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Mission Data System

Proposal for MDS Project Engagement with the POST Project

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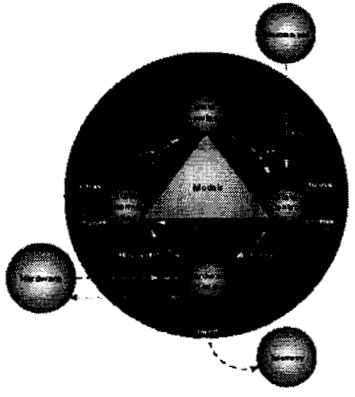
Proposal Premises

- MDS process, tools, and tests are underway at JPL
- POST process, tools, and tests are underway at JSC
- MDS might benefit from additional adaptations and deployments in order to demonstrate technology maturation
- POST might benefit from additional tool and process support to the payload customer's hardware and software development activity



PAYLOAD OPERATIONS SUPPORT TEAM
• FIT TO FLY •

Outline

- **MDS Overview**
- Concept for POST Integration
- Technology Maturity
- Proposal

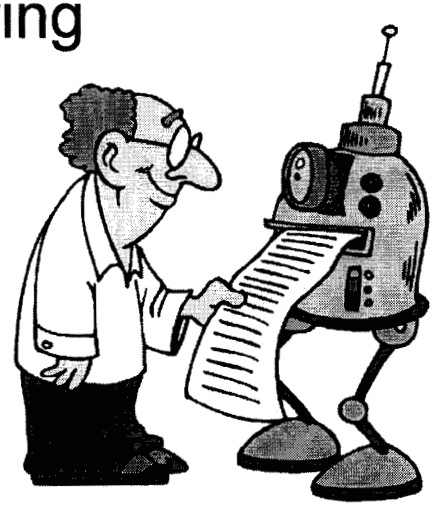
Pressures for Change

Challenging Future Missions

- ***In situ* exploration** of the solar system with vehicles on and under surfaces, in atmospheres, and on and around small bodies
- **Multi-vehicle coordination** for formation flying, rendezvous and docking, and so on
- **More complex observatories** with very demanding operational requirements
- An **interplanetary network** requiring multi-project coordination of resources scattered around the solar system

What We Need

- Highly reusable core software for flight, ground, and test
- Synergistic systems and software engineering
- Reduced development time and cost
- Improved development processes
- Highly reliable operations
- Increased functionality



Yes

The MDS Vision

A unified control architecture and methods
for flight, ground, and test systems
that enable missions
requiring reliable, advanced software

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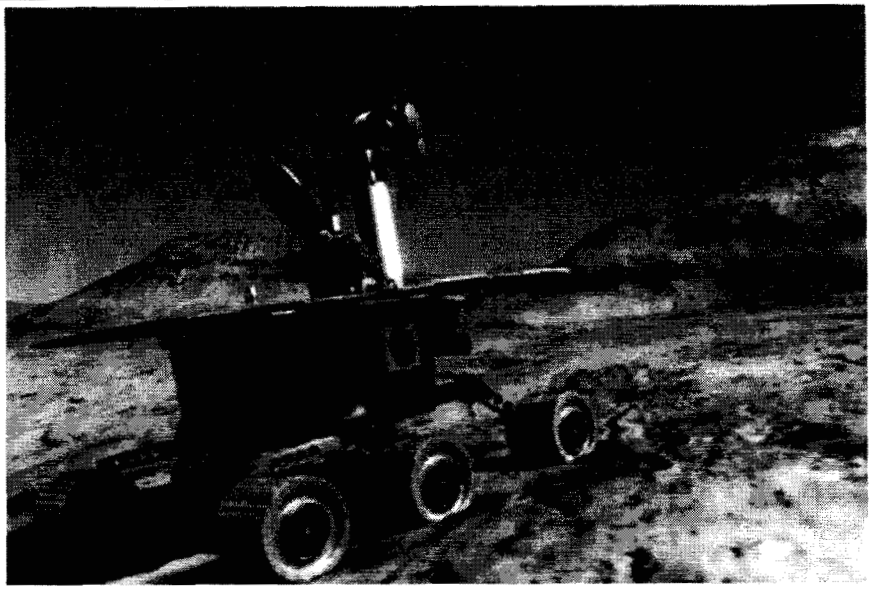
Mission Data System

Problem Domain

Control of physical systems

- Mission information, control, and operations
- Broadly applicable to mobile and immobile robots that operate autonomously to achieve goals specified by humans
- Architecturally suited for resource-limited systems



Scope

- Flight systems
- Ground systems
- Test and simulation systems

Major Parts

MDS adopts a product line (multi-mission) approach that exploits commonalities across missions

- An information & control system architecture
- Reusable & adaptable framework software
- A systems engineering methodology

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State / Model / Goal Architecture

Estimators interpret measurement and command evidence to estimate state

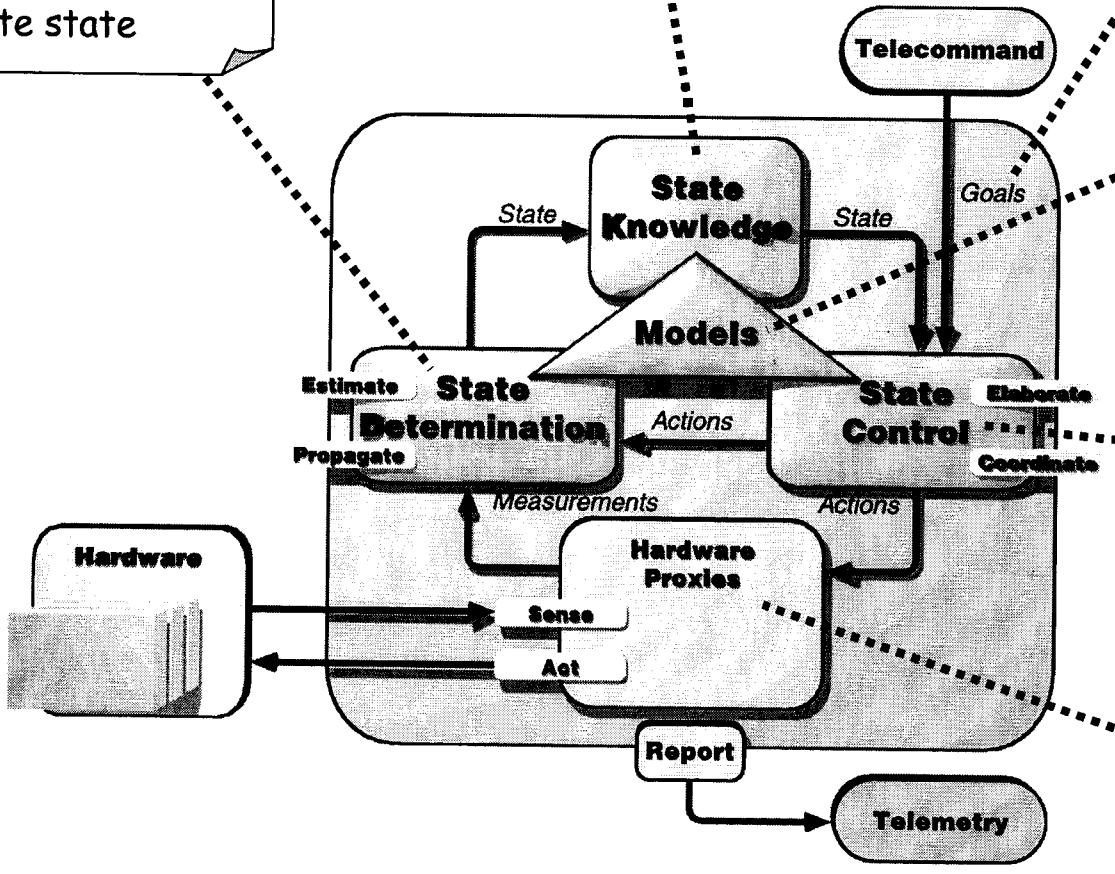
State variables hold state values, including degree of uncertainty

