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Human-rating Automated and Robotic Systems – (How HAL can work safely with astronauts)

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ABSTRACT

Long duration human space missions, as planned in the Vision for Space Exploration, will not be possible without applying unprecedented levels of automation to support the human endeavors. The automated and robotic systems must carry the load of routine “housekeeping” for the new generation of explorers, as well as assist their exploration science and engineering work with new precision. Fortunately, the state of automated and robotic systems is sophisticated and sturdy enough to do this work – but the systems themselves have never been human-rated as all other NASA physical systems used in human space flight have.

Our intent in this paper is to provide perspective on requirements and architecture for the interfaces and interactions between human beings and the astonishing array of automated systems; and the approach we believe necessary to create human-rated systems and implement them in the space program. We will explain our proposed standard structure for automation and robotic systems, and the process by which we will develop and implement that standard as an addition to NASA’s Human Rating requirements.

Our work here is based on real experience with both human system and robotic system designs; for surface operations as well as for in-flight monitoring and control; and on the necessities we have discovered for human-systems integration in NASA’s Constellation program. We hope this will be an invitation to dialog and to consideration of a new issue facing new generations of explorers and their outfitters.

INTRODUCTION

An exploration program featuring long duration human space flight missions, such as the Vision for Space Exploration (VSE) proposed by President Bush several years ago, requires several very new approaches to operations – approaches that do not fit the paradigms of current or past human space missions.

In historic as well as current human space programs, the common approach to mission operations during flight has been to assign system and subsystem management responsibilities to individuals and groups of flight crewmembers and ground-based mission controllers. This approach is not workable for the VSE, because it cannot be scaled to include a variety of flight and planetary surface assets simultaneously. The mission operations practitioners are discovering that this approach is extremely difficult to maintain even with current programs: the approach is very labor-intensive, which makes it both increasingly expensive, and increasingly dependent upon a shrinking pool of technically educated workers.

Fortunately, the space vehicles, surface vehicles, and shelters of the Constellation Program and other exploration programs will include unprecedented and pervasive automated systems, which will be able to manage routine “housekeeping” engineering activities and environmental life support necessities. Automated support will allow the humans – both flight crewmembers and ground-based operators – to spend their time and energy dealing with the unanticipated, unexpected and unpredictable aspects of the missions. Robotic systems – automated systems that can do physical work similar to the work people can do – will be continuously active and self-guiding. For this reason, they will be able to perform the “grunt work” that is either too routine or too dangerous for people to spend time doing. The control of robotic systems will span a broad spectrum of methods, from teleoperation to autonomy, just as the purposes of the systems will span a broad spectrum of work from routine environmental management to mobility and construction.

Systems engineering will be conducted holistically, with people in space and in operations control centers on Earth considered as elements of the overall system. Programs will apply their collective systems engineering capabilities to developing more than just hardware and software; they will develop the processes used to make and maintain hardware and software for extended use; the methods used to operate the integrated systems; and the ways in which both explorers and Earth-bound operators are prepared and trained to use the systems.

Some automated systems will be required to maintain the ship or habitat environment as a substitute for the benign environment of Earth. Such systems (ENose for example) are already being tested on the International Space Station (ISS) with significant success. Other automated and robotic systems will substitute for

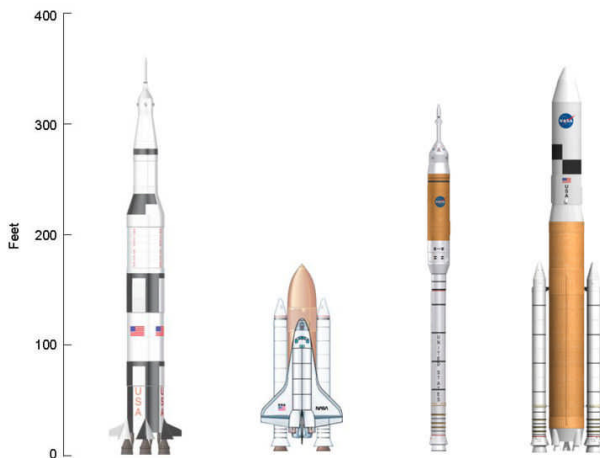
workforce elements that perform routine tasks, such as clerks and physical laborers. Such systems will include a spectrum of devices, from automated inventory management systems to monitor supplies, to automated construction equipment that will move habitat modules or build regolith barriers.

