From the NASA’s inception in 1958, the prospects of operating space vehicles and constructing structures in space led the agency to study the behavior of fluids in space.

The behavior of fluids in spacecraft was the object of a number of research efforts to design propellant management systems and other fluid systems required by emerging space technology. The development of spacecraft thermal control systems that utilize change of phase of materials for heat storage prompted questions concerning solidification phenomena in zero gravity. The possibility of the erection and repair of large structures in space by brazing and welding raised issues concerning the flow of liquid metals dominated by capillary forces.

As NASA prepared for laboratory facilities in space, the agency planned to more carefully study the behavior of fluids and materials as they relate to space operations. Some of the agency’s managers who were involved in what came to be called “materials processing in space” also hoped for the development of another space-related industry, comparable in its impact to the highly visible and successful space communications industry. Dr. Robert J. Naumann of NASA’s Marshall Space Flight Center (MSFC) expressed the hope of NASA managers who held this view:

The ultimate goal is to develop a viable commercial interest in using space (1) to perform research for improving industrial technology or developing new products; (2) to prepare research quantities of materials to serve as paradigms for comparing current earth-based technologies; (3) to manufacture limited quantities of a unique product to test market potential, or to fulfill a limited but compelling need; and (4) to produce materials in space of adequate quantity and value to be economically self-sufficient.

The motivating idea was that a space laboratory provided a fundamentally different environment for fluids than a laboratory on the Earth’s surface. Fluids standing in Earth’s gravity have a hydrostatic pressure caused by the weight of overlying layers of the fluid. The hydrostatic pressure thus decreases with height in the fluid. Bubbles and particles or fluid elements with less density than the surrounding fluid are pushed upward in response to this hydrostatic pressure gradient, whereas heavier elements sink. In Earth-based laboratories, this leads to phenomena such as buoyancy, sedimentation and convection currents, where heated elements rise and colder elements sink in a gravity field with a gradient.
Fluids in a space laboratory are in “free fall” around the Earth and have no hydrostatic pressure and no hydrostatic pressure gradient. The force of gravity in the best space laboratories is typically of the order of $10^{-6}$ of the force of gravity at Earth’s surface, and for this reason the space laboratory environment came to be called a “microgravity environment.” Naumann and others believed experimentation in this new environment might lead to discoveries that would have commercial value.

Many researchers thought of the use of a space laboratory primarily in terms of Materials Processing in Space, which was, in fact, the first name NASA used for its program in the microgravity materials sciences. Some examples of their research projects included: (1) growing ultra-pure crystals in space, since the absence of gravity-driven convection would eliminate unwanted fluctuations in composition, temperature, and flow at the surface of the growing crystal; (2) processing material without a container, which could avoid contamination of material by the container, as well as the unwanted nucleation of crystals on the container’s inner surface, while also permitting the processing of materials at temperatures beyond the melting point of the container; (3) processing hollow glass spheres with a high degree of concentricity that could be used as fuel containers for inertially confined fusion experiments on Earth; and (4) separating biological cells by the method known as electrophoresis, which could produce results superior to the results of the process on Earth, where convection and sedimentation are a hindrance.

USRA began its involvement in microgravity research soon after it was incorporated, and over the years the association has been involved in a wide variety of efforts.

In June 1971, the first president of USRA, Professor A. Robert Kuhlthau (University of Virginia), responded to a request from NASA Headquarters for USRA to review, study, and evaluate possible flight experiments relating to materials processing in space. Kuhlthau appointed Professor Henry Leidheiser Jr. (1920-2011) to direct USRA’s program on a consulting basis. For small, emerging, programs, USRA usually sought leadership from distinguished university professors on a consulting basis. Leidheiser was the Director of the Center for Surface and Coating Research at Lehigh University. As Kuhlthau reported to the USRA Council of Institutions in 1972:

The work involves providing technical guidance in the design and operation of experiments for Skylab as well as preliminary demonstrations which are