A goal is a constraint on the value of a state variable over a time interval

Models express mission-specific relations among states, commands, and measurements

Controllers issue commands, striving to achieve goals

Hardware proxies provide access to hardware busses, devices, instruments



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Bridging the Gap Between Systems and Software Engineering

Systems engineers follow a disciplined "state analysis", asking & answering questions such as these:

The state architecture bridges the gap through a shared set of architectural elements

Software engineers build the system by adapting a software framework having the <u>same</u> architectural elements

What do you want to achieve?
Move rover to rock. → ***Goal*** → Goal Network | Simulation | …

What's the state to be controlled?
Rover position relative to rock. → ***State Variable*** → State Knowledge | Hardware Proxy | Sequential Estimation

How do you know what that is?
Measure relative position with stereo camera. → ***Measurement*** → Measurement Package | Data Catalog | Graph Library

What does the stereo camera measure?
Distance to terrain features, light level, camera power (on/off), camera health. → ***Measurement Model*** → State Models | Coordinate Systems | SI Units | Naming

How do you control light level?
Wait until the sun is up. → ***State Model*** → Time Services | Linear Algebra | Event Logging | …

Where is sun relative to horizon?
…

Etc.

Cost Estimation

- With traditional systems engineering, software cost estimation has been more difficult because:
  - Requirements are expressed as "shall statements"
  - Work Breakdown Structure on prior projects typically mixes several engineering costs

- Systems engineering in MDS expresses requirements in terms of a small vocabulary:
  - Goals
  - Goal networks
  - Temporal constraints
  - State variables
  - State values
  - State effects models
  - Measurements
  - Measurement models
  - Commands
  - Command models
  - Estimators
  - Controllers
  - Hardware adapters
  - Resource allocations

These terms provide a much more detailed basis for cost estimation

Verification & Validation

- ***Leverage the state architecture***
  - Unifying concept of 'state' facilitates direct comparison between flight, ground, and simulation
  - Goals provide runtime pass/fail status (self checking!)
  - Models can be inspected/validated separately from application
  - Can simulate & test at 3 levels: state, functional, bit
  - Standard representation of state knowledge with built-in uncertainty
- ***Leverage the component architecture***
  - Check a deployment's as-built configuration against architectural rules
- ***Leverage the framework***
  - Frameworks are an important target for V&V, distinct from adaptation
  - Instrument the framework, enable/disable as desired
  - Design away some sources of error
- ***Leverage previous adaptations***

Elevating into Architecture

- Things that are "buried in the analysis" or "buried in the code" are hard to review, analyze, modify, and manage
- In many areas MDS makes things *explicit* and brings them out into the light of day. We call this "elevating into architecture". Examples:
  - State variables and behavior models are explicit design elements
  - State estimation is cleanly separated from control
  - State timelines organize both past and future state information
  - Components communicate only via connections
  - Architecture configuration is explicit, inspectable, and verifiable
  - Units of measurement are explicit and enforced
  - Initialization dependencies are explicit and enforced
  - Operation based on explicit, unambiguous constraints on state & time
  - Resources (power, etc) are managed as state allocations
- All this *explicitness* offers many opportunities for improving dependability through disciplined analysis and verification

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MDS Software Framework Packages

Application Services
Level 5

- Goal Elaboration Language
- State Query
- Data Visualization
- Simulation
- Component Scheduler

State Services
Level 4

- State Knowledge
  - -state variable
  - -state value
- Goal Achiever:
  - -estimator, controller
  - -Measurement, command
- Goal Network
- Hardware Adapter
- Graph State Variable

Complex Services
Level 3

- Components & Connectors
- Value History
  - -sampled history
  - -time-interval history
- Data Catalog
  - -collection, entry, event
  - -data product
- Data Transport
  - -sender, receiver
  - -session, request

Simple Services
Level 2

- Embedded web Server & client
- Event Log Facility
- Naming Services
- Time Services
- Data Mgmt Policy
- CCSDS File Delivery Protocol

Primitive Services
Level 1

- Initialization & Finalization
- Data Serialization
- Exception Classes
- Standard Utility classes
- Sequential Estimation
- Graph Library
- Physics Library:
  - -SI Units
  - -Coordinate systems
  - -Position, velocity & acceleration
- Math Library
  - -Linear algebra
  - -Probability dist.
  - -Polynomials
  - -6-DOF classes

OS Services
Level 0

- C++ Standard Library
- Unit Testing Package
- Adaptive Communication Environment → Real Time Operating System

