Large Space Platform Control Avionics Considerations

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GENERAL DYNAMICS
Convair Division

(Figure 1)

General Dynamics/Convair is an active participant in the conceptualization, design and development of several large space programs as shown on the facing page. During the course of this work we have identified a number of areas requiring technology efforts. This presentation identifies some of these areas associated with the avionics-oriented technologies required for design, and operation of many of these large spacecraft.

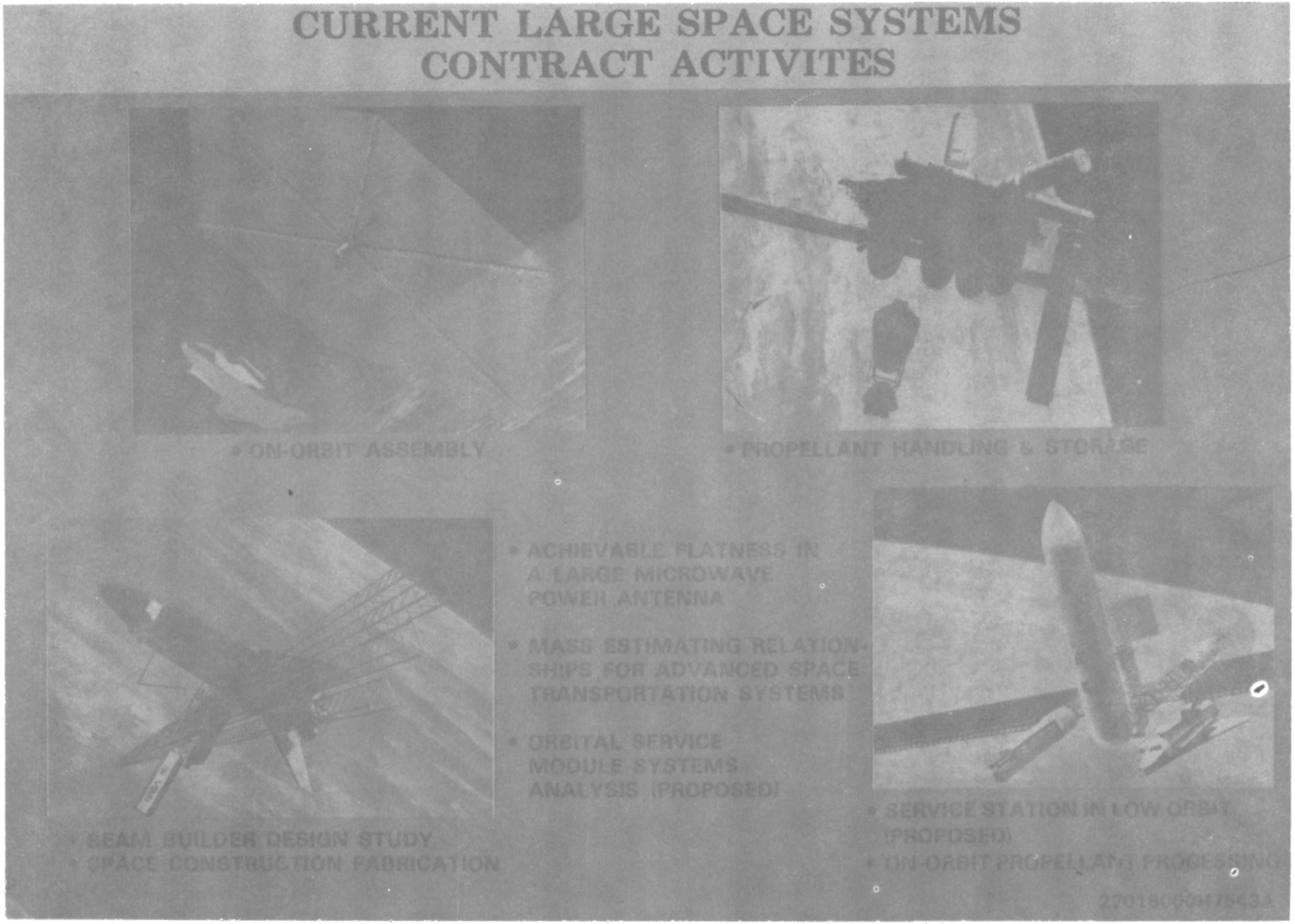

CURRENT LARGE SPACE SYSTEMS
CONTRACT ACTIVITES
• ON-ORBIT ASSEMBLY
• PROPELLANT HANDLING & STORAGE
• ACHIEVABLE FLATNESS IN A LARGE MICROWAVE POWER ANTENNA
• MASS ESTIMATING RELATIONSHIPS FOR ADVANCED SPACE TRANSPORTATION SYSTEMS
• ORBITAL SERVICE MODULE SYSTEMS ANALYSIS (PROPOSED)
• BEAM BUILDER DESIGN STUDY
• SPACE CONSTRUCTION FABRICATION
• SERVICE STATION IN LOW ORBIT (PROPOSED)
• ON-ORBIT PROPELLANT PROCESSING

Figure 1

(Figure 2)

A complete list of avionics areas recommended for advanced technology efforts would include:

a) Large structure control and stability analysis and prediction techniques.
b) Rendezvous and docking analysis and simulation tools.
c) Automated positioning and process control method.
d) Analysis of antenna/structural interrelationships, the development of analysis tools, and development of adaptive antenna systems.
e) Electrical power generation/conditioning/and distribution methods adapted for multi-kilowatt systems.
f) Increased emphasis on Orbiter payload support software development.
g) Development of common services accommodations for multiple LSS payload user systems. These would include data management, communications, pointing/stability, power and environmental conditioning functions.

A subset of areas have been selected for more detailed discussion at this time as indicated on the facing page figure. These subjects will be correlated with work being performed under a number of our present LSS Contracts including: OOA, SCAFE, and On-Orbit Propellant Handling.

LSS AVIONICS TECHNOLOGY AREAS

- SIMULATIONS
  - Control & stability
  - Rendezvous guidance
  - Docking
- ROBOTICS
  - Manipulator systems
  - Automated process control
- ANTENNA & STRUCTURAL INTERACTIONS
  - Stiffness vs RF interaction
  - Physical control vs adaptive electronics

Figure 2

(Figure 3)

Two characteristics of large spacecraft systems which differentiate them from conventional satellite systems are:

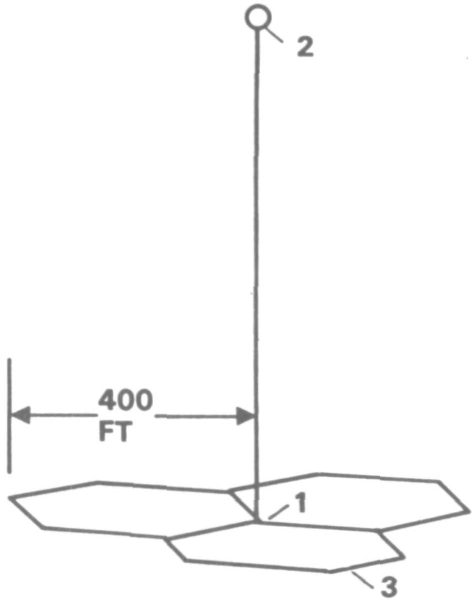
a) They will probably have a distributed avionics system in which a central data management system interfaces with and controls a number of remotely located functions for attitude control or sensing purposes.

b) They represent a class of spacecraft where, because of size or construction, their flexibility and low natural frequencies can interact with the attitude control system.