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**Electrophoresis**

In electrophoresis, a mixture of particles to be separated, particularly different kinds of biological cells, is suspended in a buffer solution. Different cell types carry different charged species and charge densities on their surfaces due to the presence of characteristic membrane molecular structures. When an electric field is applied across the suspension, the cells or particles move in response to the field, but at different speeds, owing to different charge densities and configurations on the different cell types. The result is a separation of the different types of cells or particles in the mixture.
being conducted on board during the Apollo missions. At the moment we are concerned primarily with three areas: electrophoresis; convective heat transfer; and crystal growth. The program has involved participation by a number of scientists from ten universities, eight of which are members of USRA. Through this effort USRA has a significant role in one area of the Skylab program, and indications are that the effort will double during the coming year.\(^8\)

Very early microgravity experiments were carried out in the Apollo 14, 16, and 17 spacecraft when they were in unpowered flight between the Earth and the Moon. The results of the experiments began to show that the behavior of fluids in a microgravity environment would not be as simple as first supposed.\(^9\) In particular, it was a mistake to assume that convection in fluids in space laboratories would not exist. Gradients in the surface tension of a fluid cause convective flows, for example, and since surface tension of a liquid depends on temperature, variations in the temperature of the surface of a fluid will result in convective flow.

Leidheiser managed discipline-based study groups, which became known as the “USRA Committees.” By 1974, there were five USRA Committees, including: (1) Electrophoretic, Chemical and Biochemical Separation Processes; (2) Preparation of Glasses; (3) Solidification of Metals and Semiconductors; (4) Convection and Heat Flow; and (5) Containerless Processing Systems for Space.

Each committee would meet three or more times during the year with NASA representatives. Advice was given on program plans, details of specific experiments, and the feasibility of rocket experiments that could be accomplished prior to those planned for Skylab. In 1975, the five committees each prepared a chapter for a 119-page report that served as background material for a summer study panel on space processing convened by the National Academy of Engineering (NAE).\(^10\)

Through the NAE study, NASA managers were trying to plot the future of microgravity materials research for the agency. At about the same time, in 1975, the USRA Board of Trustees established an Advisory Panel on the Orientation and Role of USRA. The panel was chaired by William M. Kaula (1926-2000) (UCLA) and had as members Drs. George B. Field (Harvard), Herbert Friedman (1916-2000) (U.S. Naval Research Laboratory), A. O. C. Nier (1911-1994) (University of Minnesota), Simon Ostrach (Case Western Reserve University), and Robert M. Walker (1929-2004) (Washington University). The panel assessed national needs and the state of space experimentation in various disciplines in which USRA might become involved. On the topic of microgravity science, the panel noted:

\[\text{To be effective, there must be much more than empirical trials of terrestrial techniques: attention must be paid to the fundamentals of convection and other phenomena.}^{11}\]

USRA’s second president, Professor Alexander J. Dessler (Rice University), took office in 1975 and one of his first acts was to appoint a task force on microgravity materials research, with Simon Ostrach as its chair. Other members of the task force included Drs. John Carruthers (Bell Labs), Elias Snitzer (1925-2012) (American Optical), Donald Uhlmann (MIT), and Jay Zemel (University of
Pennsylvania). Their report, shared with NASA, contained the recommendation that:

... principal attention of [NASA’s microgravity materials] program during the coming years should be given to understanding phenomena rather than the development of new products.\textsuperscript{12}

The task force provided implications of its recommendations in the report as well, which included:

1. Establish an extensive scientifically and technologically significant ground-based research program directed toward the elucidation of phenomena which are important in space processing, and increase significantly the funding in this program.

2. Direct increased attention in space experiments to defining phenomena and materials characteristics which are important to space processing. ... Such improved definition seems essential to achieve substantial industrial participation in the program.

3. Increased attention should be given to the use of space to obtain information which can contribute importantly to improving materials processing on Earth. Contact should be made with progressive industrial firms in various areas of technology, both to acquaint them with the characteristics and potential of space and to solicit their inputs to the program. The USRA Committees can play a significant role in establishing the desired dialog.