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- **Concept for POST Integration**
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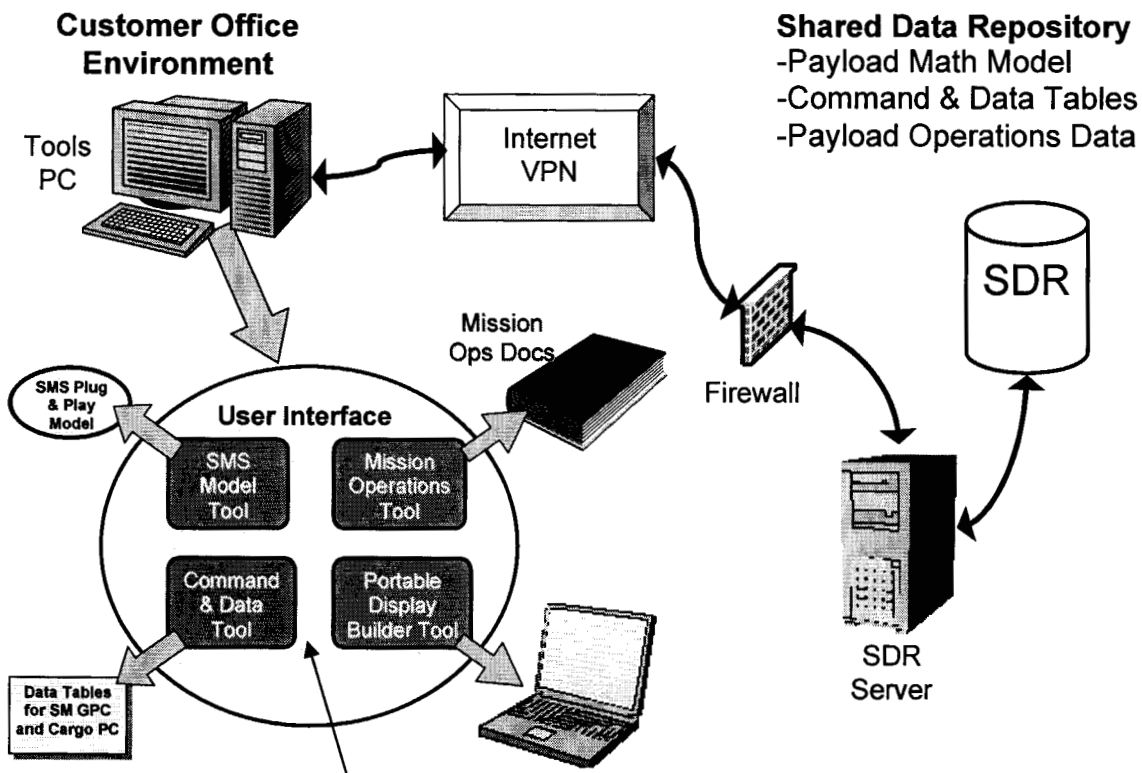
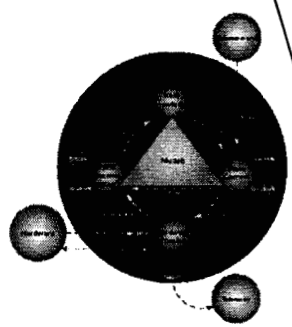
MDS in the POST Environment





MDS complements the existing POST tools, and supplements them with an innovative state analysis process for hardware and software engineering; the on-going design content can live in the SDR

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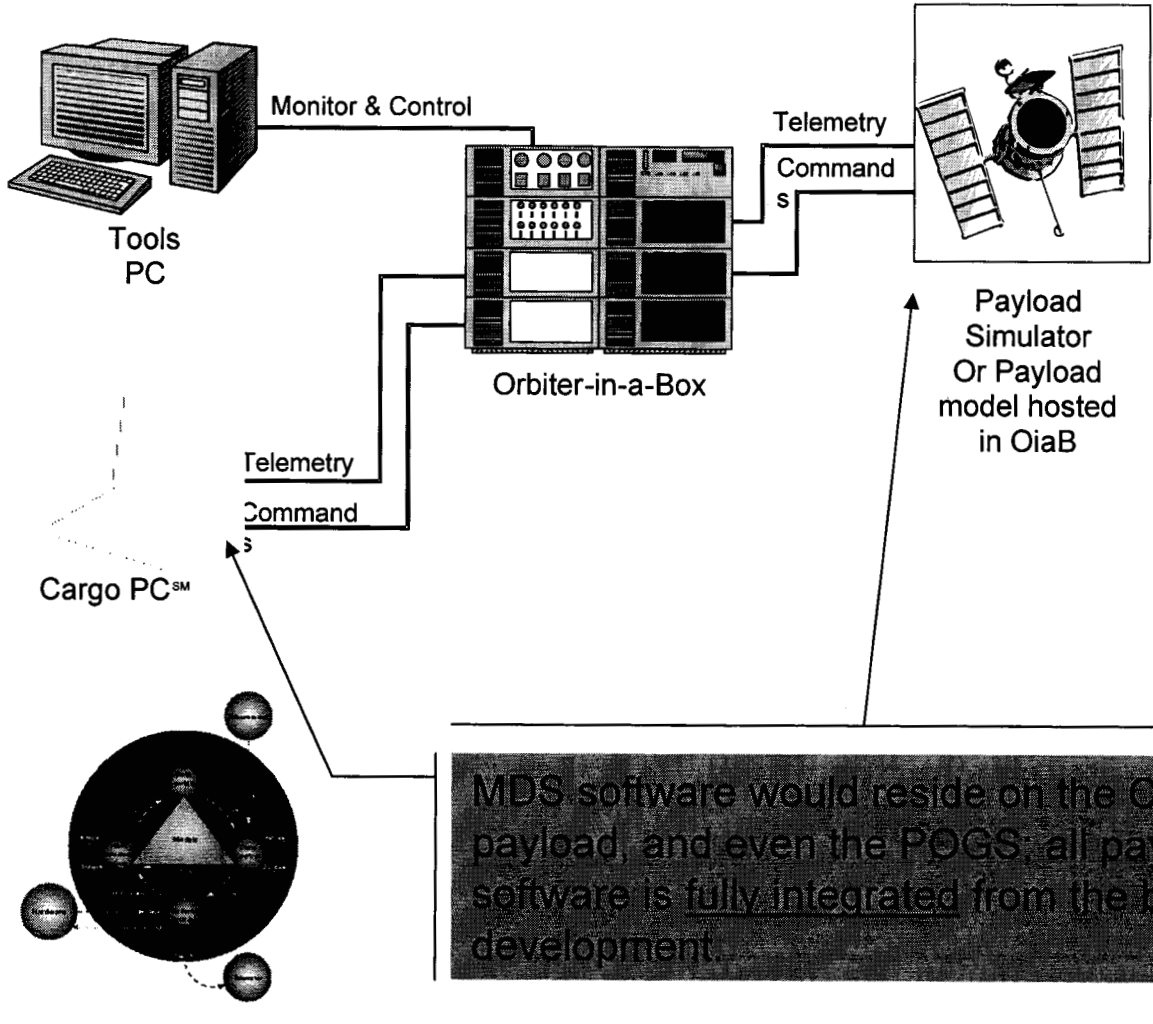
MDS in the POST Environment



MDS software would reside on the CargoPC, the payload, and even the POGS; all payload control software is fully integrated from the beginning of development.

