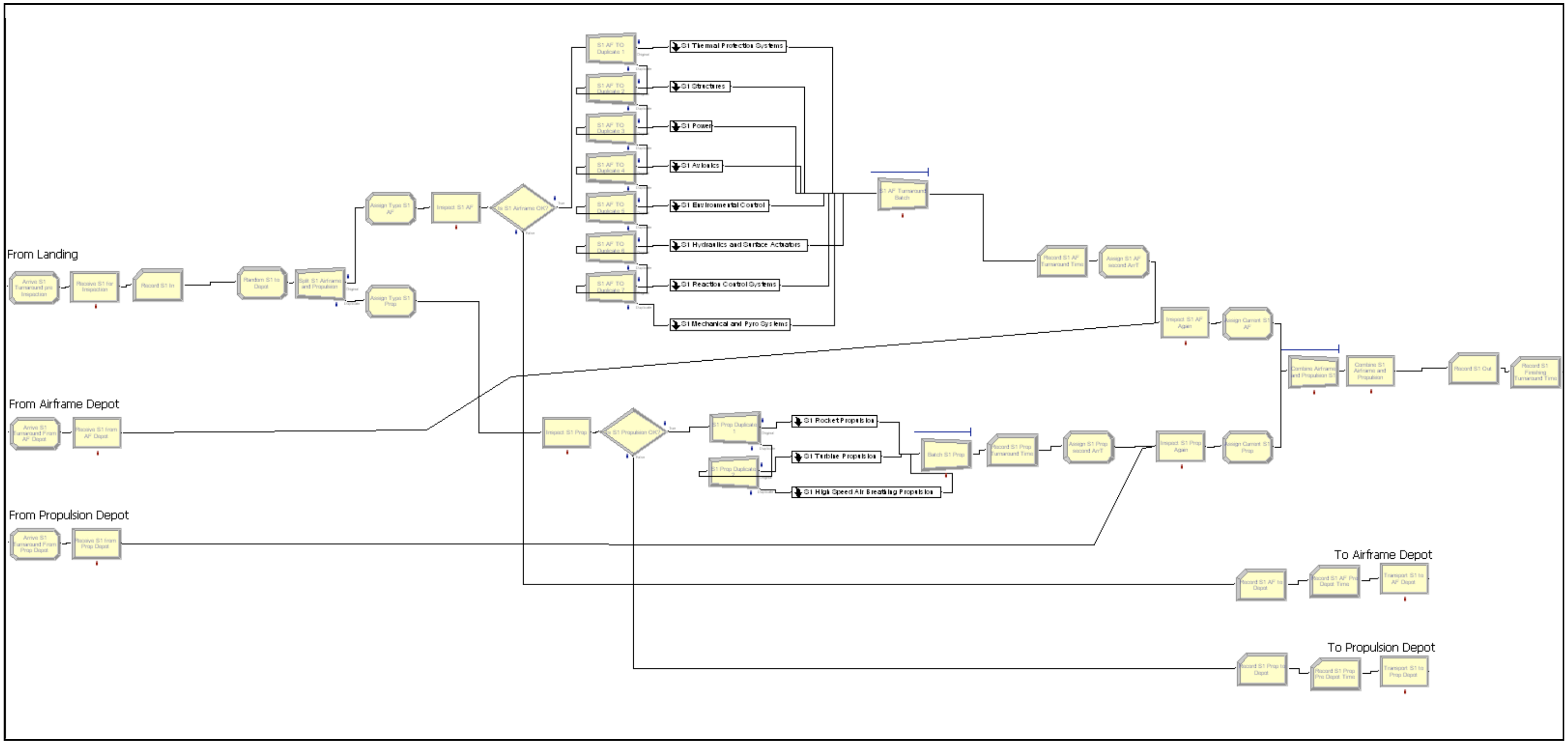
DESCARTES-HYPERPORT: MODEL SCHEMATIC



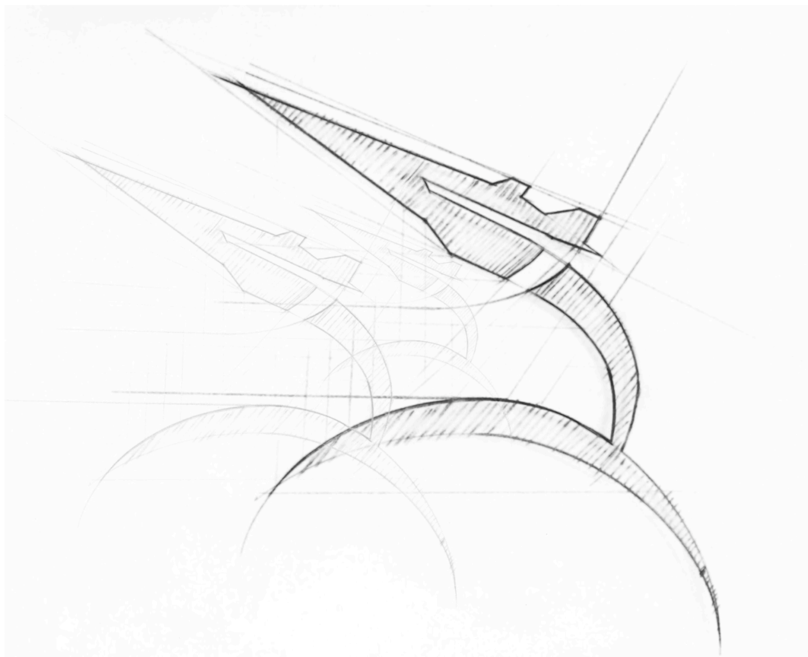
DESCARTES-HYPERPORT MODEL: TURNAROUND (INTERIM VERSION)



DESCARTES-HYPERPORT MODEL PROGRESS



