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MICROGRAVITY MECHANISMS AND ROBOTICS PROGRAM

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ABSTRACT

NASA plans to provide the scientific community with a microgravity laboratory aboard the space station. Using and maintaining the microgravity environment will require, among other things, careful attention to experimental apparatus mechanisms and laboratory robotic manipulators. This presentation describes a technology development effort toward that end.

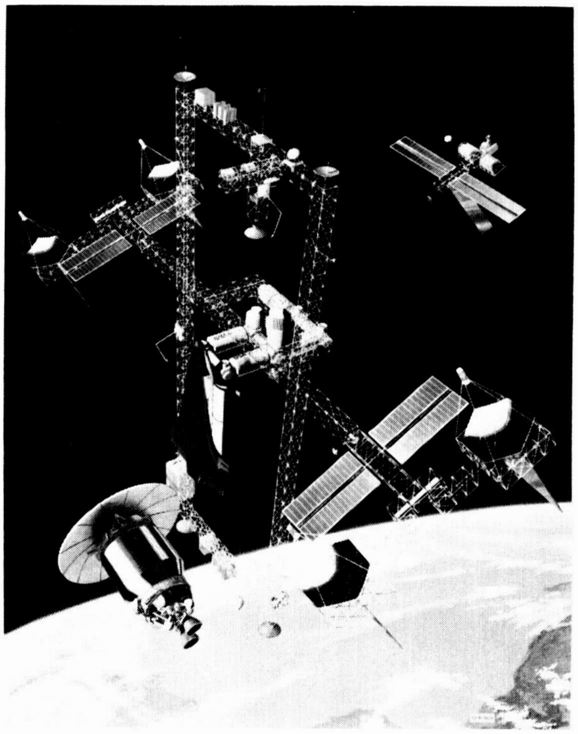
Since a variety of experiments that require microgravity also require or would benefit from motion or manipulation, techniques are needed to restrict these motions and motion-producing forces from disturbing the microgravity environment. The requirement is twofold: low-acceleration, smooth motion and reaction limitation. This program applies structural dynamics and unique roller traction drive technology to mitigating the problems of current mechanical motion control systems. The program objective is to develop the technology for providing acceleration control within and around space experiments by smooth, reactionless motion and manipulation. A series of subtasks have been initiated, including verifying needs and requirements, evaluating roller drives, developing reactionless mechanism technology, optimizing dynamic performance, and developing microgravity and reactionless manipulation. The products of this research will also be applicable to mechanism and robotic needs in other NASA space missions.

SPACE PLATFORMS

Current and future NASA missions involve the development and operation of complex space vehicles and platforms. Although each of these has a different purpose, they must all deal with the environment found away from Earth's surface, namely, reduced gravity, vacuum atmosphere, and increased radiation. In fact, some missions, for example the space station, will have as a primary purpose the utilization of this environment.

Furthermore many of these space vehicles and platforms include in their structural and mechanical design a large number of "moving parts" - as evidenced by the space station artist's concept showing manipulator arms, pointing antenna, solar trackers, and numerous other actuators, drives, and latches. Similarly the pressurized modules will contain numerous mechanisms. This combination of environment and moving parts requires new technology.

The microgravity mechanisms and robotics program involves mechanisms and robotic technology related to the scientific use of the microgravity environment.



ENVIRONMENT:

- MICROGRAVITY
- VACUUM
- RADIATION

MOVING PARTS:

- ROBOTS/MANIPULATORS
- STRUCTURAL JOINTS
- MECHANISMS

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NEEDS

NASA plans to provide the scientific community with a space station microgravity laboratory. Managing the laboratory's microgravity environment will require meaningful standards and technology for conducting experiments in microgravity. Many experiments that require microgravity also involve mechanical motions. Experiments conducted external to the laboratory or on a free-flyer will require remote manipulation capabilities. Furthermore some experiments would benefit from common laboratory equipment that requires handling or scanning motions. New technology is required to ensure that these motions within experiments or the robotic manipulator motions and reaction forces do not negate the microgravity environment of the experiment itself or those of other experiments in the laboratory.