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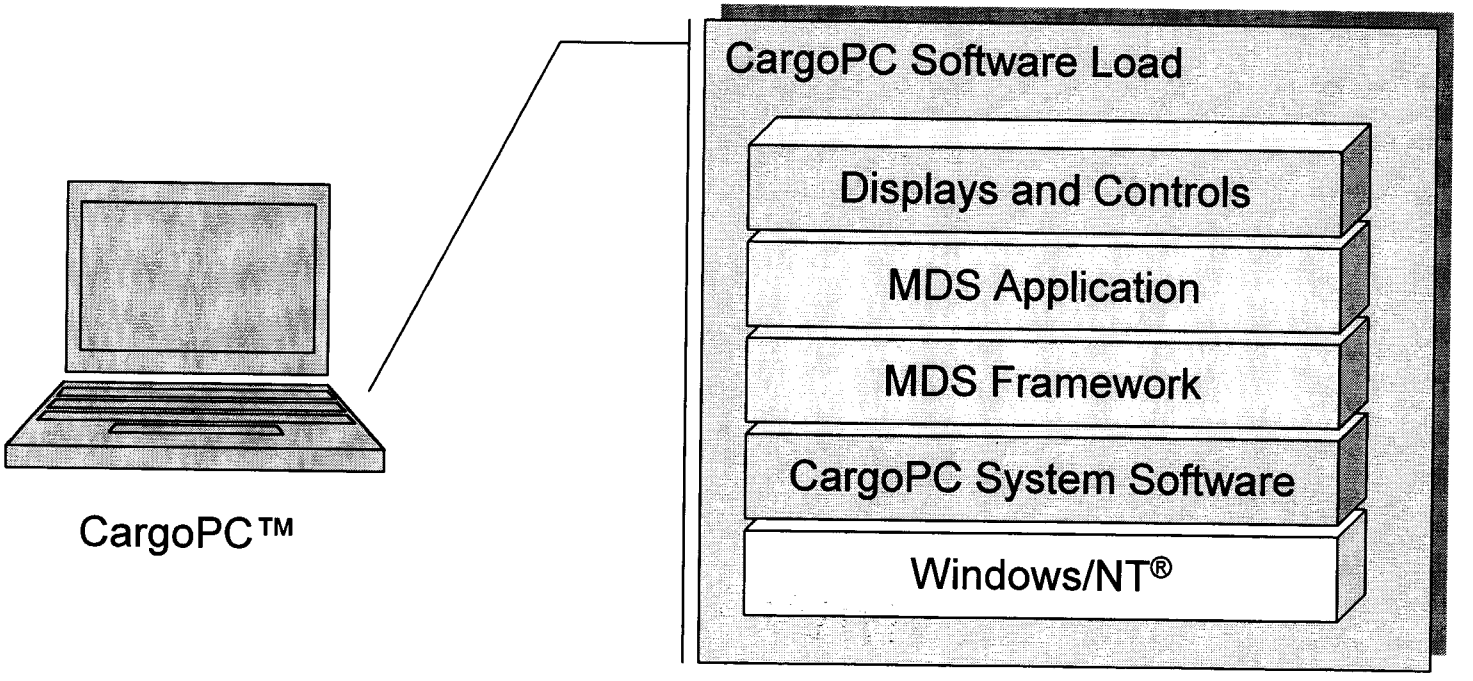
MDS Software Fit Within CargoPC



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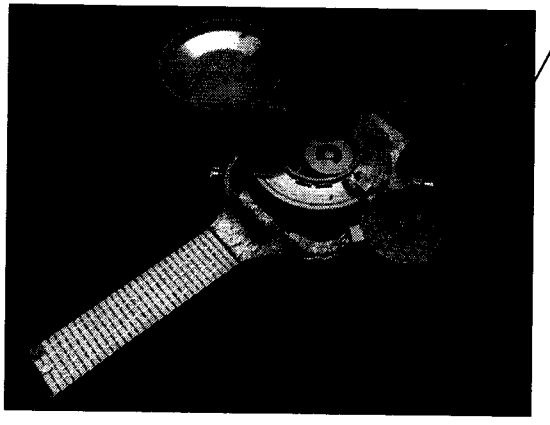
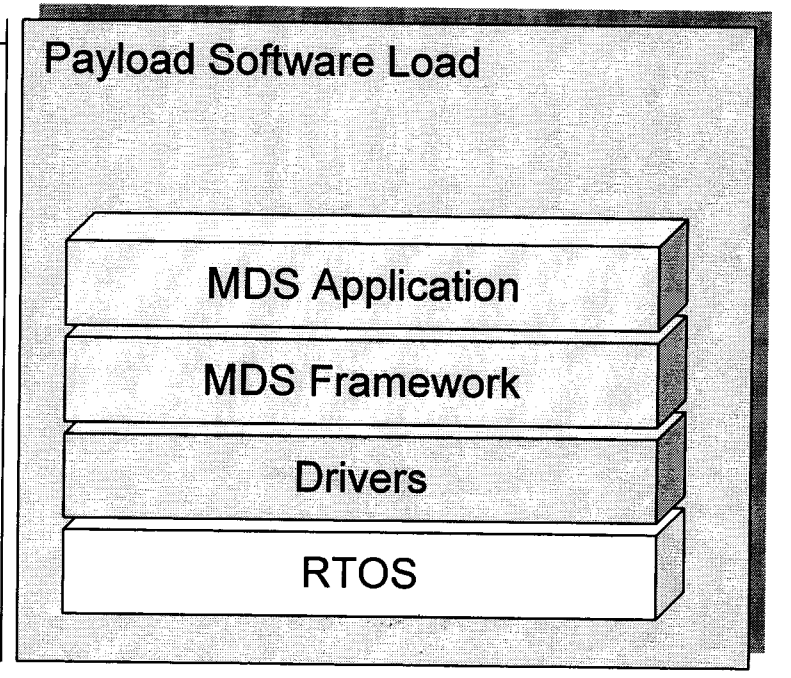
MDS Software Fit Within Payload