4. More detailed characterization of materials processed in space and comparison with Earth-processed materials should be carried out.

5. Develop through workshops and other programs the means by which potentially interested workers will be made aware of the field, its potential and its inherent interdisciplinary character.\textsuperscript{13}

The USRA report was, in part, an attempt to focus NASA’s efforts on the underlying science related to the behavior of materials and fluids in space. NASA began to implement the task force’s recommendations, perhaps because one of the members of the task force, John Carruthers, soon became the Program Director for the Materials Processing in Space Division of NASA Headquarters.

Carruthers asked USRA to form Discipline Working Groups (DWGs) to assist his efforts at NASA Headquarters. Those in the disciplines of solidification processes, fluid and transport phenomena, bioprocessing, and containerless processing were to be the top level of a managerially nested series of working groups that also included Science Working Groups, Experiment Working Groups,
Dr. Louis R. Testardi, who had been a solid-state researcher at Bell Labs, took over as manager of NASA’s Materials Processing in Space Program. The two-phase systems which form when dextran and poly(ethylene glycol) (PEG) are mixed to form aqueous solutions which are greater than a few percent in each, when appropriately buffered, have proven to be valuable as partition media for macromolecules, subcellular organelles and whole biological cells ...

USRA persevered during the changes at NASA. Rindone’s program established a liaison between USRA and European Space Agency (ESA) working groups and became involved in coordinating efforts to share experimental facilities between ESA and NASA principal investigators. In 1981, Rindone organized a review of the status of the microgravity program in the form of a conference that was jointly sponsored by the Materials Research Society (MRS) and held at their annual meeting in Boston. Rindone edited the book that was published for the symposium proceedings.

One of the papers at the MRS meeting in Boston in 1981 was by Professor Donald E. Brooks and Dr. Stephan Bamberger (University of British Columbia and University of Oregon Health Sciences Center) titled Studies on Aqueous Two-Phase Polymer Systems Useful for Partitioning of Biological Materials. The work described was performed under the support of NASA contracts to Brooks beginning in the mid-1970s from MSFC, managed by Dr. Robert S. Snyder. In their paper, the authors discussed the utility of two-phase systems for separating biological cells:

The authors noted the limitation of the separation process as carried out in ground-based laboratories and suggested that performing the separation experiment in low gravity could overcome the limitation:

Partitioning works well for relatively small cells. An inherent limitation appears for cells which sediment significantly during the time required for the phases to settle, however, since
such cells will sediment into the interface, or to the bottom of the tube, before phase separation is complete. By working in a low gravity environment cell sedimentation would be eliminated... 

The opportunity to perform the separation experiment in a low-gravity environment came a few years later. In the meantime, Testardi left NASA to become the Chief of the Metallurgy Division of the National Bureau of Standards in 1982. His successor at NASA Headquarters was Richard Halpern (1930-2009), who continued to rely on USRA. For example, Halpern followed up on Carruthers’ efforts by asking USRA to reorganize the DWGs to assist him at NASA Headquarters. Halpern, who had successfully managed NASA’s High Energy Astronomy Observatory project, used these committees to help him develop a strategic plan for NASA’s microgravity program.

The scope of work for management of the USRA Committees expanded to include the hiring of USRA scientists to conduct research at MSFC. Brooks was a member and later Chair of USRA’s Science Council for Materials Science and Applications, and he encouraged one of his PhD students, James Van Alstine, to apply for a position in USRA’s materials science program at MSFC. Upon completion of his PhD in 1984, Dr. Van Alstine joined USRA’s research group at MSFC.

While continuing to work with Brooks and others at the University of British Columbia, Van Alstine began a collaboration with colleagues at MSFC and the University of Alabama in Huntsville (UAH) to further study the phase separation process. Members of this team included Dr. Robert S. Snyder, senior NASA scientist and the manager of the Microgravity Fluid and Transport Processes Branch within MSFC; Dr. Blair J. Herren of MSFC; Dr. Laurel J. Karr, who had been a USRA Visiting Scientist and later moved to UAH; Dr. J. Milton Harris, a Professor of Chemistry at UAH; and Dr. Steven G. Shafer, also at UAH.

