United States Control Module Guidance, Navigation, and Control Subsystem Design Concept

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TECHNICAL PAPER

UNITED STATES CONTROL MODULE GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM DESIGN CONCEPT

I. INTRODUCTION

Should the Russian Space Agency (RSA) fail to participate in the *International Space Station* (*ISS*) program, then the United States (U.S.) National Aeronautics and Space Administration (NASA) may choose to execute the entire *ISS* mission. In order to do this, NASA must build two new space vehicles: the U.S. control module (USCM) and the U.S. resupply module (USRM). These space vehicles must perform the functions that the Russian vehicles and hardware were to perform, which are well defined in references 1 and 2. Basically, the USCM must:

a. Periodically reboost the *ISS*, in order to maintain the *ISS* orbit

b. Control the attitude of the *ISS* with momentum exchange devices and/or a reaction control system (RCS) until the U.S. On-Orbit Segment (USOS) control moment gyroscopes (CMG's) arrive on orbit

c. After that, periodically desaturate the stored momentum in the USOS CMG's with an RCS and provide backup attitude control for them

d. Provide power and thermal conditioning to the *ISSA* until the large USOS solar arrays and radiators are delivered to orbit.

Basically, the USRM must periodically:

a. Resupply the USCM with propellant for orbit reboost and attitude control

b. Provide new thrusters for *ISS* orbit reboost and USOS CMG desaturation and backup attitude control; this is to minimize the on-time of the USCM's thrusters, which are lifetime limited.

Consider the functions that the USCM must perform. The USCM subsystem that plays a major role in their execution is the guidance, navigation, and control (GN&C) subsystem. This paper presents a design concept for that critical subsystem. Setting the stage for this, section II briefly describes the *ISS* mission with the USCM and the USRM involved. Then, section III defines the basic requirements for the USCM GN&C subsystem. A USCM GN&C subsystem design concept for meeting these requirements is then presented in section IV. Section V summarizes analyses and simulation results to date, which support the soundness of this design concept. Concluding remarks are made in section VI.

II. MISSION OVERVIEW

Assuming NASA builds the USCM and the USRM, the new *ISS* mission profile will be a modified version of the one described in references 1 and 2. The new mission profile will look something like this.

First, a Titan IV launch vehicle will insert the USCM in a 100-nmi circular orbit with a 51.6° inclination. Then, the USCM must transfer itself into a 190-nmi circular orbit with this same inclination. After this, the USCM must maintain its orbit and control its own attitude. It must also furnish electrical power to its subsystems and provide thermal conditioning for them.

About a month later, the U.S. space shuttle will deliver Node 1 to the USCM. Node 1 is a pressurized volume that contains four radial and two axial berthing ports. The orbiter will rendezvous with the USCM and berth Node 1 to the USCM using its remote manipulator system (RMS). The Node-1/USCM represents the initial configuration for the *ISS*.

About a month after this, an Atlas IIAS will launch the first USRM and insert it into the same 100-nmi circular orbit with a 51.6° inclination. Like before, the USRM must transfer itself into a 190-nmi circular orbit with a 51.6° inclination. Then, the USRM must autonomously rendezvous and dock with the USCM. Subsequently, the USCM must utilize the USRM's thrusters and propellant to maintain the cluster's orbit and attitude. This saves the USCM's propellant and thrusters for periods when the USRM is either not available or not operational.

Over the next year, a number of shuttle flights will deliver additional hardware to the *ISS*, including the large USOS solar arrays, radiators, and CMG's. Other equipment to be delivered includes the USOS global positioning system (GPS) receiver/processors and antennas for determining the *ISS* attitude and state vector, plus rate gyro assemblies (RGA's) for determining the *ISS* angular velocity. The USOS GN&C computer and command and control (C&C) computer will also be delivered. After this hardware arrives on orbit and becomes operational, the primary tasks of *ISS* attitude control, power generation, and thermal control will be transferred to the USOS. Then, the USRM RCS, under USCM control, must periodically desaturate the stored momentum in the USOS CMG's and provide backup attitude control to them, in case they fail. The USRM's propulsion system, under USCM control, must periodically reboost the *ISS* in order to maintain its orbit.

The *ISS* assembly sequence continues over the next 3 years with the addition of research laboratory modules and personnel. When the USRM's propellant is nearly depleted, it must separate from the *ISS* and deorbit. A new USRM will be launched to take its place. Over the 15-year life of the *ISS*, a number of USRM's will be required.