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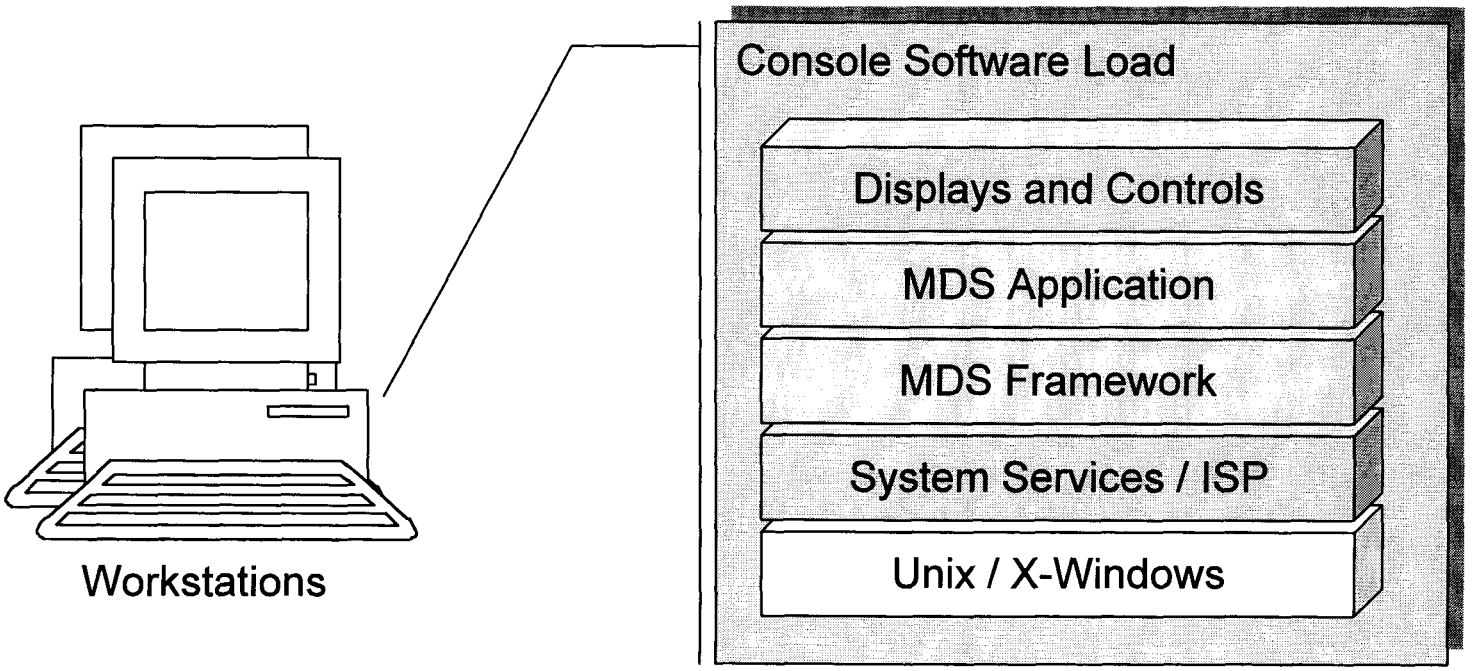
MDS Software Fit Within MCC/PCC



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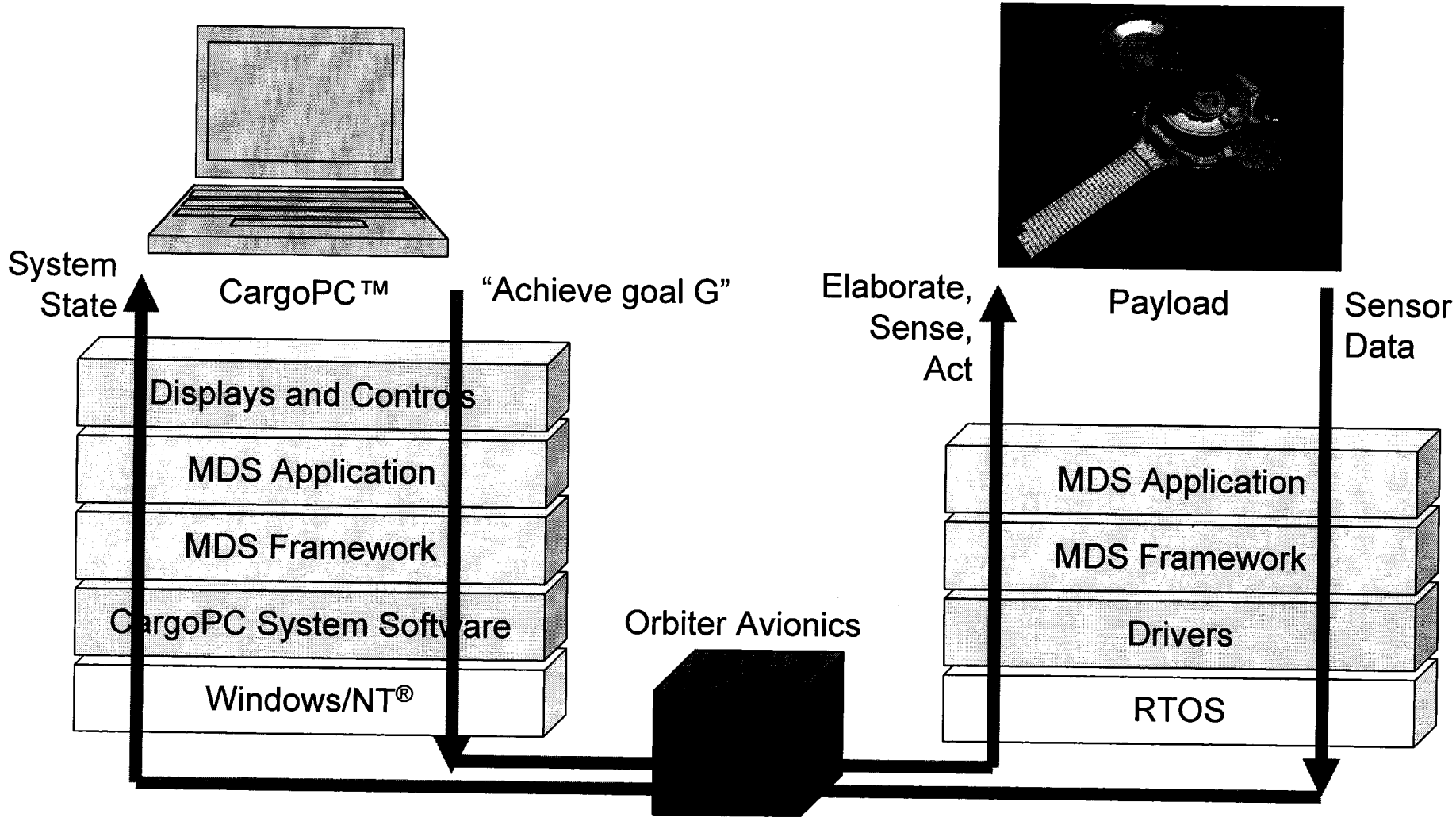
Goal-Driven Control Loops



