N95-17593

STANDARD PROTOCOL STACK FOR MISSION CONTROL

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ABSTRACT

It is proposed to create a fully "open" architectural specification for standardized space mission command and control. By being open, i.e., independent of any particular implementation, diversity and competition will be encouraged among future commercial suppliers of space equipment and systems. Customers of the new standard capability are expected to include:

- o The civil space community (e.g., NASA, NOAA, international Agencies).
- o The military space community (e.g., Air Force, Navy, intelligence).
- o The emerging commercial space community (e.g., mobile satellite service providers).

INTRODUCTION

In response to declining space budgets, the U.S. civil and military space communities both have a critical need to significantly reduce the cost of operating spacecraft, while simultaneously accommodating requirements for increased mission flexibility and capability. The emerging commercial space community has a similar need for low-cost "off the shelf" command and control systems that reduce the need for capital and operating investment.

Standardization has emerged as a key weapon in the conflict between new demands for space mission complexity and increasingly limited space mission budgets. The command and control of space mission systems is an area that is ripe for standardization. For lack of standards or guidance, space mission command and control is (by and large) re-invented for each mission; this drives up cost because a constant cycle of system redesign results in customized, non-automated operations that are highly labor intensive.

There is a pressing need to develop and emplace new standard user services that allow many different types of spacecraft, and their supporting ground networks, to appear basically harmonious from the perspective of ground controllers. With such capabilities, the spiral of constant redesign can be broken, automation may be deployed, and operations and maintenance budgets can be contained.

The new services should:

- o exploit rapid ongoing improvements in onboard data processing, storage and autonomy capabilities by encouraging the spacecraft designers to present simpler, more consistent and more mission-independent interfaces to ground operators;

- o import off-the-shelf technologies by integrating a wide range of emerging commercial data processing and data communications capabilities into cohesive systems that support high performance space mission command and control;

- o enable the mission-independent operation of spacecraft and their supporting ground networks by small teams of multidisciplinary personnel whose productivity is leveraged by the the widespread deployment of automation;

- o be backwards-compatible with existing space systems so that a smooth transition from the present to the future may be observed.

Many off-the-shelf capabilities currently exist; the primary challenge is to import these diverse technologies and to system engineer them into an integrated solution which satisfies the unique requirements of space mission operations.

It is therefore proposed to develop and functionally specify a Space Project Mission Operations Control Architecture - "SUPERMOCA" - which will provide the open systems framework around which the integration and demonstration of multi-vendor implementations of the new approach may occur.

TECHNICAL CONTEXT

To control a remote spacecraft, the user formulates command directives, transmits them, monitors their execution, and takes corrective action in case of anomalous behavior. The spacecraft executes the command directives using various levels of onboard autonomy. The control center and the spacecraft exchange information via a space communications system that includes both ground and space/ground networks.

Users in the control center also perform a similar set of actions to configure, monitor and control the remote ground data acquisition stations which are supporting the spacecraft. To facilitate automation and to reduce human staffing needs, the SUPERMOCA should promote a unified approach towards the command and control of the spacecraft and its supporting ground systems.

In the terminology of Open Systems Interconnection (OSI), the SUPERMOCA resides within the Application layer and draws upon underlying lower layer space communications services.

Figure-1 shows the SUPERMOCA operating over a space data network containing:

- o Standardized space/ground data channels, as defined for the civil mission community by the Radio Frequency and Modulation standards defined by the Consultative Committee for Space Data Systems (CCSDS).

- o Standardized space/ground networks and data links, as defined by the CCSDS Recommendations for Packet Telemetry, Telecommand and Advanced Orbiting Systems.

- o Standardized upper layer protocols, operating efficiently in a "skinny stack" configuration that is currently being defined by the joint NASA/DoD "Space Communications Protocol Standards" (SCPS) development program. The SCPS stack provides fully secure and reliable file and message transfer services in support of the SUPERMOCA layer.

