MIT
Space
Engineering
Research
Center

THE MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)

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1991 Summer Symposium

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THE MODE FAMILY OF EXPERIMENTS

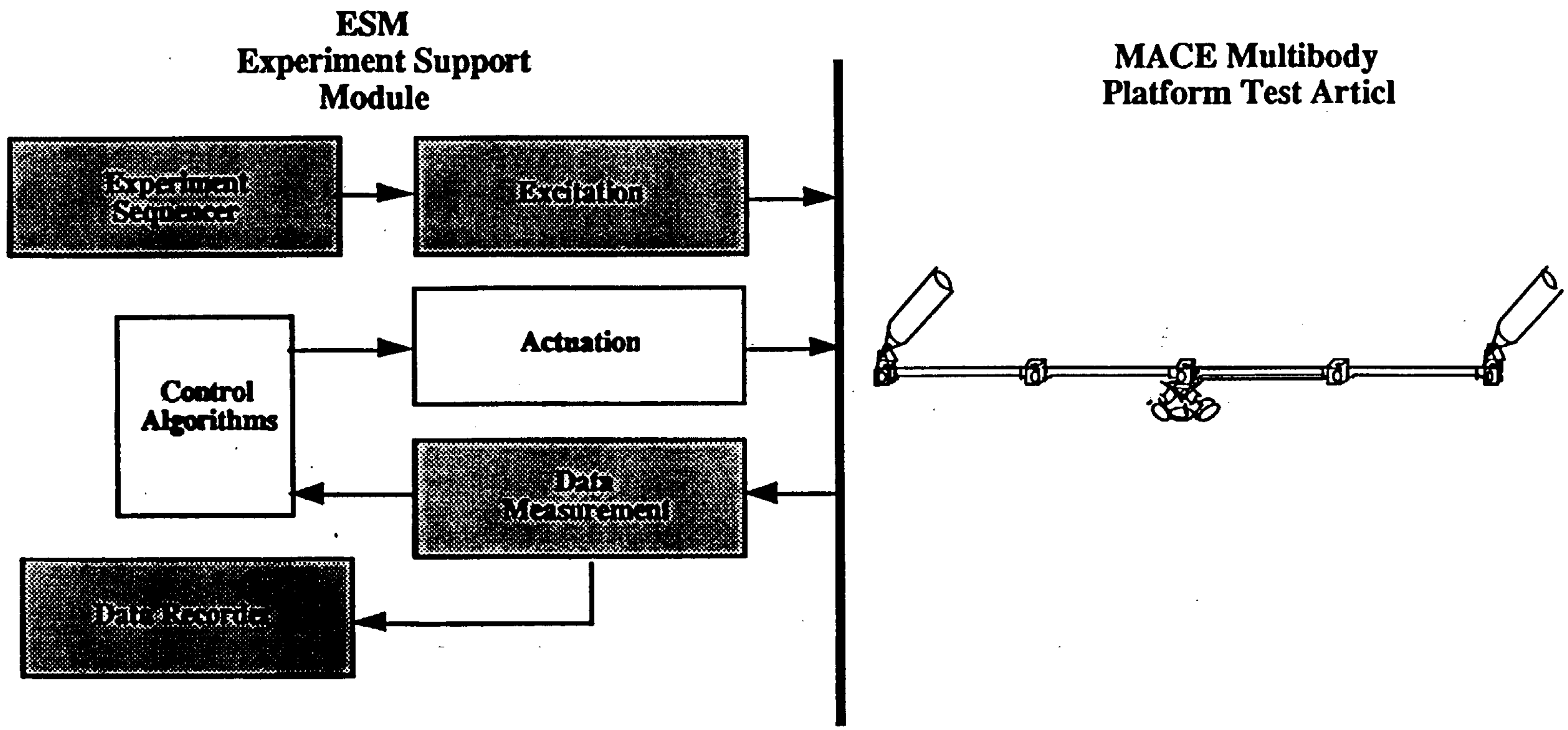
Fluid Test Article (FTA)	Structural Test Article (STA)	MACE Test Article
Coupled Non-Linear Dynamics of Fluids and Structures in Zero Gravity	Non-Linear Dynamics of Jointed Truss Structures in Zero Gravity	Influence of Gravity on the Active Control of a Multibody Platform

Flight # 1:
September 1991

Flight # 2:
June 1994

MACE is part of a logical sequence of cost-effective flight experiments designed to advance technology of interest to NASA in the area of controlled structures.

THE MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)



- Substantial commonality of ESM hardware/software
- Significant savings in integration/certification process.

TEAM: PARTICIPATING ORGANIZATIONS

Organization	Roles
MIT Space Engineering Research Center	Science, Modelling, EM Fabrication
Payload Systems Inc.	Exp. Support, Flight Hardware Fab., Integration
Lockheed Missiles and Space Co.	Science, Modelling, EM Fabrication
Sonitech International	DSP Development
MIT Center for Space Research	Financial Oversight

OBJECTIVES AND RATIONALE

Objective: To develop a well verified set of CST tools that will allow designers of future CST spacecraft, which cannot be dynamically tested on the ground in a sufficiently realistic on-orbit simulation, to have confidence in the eventual orbital performance of such spacecraft.

- Since the model fidelity required for stability and performance robustness is intimately related to the level of applied control authority, closed-loop testing is required.
- Vehicle qualification testing will most likely occur on the ground where suspension and direct gravity effects will cause the 1-g and 0-g dynamics to differ.
- Differences between the ground and on-orbit environment cause perturbations which can substantially alter closed-loop behavior.
- Therefore it is essential to perform on-orbit closed-loop testing for comparison with ground testing and analytical predictions to develop these tools.

MACE SCIENCE REQUIREMENTS

The test article must be representative of a mission or vehicle architecture so that the developed technology has clear application.