One should be aware that the term "microgravity" is generally not used literally (i.e., 10^{-6} g_o, where g_o equals the acceleration due to gravity at the Earth's surface). It refers to the fact that in low Earth orbit on a typical space platform, the gravity or acceleration field is not "zero g" but rather reduced gravity, nominally in the range 10^{-2} g_o to 10^{-7} g_o. The exact amplitude, and equally important the frequency spectrum, depend on solar pressure, atmospheric drag, the gravity gradient, astronaut motions, attitude control thrusters, rotating machinery, etc.

- **MANY MICROGRAVITY EXPERIMENTS REQUIRE INTERNAL "MOTIONS"**

- **OTHER MECHANICAL MOTIONS WILL OCCUR AROUND EXPERIMENTS**
  - **— EXPERIMENT MANIPULATION**
  - **— LABORATORY EQUIPMENT HANDLING**

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CHALLENGE

Basically the problem breaks down into two key issues. The first is moving an item, such as a protein crystal in a vial, such that it never experiences greater than some low level of acceleration. The second involves limiting the reaction forces produced when a relatively large object is moved at relatively high acceleration rates. These reactions are transmitted to the mechanisms or robot support structure and, depending on the structure's mass, stiffness, and damping characteristics, will set up an acceleration field that might be harmful to other experiments and processes.

These issues are difficult to resolve in general since many mechanisms have problems with backlash, friction, vibration, imprecision, and lack of reaction control. Furthermore a space experimenter may not have mechanism expertise; thus the Lewis Structures Division has undertaken this program.

- **KEY MOTION CONTROL ISSUES INVOLVE MOVING AN ITEM SO THAT**
  - **IT NEVER EXPERIENCES GREATER THAN MICROGRAVITY ACCELERATIONS**
  - **ITS MOTION-PRODUCING REACTIONS DO NOT DISTURB THE SURROUNDING ACCELERATION ENVIRONMENT**

- **TECHNOLOGY ADVANCEMENT**
  - **SOLVE PROBLEMS WITH EXISTING MECHANISMS**
  - **PROVIDE MOTION CONTROL TECHNOLOGY FOR SCIENTISTS**

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OBJECTIVE

The objective of the microgravity mechanisms and robotics program is to develop technology to provide acceleration control by smooth, reactionless motion and manipulation. The immediate intended use of the results is in space experiments hardware. However, the whole field of space mechanisms, robotic actuators, and precision mechanisms in general can benefit.

The program addresses the needs and problems through the application of roller drive and structural dynamics technologies. Roller drives are beneficial to mechanisms and robotic joints because of their unique zero backlash, negligible torque ripple, nonlubricated operation, high torsional stiffness, and compactness. By combining these attributes with dynamic modeling, vibration analysis, and trajectory optimization, an analytical and experimental technology base is being developed for use across the full range from experimental mechanisms to manipulators to autonomous space laboratory robots.

- **DEVELOP THE TECHNOLOGY TO PROVIDE ACCELERATION CONTROL BY SMOOTH, REACTIONLESS MOTION AND MANIPULATION THROUGH THE APPLICATION OF ROLLER DRIVE AND STRUCTURAL DYNAMICS TECHNOLOGY**
  - **ROLLER DRIVE MECHANISMS OFFER ZERO BACKLASH, NEGLIGIBLE TORQUE RIPPLE, HIGH TORSIONAL STIFFNESS, NONLUBRICATED OPERATION, AND COMPACTNESS**
  - **STRUCTURAL DYNAMICS INCLUDES DYNAMIC MODELING, TRAJECTORY OPTIMIZATION, VIBRATION ANALYSIS, AND REACTION COMPENSATION**

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APPROACH

The solution to the general problem of smooth, reactionless motion is approached through a combination of analysis and experimentation. The subtasks of the project are listed here. Upon completion of these subtasks a technology base will be in place for future reactionless microgravity mechanisms and robotic systems.