III. GN&C SUBSYSTEM REQUIREMENTS

In the *ISS* mission profile of section II, the USCM and the USRM must perform the critical functions of the Russian vehicles and hardware in the mission profile of references 1 and 2. For the USCM and the USRM to perform those critical functions and still be compatible with the rest of the *ISS*, they should perform them just as well as the Russian vehicles and hardware. Adopting this approach, the USCM and USRM GN&C functional requirements and performance requirements were derived using references 1 to 3 and the mission profile described in section II. The results for the USCM GN&C subsystem are shown in table 1. The design approach chosen to satisfy each requirement is included in the table. These will be discussed further in section IV.

IV. GN&C SUBSYSTEM DESIGN CONCEPT

Figure 1 shows a USCM design concept for meeting the GN&C requirements in table 1. This is consistent with the current thinking in the other USCM subsystems, the USRM, and the *ISS*. A set of X-Y-Z axes clearly define the USCM body-fixed coordinate system.

The USRM or the U.S. orbiter can dock to the rear of the USCM at its center. A pair of two-axis steerable reboost thrusters are mounted on the rear of the USCM near the outside edge. Each thruster has a thrust level of 200 lb and can gimbal ±15° in each axis in order to orient its thrust vector through the *ISS* center-of-mass. Hence, either thruster alone can reboost the *ISS*.

Four pods of RCS thrusters are located near the rear of the USCM also. These are used for attitude control of the USCM and the *ISS*. They also provide the angular impulse needed to desaturate the USOS CMG's. Their thrust level is 15 lb each. Two pods of thrusters are mounted on the surface of the USCM; the other two are on 15-ft booms. The booms provide a large roll moment arm, which prevents excessive RCS propellant consumption as the *ISS* approaches full assembly. Section V elaborates on this. Any three thruster pods can provide three-axis attitude control and CMG momentum desaturation.

Two sets of four GPS antennas are mounted on the USCM for attitude and state vector determination. One set is on the +Z side of the USCM, the other is on the –Z side. They provide complete global coverage for attitude and state vector determination. The antennas in a each set are located on the corners of a 1- by 3-m rectangle. Each antenna has a hemispherical field-of-view and the axes that define the centers of the fields-of-view are all parallel to one another. This is the same mounting arrangement used for the GPS antennas on the USOS.

The long tube on the USCM is a tunnel that allows for crew access to the rest of the *ISS* when the orbiter is docked to the USCM. Redundant two-axis gimbaled solar panels are mounted on the tube in such a way that they do not interfere with each other or with the deployed radiator. Two-axis gimbals allow the USCM to remain power-positive for all USCM attitudes required for normal flight and all orbiter approaches and docks, at all possible beta-angles. Figure 2 shows the most common vehicle attitudes that are required at both high and low beta angles. With the USCM's 51.6° orbit inclination, the beta angle can and will vary between +75.1° and -75.1°. Once the *ISS* is fully assembled, the normal flight orientation will be with the USCM's X axis along the orbit velocity vector (VV), its Y axis perpendicular to the orbit plane (POP), and its Z axis along the local vertical (LV).

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The two-axis gimbaled solar arrays also provide for a simple, effective USCM storage/safe mode. This mode can be enabled either from the ground, by the *ISS* or orbiter crew, or by the USCM GN&C computer. It will be enabled upon detection of an anomalous vehicle condition such as loss of attitude, excessive angular rates, or excessive depth-of-discharge of the electrical power subsystem batteries. It can also be utilized as a storage mode for the node-1/USCM/USRM configuration until the USOS GN&C hardware arrives.

When the storage/safe mode is enabled, the USCM GN&C computer is reconfigured to simply damp out any vehicle angular velocities that exceed a magnitude of 0.15°/s in any axis, using only the USCM or USRM RCS and rate gyro assemblies (RGA's). This causes the USCM to settle into a gravity-gradient orientation with its X axis aligned with the orbit local vertical and its axis of maximum principal moment-of-inertia aligned with the orbit normal. The axis of maximum principal moment-of-inertia lies close to the USCM's Y-Z plane. Also, when the storage/safe mode is enabled, the USCM GN&C computer sheds all nonessential electrical power subsystem loads. Then, the solar arrays are driven into a back-to-back orientation, with their normals aligned parallel to the USCM's X axis for low beta angles. They are aligned parallel to the USCM's axis of maximum principal moment-of-inertia for high beta angles. Once they are properly aligned back-to-back, the ground can observe the output from each array and determine which one to reorient for more solar array power. In this condition, the USCM can survive indefinitely in a power-positive state with little RCS propellant consumption.