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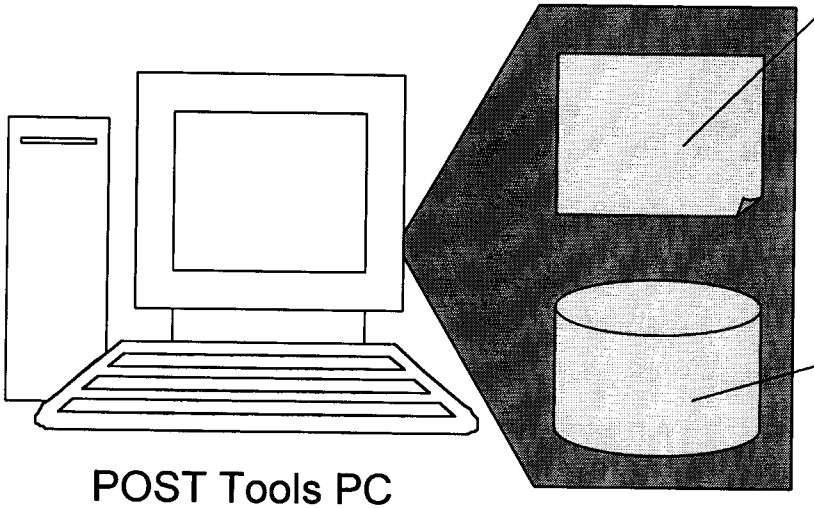
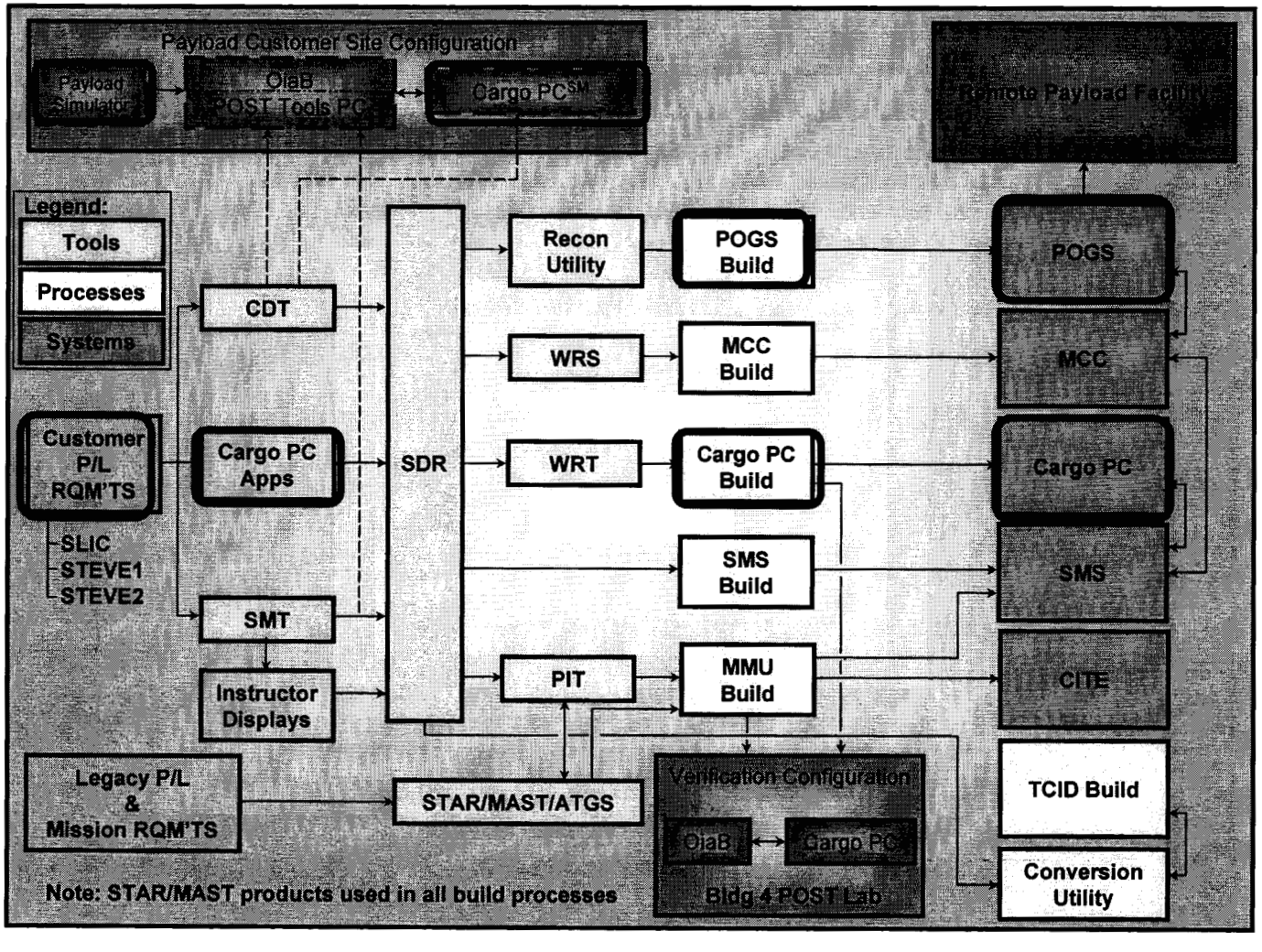
MDS Software Fit into PTPC



MDS Software Framework, providing several layers of architecture support and APIs; to be used by programmers along with Visual Studio or other tools

MDS State Database, capturing all of the results of the MDS state analysis process; to be used to support all development, verification and validation activities; browser GUI, hosted by PTPC database server

Potential MDS Footprint



MDS Footprint

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Technology Readiness Levels

- NASA Management Instruction NMI-7100
  - Integrated Technology Planning
- The TRL concept offers a taxonomy for describing maturity
  - Categorization and evaluation of proposals
    - Research and technology development
    - Mission trade studies
  - Risk assessment and mitigation

TRL Definitions

TRL 9	Actual system flight proven; successful mission operation
TRL 8	Actual system flight qualified through test and demonstration
TRL 7	System prototype demonstration in space environment
TRL 6	Model or prototype demonstration in relevant environment
TRL 5	Validation in relevant environment
TRL 4	Validation in lab environment
TRL 3	Experimental critical function; proof of concept
TRL 2	Technology concept formulation
TRL 1	Basic principals observed

Reference: John Mankins, "Technology Readiness Levels," NASA OSAT, 1995.

