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Mars Synthetic Terrain Generation And Rover Mission Simulation Using Supercomputers

Dr. David Curkendall
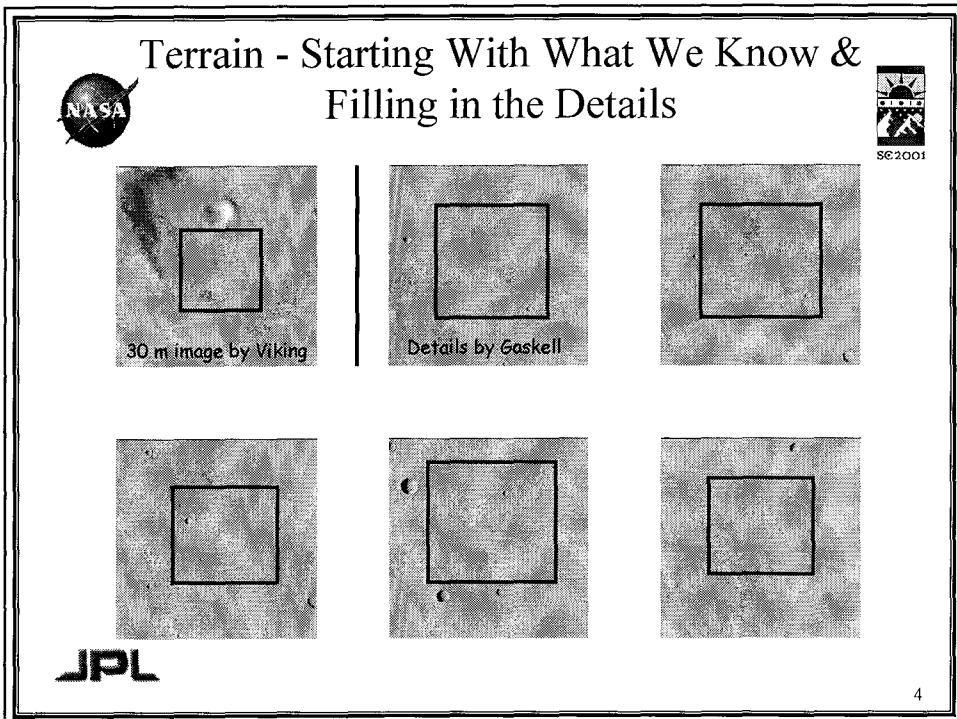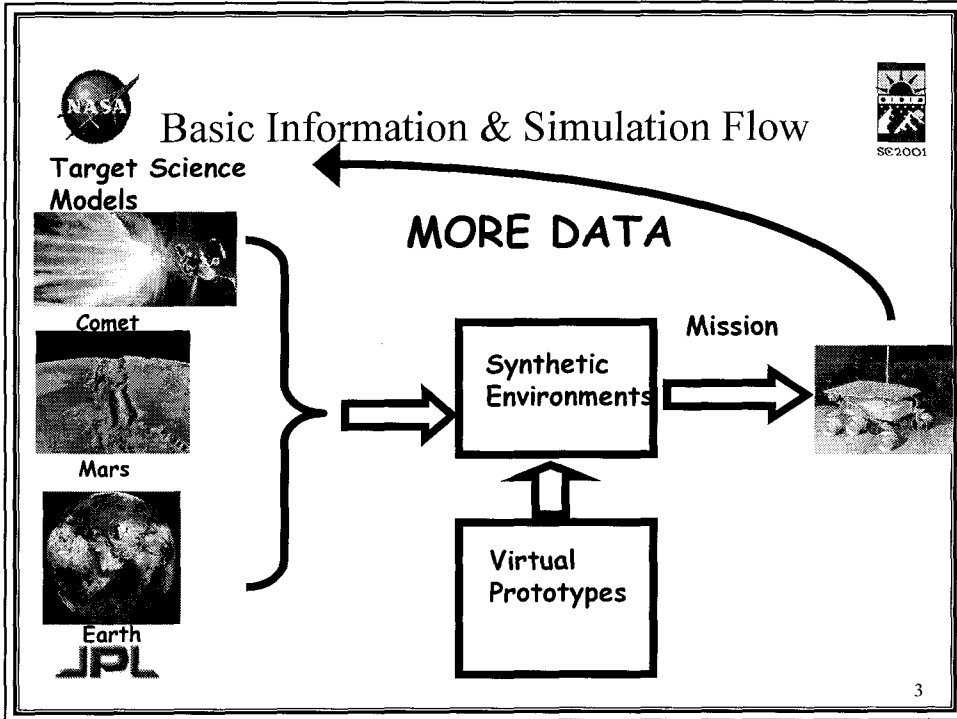## Gary Block

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1

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Our Role Has Been

- Generate & Serve Terrain (environments)
- Host Simulation Models
- Provide Visualization Services
- Provide High Performance *Ensemble* Simulation
- (jointly) Provide interfaces to the risk analysis tools