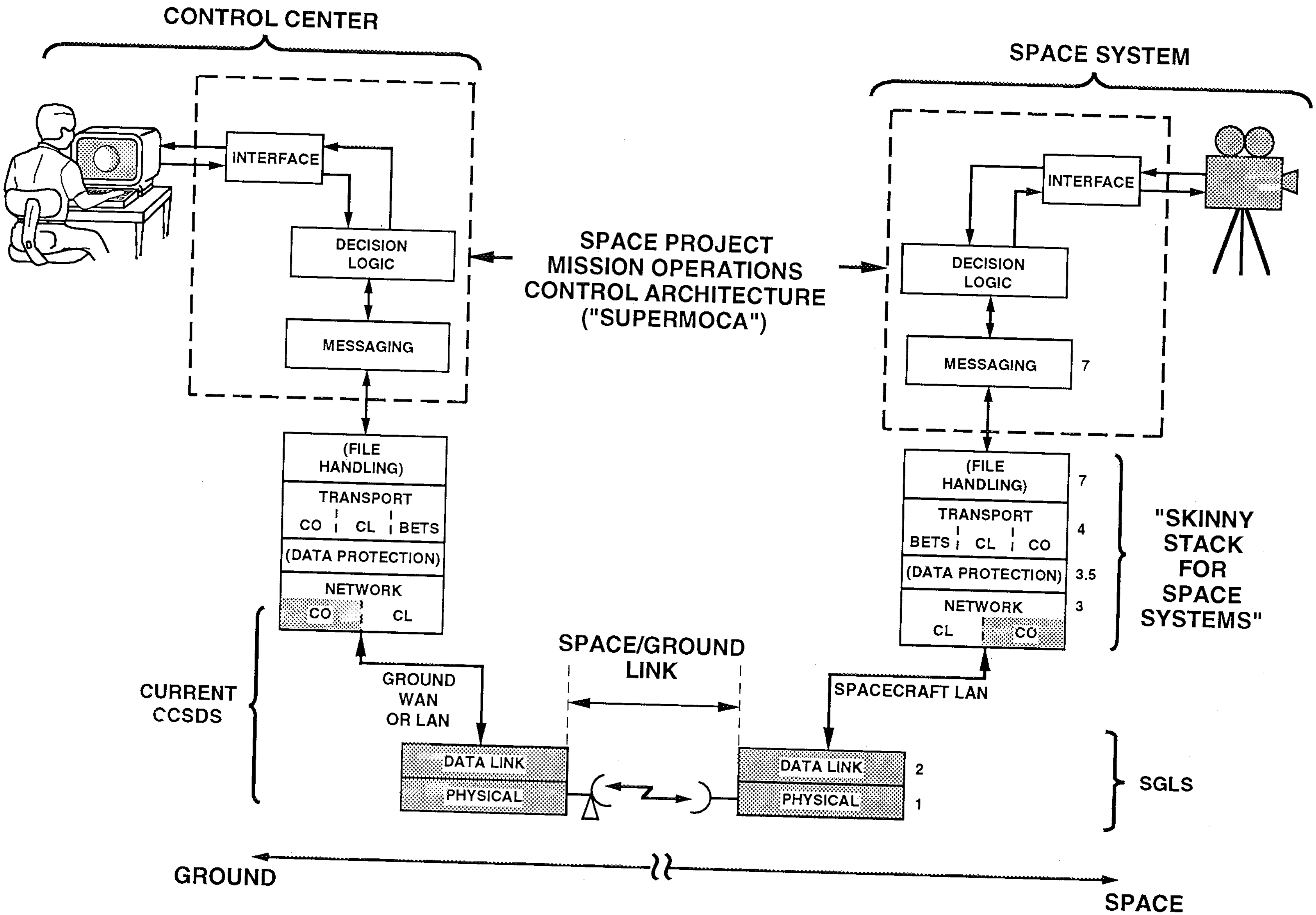

Figure 1. Context of Space Mission Control and Command

ELEMENTS OF THE SUPERMOCA

The SUPERMOCA provides an "upwards" mission control service interface to the mission planning systems which are used to construct the broad profile of desired mission activities. "Downwards" it draws upon a space communications service provided by a stack of underlying standard protocols. Figure 2 shows these service relationships, and postulates a possible internal organization of the layer.

The potential to achieve "backwards compatibility" with existing spacecraft is fundamental to the SUPERMOCA concept: this may be accomplished by locating all of the new SUPERMOCA architectural elements in the control center, and interfacing with the existing communications services that are possibly unique to that spacecraft. By retrofitting existing spacecraft into the SUPERMOCA, a smooth and rapid transition to the future is facilitated.

As currently envisaged, the SUPERMOCA contains five elements. Three of these elements (the Control Interface, the Decision Support Logic and the Space Messaging System) form the heart of the actual process control system. The remaining two elements (the Data Architecture and the System Management Architecture) supply the framework within which the other elements operate. Because they have great significance throughout entire mission lifecycle, the Data Architecture and the System Management Architecture also frame the Mission Planning System.

- Control Interface

  The Control Interface provides a human-oriented mechanism whereby a flight controller can specify and monitor the desired sequence of operations to be conducted in a remote system. It also provides the translation between high-level human directives and actual atomic-level commanded actions at the remote end.