Automated robotic systems may even be used to explore dangerous lunar surface areas or make useful materials from *in situ* resources. Such systems will be much more than extensions of a mission control console operator's hands. These automated systems will help to keep the explorers *safe*, help them to do their work *better*, and help them to implement solutions to the expected stream of unexpected problems presented by their unknown surroundings.

HUMAN RATING

It is important to understand the nature of a human-rated system, and we can start to explain this by asking a specific question: What is different about certifying the systems that carry human beings into space, from the systems that carry unique robotic payloads into space?

NASA's recently updated Procedural Requirement for human-rated systems (NPR 8705.2B) includes several new answers to this question, and these answers have been derived through study of the human experience in space exploration from the time of Mercury and Apollo programs, to the current Space Shuttle and International Space Station programs.



A variety of human-rated launch vehicles, from the Apollo Program's Saturn V, to the Space Shuttle and the Constellation Program's Ares I. Originally conceived as a cargo launch vehicle only, NASA authorized a study regarding human-rating for the Ares V in November 2008. (These NASA graphics are in the public domain.)

The new NPR 8705.2B states: "A human-rated system accommodates human needs, effectively utilizes human capabilities, controls hazards with sufficient certainty to be considered safe for human operations, and provides, to the maximum extent practical, the capability to safely recover the crew from hazardous situations."

It goes on to explain the human-rating process, presenting three basic tenets:

1. *Human-rating is the process of designing, evaluating, and assuring that the total system can safely conduct the required human missions.*
2. *Human-rating includes the incorporation of design features and capabilities that accommodate human interaction with the system to enhance overall safety and mission success.*
3. *Human-rating includes the incorporation of design features and capabilities to enable safe recovery of the crew from hazardous situations.*

The NPR concludes its definition by stating: "Human-rating is an integral part of all program activities throughout the life cycle of the system, including design and development; test and verification; program management and control; flight readiness certification; mission operations; sustaining engineering; maintenance/upgrades; and disposal."

The NPR describes the methods by which systems are certified as human-rated. What is important here is that our human space flight programs have not really considered the necessity for developing *human-rated automation and robotics*, because these systems are available for the first time to flight systems under development now – flight systems such as those that make up the Constellation Program, or the newest elements of the ISS. The level of automation now available for both flight and ground operations is unprecedented, but the interfaces and interactions between people and those systems has been examined in only a preliminary manner. Both human factors engineers and robotics engineers agree that there are physical and attitudinal issues to consider when they put people together with automation for any operational task – but especially for complex tasks, performed in hostile environments, that could last for months or years.

Human factors engineers confront the physical issues in every system they must work with:

- making the system operable
- making it useful
- designing it to help prevent and mitigate errors

They are able to address these issues in a relatively straightforward manner if the elements of a system are always operated "hands-on" by a person, although the issues are not always easily solved.

One difficulty is both cognitive and psychomotor: people frequently expect any systems they use to provide performance options the systems were not designed for, and frequently attempt to "force" physical system controls until the controls fail. (Did you ever "freeze" your computer trying to make it perform too many

operations?) Another difficulty is anthropometric: people who use the systems come in a variety of shapes, sizes, strengths and perceptual sensitivities, and they all must be able to operate the systems. (How well does the keyboard on your laptop fit your typing capability and comfort? How about the keyboard on your Blackberry?)

Human factors engineering must include considerations like shapes and structures of switches and controls, the ways in which information is presented to crewmembers on a computer screen, and ways in which systems warn crewmembers about malfunctions. All these physical issues of human engineering become more complex in space, where the humans must operate the systems under circumstances such as great acceleration or micro-gravity. (Imagine sending your friend a coherent text message while accelerating at three gravities, and with all that rocket noise...)