- The test article must be representative of expected near-term missions.
- The test article geometry, performance metric and disturbances must be representative of expected near term missions.
- Improvement in the performance must be representative of that predicted for CST spacecraft under sensor, actuator and processor dynamic range constraints. Assuming unstaged actuator dynamic range to be 40 db and sensor dynamic range to be 60 db, a performance improvement of 40 db is required.

MACE SCIENCE REQUIREMENTS

The test article must exhibit differences in its dynamic behavior between ground based and on-orbit testing.

- The test article must be difficult to test on the ground because of the effect of gravity and suspension on its flexibility.
- Detailed modeling of gravity and suspension effects on the test article flexibility is required to properly predict closed-loop behavior on the ground.
- At a 20 db performance level, gravity/suspension effects on flexibility will distinguish closed-loop behavior between ground and on-orbit tests when the same active controller is applied.
- The test article must have a performance improvement in the selected performance metric of a minimum of 20 db which must be verified by experiment on the ground.

MACE SCIENCE REQUIREMENTS

A comprehensive series of coherent ground and on-orbit tests must be performed which identify current limitations and develop plausible alternative approaches.

- Control algorithms will be implemented on orbit which are identical to those implemented on the ground. These tests identify current limitations.
- Control algorithms will be implemented on orbit which are derived from the ground model with suspension and gravity effects removed. These tests identify predictive ability.
- Control algorithms will be implemented on orbit which are derived from on-orbit dynamic test data. These test identify the ability to fine tune the control once on orbit.

CAPTURING THE ESSENTIAL PHYSICS: TEST ARTICLE REQUIREMENTS

The simulation of a vehicle with payloads and articulating appendages with pointing and positioning requirements, necessitates a test article with the following attributes:

- appropriately scaled to fit in the middeck while preserving the essential performance requirements.
- two gimballing payloads to enable implementation of multiple interacting control systems with independent objectives.
- two rigid payloads and a flexible appendage, representative of compact high mass fraction devices and a robotic servicer.
- flexible bus with resonances within the controller bandwidth and to exhibit suspension coupling, gravity stiffening and droop.
- sufficiently complex geometry such that the test article undergoes full 3-D kinematic and coupled flexible motion.

SCIENCE DEVELOPMENT APPROACH: CONTROL OBJECTIVES

Control Objectives:

- **Pointing** performance of single and multiple payloads.
- **Scanning** performance of single and multiple payloads.

Performance Metrics:

- **Stability**--RMS 2-axis angular position about pointing line of sight or scanning reference profile.
- **Jitter**--RMS 2-axis angular rate about pointing line of sight or scanning reference profile.
- **Slew response time**--time required to complete maneuver.
- **Percent degradation**--reduction from single payload performance associated with addition of an interacting, controlled payload.

SCIENCE DEVELOPMENT APPROACH: GRAVITY INFLUENCES

Objective: Identify and quantify the magnitude of the perturbation effects of a gravity field and a suspension system on the dynamics of a suspended test article.

GRAVITY FIELD EFFECTS	SUSPENSION SYSTEM EFFECTS
1) GRAVITY STIFFENING/DESTIFFENING • changes in membrane energy due to small deformations and loading of the structure can be modelled as system stiffness perturbations. **2) FINITE DEFLECTIONS** • finite deflections require a redefinition of the reference structure; stiffness modifications do not capture the perturbation to the eigenstructure.	**3) STATIC B. C. PERTURBATIONS** • static translational stiffnesses in the horizontal and vertical directions are prescribed by the suspension system at each attachment point. **4) DYNAMIC B.C. PERTURBATIONS** • modal coupling with the suspension dynamic modes results in dynamic impedances at the attachment points.
5) DYNAMIC LOADING DUE TO GRAVITY FIELD AND SUSPENSION CONSTRAINTS • dynamic torques which result from center of mass axis offsets with respect to the suspension support plane(s).	

HARDWARE DEVELOPMENT

- Three sets of hardware are being developed under the MACE program:

    The Development Model for science development
    The Engineering Model for prototyping flight hardware
    The Flight Hardware for actual flight

- The purpose of the Development Model is to develop the science associated with the MACE program by validating theory through experimental implementation.

- The purpose of the Engineering Model is to attempt to redesign the DM and its support equipment to operate within the constraints of the STS middeck.

- The purpose of the Flight Hardware is to provide one unit for crew training and spare parts and one unit for flight.