- Decision Support Logic

  The Decision Support Logic provides the capability whereby rules for command execution may be programmed into a distributed inference engine, which may be located wholly on the ground, wholly in space, or partitioned in varying degrees between the two. Commands may only be issued to end effectors in space when they conform to the flight rules that are programmed into the engine. Responses from end effectors will be compared against rule-based expectations, and the Decision Support Logic may take further preprogrammed command actions based on the observed performance.

- Space Messaging System

  The Space Messaging System translates the machine-readable command calls from the user's Control Interface into standard-syntax messages which invoke the desired actions and responses in the remote space system. At the receiving end, generic device manipulations are translated back into concrete, atomic-level actions via the Control Interface.

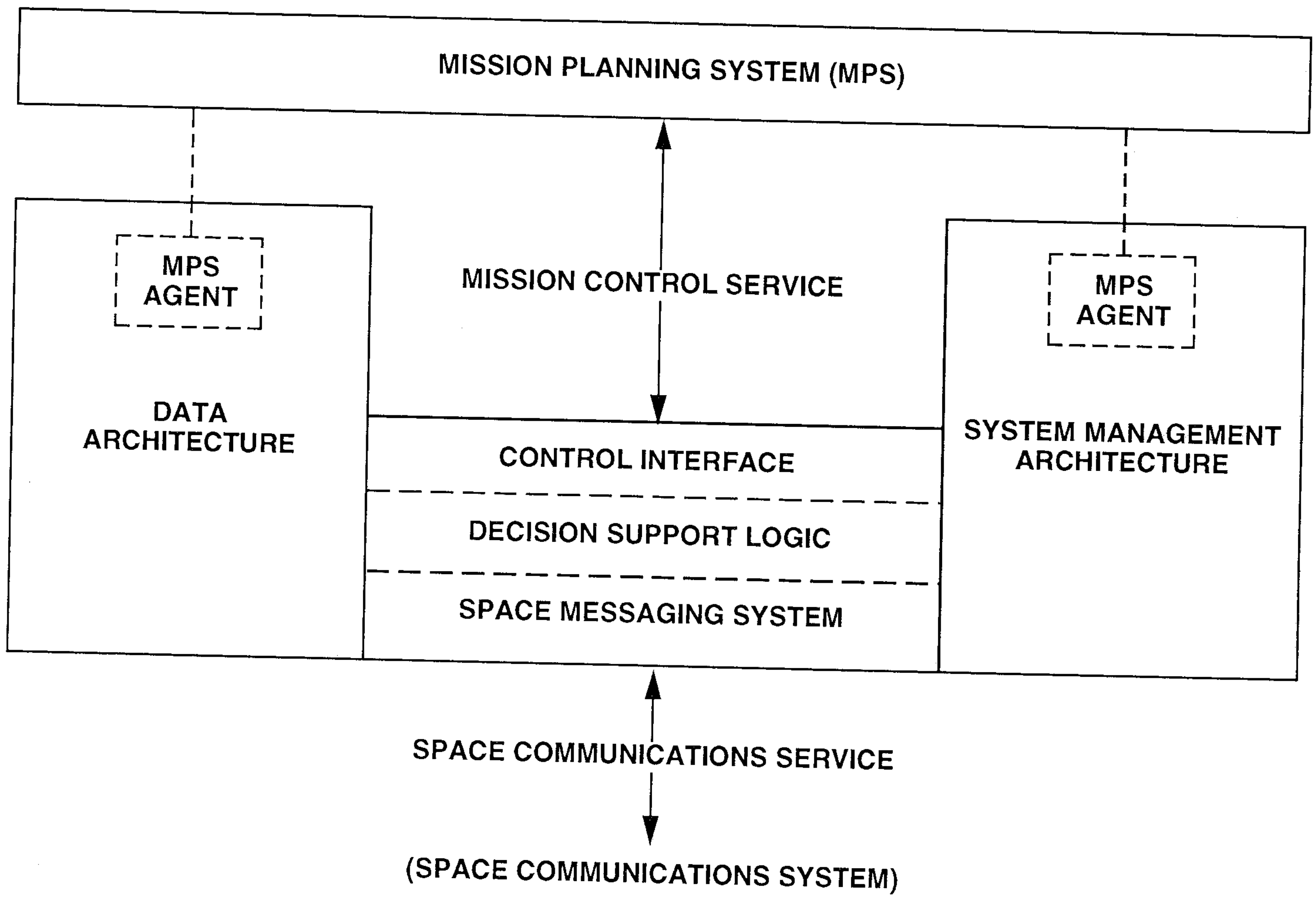

Figure 2. Elements of the Control Architecture

- Data Architecture

  The Data Architecture provides the mechanism whereby the precise characteristics of a concrete spacecraft system can be captured and described in abstract terms. It allows specific spacecraft devices to be described in standardized ways and for this information to be compiled into data dictionaries and encyclopedias. These data descriptions can be gathered starting at the earliest point in the project design lifecyle, thus supporting the progressive and seamless refinement, extension and translation of information from conceptual mission planning, through operations, and into post mission evaluation.