So the physical issues related to human-systems integration are difficult, but relatively straightforward. The affective or attitudinal issues that automated systems create for people are much more subtle and difficult to deal with using just physical design solutions, because these issues involve human emotional responses to automated systems themselves. The human factors engineers and the systems design engineers must work hand in hand to develop automation and robotics that crew members will *trust* – systems that crew members will consider reliable enough to entrust with their lives and health while in a distant and hostile environment. Crewmembers must believe that they can always predict the system's behavior in a given situation – and that the system's behavior will never be hazardous to them.

Consider how long it might take you to build such trust for another person, and then imagine the difficulty in trusting a machine in the same way. A mechanical device clearly does not share your culture, your value system, and your emotional foundations. It *emulates human performance* by making decisions regarding its behavior based on a relatively limited set of possible responses to a variety of programmed situations, and then communicates those decisions to you...

If that system were making decisions that affected your survival, you would want to have final authority to shut the system down if, in the last instance, you disagree with its operational direction. Of course this option is actually required for all human-rated systems: the humans must be able to override system operation, to manually control a normally automated function – so long as that override does not cause a catastrophic event. Does this mean that the automated system must determine whether the transition to manual control will be more hazardous than its automated direction? Does this requirement invite strange “arguments” between the crew and the navigation computer, regarding who is the better pilot?

You can see the difficult philosophical and policy issues related to control and control authority when we begin

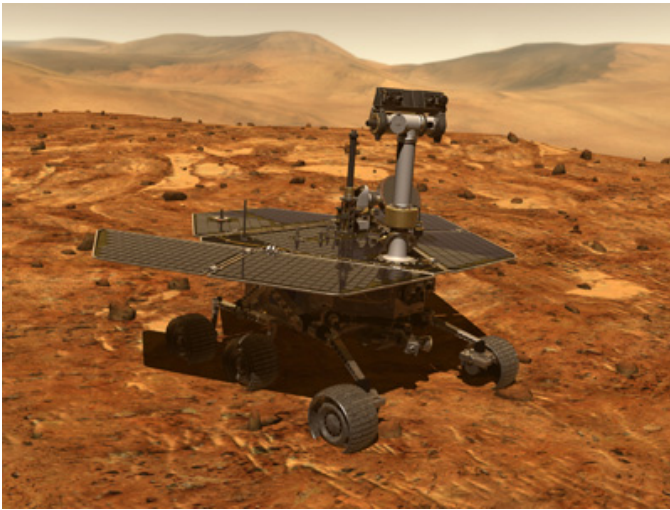
considering how to human-rate an automated system that may ultimately be responsible for human lives.

A NEW DESIGN STANDARD

NASA uses design standards as drivers for developing program or system requirements. Standards are always the best knowledge available regarding the topic under consideration. A standard is *a rule or principle that is used as the basis for judgment*, something considered by authorities or by general consent as a basis for comparison. Standards exist within NASA for hardware design, for electrical system design, for the official colors and shape of the NASA logo, and so on – and even for human factors engineering, in the well-known STD-3000, NASA's *Man-System Integration Standards* (MSIS). The authors were among the team that used STD-3000 to derive the Human-Systems Integration Requirements (HSIR) for the Constellation Program.

HUMAN-SYSTEMS DESIGN NEEDS – Standards are living rather than static, because when new research is completed and new principles or measurements are discovered, standards must be updated to continue as authoritative. An update and upgrade of NASA's STD-3000 is essential, and is being developed presently, under the leadership of the Habitability and Human Factors Branch at Johnson Space Center. The upgrade will likely add new volumes and revise existing volumes, because research has added a great deal to the human factors knowledge within the agency over the last twenty years. The update will address the existing in-space (milli- and microgravity) design requirements, which need to be brought up to date, based on both flight experience and on a series of carefully-planned and carefully-conducted experiments onboard the ISS. The new STD-3001 will again be based on experiment and should address planetary environments: such as Mars, the moon, and event asteroids, as well as shipboard environments.

Logically, all these sections do not need to be developed at once; the microgravity and lunar environments should be addressed immediately, and the “deep-space” design requirements should be developed as we gain additional experience and experimental knowledge. In support of the revision and creation of these volumes, a major effort should be undertaken to develop a research program on both ISS and on earth to systematically examine human performance in long-duration off-earth environments. The experimental facilities for the lunar environments should include both earth-based assets (neutral buoyancy facilities, suspension facilities, and the like); and the ISS, outfitted as a testbed for research on strength, endurance, and performance, as well as design concepts for long duration flight.