New techniques for control and stability must therefore be developed along with the analysis and behavior prediction tools to design the spacecraft and properly select its systems components.

The facing page figure shows sample results of one such simulation capability supporting LSS design efforts at General Dynamics/Convair. The spacecraft used in this example was three expandable tetrahedral rings joined together and attached to 1000 ft tower. Each ring is 400 ft by 346.5 ft, and attitude rate data is shown plotted about the roll axis for three widely separated spacecraft locations.

LSS CONTROL SIMULATIONS PREDICT LSS BEHAVIOR
(Dynamic Response to Attitude Control System On-Orbit at GEO)



Attitude & rate sensors & torquers located at middle of platform

Control frequency = 0.005 Hz

Structural damping = 0

Initial disturbance = 0.5 deg/sec

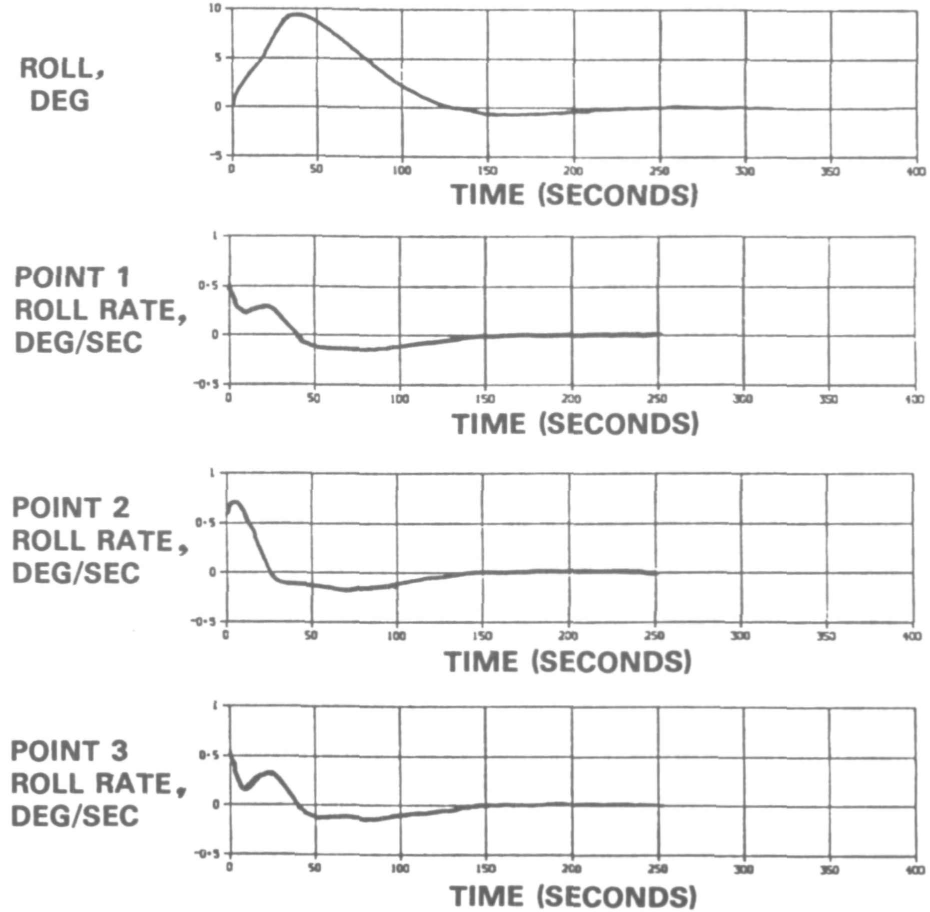


Figure 3

(Figure 4)

Operation or construction of many large space system concepts involves multiple visits by the Orbiter, LSS assembly, or other vehicles. A necessary tool in development of the avionics and propulsion systems to accomplish this function is a simulation of the Rendezvous guidance phase of the Rendezvous and Docking operation. Simulation output of rendezvous trajectories vs. initial position dispersion allow determination of avionic requirements and accuracy characteristics for rendezvous sensors, navigation,and attitude control subsystems.