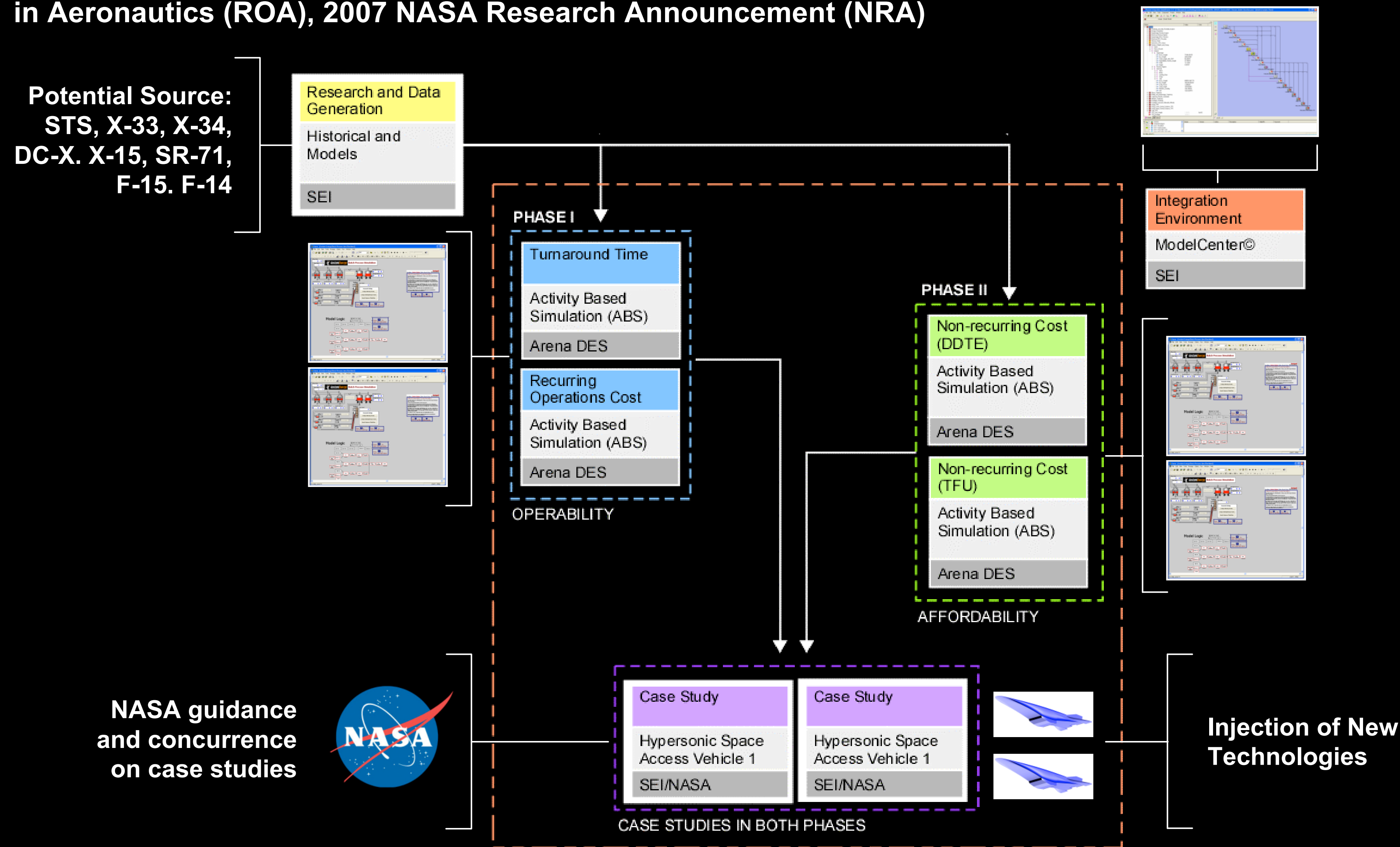
– Stage turnaround currently consists of 8 (S1) or 12 (S2) airframe processing submodels and 3 propulsion processing submodels
  - **Airframe:** TPS, Structures, Power, Avionics, Env. Control, Hydraulics/Actuators, RCS, Mechanical/Pyro; OMS, Thermal Control, Payload, Cockpit/Cabin
  - **Propulsion:** Rocket, Turbine, High-speed Air-breathing