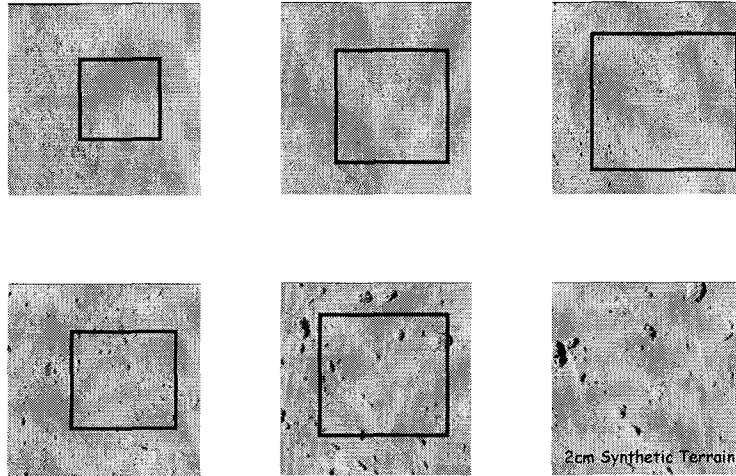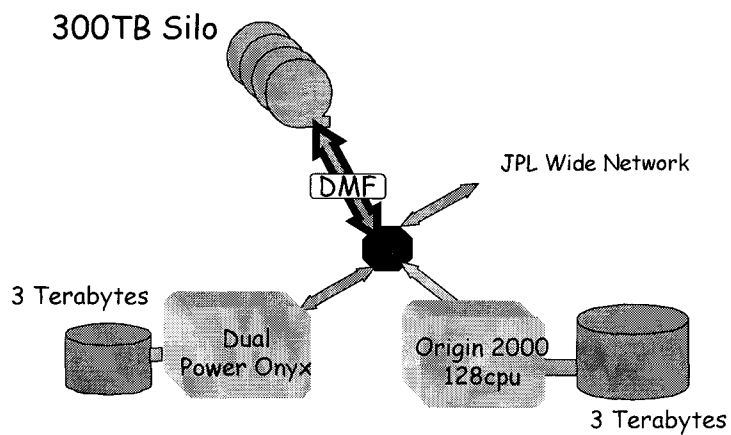Joint Goal: Perform a complete risk analysis from scratch in a single afternoon.

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2

Basic Information & Simulation Flow

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Target Science Models

MORE DATA

Comet

Mission

Synthetic Environments

Mars

Virtual Prototypes

Earth

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3

Terrain - Starting With What We Know & Filling in the Details

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30 m image by Viking

Details by Gaskell

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4

More Details

2cm Synthetic Terrain

5

Terrain Server is meant to be 24/7 capability for wide spectrum customers

300TB Silo

DMF

JPL Wide Network

3 Terabytes

Dual Power Onyx

Origin 2000 128cpu

3 Terabytes

6

Basic Rover Simulator

Sensors

Terrain

Synthetic
Terrain

Sensor
Data

Terrain Estimation
Algorithms

Estimated Terrain

New
Rover
State

Navigation
Algorithms

Rover Control
Commands

Rover Movement

7
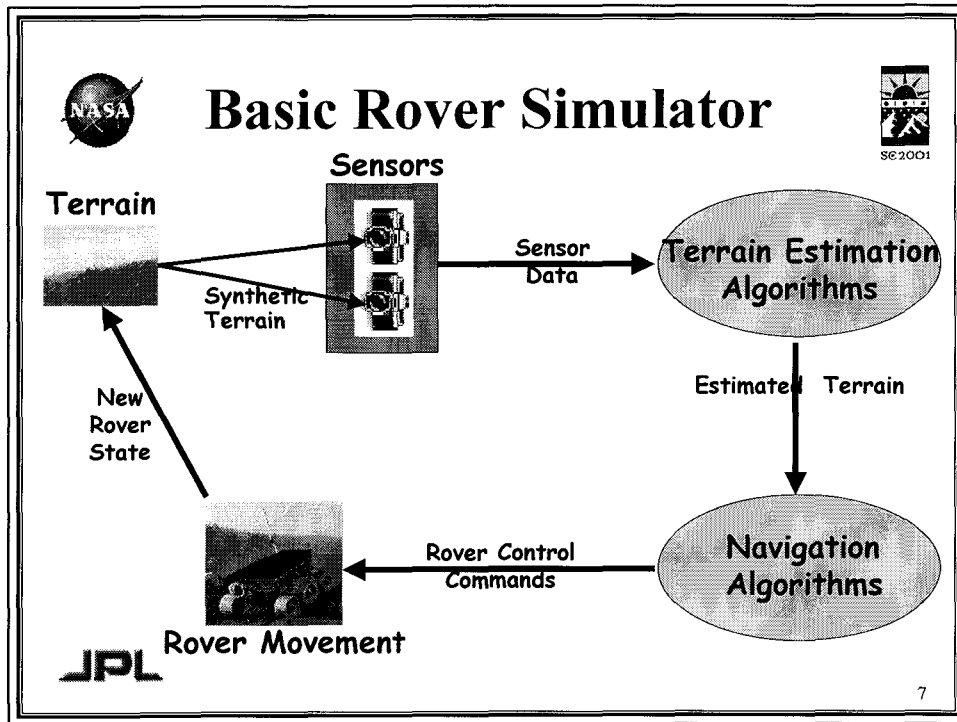
Creating the Virtual Environment and Simulation Model Is the Hard Part…...

- But It's Not Enough!
- To Be Effective These Modules Should Be Embedded in an 'Ensemble' Simulation Environment.