RENDEZVOUS GUIDANCE SIMULATIONS

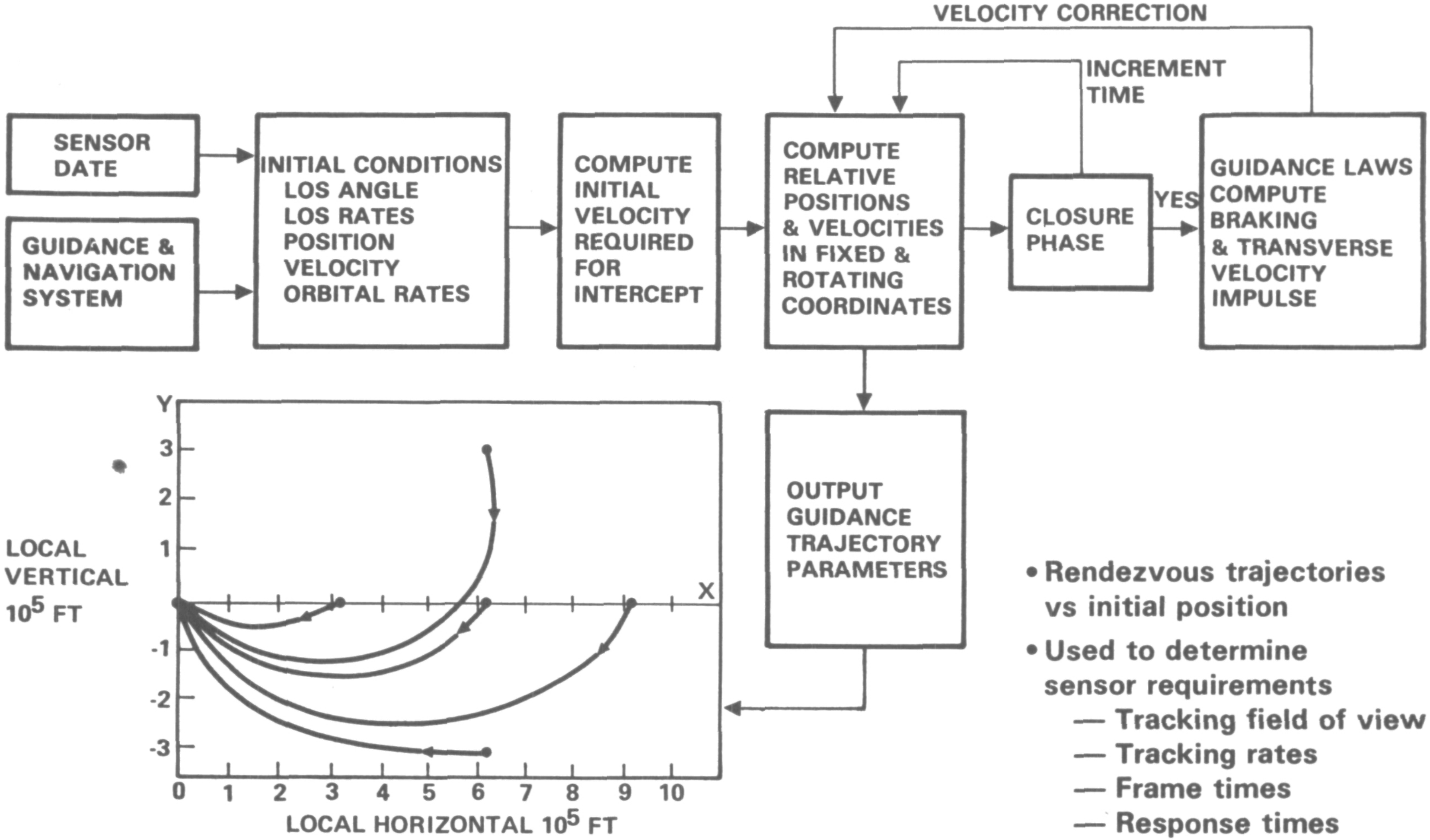


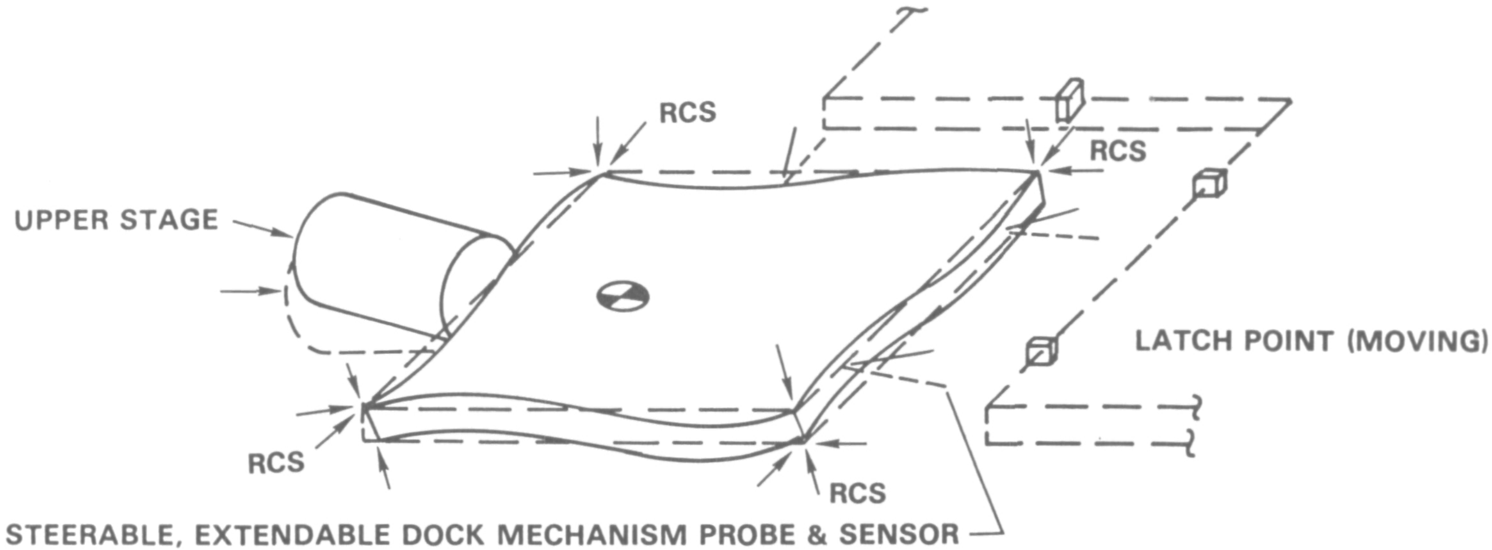
Figure 4

(Figure 5)

The second phase of the multiple visit operation associated with many large spacecraft systems under consideration involves terminal phase docking between one LSS and another or between a LSS and a service vehicle such as the Orbiter or orbit transfer vehicle. Unlike docking operations in previous space programs, LSS docking will likely be characterized by a) remote control, b) soft docking techniques and c) difficulties caused by flexible structure/attitude control interactions.

The figure illustrates this problem peculiar to remote assembly of two large highly flexible spacecraft modules. In this example, the chase/upper stage module is active while the primary or mother module is cooperative but essentially inactive. Simulations of these operations will allow determination of LSS subsystem requirements for docking operations including attitude control and stability functions, docking sensors, operational techniques and timing, and docking mechanisms. The effects of communication delays for control/monitoring purposes and vehicular dynamic interactions during latch-up may also be determined.

LARGE SPACECRAFT DOCKING



- Associated with many LSS operations
  - Orbiter-to-LSS docking
    - In-space assembly or servicing
- Characterized by
  - Remote control
  - Soft docking
  - Flexible structures

Figure 5

(Figure 6)

The figure on the opposite page shows the basic elements of a two body docking simulation involving large spacecraft systems. It takes into account the physical model (rigid and flexible body characteristics) of both chase and mothercraft, initial position and velocity conditions, docking sensor and autopilot models and the effects of environmental influences. The latter include forces due to solar wind, solar heating, gravity gradient, and magnetic torques. For the simulation shown, the chase craft is being maneuvered into a position, relative to the mother, suitable for docking. This chase attitude and translation position occur when all docking mechanisms are at their neutral position and ready to latch. This situation must be maintained, within control system limits, by chase RCS control while the docking mechanism latch point is steering into position and latched and despite RCS limit cycling, chase flexure and mothercraft motion.

Just after latch the simulation dynamic situation significantly changes. Contact forces are applied between modules and can cause control problems. Presently we envision turn-off of the chase autopilot for neutralization of docking mechanism forces with the mother still under its autopilot control as an appropriate control system concept for post-latch.