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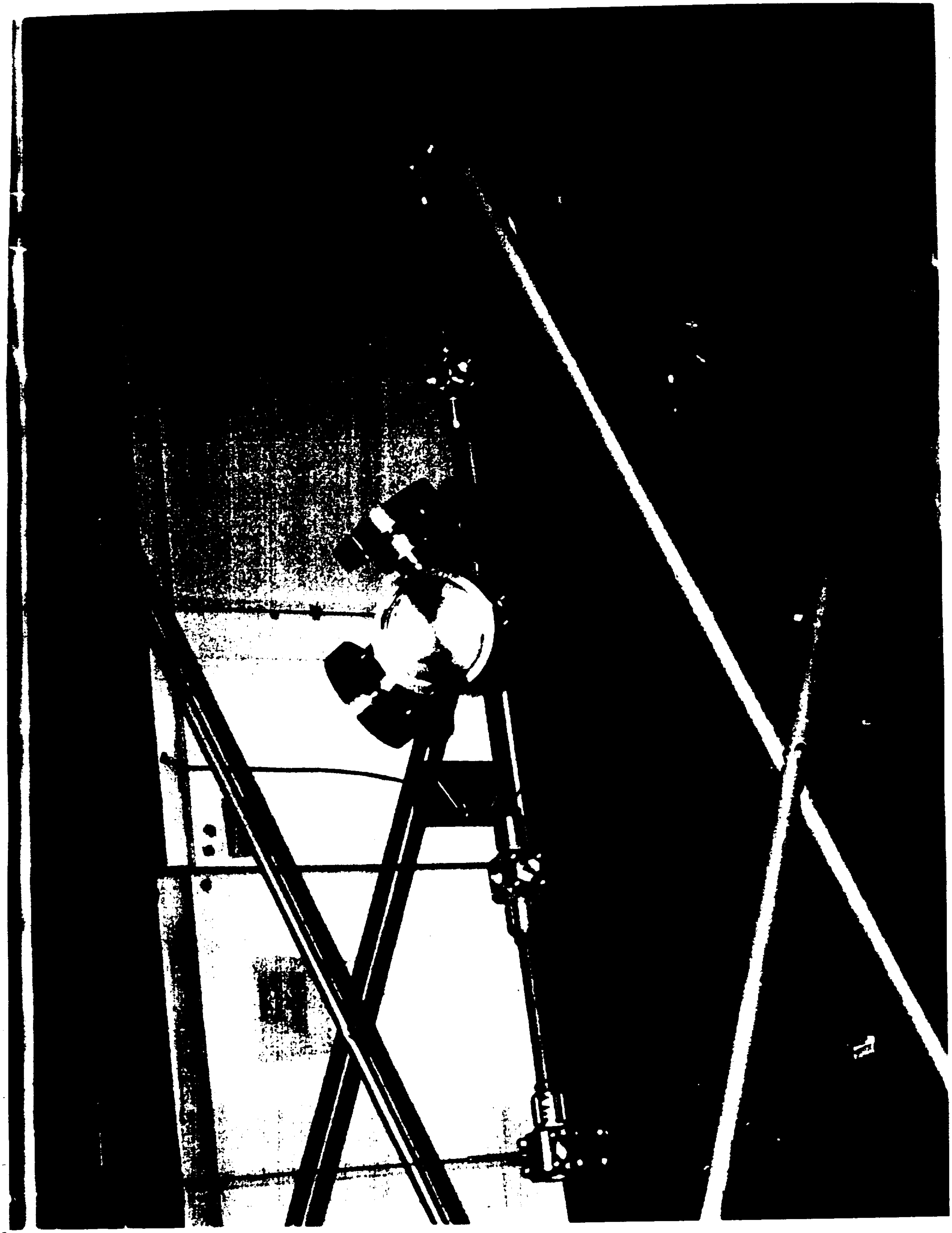