Robotic systems like the Mars Exploration Rovers are operated by programming instructional sequences and sending them to Mars by radio – there is a time latency of up to twenty minutes, so the systems can hardly be teleoperated in real time! It will be many years before humans are working side-by-side with robots on the Martian surface. (NASA photo in the public domain.)

A STANDARD FOR HUMAN-RATED AUTOMATION AND ROBOTICS – A new document is now needed, analogous to MSIS or written as an additional section for it. This new documentation should address the human-rating issues related to:

- Automated systems that will monitor and control any elements of human space flight vehicles and habitats (such as life support systems, flight control systems, engineering “housekeeping” functions, and others)
- Robots which are teleoperated, or controlled directly by human beings through direct manipulation or other means involving telepresence (such as the ISS robotic arm, or the Mars Exploration Rovers)
- Robots which are intended to be collaborative automated workers (often in the presence of human workers), and which may be subject to similar functional constraints as humans at work (such as reach, visibility and situational awareness, etc.)

We call the new document the *Automation and Robotic Systems standard*, or ARS. The ARS will have to be created by discipline experts in a variety of disciplines, with the same breadth of perspective on these issues as human engineers will need in developing the rest of STD-3001. Human factors engineers will be critical to the ARSS, but so will robotics engineers, behavioral scientists, space systems engineers, computer scientists, mission operations systems engineers, and others. The authors have actually proposed that the new ARS standard be developed under the banner of the NASA Engineering and Safety Center (NESC) because that organization’s perspective and influence crosses center and discipline boundaries with multi-disciplinary credibility.

CHARACTERISTICS OF A NEW STANDARD – We believe there are other important characteristics the new standard should demonstrate:

1. It should include both *process* and *technical* points. The ARS should not only set measures for the automation and robotic products themselves; it should guide the methods by which these products are designed and developed, and especially the ways in which automated and robotic systems are used by people in the context of exploration.
2. It should not re-invent current standards. Where applicable and feasible, the ARS should reference current standards for the human interface with automated and robotic systems (an example might be the Federal Aviation Administration’s standard for design of human operated automated systems, or the United State Navy’s standards for monitor and control of environmental systems in ships).
3. ARS should identify and address NASA’s *unique applications* of automated and robotic systems – those applications related to human space flight and exploration. For example: while some of ARS may be derived from similar standards for systems like Unmanned Aerial Vehicles, there are important differences even in teleoperated systems which are thousands or millions of miles away and introduce major signal latency issues.
4. ARS should help programs by including guidelines for developing requirements and verifications. We believe that actual examples or templates would be most useful in this respect.
5. It should define and describe the *full spectrum* of automation and robotics. ARS must address not only teleoperated physical robots, but autonomous robots that operate in isolation or near humans, and automated monitor and control systems that operate shipboard or habitat-based physical systems. Each of these will have specific requirements for human interface and interaction.
6. ARS should contain its own guidelines for change and future modification. Standards drive system requirements for programs and project; but human knowledge becomes more complete and accurate over time, so standards must be themselves driven to updates by new knowledge.

KEY ISSUES IN HUMAN-ROBOT INTERACTION – We believe there are certain key issues the standard must deal with in the area of human interaction, and these issues are broader than the traditional physical human interface issues that are so well understood by human factors engineers. The first of these issues is the assignment and transfer of control authority among systems, and between human beings and automated systems. Policies will have to be developed that govern how control authority is initially assigned among people

as well as among the automated systems; and policies will also have to exist that define the reasons and protocols for transferring control from person to person, from person to system, and from system to system. The policies will have to address these issues for both nominal and off-nominal task execution and operations.

The importance of this issue becomes very clear when you consider the contrast between current mission operations paradigms for human space missions, and required operations approaches for long-duration space flights with very long latency in signal. How can ground-based operators take control of rapidly evolving situations on a space ship that is millions of miles away, with a round-trip time for signal and message transfer of thirty minutes? And how can a single operator keep control authority, when there may be multiple robotic assets operating simultaneously on the lunar surface?