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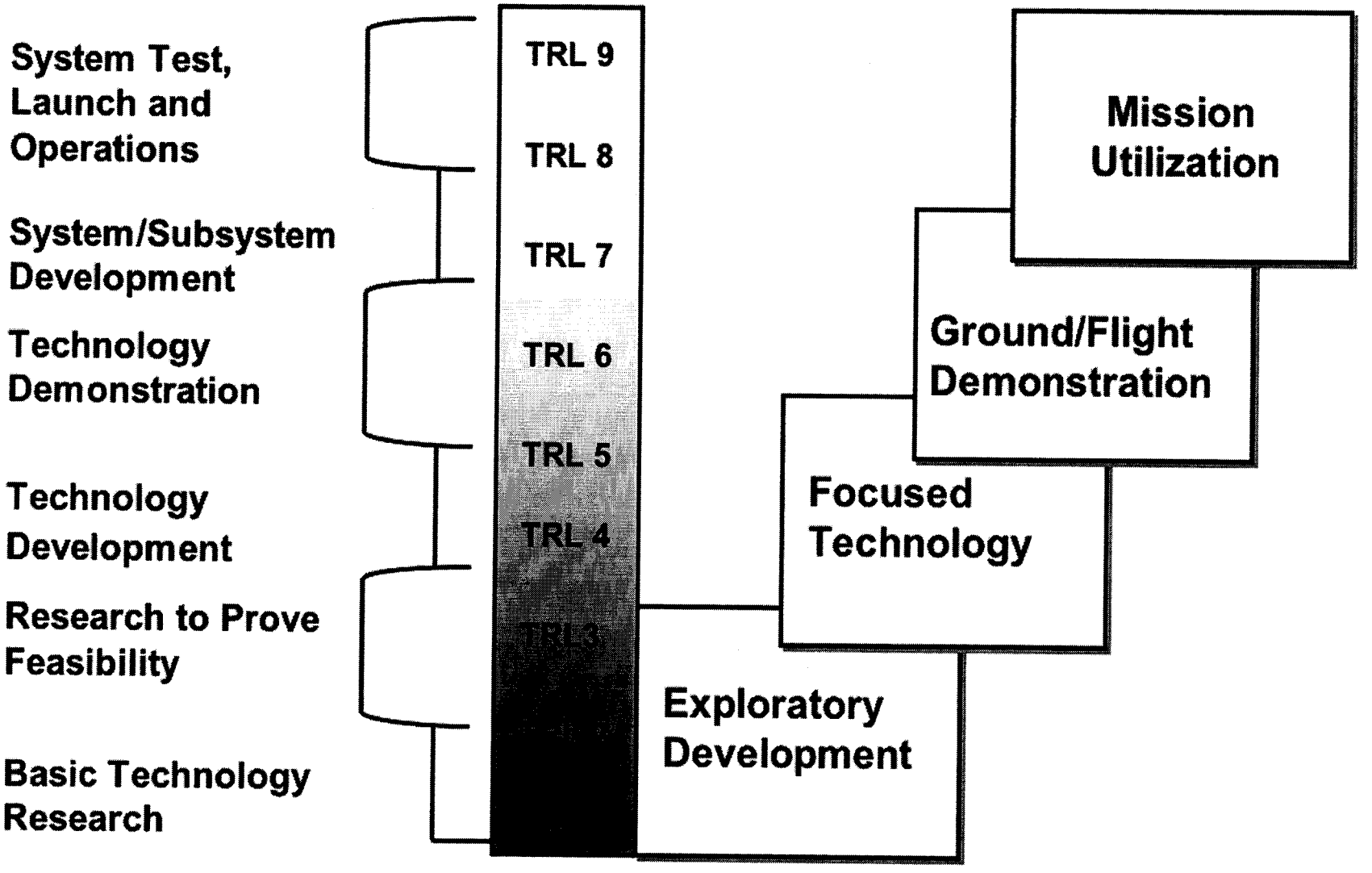
TRL Model



Reference: John Mankins, "Technology Readiness Levels," NASA OSAT, 1995.

Technology Infusion Platform

- As an architecture, MDS defines elements and interfaces and relationships that help structure system designs
- This includes for:
  - Goal planning and scheduling
  - Real-time scheduling
  - Commanding
  - State estimation
  - Fault diagnosis
  - Data management
  - Onboard data processing
  - Data transport
- The interfaces are technology-neutral; MDS doesn't prescribe a single solution; Different technologies can be used.

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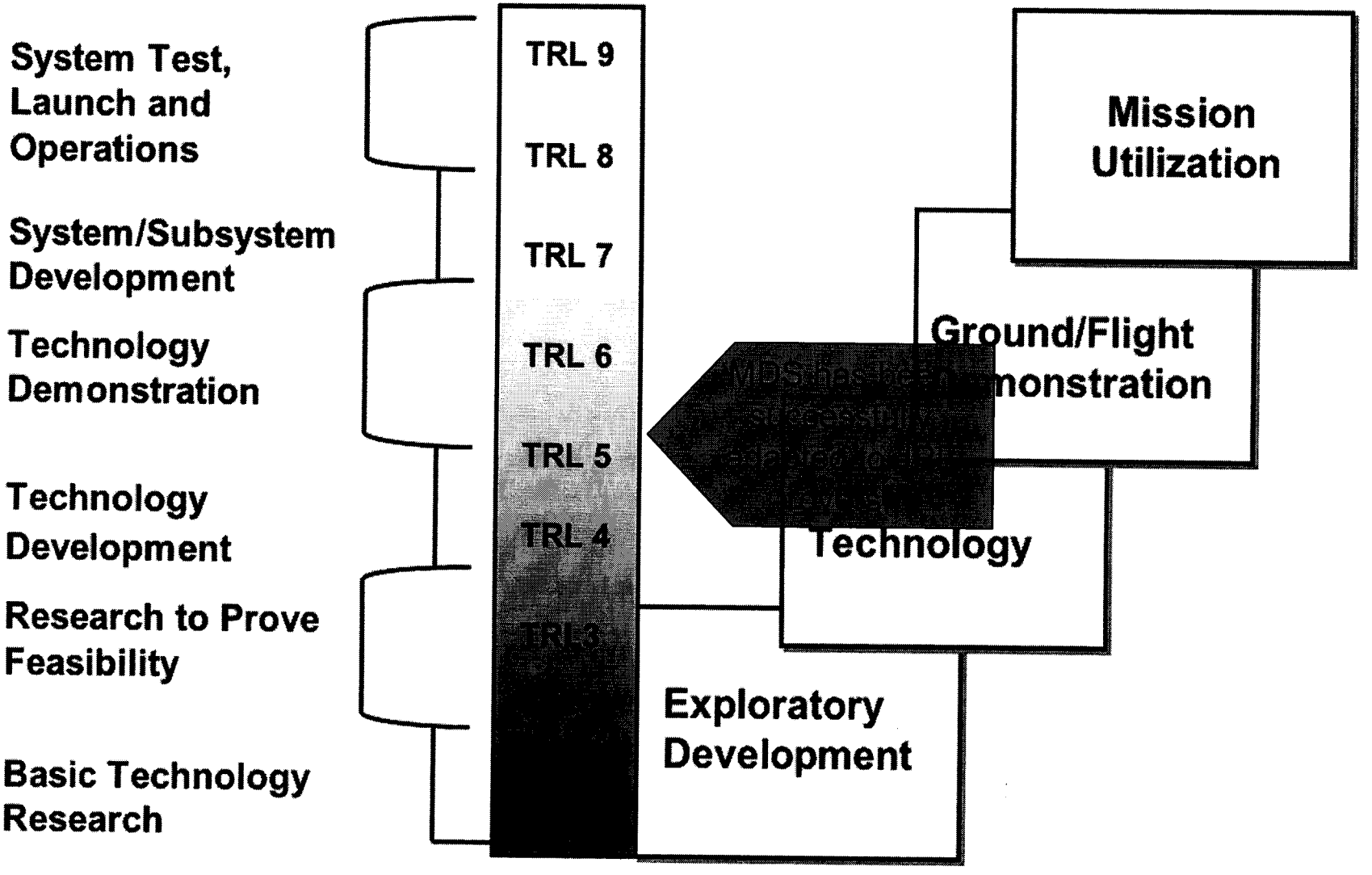
MDS Current TRL