Ensemble simulation is the performance key for:

- Rapid Design Space Exploration
- Monte Carlo Risk Analyses
- Mission Replan During Operations

8

Some Performance Results

- Terrain Generation - Several Hours to Several Minutes

- Can run ~ 100 simulations at once

- By moving to a 'data agile' environment, the execution time of each simulation went from 6 hours to 45 minutes.
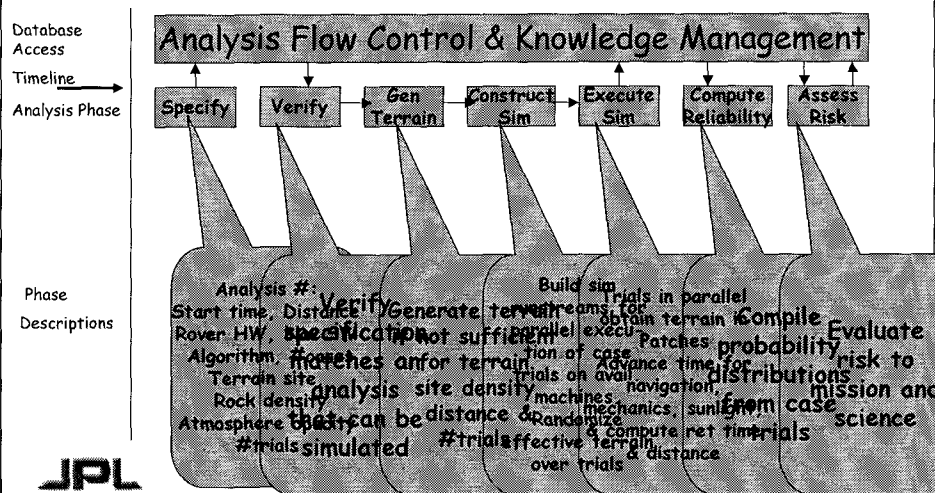
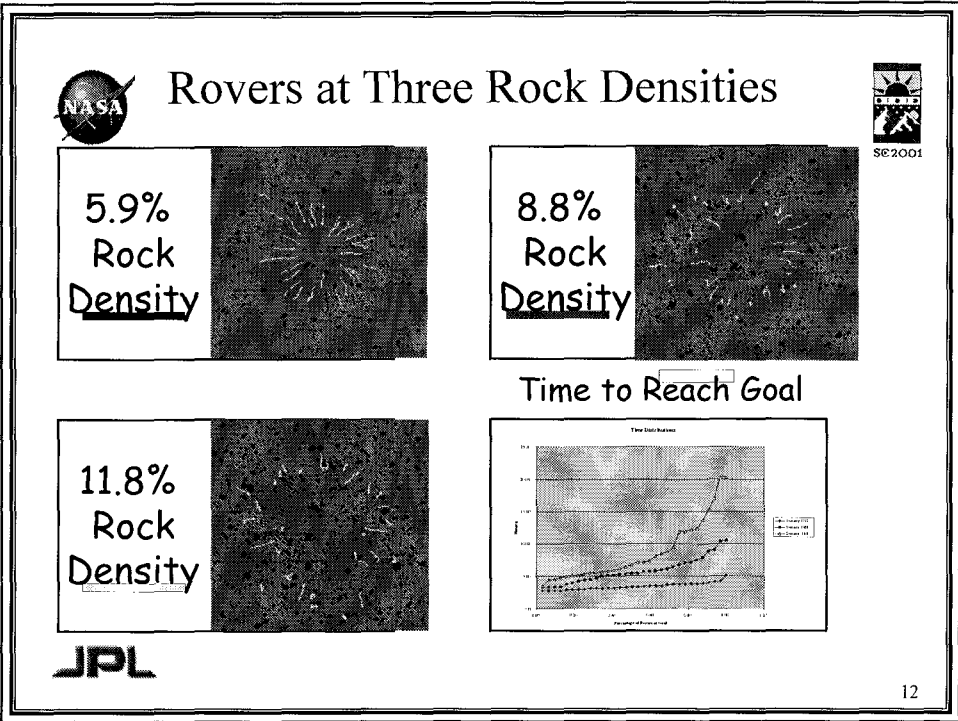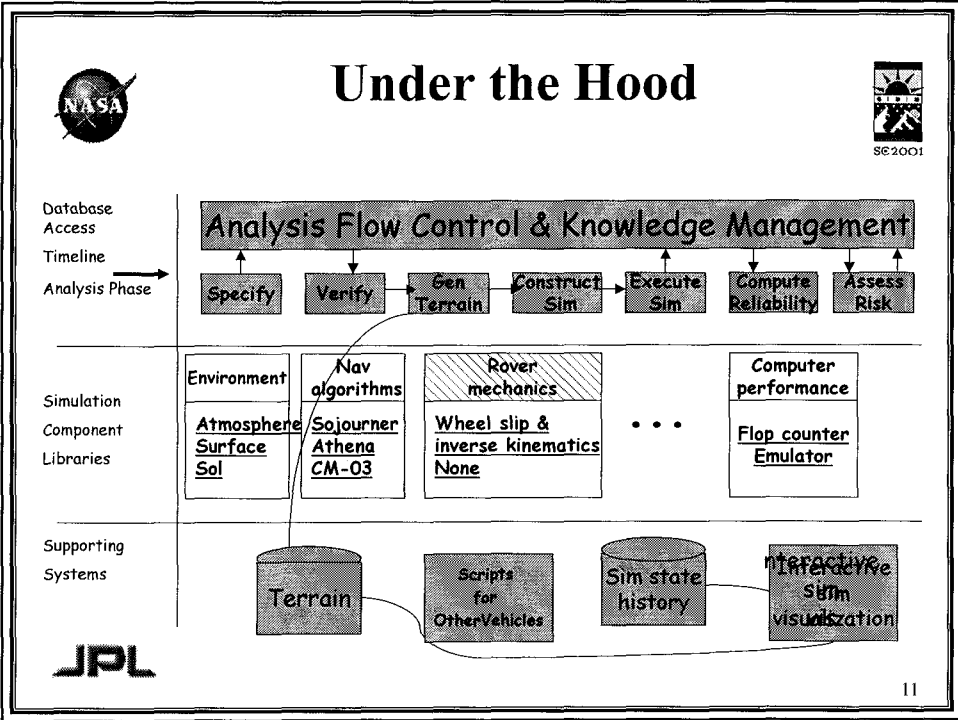   **Overall - An improvement of nearly 3 orders of magnitude!**