The initial question Van Alstine’s research group wanted to examine was why a simple model based on thermal energy considerations couldn’t explain the results of phase-separation “distribution” experiments in laboratories on the Earth’s surface.

Cells which, on the basis of their adsorption free energy would be expected to be found at the interface [of the two phases] following a distribution experiment, have been removed from that location and released into the bulk phase by forces which are not thermal in nature.

Van Alstine and his colleagues felt that if these non-thermal forces could be identified:

It should be possible to design a separation process that minimizes this influence. Much higher resolution separations would result, with attendant benefits to biomedical investigations and biotechnology.

Van Alstine, Brooks and their teammates suspected that the “other forces” were shear forces in the fluid that resulted from convection in the ground-based laboratory, and they proposed to test this hypothesis by flying a separation experiment in space. At this early stage of microgravity fluid experimentation, Van Alstine and his research group were not even sure that the phases, once mixed, would separate in a reasonable amount of time. In a Skylab experiment, oil and water emulsions were stable over a period of 10 hours, whereas the fluids separated completely on earth in 10 seconds.

Van Alstine led the development of a simple hand-held phase-partition experiment (PPE) for the fourth flight of James Van Alstine
the Space Shuttle Discoverer in April 1985 (STS 51D). The device had fifteen chambers, each containing variations of the two-polymer phase system that Brooks and Bamberger had used – dextran and PEG. On Earth, these polymers rapidly separate into a less dense phase floating on top of the heavier phase. In the space experiment, the handheld device was shaken and the chambers were then photographed at intervals of time. The phases were observed to rapidly separate or demix, though slower than on the ground. The dextran-rich phase suspended, like an egg yoke, in the PEG-rich phase, which preferentially wetted the glass and plexiglass walls of the chambers. In related ground-based research, the team used wall coatings developed at UAH to control which phase would preferentially wet the walls of a container.22

The key to understanding the demixing process was to find the analytical form of the rate of demixing. The team had derived some approximate relations that described different scenarios for drop coalescence. If diffusion of small drops into larger ones was the dominant process, then the characteristic size of the drops was expected to increase as \( t^{1/3} \), where ‘t’ is the time from the onset of the mixing. If coalescence was produced by externally applied shear, such as might be present as a residual from the mixing process, the size of the drops was expected to increase exponentially with time. If coalescence was caused by shear produced by the local fluid disturbance generated by coalescence of two other drops, the size of the drops...
was expected to increase linearly with time.23

A measure of the rate of demixing was obtained by projecting the time-tagged photographs of the chambers, tracing the outlines of the connected domains, and then estimating the surface area and characteristic lengths of the domains of each phase as a function of time.

The initial space experiment on phase separations wasn’t free of problems. It was found, for example, that the light source necessary to make the photographic record probably heated the fluids in the chambers by a few degrees, so data for only the first ten minutes of demixing was used in the analysis. Nevertheless, some conclusions could be drawn from the experiment. The team’s analysis indicated:

... the slow mechanism of Ostwald ripening which involves the growth of large phase droplet regions by diffusive transport of material from smaller droplets culminating in a single large region of radius, \( r \), growing asymptotically with time \( (t^{1/3}) \), is not responsible for demixing of these systems in low-g.24

The most likely cause of the growth of droplets was coalescence, perhaps from externally applied shear, or slightly more likely from coalescence-induced shear.25 As will be shown at the end of this essay, the results of the phase partition experiment were perhaps less important than the processes related to the experiment.

There were shuttle reflights of the PPE,26 one on Space Shuttle Challenger, destroyed in flight on 28 January 1986. Space Shuttles were grounded after the tragedy while NASA sought to fully understand the reason for the catastrophic failure. During the down time, USRA continued to support NASA as the agency prepared for a resumption of shuttle flights and the construction and operation of what would become the International Space Station. In December 1986, USRA President Paul Coleman appointed Dr. Martin E. Glicksman (Rensselaer Polytechnic Institute) to succeed Henry Leidheiser as director of USRA’s Microgravity Science and Applications program. Van Alstine became Glicksman’s deputy and manager of USRA’s materials science program at MSFC.