A hardware block diagram for the proposed USCM GN&C subsystem design concept is shown in figure 3. The USOS GN&C subsystem block diagram is also shown. The USRM GN&C hardware that interfaces with the USCM GN&C computer is shown too. The USCM GN&C subsystem is structured like the USOS GN&C subsystem for commonalty and compatibility, the USRM GN&C subsystem is too.
ISS attitude control can be performed by the USOS GN&C subsystem or by the USCM GN&C subsystem. Control can be transferred between the two by commands from either the ground or the flight crew. These commands can also be generated by the GN&C computer if and when it detects an unsolvable problem in the USOS GN&C subsystem.

Either the USCM or the USRM thrusters, under USCM GN&C computer control, can be used for USOS CMG momentum desaturation, maneuvering to change *ISS* attitude, or maneuvering during orbit reboost. Also, the USCM GN&C computer can utilize the GN&C sensors on either the USCM or the USRM for increased reliability.

A detailed description of the baselined USCM GN&C components is shown in table 2. The GPS equipment and the RGA's are the same type used in the USOS GN&C subsystem. The readout rates for all sensors and the command update rates to all actuators are chosen to be the same as those in the USOS GN&C subsystem, again for commonalty and compatibility.

Redundant GPS receiver/processors, cross-strapped to the two sets of GPS antennas, are baselined for the USCM. Should they fail after USCM orbit insertion, but before the USRM arrives 2 months later, the USCM's storage/safe mode can be enabled. When the orbiter brings Node 1 to orbit, it can also bring new GPS receiver/processors. Then, the USRM can be launched as planned, and it can rendezvous and dock with the USCM. This procedure will be used if necessary, because both the USCM and the USRM

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require functioning GPS equipment for the USRM rendezvous process. If the USCM GPS equipment fails after the USRM arrives, the *ISS* crew can perform an extravehicular activity to move some GPS equipment from the USRM to the USCM just prior to USRM separation and deorbit. In fact, this approach could be used to replace failed RGA's, and possibly other failed GN&C components, on the USCM. This makes the USRM a resupply vehicle in the broadest sense.

V. GN&C SUBSYSTEM ANALYSIS AND SIMULATION RESULTS

A detailed computer simulation model of the *ISS* was developed previously by NASA/Langley Research Center engineers for *ISS* GN&C subsystem analysis and design. This tool was used effectively for rapid analysis of the USCM GN&C subsystem design. Simulation runs performed by NASA Langley's Pat Troutman and his colleagues showed that the USCM reboost thrusters need to gimbal $\pm15°$ in each axis in order to ensure that their thrust vectors can be directed through the *ISS* center-of-mass at any stage in the *ISS* assembly process. Figures 4 to 8 show the details of this. Simulation runs established that a considerable amount of propellant can be saved by placing the USCM roll thrusters on 10- to 15-ft booms. Table 3 gives these results. NASA Langley simulation results also determined that the USCM/USRM propellant required for *ISS* attitude control prior to the arrival of the USOS CMG's is about 1,500 lb. This assumes the Node-1/USCM/USRM configuration flies in a torque equilibrium attitude. Figure 9 show the details of this. Of course, if the USCM storage/safe mode is used until the USOS CMG's arrive, then the propellant required will be considerably less than 1,500 lb.

VI. CONCLUDING REMARKS

This paper has presented a USCM GN&C subsystem design concept. The one proposed is very similar to the one baselined for the USOS GN&C subsystem. It is also very robust. For example, the USCM can assume a variety of vehicle attitudes and remain power-positive indefinitely. It has a storage/safe mode that puts the USCM in a gravity-gradient orientation for extended periods of time, while remaining power-positive and consuming very little RCS propellant. It also makes maximum utilization of all GN&C sensors and effectors on both the USCM and the USRM.

REFERENCES

1. "Russian Segment Specification, *International Space Station Alpha*," NASA Johnson Space Center document No. SSP-41163, September 27, 1994.

2. Shireman, K., and Sunkel, J.W.: "Functional Description of the GN&C System for *International Space Station Alpha*." 18th Annual American Astronautical Society Guidance and Control Conference, Keystone, CO, AAS paper No. 95-015, February 1–5, 1995.

3. "Prox Ops-Imposed *ISS* Controllability Requirements," fax from Kirk Shireman, NASA/Johnson Space Center, June 1995.