DOCKING SIMULATION BLOCK DIAGRAM

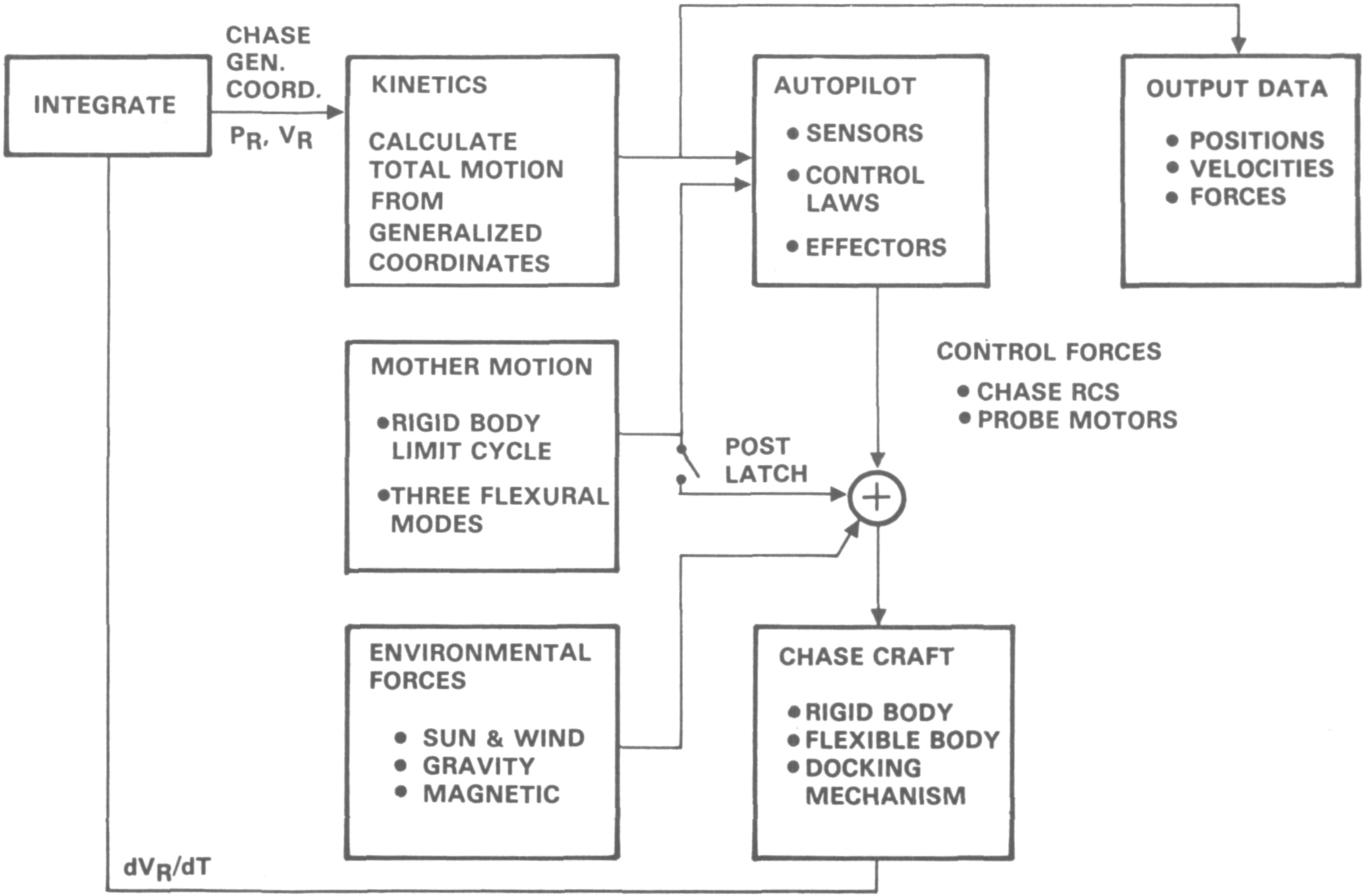


Figure 6

(Figure 7)

The baseline Space Construction Automated Fabrication Experiment (SCAFE) system is shown in the illustration. It represents a major step in utilization of space as a working environment, and demonstrates one technique for implementing Large Space Structures. In this technique automated fabrication/assembly systems and prepackaged raw materials are delivered by Shuttle to the construction circular orbit at 300 nautical miles (556 km).

Upon system deployment from the stowed position, a beam builder, moving to successive positions along a Shuttle-attached assembly jig, automatically fabricates four triangular beams, each 200 meters long. Retention and manipulation of the completed beams is provided by the assembly jig.

The beam builder then moves to the position shown and fabricates the first of nine shorter, but otherwise identical, crossbeams. After crossbeam attachment, the partially completed assembly is automatically transported across the face of the assembly jig to the next crossbeam location, where another crossbeam is fabricated and installed. This process repeats until the "ladder" platform assembly is complete. During this process an opportunity to develop/evaluate EVA is provided by the difficult-to-automate task of sensor/equipment attachment, as shown.

SPACE CONSTRUCTION AUTOMATED FABRICATION EXPERIMENT DEFINITION STUDY (SCAFEDS)

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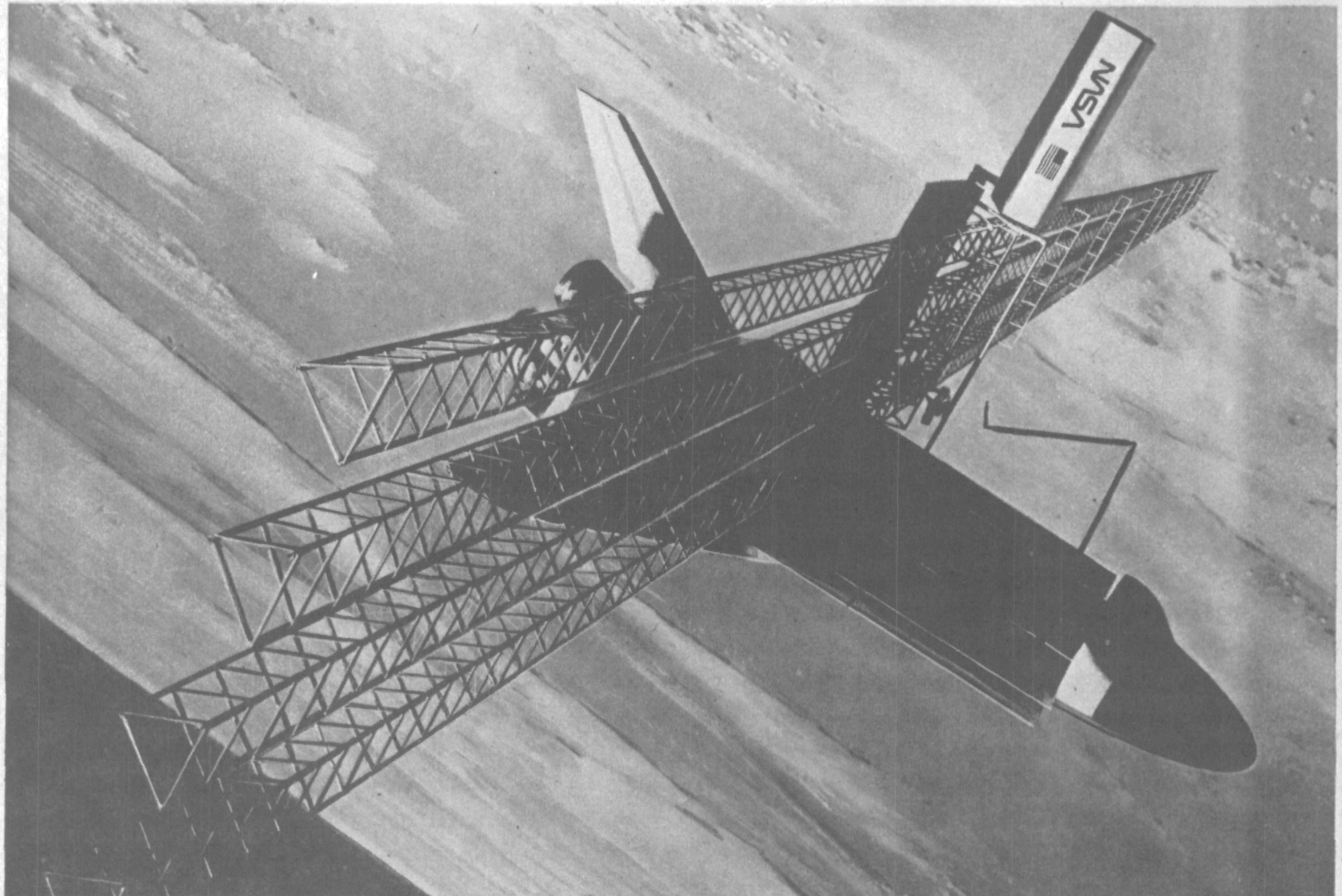

Figure 7

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(Figure 8)

This conceptual drawing serves to illustrate the arrangement and function of the selected beam builder configuration. Automated beam builder machine functions under the executive control of the Orbiter crew and major configuration features are summarized as follows:

Machine Operations

- Storage - Flat continuous strips wound in rolls, cord wound on spools, cross members preformed and precut and stored in clip feed mechanism.
- Heating - Electrical resistance wire reflective strip heaters.
- Forming - Rolltrusion.
- Cooling - Fluid cooled platens.
- Drive - Friction roller drive.
- Cross member Positioner - swing arm, single drive.
- Cord Positioning and Pretensioning - Reciprocating cord plyers on reversing screws with constant force tensioning mechanisms.
- Joining - Ultrasonic spot weld head.
- Cutoff - Shears.