- **QUANTIFY AND ANALYZE REQUIREMENTS**
- **EVALUATE ROLLER DRIVE CONCEPTS FOR APPLICATION TO EXPERIMENT APPARATUSES**
- **STUDY REACTIONLESS MECHANISMS IN ORDER TO DEVELOP AND DEMONSTRATE TECHNOLOGY**
- **ANALYZE DYNAMICS AND KINEMATICS FOR OPTIMUM PERFORMANCE**
- **DEVELOP MICROGRAVITY AND REACTIONLESS MANIPULATION TECHNOLOGY ON MULTI-DOF TEST BED**

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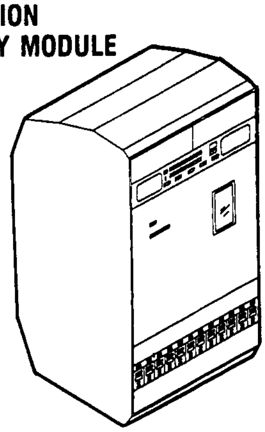
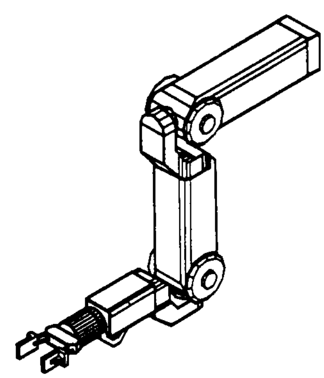
IDENTIFICATION OF REQUIREMENTS

The first step has been to quantify the needs and physical requirements for reactionless microgravity mechanisms and robotic manipulators. Two need avenues are being pursued: motion and mechanism needs within space experiment apparatuses and manipulation needs within the space station laboratory module.

Analysis of experiment mechanism needs includes identifying actual mass, velocity, and distance parameters, as well as studying the transmissibility of forces and accelerations within experiment racks and the entire facility. Robot manipulation can include laboratory housekeeping functions in addition to actual experiment operation, thus offering savings in crew time and enhancing experiment productivity.

The output of this task will be a set of requirements to guide this program's technology development and future system design.





EXPERIMENT MECHANISMS

- **ANALYZE EXPERIMENT APPARATUS**
- **IDENTIFY PHYSICAL NEEDS**

ROBOTIC MANIPULATION

- **ASSESS NEEDS AND BENEFITS**
- **DEFINE INTEGRATION AND INTERFACE REQUIREMENTS**

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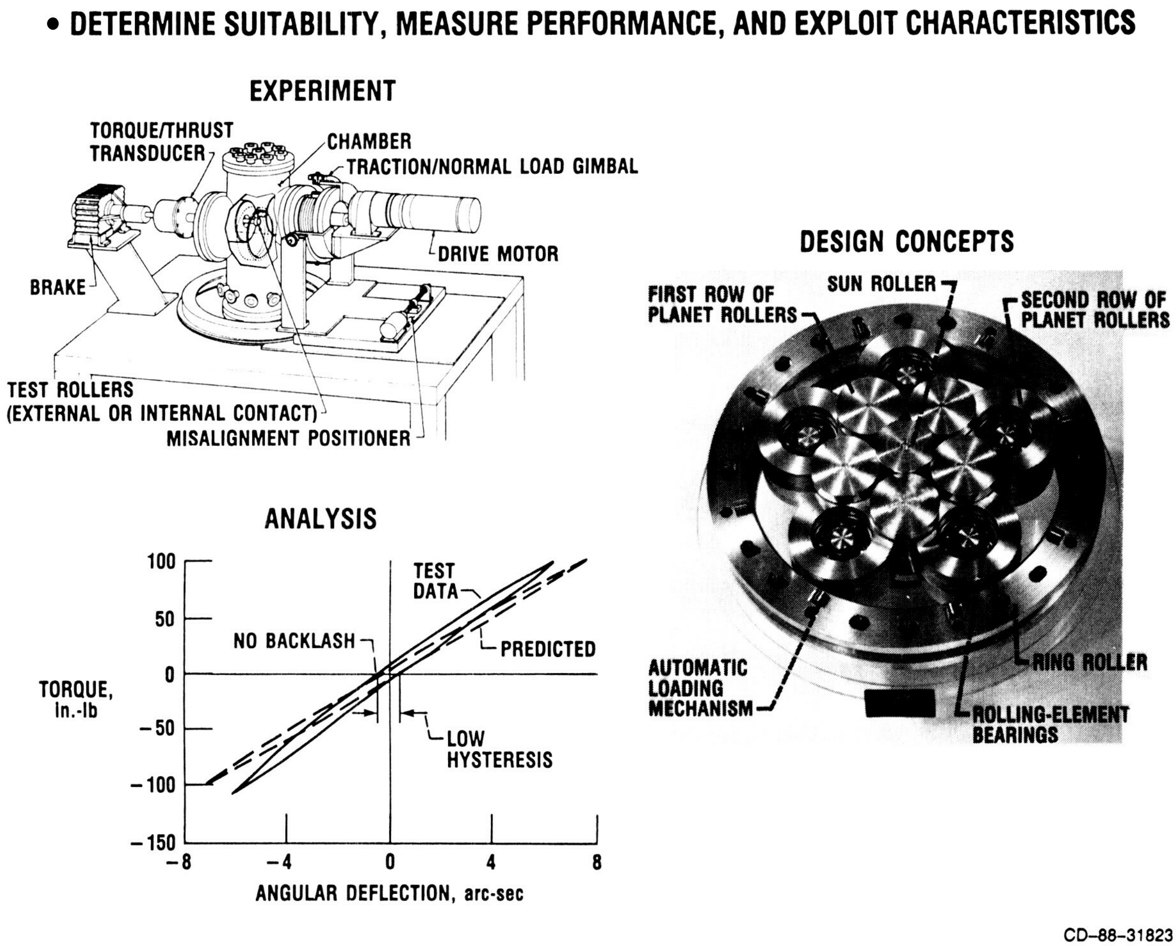
ROLLER DRIVE EVALUATION