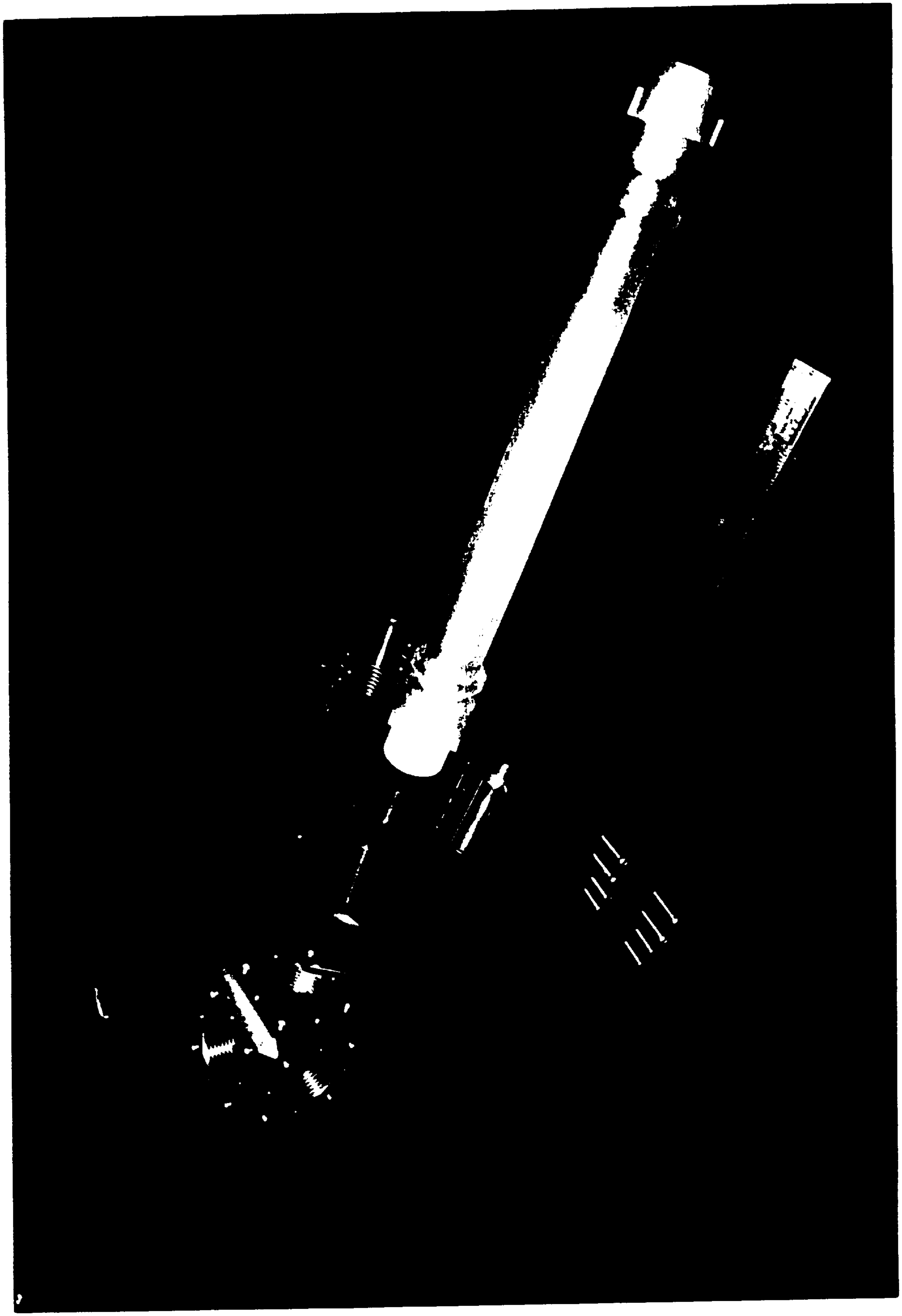

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