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9

A Comprehensive Environment Linking Synthetic Environments, Simulation, & Risk Analysis Is Key And Is This Year's Focus
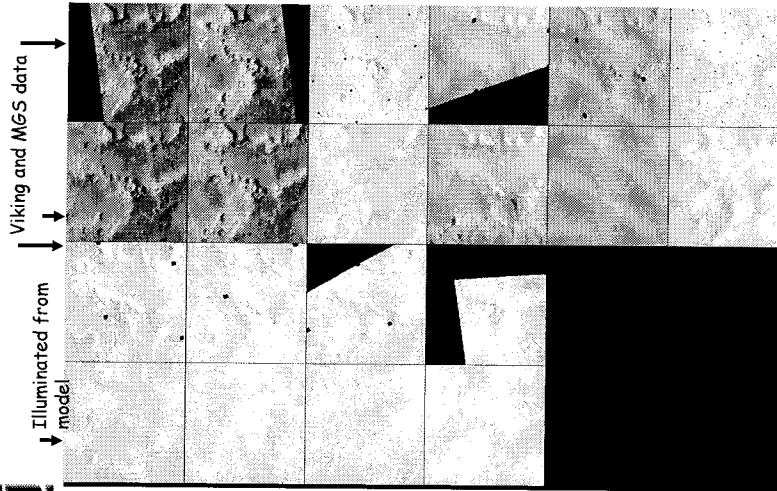
Database Access

Timeline

Analysis Phase

Phase Descriptions

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10

Under the Hood

Database
Access

Timeline

Analysis Phase

Analysis Flow Control & Knowledge Management

| Specify | Verify | Gen Terrain | Construct Sim | Execute Sim | Compute Reliability | Assess Risk |

Simulation
Component
Libraries

| Environment | Nav algorithms | Rover mechanics | | Computer performance |
| Atmosphere Surface Sol | Sojourner Athena CM-03 | Wheel slip & inverse kinematics None | • • • | Flop counter Emulator |

Supporting
Systems

Terrain

Scripts for OtherVehicles

Sim state history

Interactive Sim visualization

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11

Rovers at Three Rock Densities

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5.9% Rock Density

8.8% Rock Density

Time to Reach Goal

11.8% Rock Density

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12

Starting With What We Know & Modeling It
A Candidate Mars '03 Landing Site in Isidis

Viking and MGS data

Illuminated from model

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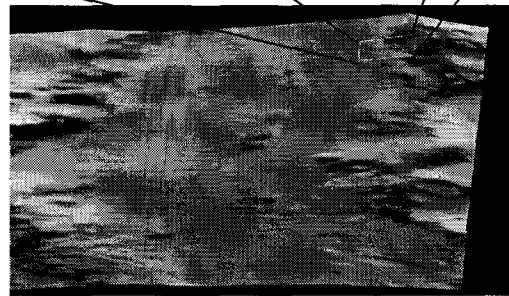
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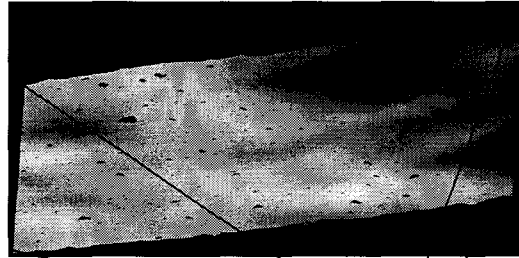
13

Validation with Laser Altimetry
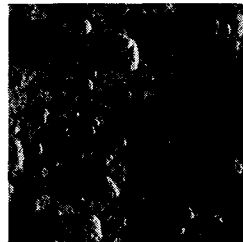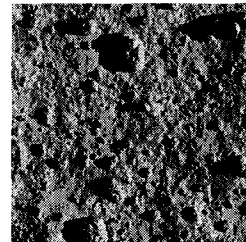
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MOLA DATA

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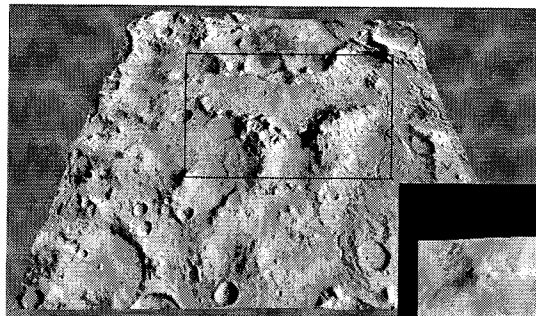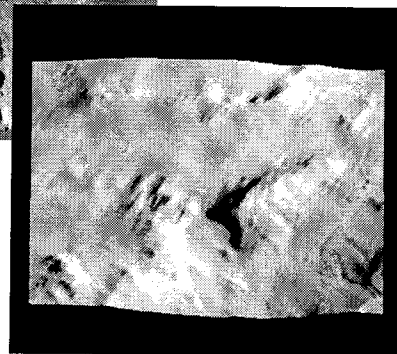
First Light: Real Terrain Enriched Synthetically
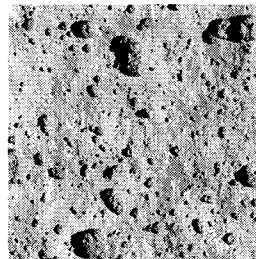