The use of roller traction drives in mechanisms is a key part of this investigation. Rig tests are being used to determine lubrication suitability in a vacuum, or other experimental atmospheres, contact forces required, and fineness of control. Design studies are analyzing traction drive concepts for use in the full range from individual experiment mechanisms to robotic manipulation systems. Methods that compensate for momentum and dynamic reactions, which also exploit traction drives' unique smooth operation for motion control, will be incorporated.



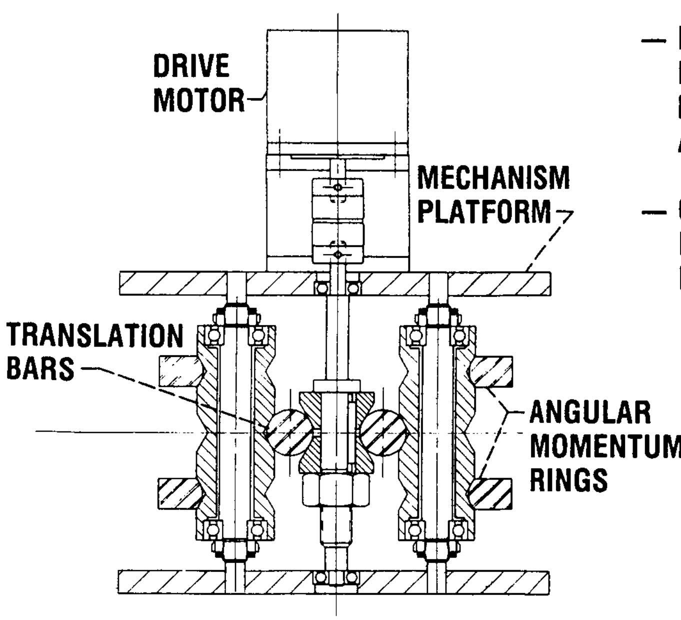
REACTIONLESS MECHANISM TECHNOLOGY

A single-degree-of-freedom roller-driven translating device is being studied as a reactionless mechanism. This mechanism is representative of linear motion devices that may be required to translate a heating element or a cooling manifold in an experiment requiring a rapid quench.

An example is the rapid solidification of molten materials, where a sample must be rapidly cooled while it remains in a microgravity environment. To pull it out of a furnace and place it in a quenching chamber would obviously cause accelerations to be placed on the sample. An alternative is to move the furnace out of the way and quickly bring a quenching block in its place while the sample is motionless. This requires a mechanism that can translate the equipment without allowing reaction forces to be transmitted back into the support structure and thus show up as accelerations.