U.S. Control Module Concept Showing Selected GN&C Components
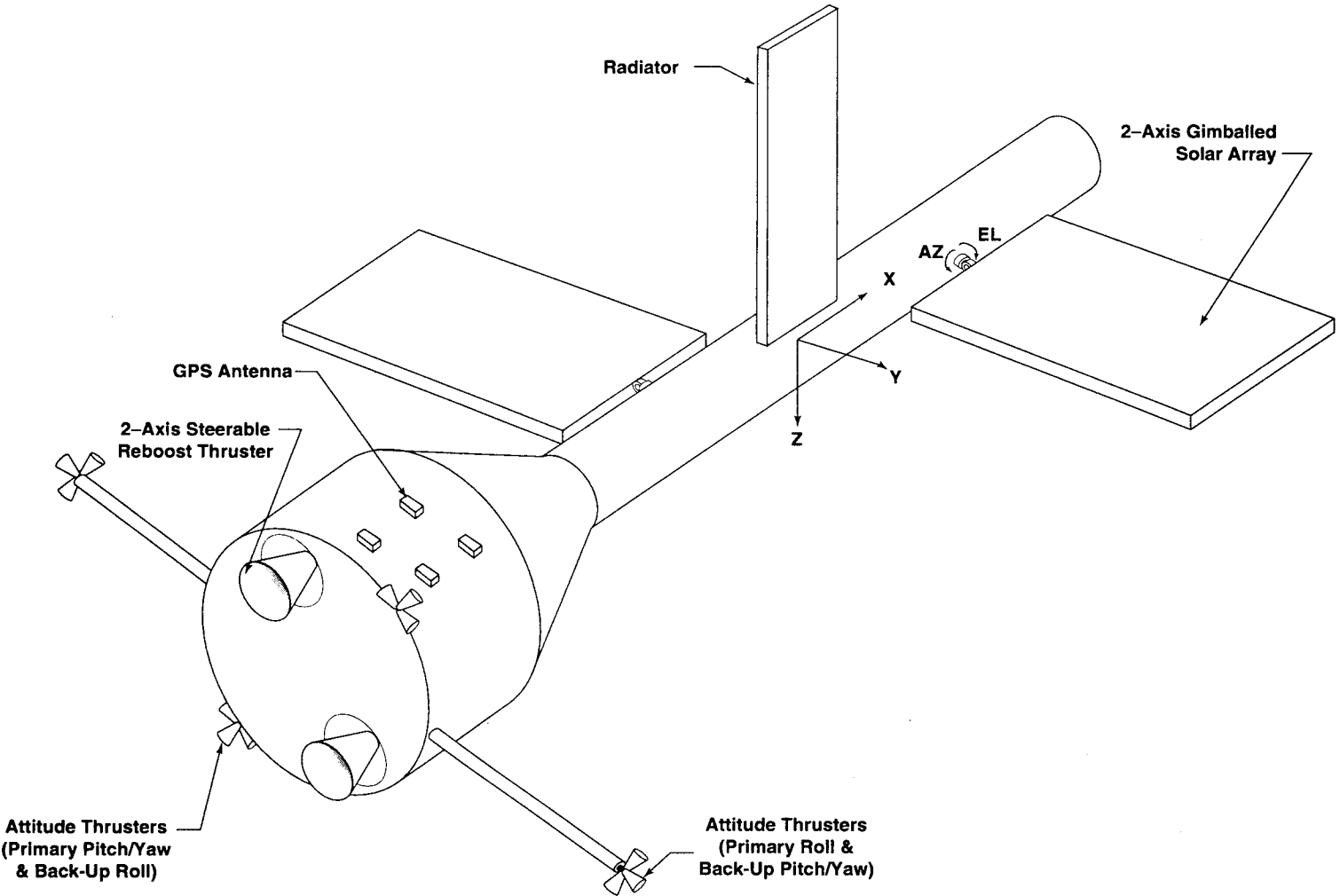
Figure 1. USCM concept showing selected GN&C components.

Common U.S. Control Module Attitudes

Orbiter Approach/Dock
(X–LV, Y–POP, Z–VV)

Low-Beta Angle

Normal Flight and
Orbiter Approach/Dock
(X–VV, Y–POP, Z–LV)

Orbiter Approach/Dock
(X–LV, Y–POP, Z–VV)

Orbiter Approach/Dock
(X–VV, Y–POP, Z–LV)