- System Management Architecture

  Space mission process control fundamentally boils down to a problem of meeting mission success and safety-related criteria. The SUPERMOCA accomplishes this through the allocation and control of shared onboard resources, and by managing the relationships which describe how individual systems interact with the operating environment. To achieve this, "operations envelopes" are assigned to individual users, granting them certain "environmental rights" to conduct their operations and consume an allocated share of system resources, and certain "environmental privileges" to perturb the overall system environment. Providing users stay within their assigned envelopes, they are free to operate without detailed supervision. Potentially dangerous activities are precluded via a combination of software controls on command execution, plus hardware inhibits and interlocks which preclude unsafe or undesirable operations from occurring unless the system is prepared for them.

DEVICE MODEL OF OPERATIONS

The SUPERMOCA is conceptually founded in terms of a powerful "device model" of space mission command and control, which is illustrated in Figure 3. Within this model, all of the functions of the space mission are allocated to devices. A device may be physical hardware, a software module which serves as a control interface for hardware, a pure software function, or a combination of these. Each device has a function or functions which it performs: a pump circulates its working fluid; a motor rotates a solar panel; a software module calculates the pointing vector to the sun to guide the solar panel drive motor.

Devices exist at many levels; normally, low-level devices will be aggregated into higher level devices, such that the operator can issue high level commands to the higher level devices, which will themselves orchestrate the function of the low-level devices to accomplish a complex function. A complete spacecraft (and, for that matter, its supporting ground system) is thus composed of many concrete low-level "space devices" which are assembled into complex subsystems that are integrated into an operating mission system.

A space device has a standardized input/output interface through which the external world can know about it, or can control its behavior. This interface can be accessed by sending commands and receiving data or status messages. Attributes describe the device: they include information about the current operation of the device (such as temperature, mode, state, etc.) and descriptors of the device itself (such as serial number, date of manufacture, capacity, operating limits, etc.). Attributes can also include information about the intended use of the device, such as its redlined operational limits.