SCAFEDS BEAM BUILDER CONCEPT

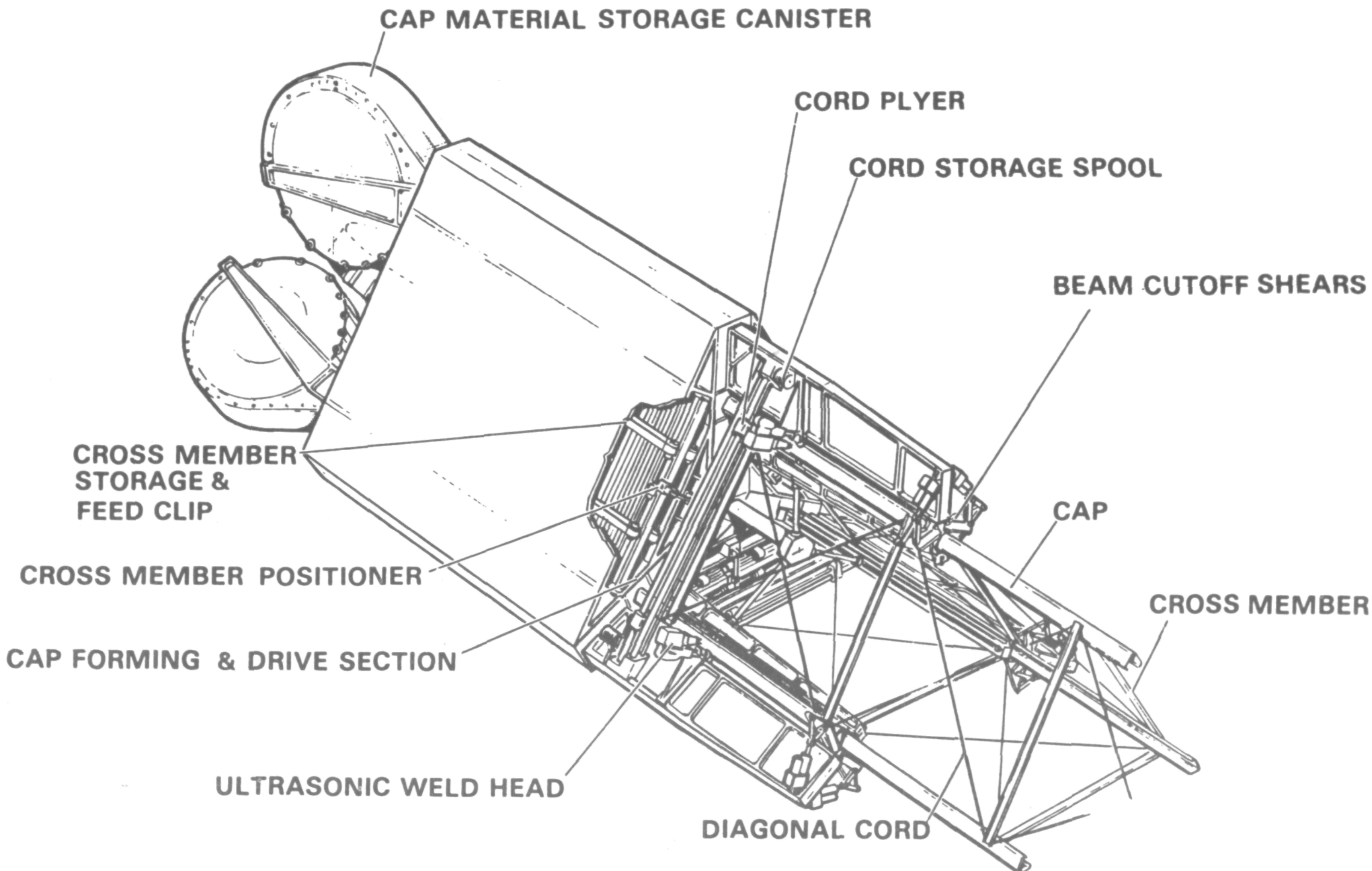


Figure 8

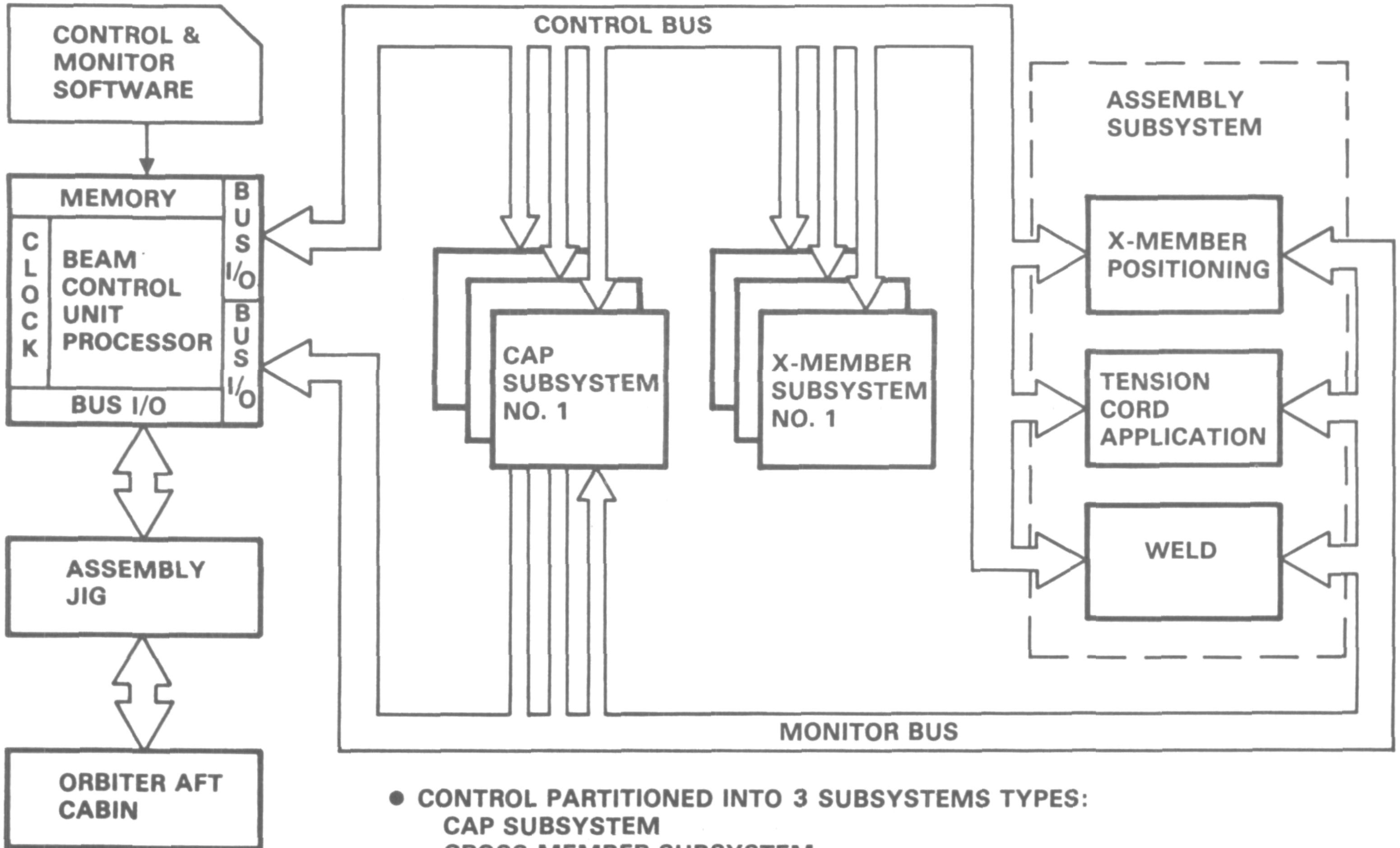
(Figure 9)

The beam builder control and monitor system is housed within the beam builder machine and provides the real-time process control operations to fabricate beam elements to the correct length and straightness.