Glicksman had served two terms on the USRA Board of Trustees and as chair in 1983-84. He came to the microgravity program as an internationally renowned materials scientist who would later act as Principal Investigator for three successful experiments, the Isothermal Dendritic Growth Experiments (IDGE), flown by NASA in 1994, 1996, and 1997 on Space Shuttle Columbia. IDGE experiments were to measure fundamental tests of the theories of kinetics and morphology of dendritic growth without complications induced by gravity-driven convection.27

Glicksman shared the views of many of his university colleagues about first understanding the underlying science before attempting to develop space applications of material science:

Our experience on the IDGE gives support of our view that the best benefit of microgravity research in materials science is not to make something in space, but to try to gain scientific understanding.28

Dendritic growth is a fundamental process observed in the casting of metals. This image is of dendrites of succinonitrile grown in space during the first IDGE flight.27
As IDGE was being developed, NASA suggested to Glicksman that the experiments could be used to test recently developed telescience technology, which would allow members of the IDGE team to remotely control the experiment. Glicksman accepted the suggestion and telescience (or tele-operations) was incorporated into the IDGE missions. At another of its institutes, USRA had been heavily involved in the development of telescience and thus had an indirect, but important, impact on the IDGE mission. In his report of the first IDGE mission, Glicksman and his colleagues at Rensselaer wrote:

> Tele-operational controls enabled optimization of finite resources, such as film capacity and orbital time, to accomplish specific goals despite several unpredicted events. We did not anticipate, for example, several eventualities encountered in the operation of the experiment. Without tele-operational control, the IDGE team would not even have known about some surprises until several months after the flight. Certainly we could not have altered the preset operational parameters to either avoid, or take advantage of those surprises and, in the process, improve the quality and quantity of the scientific data return.30

Glicksman was elected to the U.S. National Academy of Engineering in 1996. He authored two major materials science textbooks, *Diffusion in Solids*, and *Principles of Solidification*. He has been the recipient of several awards, including the Frank Prize of the International Organization of Crystal Growth (IOCG) in 2010.

In 1996, an international search identified Dr. Alexander A. Chernov as the leading candidate to direct the Alliance for Microgravity Materials Science and Applications, which was a new collaborative effort between USRA, MSFC, the University of Alabama in Huntsville, and the Alabama Space Grant Consortium. Glicksman helped to persuade Chernov to take the job. Chernov, a distinguished Russian physicist, was an expert in crystal growth. He had been elected to the USSR Academy of Sciences in 1987 and was the recipient of several prizes for his contributions to science, including the first Frank Prize of the IOCG in 1989.

When Chernov arrived at USRA, one of the topics of intense interest at MSFC and worldwide was protein crystal growth. The first “let’s see” experiments showed that crystallization of proteins or other biological macromolecules in the microgravity environment sometimes resulted in crystals of improved quality, probably owing to the elimination of convection near growing crystal surfaces. It was thought that these more perfect crystals might allow higher resolution diffraction that could better reveal the structure of the biomolecule that forms the crystal.31 The data showed that about 20% of the protein crystals grown in space were of better quality and larger than their terrestrial counterparts. A clear-cut explanation of this improvement and the conditions to consistently grow better crystals had not yet emerged.32 Chernov and his colleagues assumed that, similar to inorganic materials, the lack of quality in the protein crystal was owing to the presence of impurities in it. For example, an impurity can distort the crystal lattice if the linear size of the impurity molecule exceeds that of the cavity that the lattice is able to provide.33 Incorporation of the impurity into the crystal lattice causes lattice distortion and thus stress in the crystal. That stress is relieved by shifting the orientation of planes within the crystal structure, a phenomenon called mosaicity. Chernov and his colleagues argued that:

> Understanding the principles controlling...
impurity distribution and establishing correlation between impurity content and the crystal perfection may suggest rational improvements in crystallization conditions.\textsuperscript{34}