15

Hi Fidelity Sun Angle Modeling
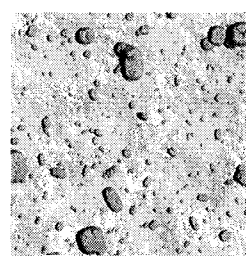

10 Deg

30 Deg

50 Deg

70 Deg

16

This Approach Enables Value Focused Thinking & Probabilistic Reasoning for Space Mission Design

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Outcome as Value Model

Risk Model

Alternative Mission Implementation

Mission Outcomes

Mission Value

probability

Risk-Adjusted Mission Value

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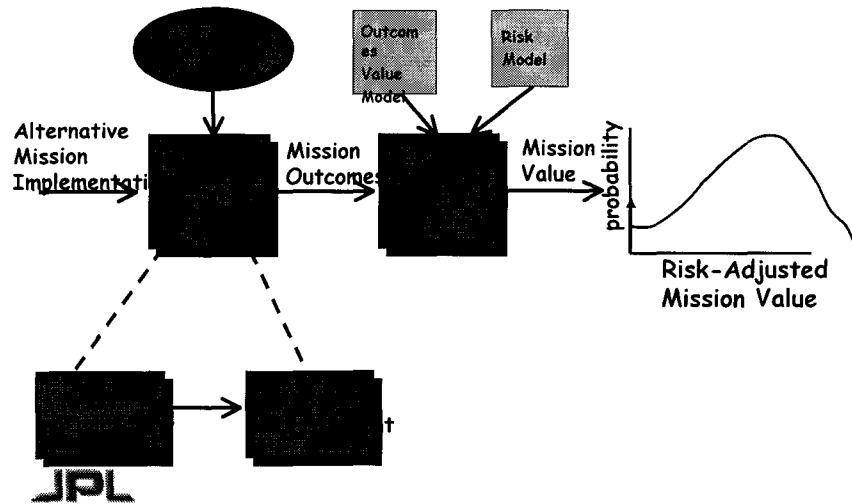
17

A New Paradigm for System Validation

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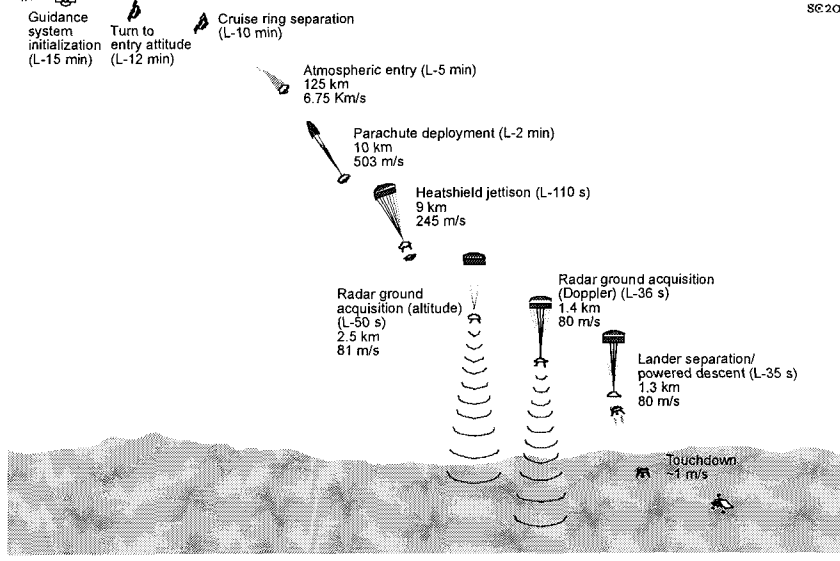Validation - Ensuring that the system will work as required