The mechanisms that will actually make the transfers will have to be included in the standard too. These mechanisms must prevent inadvertent commanding of assets, but at the same time allow human intervention or autonomous action, when necessary, to preserve crew or operator safety. Our compelling example: an explorer walking across the lunar surface in a pressure suit, accompanied by her robotic assistant, which is a huge six-legged spider with powerful manipulators (the planned ATHLETE robotic system). Our explorer does not want the robot to walk too far ahead of her, or too far behind her, but she certainly does not want ATHLETE to touch her fragile suit – unless she falls and breaks her leg! Then, she wants her giant robotic assistant to pick her up and carry her back to the base safely – even if she is unconscious and cannot ask for this help...



NASA's test version robotic mobility system ATHLETE (All-Terrain Hex-Legged Extra-Terrestrial Explorer) carrying a lunar habitat module during tests of future moon systems at Moses Lake, Washington. Photo from NASA Jet Propulsion Laboratory public web site.

Another important issue is the manner and frequency with which each system will report to the humans in command. For example: if an automated environmental management system is programmed to make minor adjustments in atmospheric conditions based on trends it measures during regular monitoring, how often must it

report those adjustments to the people? If a single adjustment corrects the trend, perhaps the system must report only once, in a briefing to the commander before the end of the day. If the adjustment does not correct the trend, perhaps the system must report quickly, so that a human (or robotic) repair team is notified in time to prevent problems.

STRUCTURE OF THE ARS INTERFACE SECTIONS – We believe that there should be several sections in the initial release of the ARS document that specifically address both physical and functional interfaces and interactions among human beings and automated or robotic systems. The standard will be iterated over time into a structure that is most useful, and most easily used.

The first section should address design considerations and design requirements for assembly and integration of automated systems and of worker robots. This section would describe a standardized set of robotic functions and capabilities, preferably modular in nature so that robots for a particular mission could be assembled from a standard functional design portfolio to meet the mission goals. The various physical subsystems for robots would be available for a mission designer basically “off-the-shelf,” based on modular functional design necessities and collective operational requirements.

Chapters of this first section of the standard would address propulsion or locomotion, command and control, communications, mechanisms, end effectors, and sensors. One chapter must address the integration of the various systems, and one chapter must address the levels of autonomy a particular design can achieve. In addition, there must be at least one chapter on requirements for maintenance of the robots by humans (and ultimately by other robots), but this chapter will only address those requirements that are unique to robot maintenance and are not found in other maintenance sections of the updated NASA STD-3001.

This approach to function-based standardization will reap huge benefits in long-duration missions in terms of logistics and spares, maintenance, and ground and flight crew training. While it can encourage the use of a wide variety of individual robots, the assembly of those robots from standardized components will certainly make them more affordable and more reliable. The flow-down benefits to short-term missions and the design of free-existing robots are apparent but are not drivers.

The second interface section of ARS should address design considerations and design requirements for development of systems that will be manipulated – maintained, transported, or stowed – by robots. This will include design requirements for developers of spacecraft that will be serviced by robots; by “spacecraft” we refer to robotic or uncrewed planetary satellites and propulsion modules, as well as in-space and planetary crewed vehicles, including habitats.

Since we are including essentially all future spacecraft, this section will have very deep and long term ramifications. It will address the work envelopes that the standard robots must perform within, including issues such as: the strength capabilities of these robots; the hardware and “humanware” interfaces they are capable of manipulating (fluid, electrical, and data connectors; fasteners; volumes and dimensions, etc.); and the structural and dynamic characteristics of the hardware. These are in almost every way analogous to the design issues addressed in other areas of the updated NASA-STD-3001, but specifically applied to automated and robotic systems. This is necessary for a variety of reasons, not least because humans and robots face the same sorts of physical constraints when performing tasks: both must be able to detect (“see,” in the case of humans) and reach a hardware interface to manipulate it, and the manipulated component must conform to the constraints of the human (e.g., hand size, strength) or the robot (e.g., tool fitting size, cybernetics).