Other reactionless concepts and techniques will be evaluated and developed for more specific applications.

- **DEVELOP TECHNIQUES FOR SMOOTH, REACTIONLESS, RAPID MOTION FOR MICROGRAVITY EXPERIMENTS REQUIRING INTERNAL MOTION**



— LINEAR ROLLER DRIVE DESIGNED FOR NOMINAL MOTION (MASS, SPEED, AND DISTANCE)

— CONCEPTS, TECHNIQUES, AND PROTOTYPES WILL BE STUDIED FOR SPECIFIC APPLICATIONS

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DYNAMIC ANALYSIS AND OPTIMIZATION

Kinematic and dynamic analyses are being developed to model reaction compensation techniques useful in mechanisms such as translators and multiple-degree-of-freedom systems. Emphasis has been placed on the control of reaction forces through the novel use of redundant degrees of freedom for momentum compensation and on other mechanical compensation devices.

Although much of the program involves hardware issues, we are also studying optimization techniques, reaction-force minimization strategies, and actuator controls that exploit hardware capabilities. A portion of this work will be presented separately in this symposium.

- **DEVELOP STRATEGIES FOR MINIMIZING DYNAMIC BASE REACTIONS AND END-EFFECTOR ACCELERATIONS**
  - **KINEMATIC/DYNAMIC MODELING**
  - **REACTION MINIMIZATION STRATEGY**
  - **TRAJECTORY OPTIMIZATION**
  - **JOINT ACTUATOR DYNAMICS AND CONTROL**

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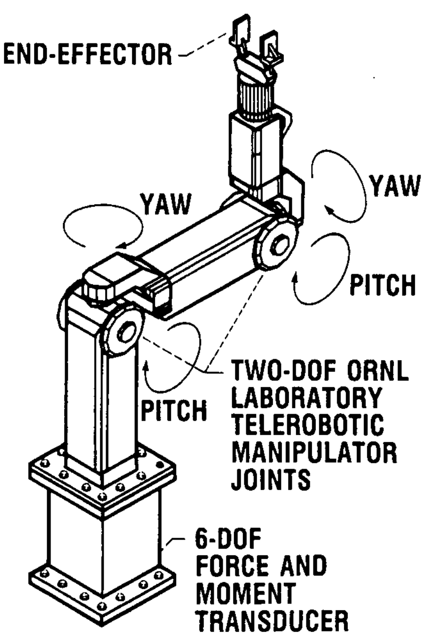
MULTI-DOF "MICROGRAVITY" MANIPULATION EXPERIMENTS

A multiple-degree-of-freedom (DOF) experimental test bed is being developed in order to study how structural dynamics, reaction compensation, and low-acceleration handling analyses interact with manipulator flexibility, roller joint dynamics, actuator control, and end-effector accuracy phenomena. The overall objective is to physically develop, demonstrate, and evaluate models, strategies, and mechanisms for manipulation in a microgravity laboratory. The first phase of this activity, involving reaction compensation and Oak Ridge National Laboratory (ORNL)-designed two-DOF roller-driven joints, is the subject of a poster presentation in this symposium.

Conceptual development on an advanced test bed includes consideration of low-acceleration handling, structural interactions, and actuator and end-effector research. Technology developed here and throughout the program will be channeled into future microgravity robot system definition.

- **DEVELOP, DEMONSTRATE, AND EVALUATE DRIVE MECHANISMS, OPTIMIZATION STRATEGIES, AND CONTROL MODELS FOR MANIPULATION IN A MICROGRAVITY LABORATORY**



- **REACTION COMPENSATION**
- **LOW-ACCELERATION HANDLING**
- **DYNAMIC/STRUCTURAL INTERACTIONS; VIBRATION**
- **ACTUATOR TECHNOLOGY**
- **END-EFFECTORS**
- **PRECISION AND ACCURACY**
- **MICROGRAVITY SYSTEM DEFINITION**