IMPLEMENTATION

OVERALL PROJECT MAP

NASA Aeronautics Research Mission Directorate (ARMD) Research Opportunities in Aeronautics (ROA), 2007 NASA Research Announcement (NRA)



DATA PLAN

- One large issue is the population of Descartes-Hyperport model with accurate data for subsystems of vehicle concepts
  - Distributions on Descartes model inputs allow for probabilistic simulation
- Multiple sources of operational times and costs identified and have already obtained many relevant data points
  - STS, X-15, HL-20, X-33, X-34, ALS/PLS, DC-X, SR-71, XB-70, F-15
- Leverage existing aircraft maintenance operations knowledge (e.g. Robins AFB depot-level maintenance of C-130s, F-15s, C-5s, and other USAF vehicles)
- Examining existing models and sources
  - RMAT
  - Root-Cause Analysis (RCA)
  - Operations Simulation and Analysis Modeling System (OSAMS)
  - COMET-OCM
  - REWARD

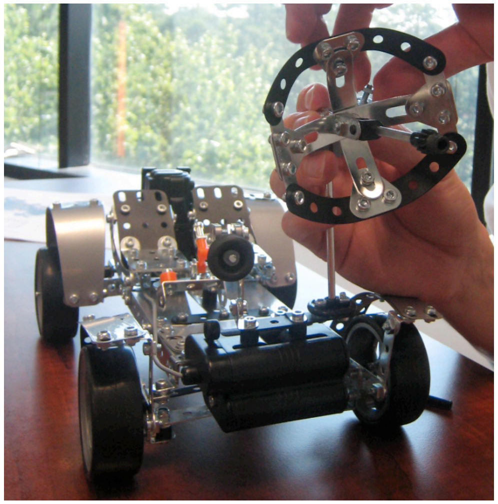


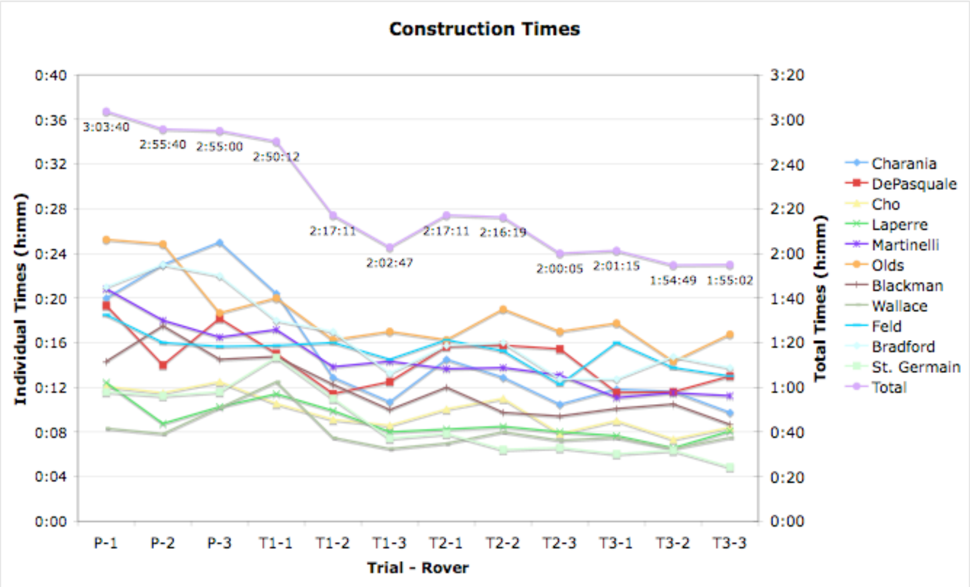

ROBINS AFB VISIT

- Toured Robins AFB in Warner-Robins, GA on July 30
  - Home of Warner-Robins Air Logistics Center
  - Employs over 25,000 military and civilian personnel
  - Performs depot-level maintenance of C-130s, F-15s, C-5s, and other USAF vehicles

- Some lessons learned:
  - Three tiers of AF maintenance
  - 50-50 mix of direct-indirect man-hours during depot maintenance
  - Newer vehicles can emphasize maintainability through better access to key components
  - Breakdown of depot maintenance into 4 cycles, ordering parts 1 cycle in advance

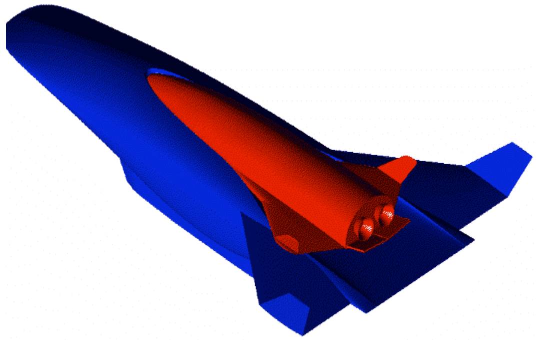
- SEI Staff formed an assembly line for erector set rover kits
- Total of 13 rovers built; data used to build Descartes model of assembly line
  - Model included learning curves, randomness, and some assembly line congestion.
- Lessons Learned include:
  - Generalized learning curves and simplified random distributions can generate accurate results

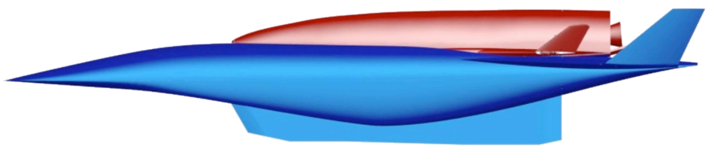




	Average Man-Hours	Average Flow Time
Arena Output	135.5 min	106.4 min
Actual Data	130.5 min	104.2 min
Diff.	3.7%	2.3%

CASE STUDY VEHICLE 1: HRRLS-1A VEHICLE CONCEPT





Architecture Information
- TSTO-horizontal takeoff & landing
- 2-D lifting body booster, fully reusable winged-body rocket upper
- All HC fueled for both stages (plus H2O and LOX)