- The old paradigm.
  - **Tests** validate the **system**.
- The new paradigm.
  - **Tests** validate the **simulation**.
  - The **simulation** validates the **system**.
- Example #1 – Validating Pathfinder Descent.
  - Parachute, backshell, bridle, and lander tested at China Lake.
  - System simulator replicated the China Lake results.
  - Simulation using the projected Mars environment validated the flight system.
- Example #2 - Similarly, the Mars Yard can validate Mars Rover simulations under both obstacle and lighting conditions.
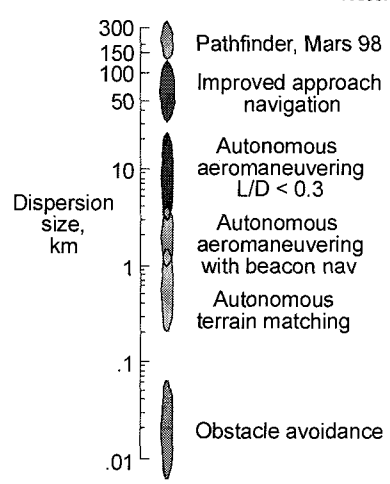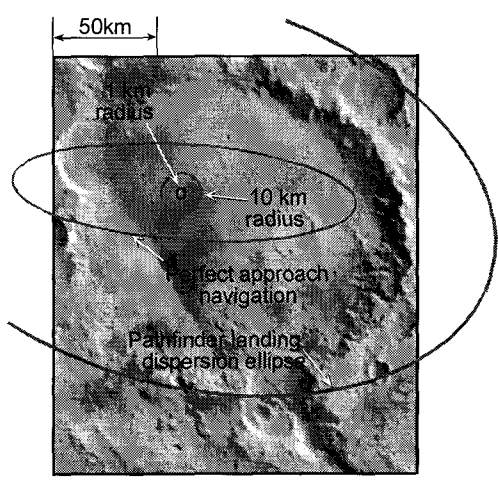
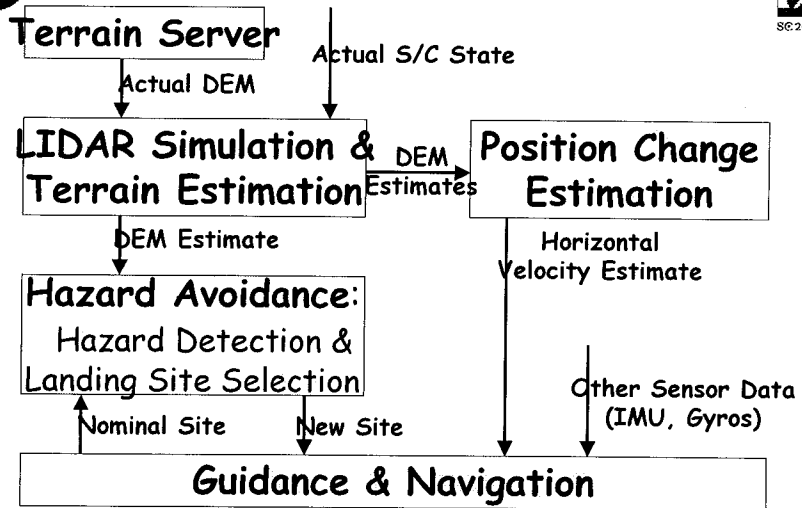JPL

18

Entry Descent& Landing - A Second Example

Guidance system initialization (L-15 min)

Turn to entry attitude (L-12 min)

Cruise ring separation (L-10 min)

Atmospheric entry (L-5 min)
125 km
6.75 Km/s

Parachute deployment (L-2 min)
10 km
503 m/s

Heatshield jettison (L-110 s)
9 km
245 m/s

Radar ground acquisition (altitude) (L-50 s)
2.5 km
81 m/s

Radar ground acquisition (Doppler) (L-36 s)
1.4 km
80 m/s

Lander separation/ powered descent (L-35 s)
1.3 km
80 m/s

Touchdown
~1 m/s

The EDL Architecture Problem

50km

1 km radius

10 km radius

Perfect approach navigation

Pathfinder landing dispersion ellipse

Dispersion size, km	
300	Pathfinder, Mars 98
150	
100	Improved approach navigation
50	
10	Autonomous aeromaneuvering L/D < 0.3
	Autonomous aeromaneuvering with beacon nav
1	Autonomous terrain matching
.1	
	Obstacle avoidance
.01	

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20

Hazard Avoidance & Precision Landing

Terrain Server

Actual DEM

Actual S/C State

LIDAR Simulation & Terrain Estimation

DEM Estimates

Position Change Estimation

DEM Estimate

Horizontal Velocity Estimate

Hazard Avoidance: Hazard Detection & Landing Site Selection

Nominal Site

New Site

Other Sensor Data (IMU, Gyros)

Guidance & Navigation

21

Multi-Center Simulation Architecture

Langley Hypersonic Entry Ensemble Simulator

Individual States

JPL EDL Ensemble Simulator

Visualization & Control

22
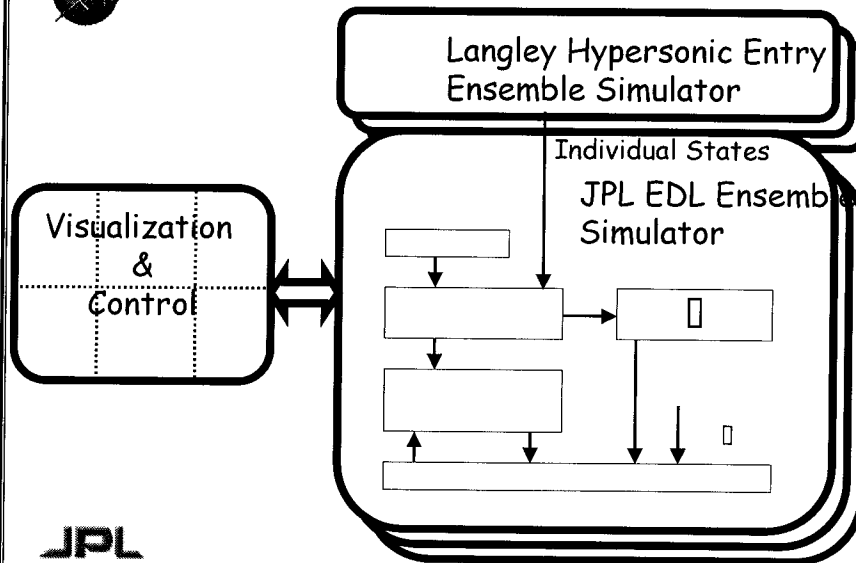
View of landing site with synthetic terrain enhancement.