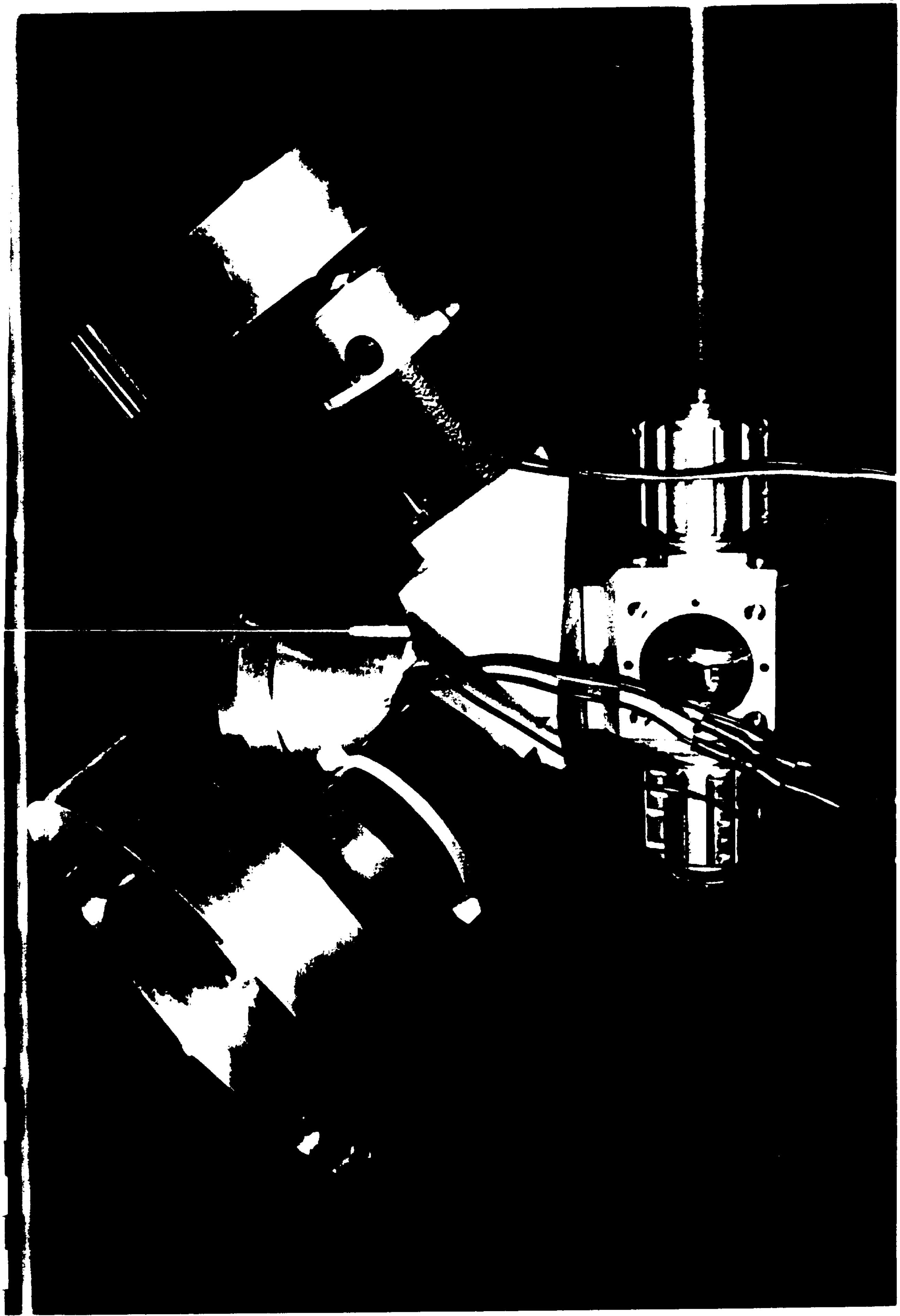
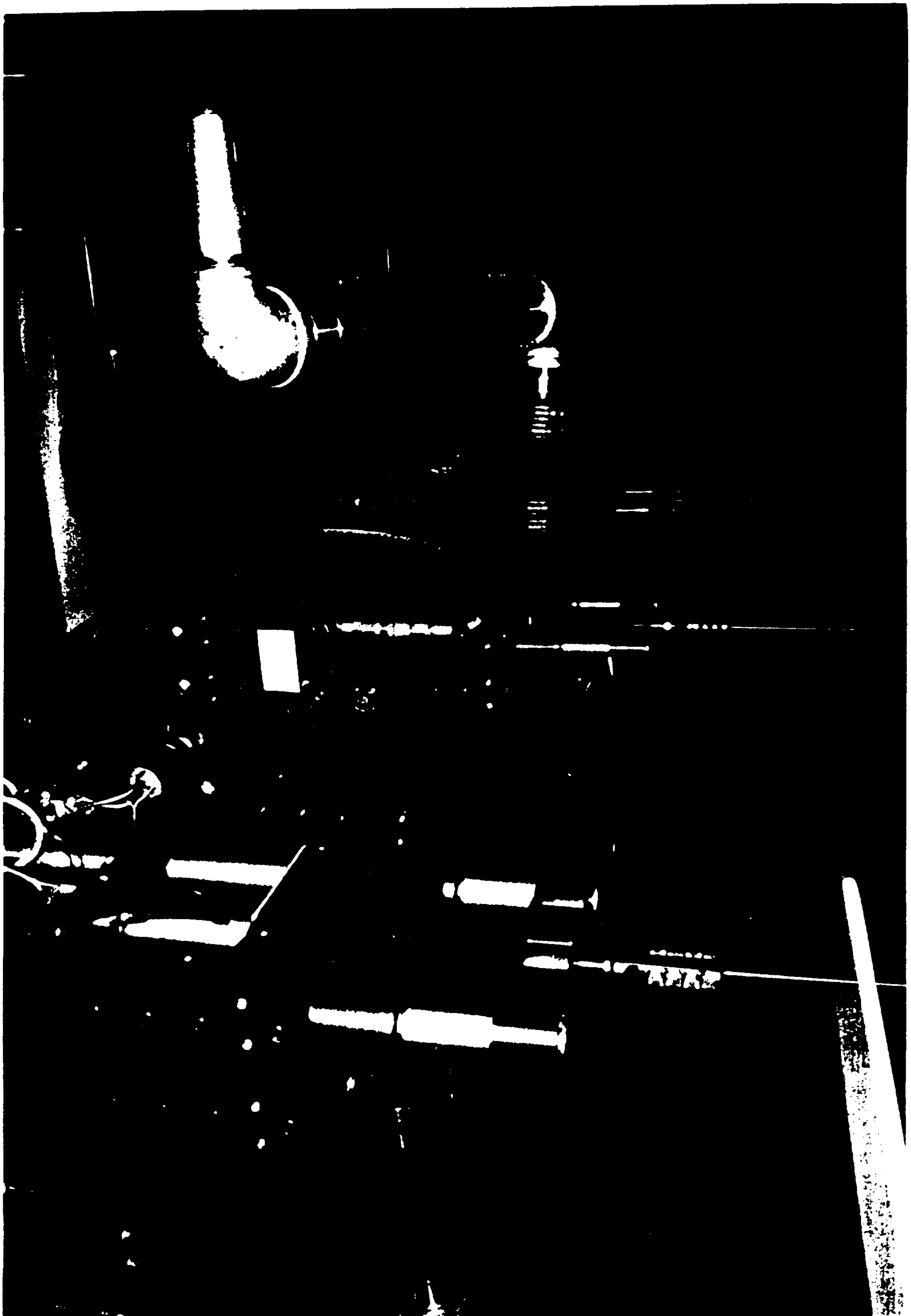