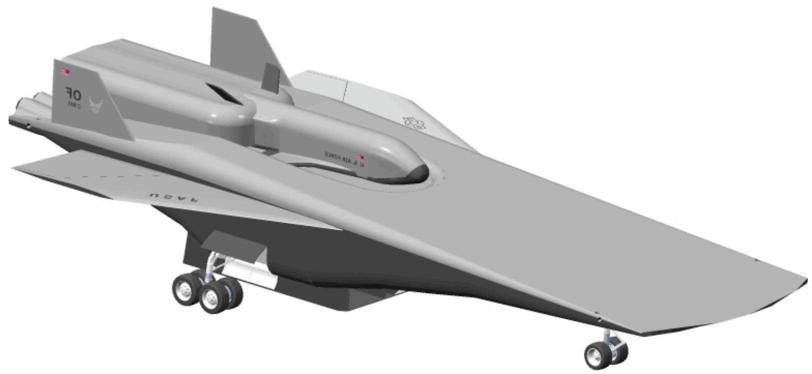
Reference Mission Characteristics
- Payload: 4 crew
- Launch & landing site: KSC
- Orbit: 50x160 nmi, 28.5° inclination
- Supports baseline Exploration LEO rendezvous scenario (TRL=6 by 2017, IOC 2025)

Airframe Technology Suite
Booster & Orbiter
- Ti-Al or Al-Li primary structure
- (Booster) Integral conformal Al-Li HC tanks
- (Booster) Multi-lobed Al-Li LOX tank (if rocket req'd)
- AETB-8 ceramic composite tile and TABI blanket TPS
- Advanced polyimide foam (APF) insulation on tanks
- High temperature metallic wings, tails and control surfaces
- Coated carbon-carbon leading & trailing edges

Propulsion Technology Suite
- Lowspeed (Mach 0-3.5)
  - F135 w/ water injection
  - In over-under configuration with high speed propulsion system
- Highspeed (Mach 3-8)
  - Fully variable geometry dual mode scramjet (inlet flap rotation, cowl vertical translation)
  - Mach 7 shock-on-lip, actively cooled, high temperature metallics
- External Rocket System
  - Booster requires linear aerospike tail rocket to assist with takeoff and transonic acceleration
- Upper stage rocket
  - Conventional HC/LOX bell nozzles; upper stage cross fed and operated during takeoff and transonic

Source: NASA LaRC Hypersonic Team (J. Robinson), NASA Hypersonics Project, HRRLS-1A Status

CASE STUDY VEHICLE 2: QUICKSAT MILITARY SPACE PLANE



CONCEPT DESCRIPTION AND TECHNOLOGIES

System
- HTHL TSTO with RTLS
- Reusable Booster and Expendable Upperstage

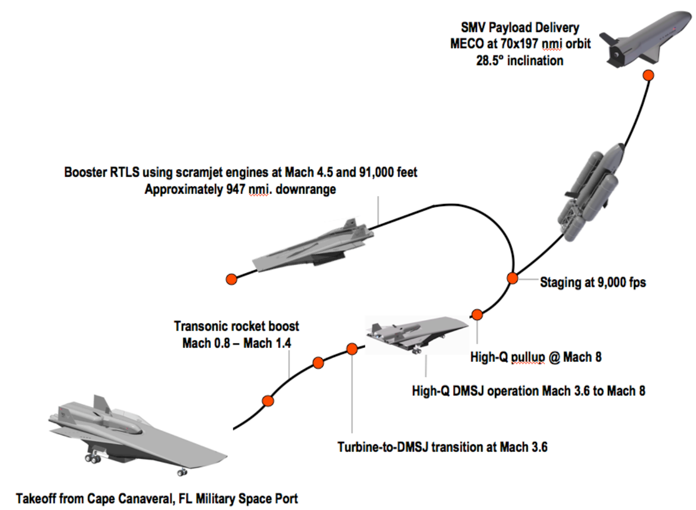
Booster
- 2-D lifting body capable of fully autonomous flight
- Mach-8 SOL with 3-ramp compression system
- H_2O_2/JP-7 propellants
- (6) advanced turbines from Mach 0-3.6, (4) DMSJ from Mach 3.6–8
- (4) Tail Rockets for transonic and from Mach 8 to ~9 (staging)
- ACC, AFRSI, and CRI TPS
- EHAs, IVHM, Gr-Ep airframe structures, Ti-Al wings/tails