And further:

Since molecular interactions are not affected by gravity, the only rational explanation of ... improvement, if any, should be associated with convective versus diffusion transport difference and related changes in [protein crystal growth] surface processes.\textsuperscript{35}

To explain why some crystals are grown with more perfect structures in space, whereas more often they are not, Chernov developed the idea that the outcome depends on whether the growing crystals preferentially trap stress-inducing impurities.\textsuperscript{36} Chernov explained:

Chernov’s hypothesis of diffusional self-purification of crystallization in microgravity has been accepted by research groups around the world. More generally, Chernov’s work on understanding fundamental processes in biomacromolecular crystals has had a large impact on a growing and diverse science:

Crystallization of large biomacromolecules, acknowledged to be the rate-limiting step for structural proteomics and genomics, is also of fundamental interest as a new domain of phase transformation physics in general. Biomacromolecular crystals are also relatively new objects from the perspective of solid-state physics. Crystallization is based on molecular recognition and, as such, is of general biological interest, e.g., for enzymatic reactions and other similar problems of molecular biology and self-assembly.\textsuperscript{38}

Following seven years of service with USRA, Chernov joined the scientific staff of the Lawrence Livermore National Laboratory.
NASA’s microgravity program had a difficult birth - between 1978 and 1989 there were seven different leaders of the microgravity program at NASA Headquarters. One of these managers, Dr. Frank Lemkey, was a Senior Research Fellow at United Technologies on loan to NASA through a senior executive exchange program. In the fall of 1989, Lemke wrote an article for a USRA newsletter in which he discussed the status of NASA’s microgravity program:

“We still suffer from the predictions and hyperbole of zealots who prophesied early commercial exploitation of novel semiconductors and space medicines.”

No novel space medicines, perhaps, but through a somewhat strange path, microgravity research eventually influenced the development of some very important medicines that are now produced in ground-based laboratories. The work of Van Alstine, Harris, Brooks and their teammates on surface coatings that were required for the Phase Partition Experiment (PPE) for Shuttle flights led to a USRA patent (US4690749A) on the use of polymer-coated surfaces to control the electric potential on these surfaces.\footnote{Among Van Alstine’s co-inventors were Robert Snyder and Blair Herren of NASA, and Milton Harris and Steven Shafer of UAH. This was the first filed patent on what is now an industry-standard approach for controlling electroosmosis, or the movement of the whole fluid (not just its ions as in electrophoresis) under the influence of the electric field, in electrophoresis devices. This control has been particularly important for capillary electrophoresis (CE), which, at this writing, is one of the most efficient separation techniques for the analysis of both large and small molecules. CE in coated capillaries is now a common bioanalytical method, as is the affinity electrophoresis method that also grew out of this work, and which is based on another of Van Alstine’s patents (US5108568).}

The research group with members at the University of Alabama in Huntsville, the University of British Columbia, and MSFC also began to work on PEG-related topics in biomedical research, noting:

“The same chemistry used to covalently couple PEG to amino groups on glass surfaces can be employed to covalently link PEG molecules to protein gamma amino groups...”\footnote{Members of the group began to further examine the covalent bonding of PEG to proteins, a process that came to be called “PEGylation.” They and others found that PEGylated proteins could be of value by, among other things, increasing a medicine’s half-life in a patient’s bloodstream.}
Following his research and research leadership at USRA, Van Alstine was appointed Professor of Chemistry at UAH, where he continued to work with Milton Harris and others. Van Alstine subsequently was appointed Professor of Surface Biotechnology at the Royal Institute of Technology in Stockholm, Sweden, before joining General Electric Healthcare in 1999.

Milton Harris remained at UAH and, in 1992, founded Shearwater Polymers, Inc., to advance PEG-related technologies. Harris’s company helped develop several important drugs, among them Pegfilgrastim (sold under the brand name Neulasta®) and a PEGylated Interferon, Peginterferon alfa-2a (sold under the brand name Pegasys®). Pegfilgrastim is used to stimulate bone marrow to produce more white blood cells to fight infection in patients undergoing chemotherapy. Peginterferon alfa-2a has a longer life than Interferon and is thus better able to fight viral infections in the body.