Notice the reference to “humanware” as manipulated by robots. We expect that, in addition to performing other tasks, some robots will transport or be transported by human beings; some will provide temporary life support for people; some will perform surgery or other health care procedures on humans; some will act as task assistants; and most will understand and react to human commands (either verbal, visual, or digital) and provide information to humans in understandable formats. (These issues will need to be addressed in human interface standards with other, non-robotic automated systems, as well.)

A new approach to design will be needed in a third interface section: a standard for space hardware systems that are serviceable by *both* humans and robots. The design requirements derived from this part of the standard will apply to Replaceable Units (RUs), including Orbital Replaceable Units (ORUs), Inspace Replaceable Units (IRUs), and Planetary Replaceable Units (PRUs).

We expect that most in-space and planetary structures will have RUs. This design standard will have to include the packaging of all RUs such that they may be removed and replaced by either a human or a robot. The overarching concept is that RUs should be “plug-and-play,” to the fullest extent possible, and that either humans or robots should be able to “plug” them. This approach was begun in ISS robotics, for the Remote Manipulator System and Special Multipurpose Dexterous Manipulator System. This new standard should expand the issue to all RUs, to allow operational flexibility. In most future cases, when robotic systems achieve a level of refinement they do not now have, these requirements will be limited by human capabilities. This constraint will still allow for redundancy of servicing methodologies.

One chapter of this section will address RUs to be manipulated in an unpressurized or low-pressure environment (“low-pressure” means that pressure level

below which astronauts require pressure suits). The requirements for envelopes, strength, and other manipulative factors must be covered in the revised STD-3001. Those RU requirements should be referenced to emphasize the special constraints of suited task performance. The chapter should address those characteristics of the RU that make it “plug-and-play” in the unpressurized environment – including connectors for fluid, data, and electrical; handling/transportation interfaces; alignment and sliding guides; tool interfaces; and fastening. Both robot/human RU interfaces and RU/system interfaces must be addressed in the chapter.

A chapter will address “shirtsleeve” or pressurized environments. Most issues will be the same as for unpressurized environments; but in many cases, the interfaces for both humans and robots can have a finer “grain” – smaller fasteners may be used, less robust connectors, and finer sensory cues than are possible in low-pressure environments. This design philosophy and approach will be driven by the strong increase in human capabilities in this environment. The modularity of the RU design philosophy will derive from the need for robotic support, again, to allow operational flexibility.

We believe that the shirtsleeve maintenance environment will remain the domain of humans for some time to come, but the need for robotic assistants to perform at micro or even smaller levels will drive these requirements. These robotic workers will be an essential part of the flight crew for any long-duration mission outside Low Earth orbit, because they will not consume resources that must be transported from the earth’s surface (oxygen, water, foodstuffs). They will be necessary to keep the crew size down and to free the human explorers from routine housekeeping duties, allowing the people to perform flight and scientific mission tasks that are non-routine and involved with the surprises and uncertainties of exploration missions. (While human mental and physical flexibility will surpass that of the robots, the application of this standard to the shirtsleeve environment will support overall mission goals by removing humans from routine operations where automated systems excel.)



ASIMO, Honda’s autonomous robotic system, prepares to conduct the Detroit Symphony Orchestra. Orchestra members reported that the robot was easy to follow and very precise in its movements. Honda

Research Institute, Advanced Telecommunications Research Institute and Shimadzu Corporation have collaboratively developed the world's first Brain Machine Interface technology to enable teleoperation of a robot by human thought alone. (Photo is in the public domain.)

TRUSTING THE SYSTEMS – There are many reasons for human-rating the automated and robotic systems that will assist us in space exploration, but perhaps the most compelling is that the explorers must feel that they can trust the systems they use as exploration tools. Our American cultural view of robots and automation precludes an automatic, dependent trust on such systems: consider the modern folklore related to automation and robotics, expressed in movies such as *Terminator* and *Space Odyssey!* (The Japanese cultural view, by contrast, is that robots are much more benign, as demonstrated by depiction of robots as toys and protectors of human interests in television programs like *Transformers*; and in their development of robotic assets like Honda's Asimo, which recently conducted the Detroit Symphony Orchestra...)