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MDS Summary

- MDS is a significant program at JPL aimed at improving how we engineer, build, validate, and operate our missions
- MDS is a product-line approach based firmly on:
  - software architecture
  - systems engineering process
  - framework software
- MDS is baselined for the 2009 Mars Science Laboratory mission

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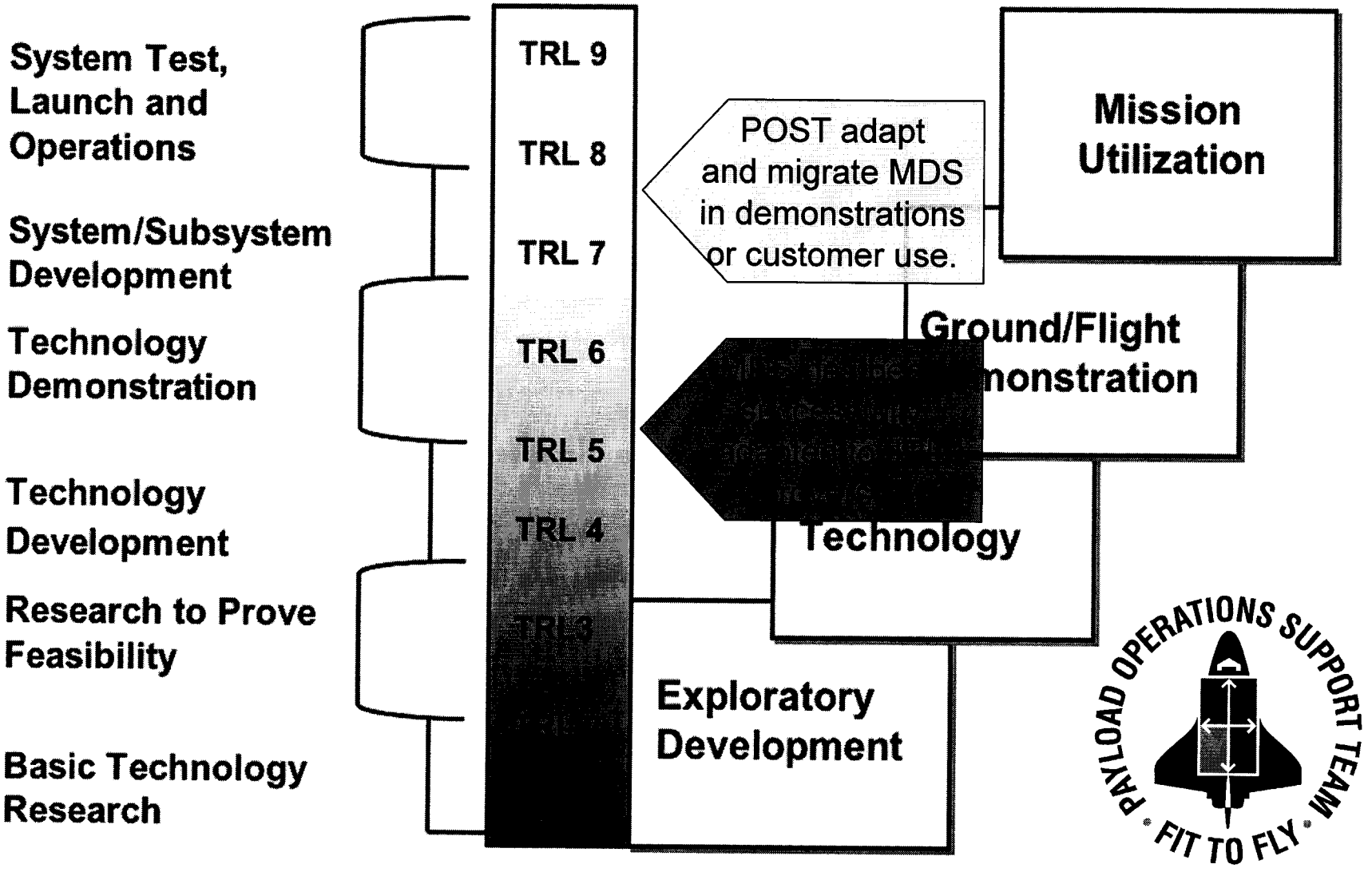
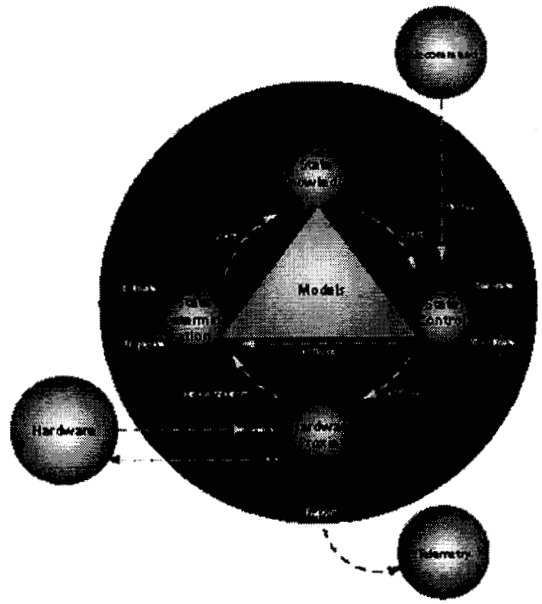
POST Contributions to MDS



MDS Contributions to POST

- Multi-mission product line package supported by
  - System engineering methodology
  - Unified information and control system architecture
  - Reusable and adaptable software framework
- Unified architecture for Payload, POGS and CargoPC
- Software filling gap between CPCSS and PDB
- New features with little impact to current tool



MDS Collateral Potential

- The JPL relationship with CMU-West introduces:
  - Training in MDS approach to system engineering
  - State-of-the-art early design evaluation technology
  - Novel human-computer interface design technology
  - "Collaborative computer" technology

Carnegie Mellon

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Photo of MERBoard from Space.com credit IBM.

Proposal

- POST project consider merits of incorporating MDS products into POST tool suite
- USA, MOD and JPL approach SSPO for funding project
  - Identify integration points and requirements
  - Identify POST process changes
  - Training for all involved
  - Integration and adaptation of tools
  - End-to-end demonstration test
- Compare results with current POST end-to-end test results