This system is made up four major subsystem functions as shown in the figure. These are the: (1) beam control unit, (2) cap fabrication subsystem, (3) cross member positioning subsystem, and (4) beam fabrication subsystems. The Beam Control Unit (BCU) performs overall control and monitoring of beam builder operations and contains a microprocessor with interval timer, approximately 4K of memory and input-output interfaces to the assembly jig and the three fabrication control systems. It receives executive control from the Orbiter crew via the Orbiter MDM/data bus interface located on the assembly jig and provides status data back to the crew.

The cap subsystems contain those motors/actuator controls and sensors necessary to control fabrication of the three cap member sections. The cross member subsystems contain the motor/actuator control and sensors to remove the preformed cross members from the storage clips, and position them for final assembly, apply the tension cords and finally to weld the beam components together into one integral bay length unit.

BASELINE BEAM BUILDER CONTROL SYSTEM



- CONTROL PARTITIONED INTO 3 SUBSYSTEMS TYPES:
  - CAP SUBSYSTEM
  - CROSS MEMBER SUBSYSTEM
  - ASSEMBLY SUBSYSTEM
- BCU FUNCTIONS SIZED FOR 8-BIT MICROPROCESSOR

Figure 9

(Figure 10)

Typical beam builder automatic process control operations are shown in the illustration for the cap control subsystem. In this subsystem, control and monitor functions are provided to process flat graphite thermoplastic material from the storage reel into formed structural members of the desired length. Upon entering this subsystem the material is heated to 425°F in the heating section and maintained at that temperature in the forming sections. Heating is accomplished using four sets of helically wound elements connected to individual control unit under BCU control. IR-type temperature sensors will be monitored for this purpose.

From the heaters the material passes into the cooling section where platens will be commanded closed for 38 seconds during the assembly portion of the cycle.

Cap length control is the basis of beam alignment control for the baseline configuration. As such, each cap subsection will contain dual redundant variable speed beam drive motor units. In operation a travel sensor system with a resolution of 0.25 mm will provide cap length data for each cap to the BCU processor. The final step of the cap fabrication system occurs when the desired total beam section length has been produced. On BCU command the three cap subsystem shear mechanisms will be activated.

Areas recommended for continued technology development to support this and similar efforts are as follows:

- Specific Recommendations
  - Heater elements and temperature control
  - Beam alignment control subsystem
  - Ultrasonic weld process control
  - Platform instrumentation/experiment accommodations

- General Recommendations
  - Design/selection of space qualified limit sensors
  - Design/selection of mechanism drive motors
  - Detailed automation timing/control software development

CAP MEMBER SUB-SYSTEM CONTROL DIAGRAM

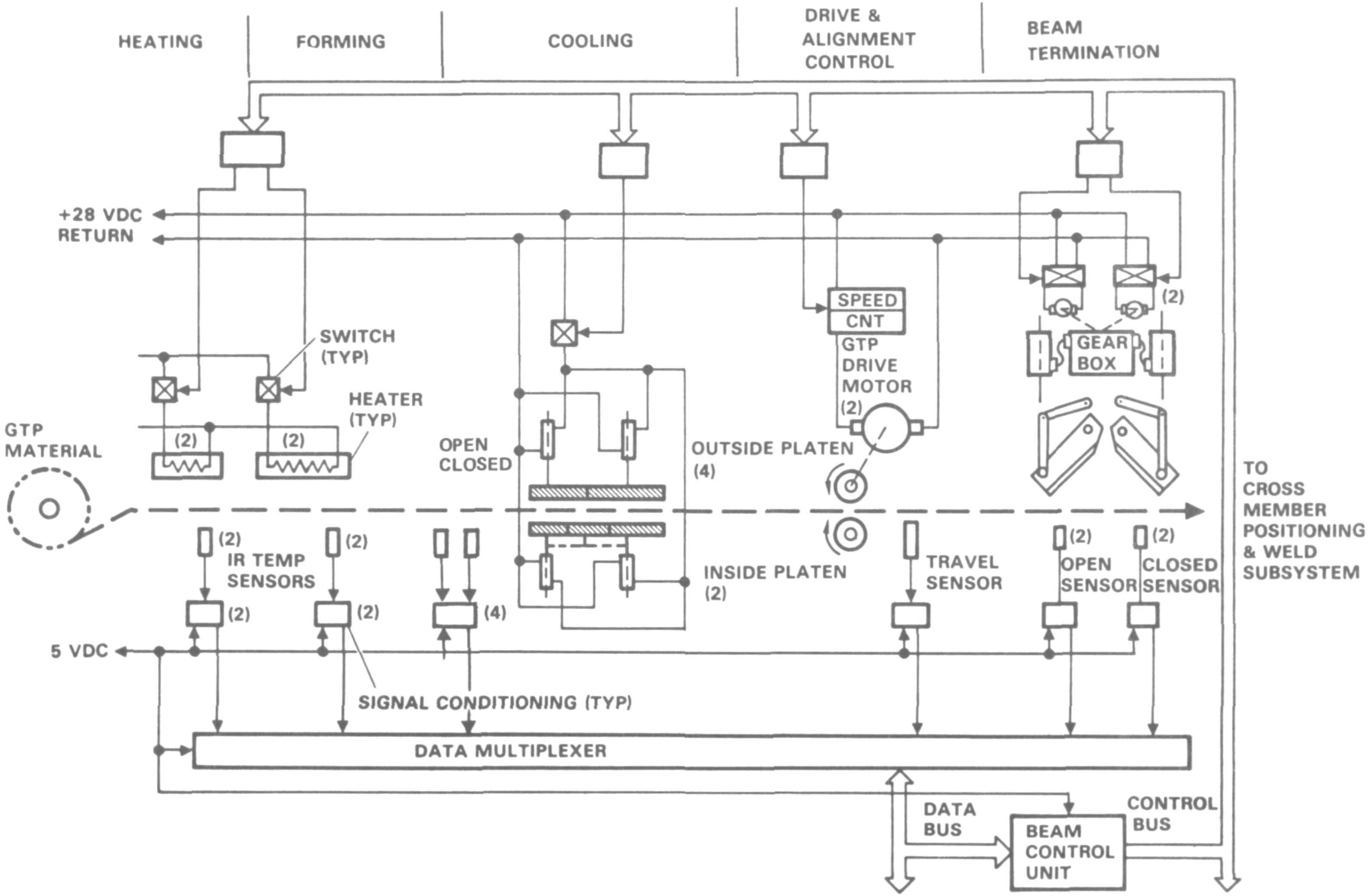


Figure 10

(Figure 11)

During the early 1980's space activities will shift from expendable launch vehicles to the Space Shuttle. This is expected to be followed by the introduction of larger reusable vehicles (Orbital Transfer Vehicle) and satellites which will require replenishment of expendables.