For that reason, the human-rating standard for these automated systems must address fault detection in a very complete way. Design of fault identification, reporting and recovery methods must be carefully addressed in the standard; and verification methods for each must be explained and modeled there. Especially important will be the fault reporting interface between the systems and people – how faults are reported, how frequently, and with how much detail. Increased depth of fault reporting can bring increased crewmember trust, but if a system's reporting protocol can't "get to the good stuff" quickly enough, there is risk of perceptual slips by those receiving the reports.

In addition, the nature and operating standard for self-diagnostics in automated systems must also be well explained in the standard, and verification methods for ongoing self-diagnostics must be explained thoroughly. After all, self-diagnostics are the "conscience" of an anthropomorphized automated system...

ANTHROPOMORPHIZING THE SYSTEMS – There is danger in considering an automated system to be a "partner" or "helper" rather than a tool, and inspiring too much of the wrong type of trust in the system. The danger is that of unrealistic expectations from the system. Other human beings will always share certain worldview elements with us, based on our shared experiences and shared value sets. Our automated systems cannot share our experiences because they do not have our complex sensorium, nor our holographic processing capability that allows analog comparisons and pattern recognition even among unlike items and events.

Nevertheless: we anthropomorphize the systems if we can because we are people and we use ourselves as the analog for nearly all activity we see in the world! Take a look at ASIMO in the previous column and try to think of it as "it" instead of "he." That recognition is even more difficult with android-type robots like Japan's Repliee,

which has appeared on Japanese television talk shows wearing a cute skirt and a "Hello Kitty" sweatshirt...

ARS LABORATORY AND TESTBED – The authors have considered that the ARS standard will surely lead to new approaches in development and implementation of automated and robotic systems – not just new design approaches, but new approaches in the ways human beings must interface and interact with those systems. This will include new attitudes toward using the systems, as well as new psychomotor skills. One crewmember directly told one of the authors, "We want HAL 9000, to take care of our needs and our environment, but we don't want HAL's personality..."

As a "next step" to help implement the standard in a standardized way, and to work out the interactive protocols among people and systems, we propose establishing a distributed Automation & Robotic Systems Laboratory and Testbed. This facility would be used to develop automated system elements, test operations, and train both crewmembers and mission operations personnel in their use. This distributed facility would be created and maintained at several NASA centers simultaneously – probably Ames Research Center and Jet Propulsion Laboratory in California, and Johnson Space Center in Texas. Each center would specialize in development, test, and training related to specific robotic or automation elements within the integrated system of human exploration operations.

We will have to complete the ARS standard itself in order to derive the types of program needs that should be addressed by the ARS lab and testbed, and therefore the design of the facility, but we can make certain conjectures based on what we have forecasted here regarding operations issues. For example, we know there should be development and test capability for integrated multi-asset operation (of various combinations of teleoperated and autonomous assets). This capability might be spread among all three centers, with mission control workstation facilities at JSC and JPL (where human and robotic missions are already operated), and asset simulation capability at ARC (the leading center for intelligent systems development). Development and test might take place at the centers most experienced in a specific type of operations, and training of operations personnel and crewmembers would take place at the center typically responsible for that type of training.

We look forward to developing a comprehensive plan for the ARS lab and testbed following completion of the ARS standard.

CONCLUSIONS

Unprecedented automated and robotic systems will make long duration space missions both possible and productive, but they will also force everyone who plans our human space flight programs to pay attention to how explorers will control and interact with these systems.

Our NASA approach to human-rating the systems that take people into space must be applied to the automated and robotic systems that will help people stay there for long terms. The new NPR for Human Rating makes this application more likely and more easily accomplished. We must develop a standard for these systems that can drive programmatic requirements, and provide guidance to a development and test facility for the systems themselves. That challenge is bigger than any individual NASA center, and will demand the collaborative work of several centers to achieve.

Please consider this paper a call for conversation and collaboration, as we begin the task of making automated and robotic systems more useful, and the task of helping people to use the systems better!

Lynn Baroff is the Principal Investigator for the proposed standard development project referred to in this paper, the Automated and Robotic Systems standard. Charlie Dischinger and David Fitts are Co-Principal Investigators on the proposed project.

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