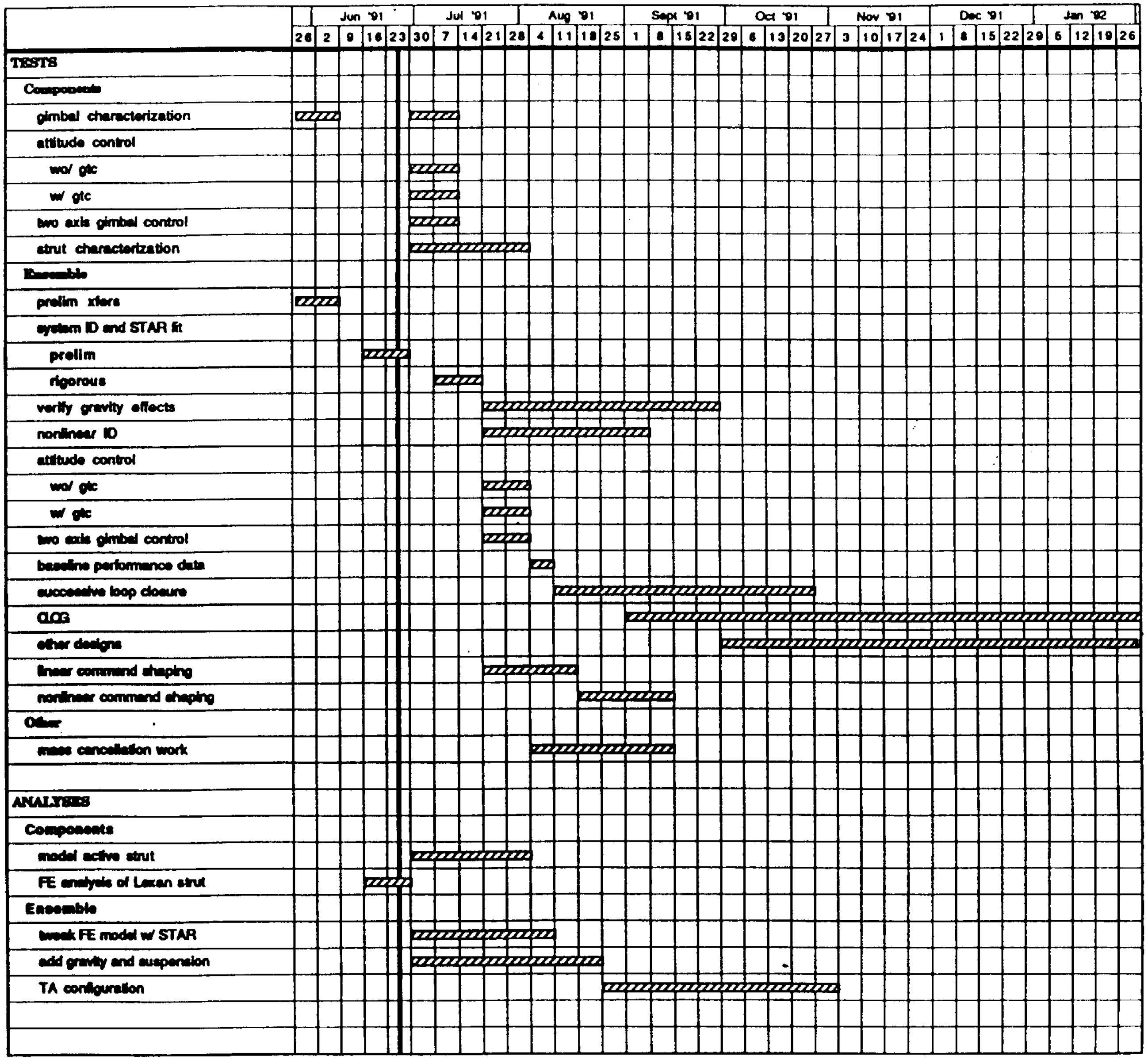
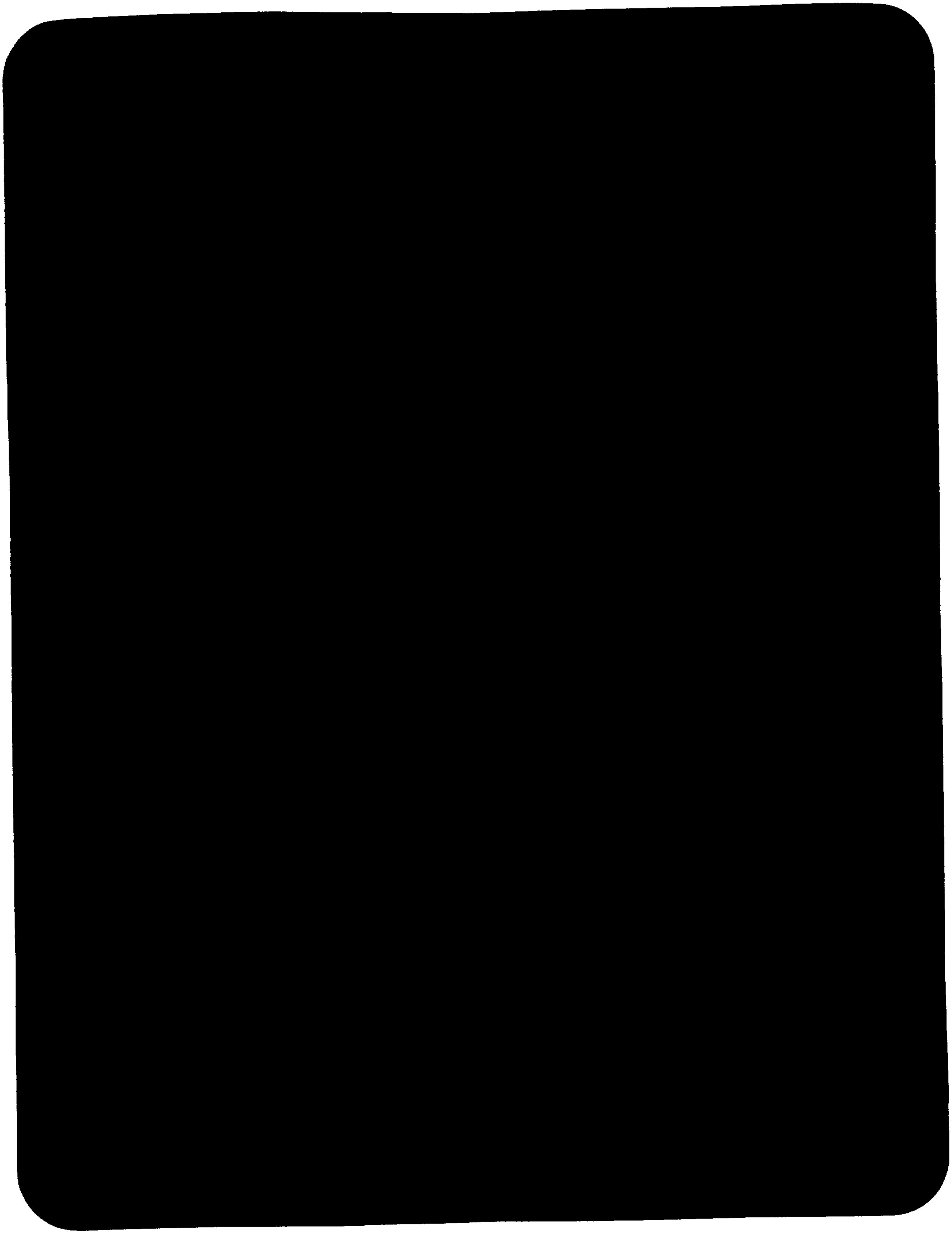