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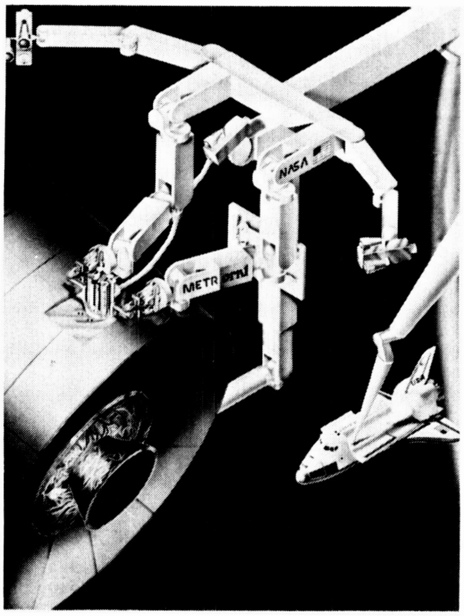
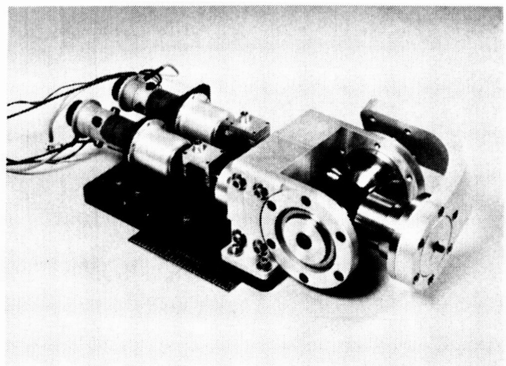
Much of the technology developed in this program can be used in other mechanism and robotics programs, particularly the telerobotics technology research at NASA Langley and the telerobotics development for space station use at NASA Goddard. ORNL, under NASA Langley sponsorship, has developed a space telerobot concept and tested baseline joints that take advantage of the roller drive's stiffness and lack of torque ripple and particularly of its zero backlash. The pitch/yaw joint was designed by ORNL using Lewis-developed roller traction drive technology and will be used in this program's manipulation experiments.



OAK RIDGE NATIONAL LABORATORY'S SPACE TELEROBOT CONCEPT



BENCH-TEST PITCH/YAW JOINT BASELINED WITH ROLLER DRIVE DIFFERENTIAL

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MICROGRAVITY MECHANISMS AND ROBOTICS TECHNOLOGY

The primary goal of this program is to produce the motion control tools necessary to enhance and enable a particular NASA mission: space-laboratory-based microgravity experiments. To that end, a spectrum of technology is being and will be produced that is focused in the disciplines of precision mechanisms and robotics. This core technology will be applicable to future mechanism and robotics efforts in the Lewis Research Center's Structures Division.

RATIONALE:

- **RESPOND TO MICROGRAVITY EXPERIMENT NEEDS**

APPROACH:

- **APPLY STRUCTURAL, MECHANICAL, AND SYSTEMS TECHNOLOGIES**

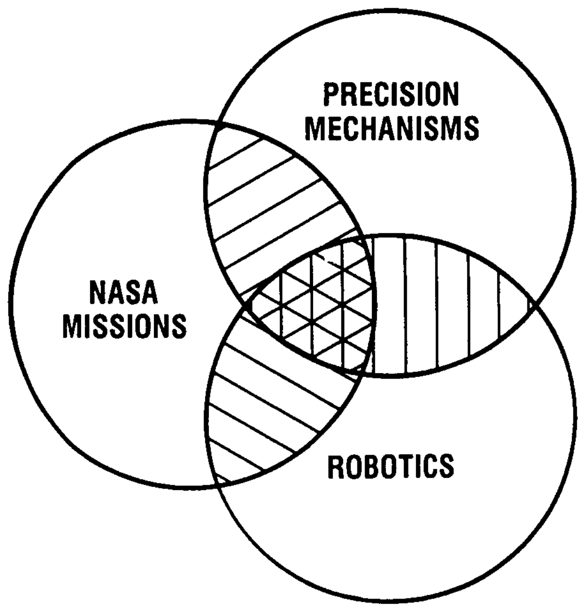
GOAL:

- **DEVELOP TECHNOLOGY**

FUTURE:

- **SPIN OFF TO MECHANISM AND ROBOTIC NEEDS IN OTHER NASA SPACE MISSIONS**

FOCUS:



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