Obtaining the maximum benefit from this new generation of spacecraft will require propellant supply services that cannot easily be provided by standard Shuttle payload accommodations. General Dynamics, in 1976 began conceptual work for alternate propellant delivery techniques which capitalize on Shuttle's contingency payload capability.

With this approach, excess Shuttle payload capability is consigned to water stored in tanks beneath the Orbiter's payload bay. Water is a suitable Shuttle contingency payload since it is relatively dense, has very simple container requirements, and causes no Shuttle safety concern. This water is delivered to an orbiting processor as an ancillary payload during deployment of dedicated mission payloads. The propellant processor uses solar energy to reduce the water to gaseous hydrogen and oxygen, liquefy the propellants, and reliquefy boiloff from the storage tanks. Using this method, the propellants can be accumulated in low earth orbit for use by other vehicle or satellite systems.

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ON-ORBIT PROPELLANT PROCESSING

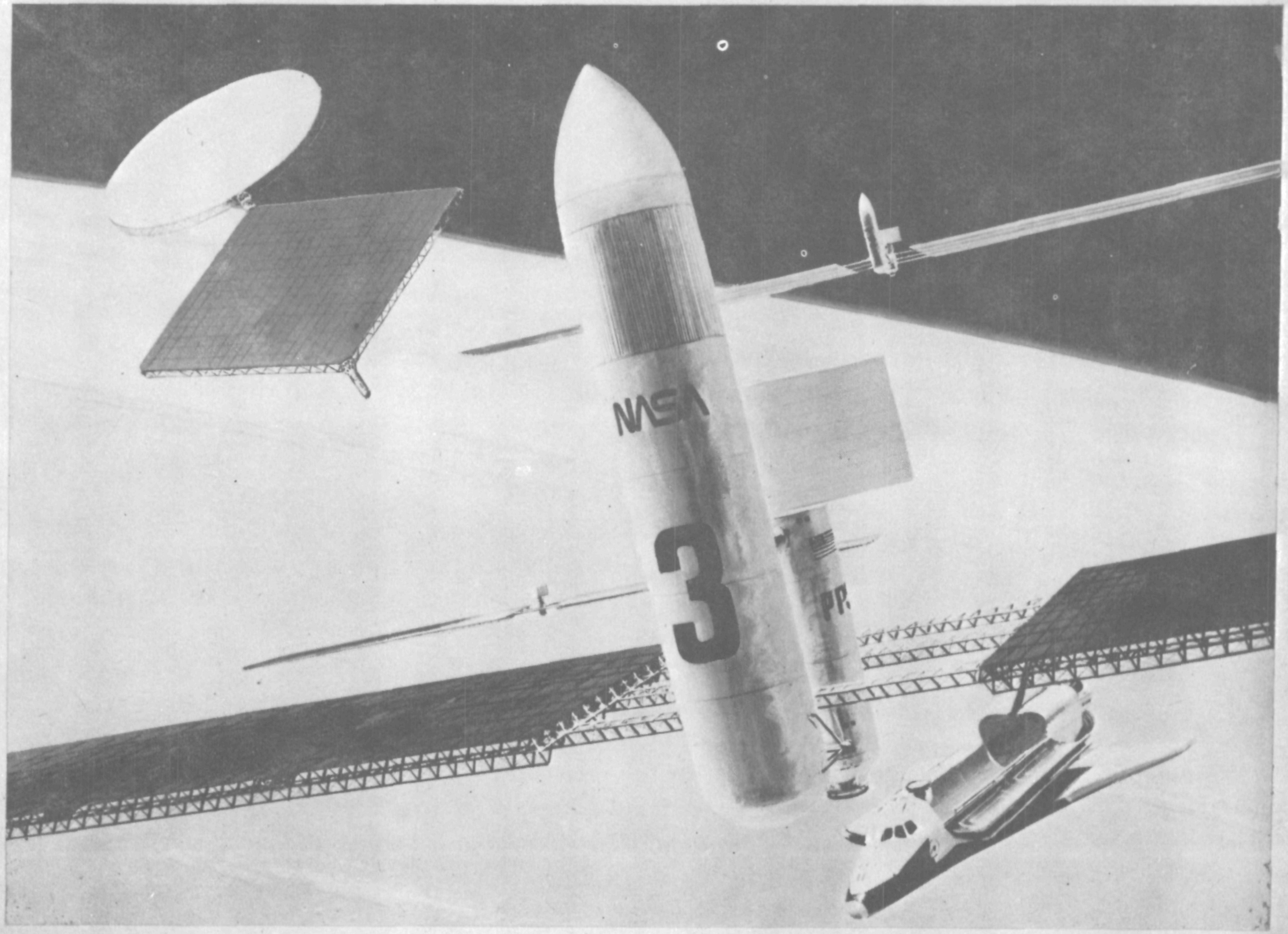

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Figure 11

(Figure 12)

The propellant processor represents a large spacecraft system which will pace the technology development required for the majority of large space structure applications. Avionics subsystems utilized include: (1) power monitoring and control, (2) propellant processor monitoring and control, (3) processor stationkeeping, (4) processor attitude and solar panel pointing control, (5) rendezvous and docking, (6) communications and data management, and (7) safety. These functions are shown in the block diagram of the facing page figure.

Propellant processor control functions encompass water storage/supply control, electrolysis control, liquefaction control, and propellant storage control. These functions will be dependent upon requirements resulting from command and monitoring data rates, response times, and software for data processing, storage, and control.

Propellant processor stationkeeping, stability, pointing and attitude control requirements are important for determining operational phases and control functions. These include solar array sun tracking, radiator panel pointing (perpendicular to solar vector), and rendezvous and docking control/stability. Attitude control and data management systems and associated sensors for performing these functions are candidate areas for future technology development.