Upper stage
- H_2O_2/JP-7 propellants
- Single aft rocket
- Orbital Insertion @ 70x197 nmi. @ 28.5º

PERFORMANCE SUMMARY

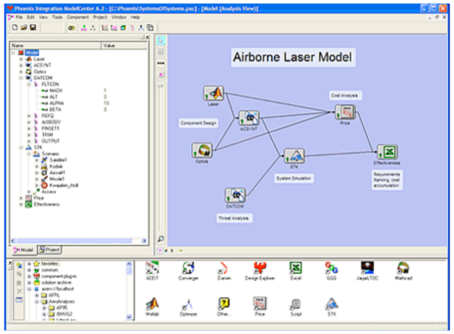
System Gross Weight (lbs):		682,000
Booster		
	Gross Weight (lbs):	575,000
	Dry Weight (lbs):	151,765
	Length (ft):	118.2
	Takeoff T/W:	0.53
	Flyback Range (nmi):	947
	Mass Ratio (to staging):	2.275
Upper stage		
	Payload:	SMV
	Payload Weight (lbs):	13,090
	Gross Weight (lbs):	88,435
	Dry Weight (lbs):	4,285
	Length (ft):	52.1
	Initial T/W:	1.15

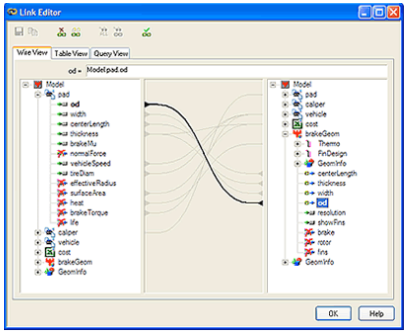
MISSION OVERVIEW

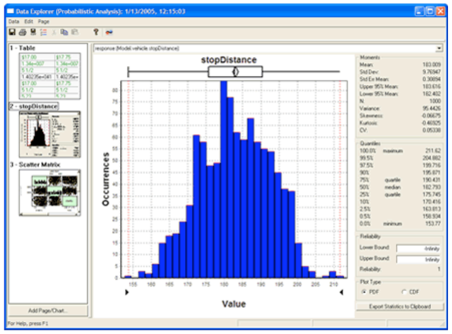


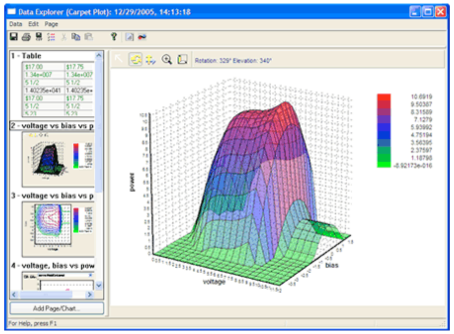
MODELCENTER

- Descartes-Hyperport will be integrated into Phoenix Integration, Inc.'s ModelCenter and Analysis Server products
- Enables integration of different engineering software tools located locally or remotely on disparate computing platforms written in different computing languages (Fortran, C++, Java, Excel, Matlab, etc.)
- Able to easily and immediately utilize a whole host of built-in analysis capabilities such as: Monte Carlo Simulations, Response Surface Modeling, gradient and non-gradient based optimizers, advanced graphing methods, multi-variable trade studies, parallel processing, distributed analysis, etc.
- Integration with performance disciplinary analysis tools enables vehicle design optimization









SPACE IS GO

Engineering Today Enabling Tomorrow

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