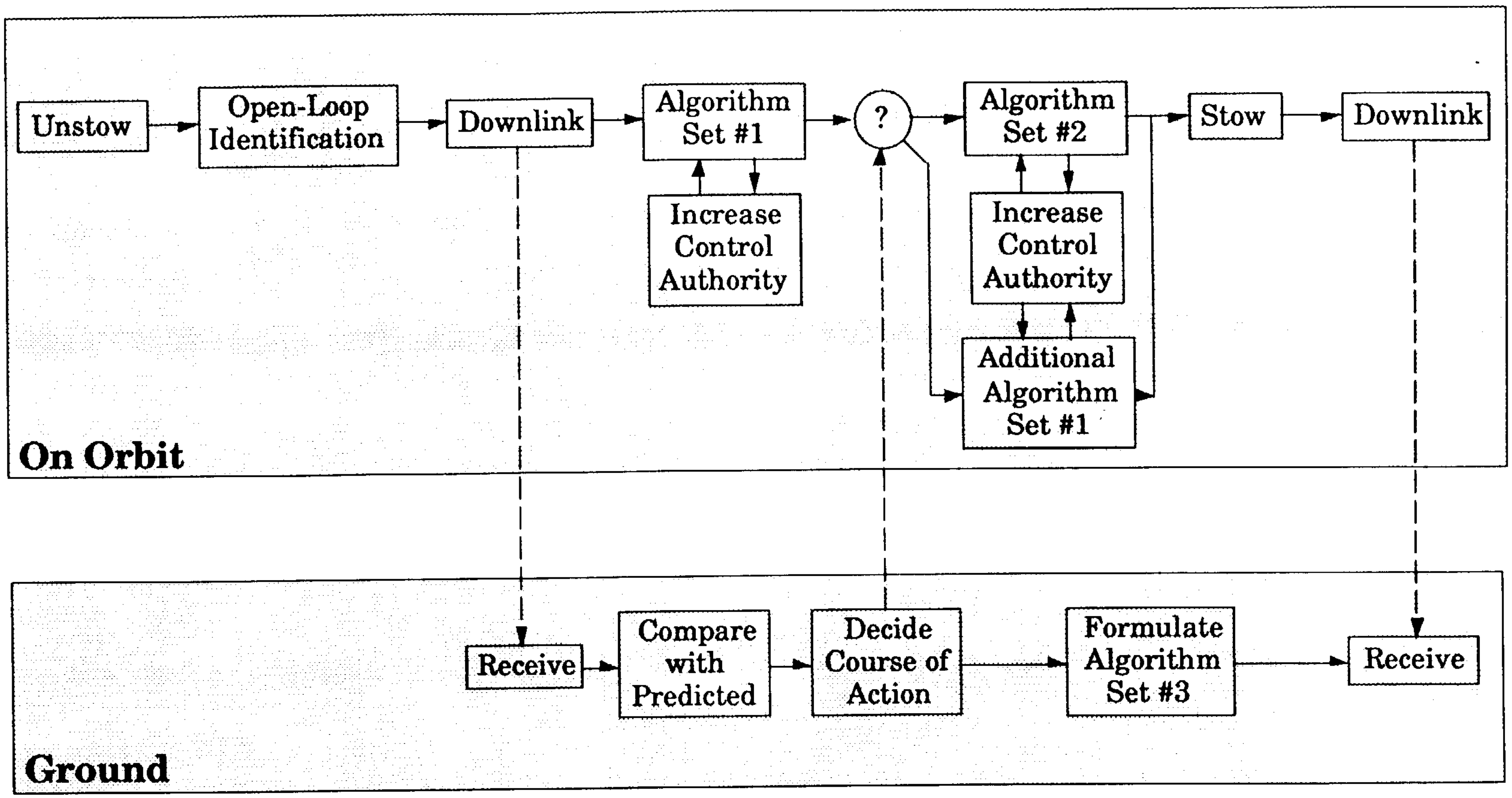


DEVELOPMENT MODEL TEST PLAN





EXPERIMENT OPERATIONS: DAY ONE



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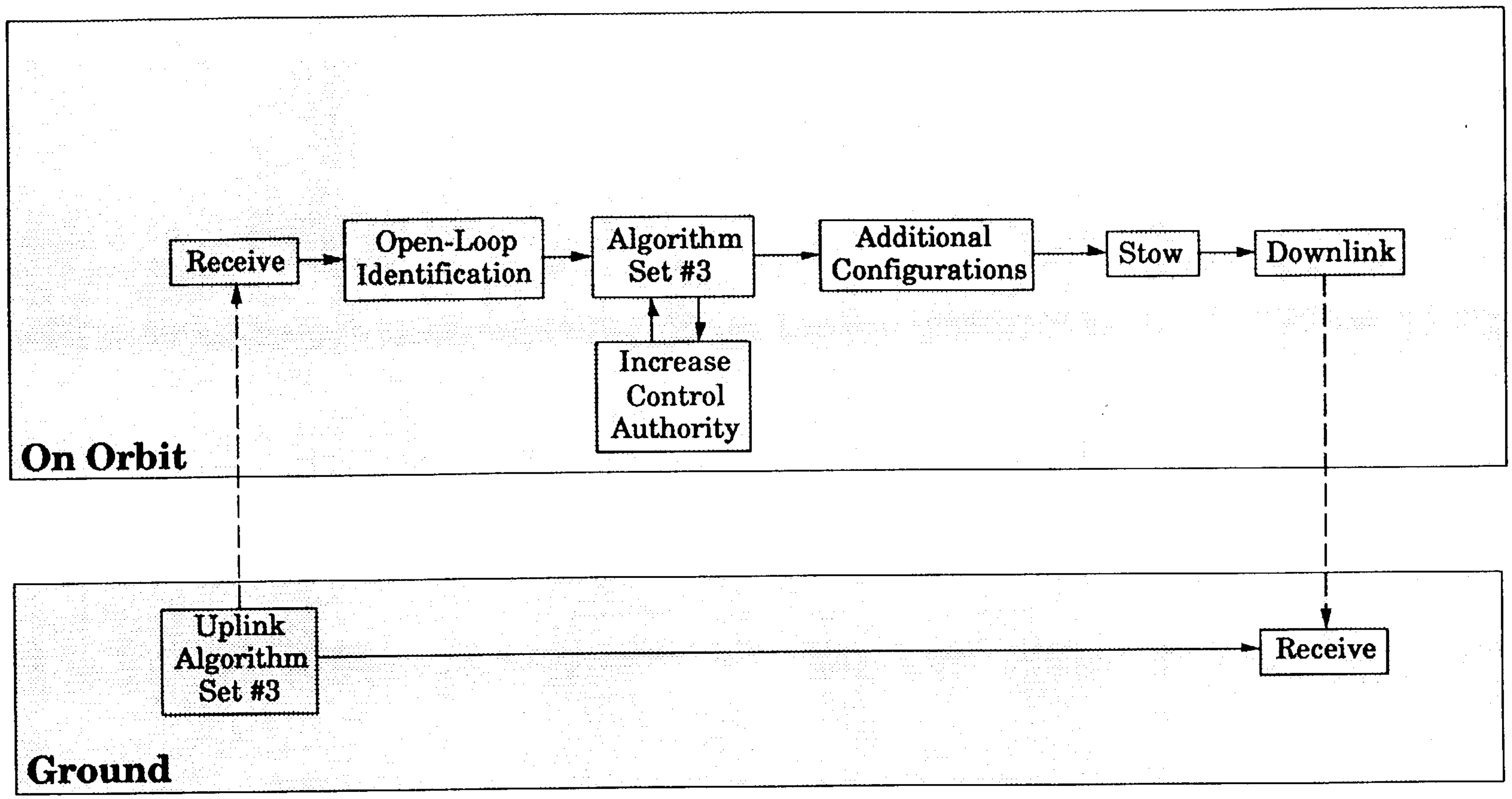
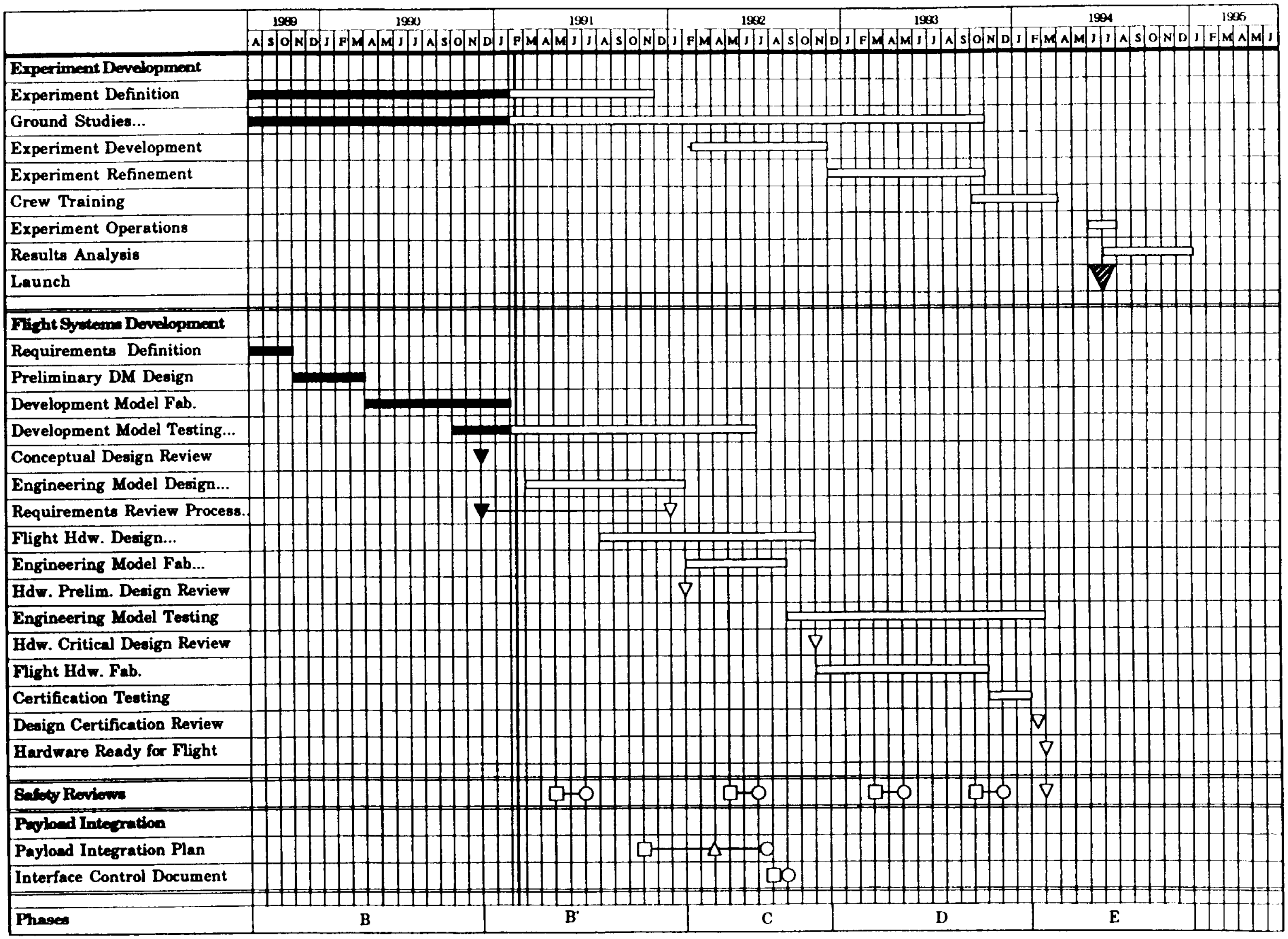


SCHEDULE: EXPERIMENT DEVELOPMENT



SUMMARY

- The MODE family of flight experiments is designed to verify analytical tools developed to predict the gravity dependent behavior of proposed space structures.
- The MODE family of flight experiments uses reusable dynamic and control tests facilities and exploits the unique environment on the STS middeck.
- MACE investigates gravity dependent phenomena pertinent to the closed-loop dynamics of proposed space structures.
    - By comparing performance as a function of control authority between ground and on-orbit testing, perturbations in the dynamics due to the change from 1 to 0-g will be identified.
    - By noting the level of control authority where these performance deviations occur, either analytical predictive capabilities or on-orbit identification procedures can be refined.
- The MACE program consists of a strong consortium of university, government and industry to develop a CST flight experiment which is technically relevant, mission relevant and cost effective.