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23
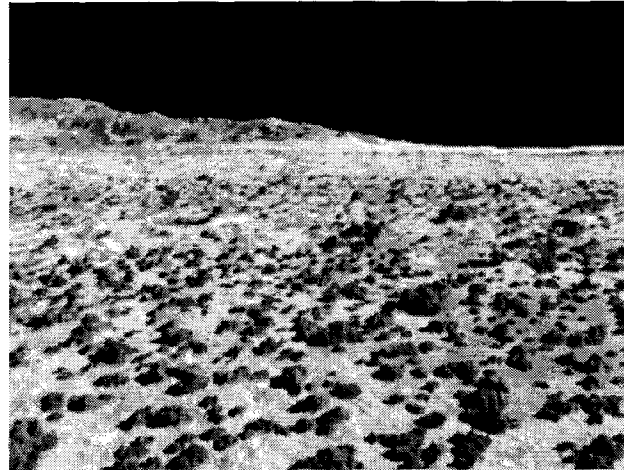
An Ensemble EDL Simulation - Keeping Track

The Ensemble

Terrain

Lidar Data
(for red bordered terrain region)

Terrain Estimate
(from Lidar Data)

Hazard Map
(from Terrain Estimate)

Guidance

Altitude

Fuel

Hazards

Time

Monte Carlo Statistics

% Landed

% Safe Landings

% Within Target Zone

Avg Fuel Reserves
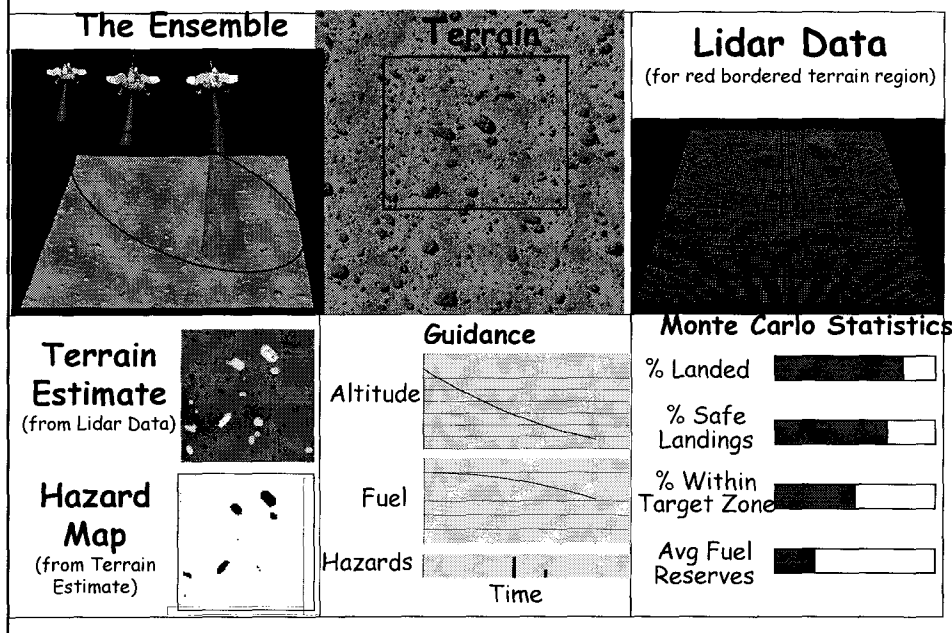
Integrated Processes

Conceptual Design Process

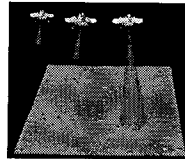| Configure a feasible system solution |

Knowledge Management
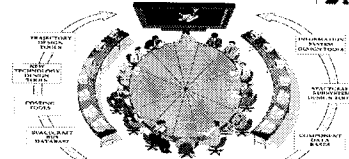
JPL's Product Design Center (PDC)

Product Formulation Process

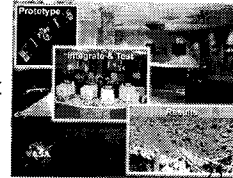| Test every aspect of proposed system/mission change or addition |

Knowledge Management

JPL's Proposed
Mission /
Technology
Analysis and
Synthesis
(MTAS) Center

Detailed Design & Implementation Process

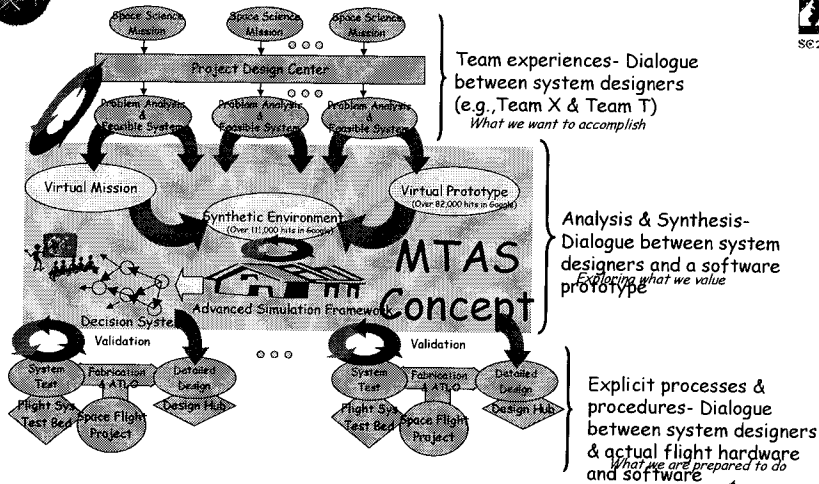| Bricks have been laid - execute implementation plan |