During the 1970s and 1980s, USRA provided a steadying influence on the emerging discipline of microgravity science by staying true to the vision of the second NASA Administrator, James Webb. Webb saw that an association of major research universities could bring needed expertise and insight as NASA encountered new scientific and technical challenges. In the case of microgravity science, the needed guidance came initially from Simon Ostrach’s task force, which stressed the priority of understanding phenomena over making things in space. Coming from an association of research universities, such a view was perhaps predictable, but it has been amply validated as the proper course, because, as often happens, fundamental research has led to unexpected, but extremely important, applications.


4 Ibid., p. 18.

5 Ibid., p. 23.

6 Ibid., p. 29.

7 Skylab was a U.S. space station that orbited the Earth from 1973 to 1979. It was manned intermittently, with three work sessions between May 1973 and February 1974. Skylab contained a materials processing facility and a multipurpose furnace system.

8 Annual report of the USRA president. 1972. Appendix V of the minutes of the annual meeting of the USRA Council of Institutions. USRA Archives.


13 Ibid., pp. 8-9.


15 In reviewing the history of USRA’s involvement with NASA, one finds NASA managers who not only had a very good understanding of their science and/or technology but also an appreciation for the role of university researchers and USRA. Robert Snyder was one of those individuals, whose support for science and for USRA from within NASA was often crucial in allowing the collaboration between NASA and the university research community that was envisaged by the second NASA Administrator, James Webb.


17 Ibid., p. 234.

18 Van Alstine, Brooks and Harris had collaborated on research related to polyethylene-glycol (PEG) while Van Alstine was pursuing his PhD in Chemical Pathology at the University of British Columbia.


26 In one of the reflights (Shuttle Transportation System (STS) 51G in June 1985) Van Alstine assisted Saudi Arabian engineers in the preparation of their experiment with the device. The person who conducted the phase partition experiment in that flight was Sultan bin Salman bin Abdulaziz Al Saud, who was a Lieutenant Colonel in the Royal Saudi Air Force. At the time Salman Al Saud was the youngest person to fly on the Space Shuttle (at the age of 28) and the first Arab to fly in space.

In 1988, a PPE was included on the STS 26, which was the first Shuttle flight after the Space Shuttle Challenger disaster of 28 January 1986. The experiment was flown on several other missions, the last being the First International Microgravity Laboratory (STS 42) in 1992. Many of these results were summarized as a chapter in a book providing an overview of low gravity fluid dynamics and transport phenomena. See Bamberger, S., Van Alstine, J. M., Brooks, D. E., Boyce, J., and Harris, J. M. (1990). Phase partitioning in reduced gravity. In J. N. Koster and R. L. Sani (Eds.) Low gravity fluid dynamics and transport phenomena, v. 130, (pp. 603-630). Progress in Astronautics and Aeronautics, A. Richard Seebass Editor-in-Chief, American Inst. of Aeronautics and Astronautics, Washington D. C.


28 Ibid., p. 54.
USRA's Research Institute for Advanced Computer Science (RIACS) did the pioneering research and development on telescience at NASA, beginning in 1986. Specifically, the RIACS Networking Group, led by Dr. Barry Leiner (1945-2003), did the research and development, part of which involved the coordination of a Telescience Testbed Project for NASA that involved 15 research universities.


Patent US4690749 - Polymer-coated surfaces to control surface zeta potential. The patent is described as providing a method for eliminating or controlling electroosmosis and other zeta-potential-related phenomena in electrophoresis by using electrophoretic surfaces coated with covalently-bound hydrophilic, neutral polymers. When a charged particle is in a fluid or on the surface of a container holding a fluid that contains ions, the electric field of the charged particle is partially shielded by surrounding ions that have charge opposite to its charge. The “zeta potential” refers to the residual electric potential difference between the partially shielded charge and the fluid.