PROCESSOR AVIONICS SYSTEM ELEMENTS

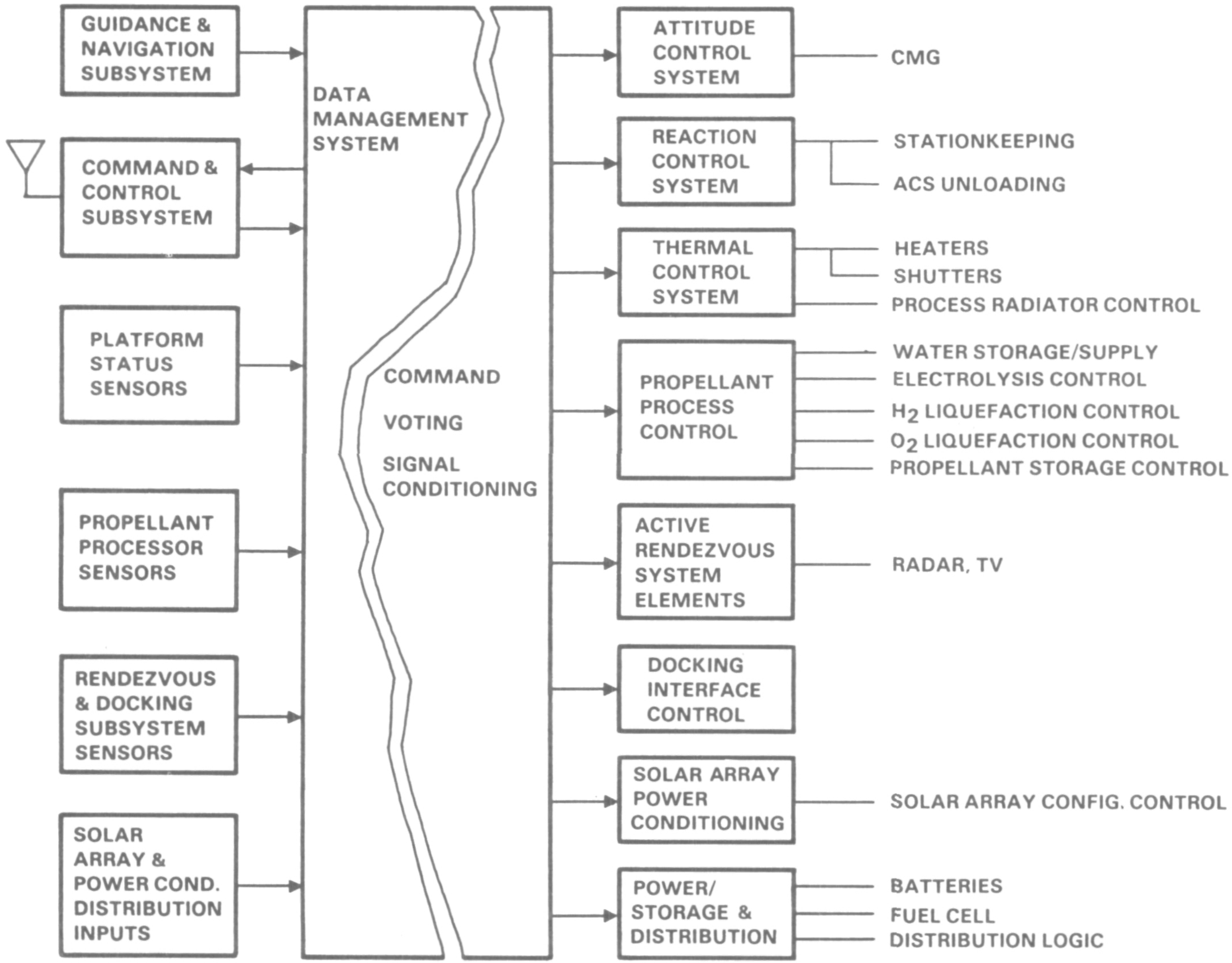

Figure 12

(Figure 13)

One of the more exciting applications of Large Space Structures technology is the development of very large space-based antenna systems. The illustration shows one large antenna concept based on an active lens phased array technique. New technology effort based on these LSS applications include:

a. Development of antenna designs compatible with LSS antenna deployment or assembly techniques.

b. Development of methods for distribution of power and control networks which have low impact on assembly and operation.

c. Development of antenna elements and systems which track and adopt to structural warpage and dynamic affects.

d. Analysis and simulations associated with the interactions between structural characteristics, the antenna element implementation and resulting RF/antenna operating performance. These include effects due to structure depth and blockage, surface control or element misalignment, and grating lobes vs antenna gap or irregularity.

LARGE ANTENNA CONCEPT BASED ON LSS

- TECHNOLOGY EFFORTS REQUIRED IN
  - — DEPLOYMENT CONTROL
  - — POWER DISTRIBUTION
  - — ADAPTIVE RF ELEMENTS
  - — STRUCTURAL/ANTENNA INTERRELATIONSHIPS

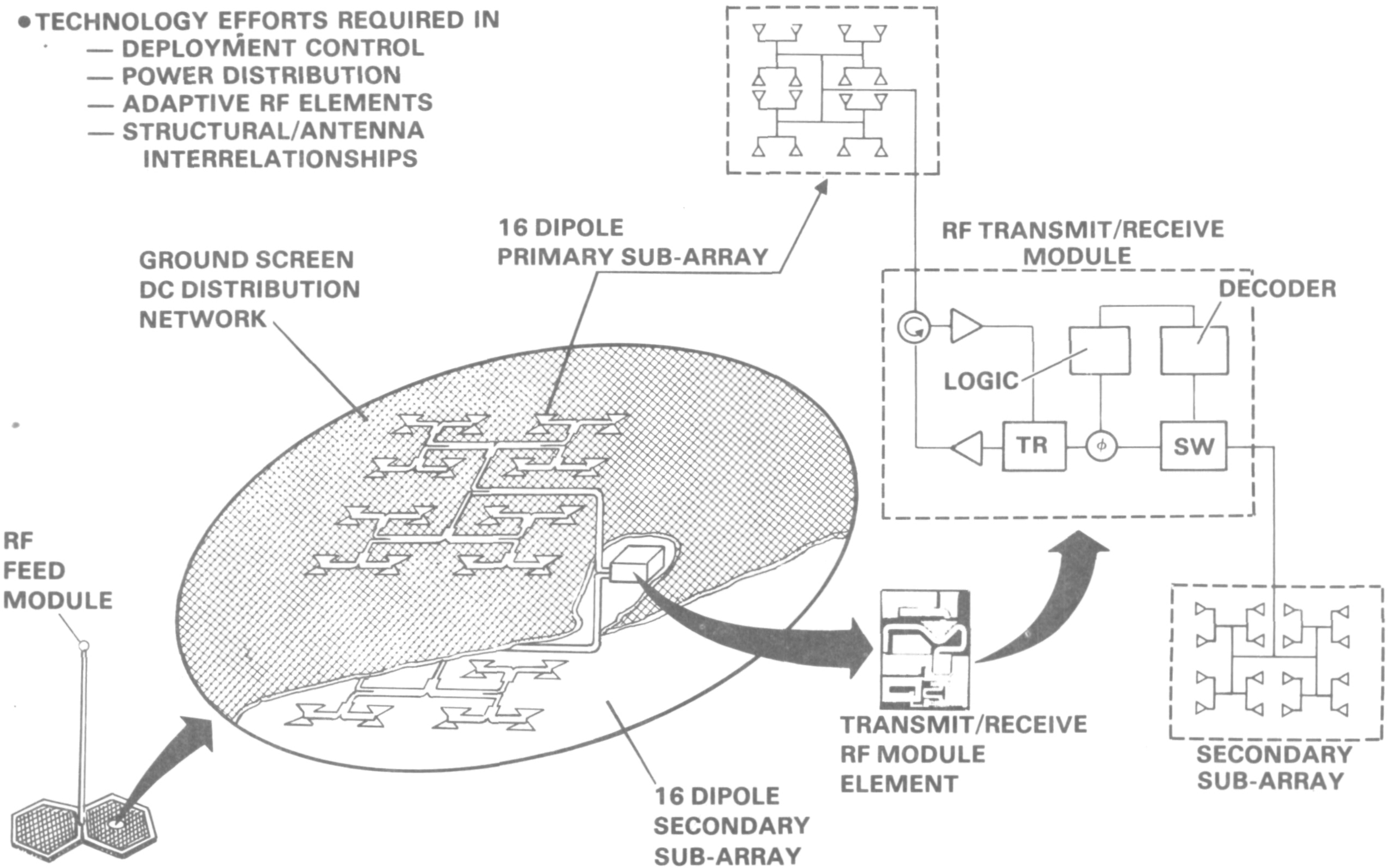

Figure 13

(Figure 14)

Our efforts in the concept development and design of future large spacecraft systems has resulted in the identification of new technologies peculiar to development or functional operation of these systems. A number of these have been discussed in the preceding material and are summarized in the table.

SUMMARY
CONTINUED TECHNOLOGY EMPHASIS

- Large structure system behavior analysis prediction tools

- Automated process control
  - Sensors
  - Actuators & mechanisms
  - Welding & joining techniques

- Antenna systems development
  - Surface control
  - Analysis
  - Deployment techniques

Figure 14