JPL's Design
Hubs & Flight
Systems
Test beds

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The Big Picture

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Team experiences- Dialogue
between system designers
(e.g.,Team X & Team T)
What we want to accomplish

Analysis & Synthesis-
Dialogue between system
designers and a software
prototype *Exploring what we value*

MTAS Concept

Explicit processes &
procedures- Dialogue
between system designers
& actual flight hardware
and software *What we are prepared to do*

Major benefit: MTAS allows you to test and iterate your
design without committing resources to detailed design
and acquisition

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26

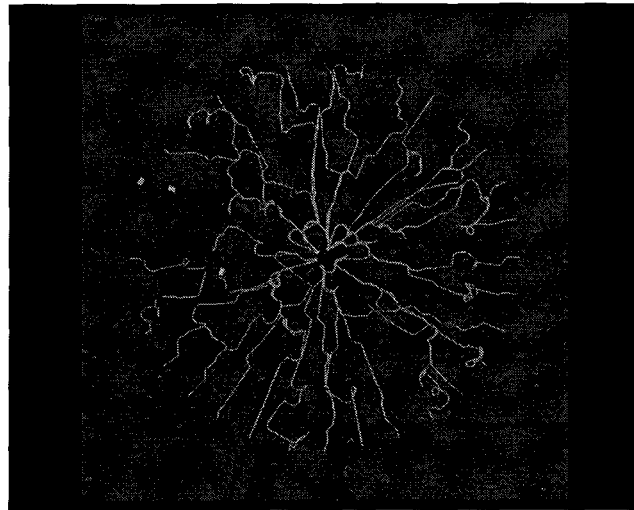# Schoppers Algorithm, 30 cm Hazards
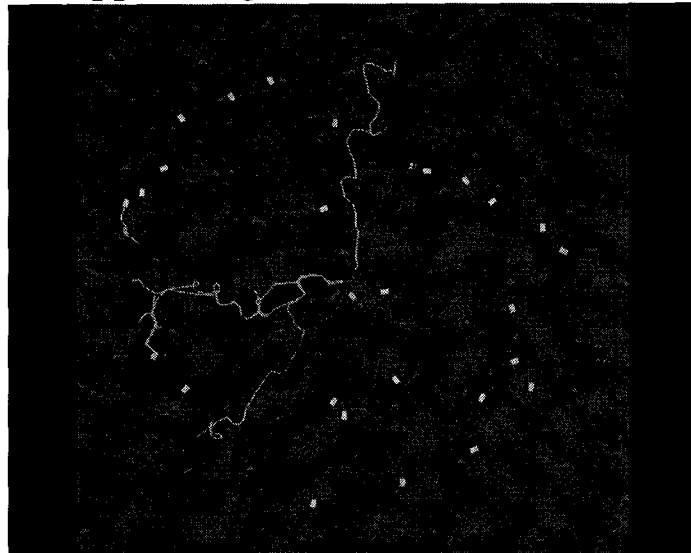

27
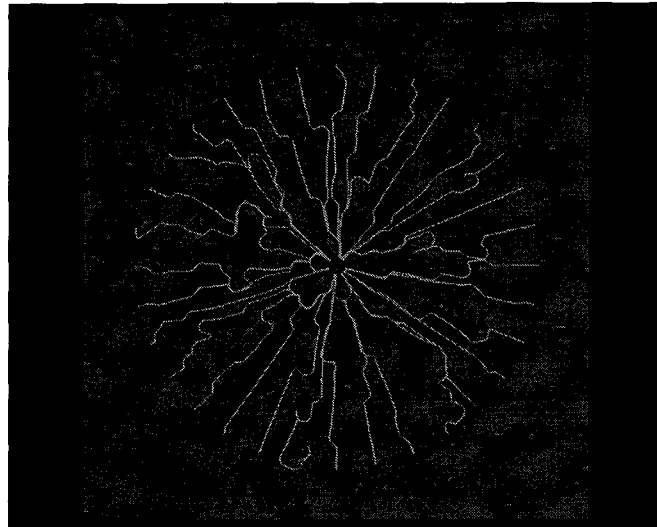
Schoppers Algorithm, 25 cm Hazards

28

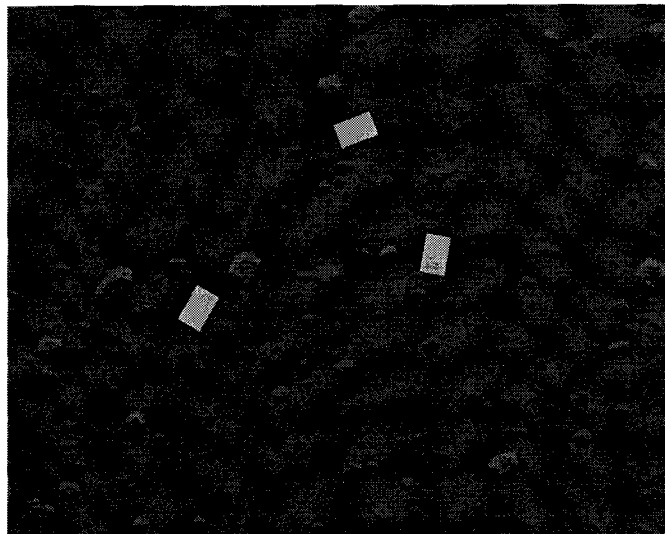Schoppers Algorithm, 20 cm Hazards

29

Time To Call Home

30