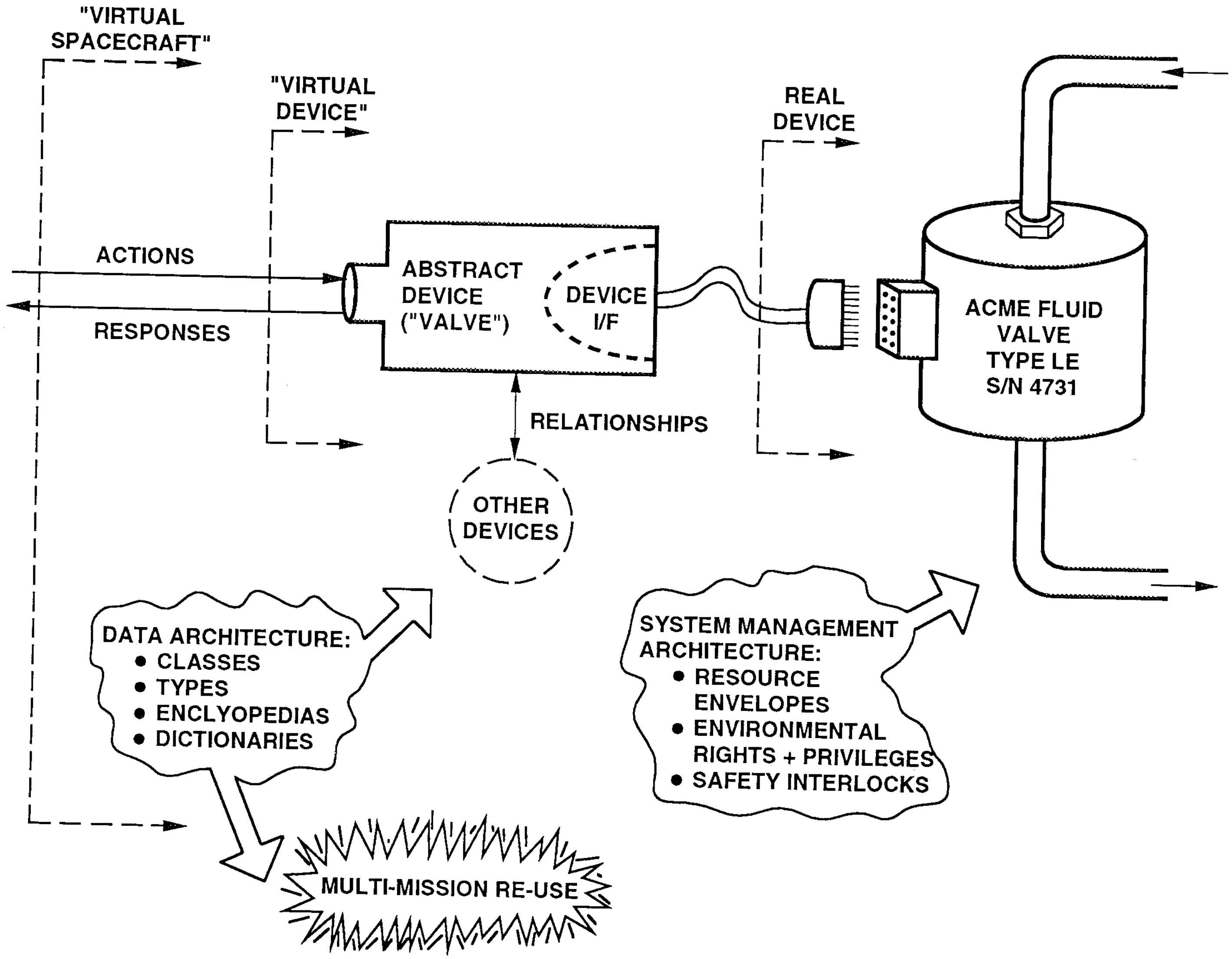

Figure 3. Device Model of Space Mission Control

A device may exhibit one or more behaviors: an oven heats at a rate of 50 degrees per minute; software sends a particular response to an invalid command; an instrument will slew from one pointing direction to another without pointing at the sun. A device may issue messages indicating that specific events have occurred: a parameter may be out of limits, a function may have failed, or a hazardous condition might be noted.

Relationships describe the context for a device. A device may be a part of a higher level assembly, connected to a particular data bus, communicating with another device over the data bus, powered by a a specific power supply, outputting a signal which becomes an attribute of another device, and configured with certain software to perform its functions.

Device types are abstractions which provide a single definition for a family of related "virtual devices" (e.g., all valves, or all pumps, or all pointing actuators, or all voltage regulators, or all transponders share common features; which means that within a family, the same device interface exists for all of them). Therefore the general interface for a device type may be stored in dictionaries and encyclopedias that can be re-used and inherited across multiple space missions.

By masking the uniqueness of a particular space system from its human operator, while providing the tools to progressively capture and exploit knowledge across multiple systems, the device model for space operations will enable the widespread and progressive standardization of the way in which human beings interact with complex, concrete systems in simple, abstracted ways. In particular, adoption of the device model will inject the discipline of standardized system description throughout all phases of space project design: this provides a powerful mechanism for creating a "design to operate" philosophy early in the project lifecycle. From the embryonic stages of mission planning, through operation and post mission evaluation, a seamless flow of data capture is created.

CONCLUSION

It is suggested that a completely standardized mechanism for space mission control is within our reach. By importing and marrying many diverse off-the-shelf technologies, powerful new capabilities may be emplaced that contribute significantly to reducing the cost of operating space systems. Since the needed capabilities will be functionally defined in the form of an "open" specification, the SUPERMOCA will encourage a diverse set of compatible implementations to be placed on-the-shelf by the private sector, for shared use across the entire space mission community.

ACKNOWLEDGMENTS

The work described in this paper was carried out at the Jet Propulsion Laboratory/California Institute of Technology under a contract with the National Aeronautics and Space Administration. The SUPERMOCA concept was developed by many talented individuals affiliated with the AIAA Spacecraft Control Working Group: special thanks go to Bob Easton of McDonnell Douglas; Randy Heuser and Gael Squibb of JPL; Chuck Fuechsel of NASA Headquarters; Connie Golden of LORAL; Brian Buckley of Interface and Control Systems; Captain Vern Veglia of the United States Space Command; and Randy Davis, Elaine Hansen and Sam Siewert of the University of Colorado.