High-Beta Angle

Normal Flight
(X–VV, Y–LV, Z–POP)
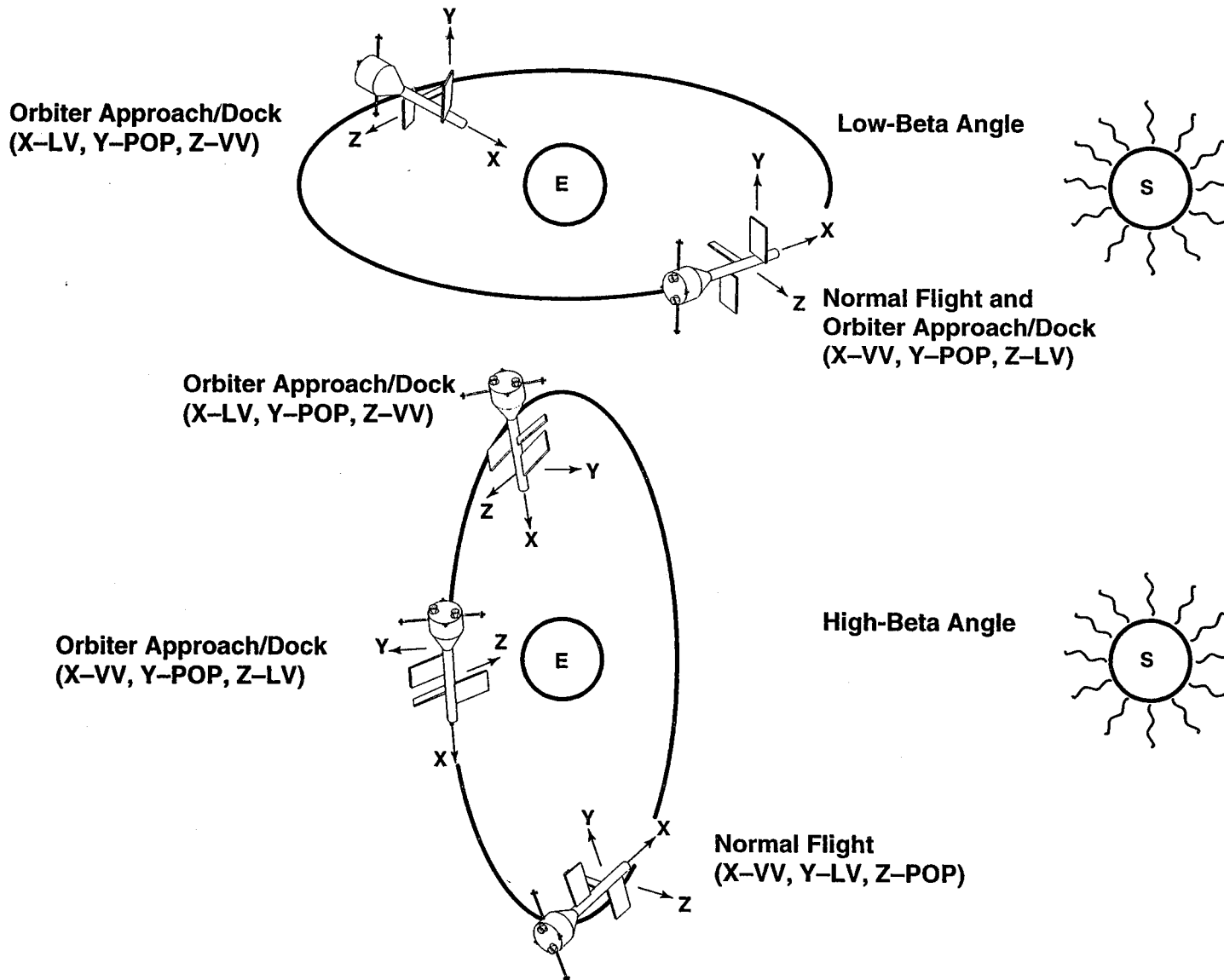
Figure 2. Common USCM attitudes.

U.S. Orbital Segment

U.S. Orbital Segment
Command & Control
Computer

U.S. Orbital Segment
GN&C
Computer

GPS
Receiver/
Processors
(2)

GPS
Antennas
(4)

Rate Gyro
Assemblies
(2x3)

2 Boxes of 3 Orthogonal
Honeywell RLGs

Double Gimbal
CMGs
(4)

Allied-Signal
3500 Ft-Lb-Sec
CMGs

U.S. Control Module

U.S. Control Module
Command & Control
Computer

U.S. Control Module
GN&C
Computer

GPS
Receiver/
Processors
(2)

GPS
Antennas
(8)

Rate Gyro
Assemblies
(2x3)

Identical to
ISSA RGAs

Drive Electronics
Assemblies
(2)

2-Axis Gimbal Solar Array Drive Assy's
(2x2)

Thruster Valves
(12+2)

Reboost Thruster Actuators
(2x2)

Thruster Latching Isolation Valves
(72)

GPS
Receiver/
Processors
(3)

GPS
Antennas
(12)

Rate Gyro/
Accelerometer
Assemblies
(2x6)

Drive Electronics
Assembly
(1)

Thruster Valves
(24+2)

Reboost Thruster Actuators
(2x2)

Thruster Latching
Isolation Valves

Internal Dual
Redundancy Through-Out
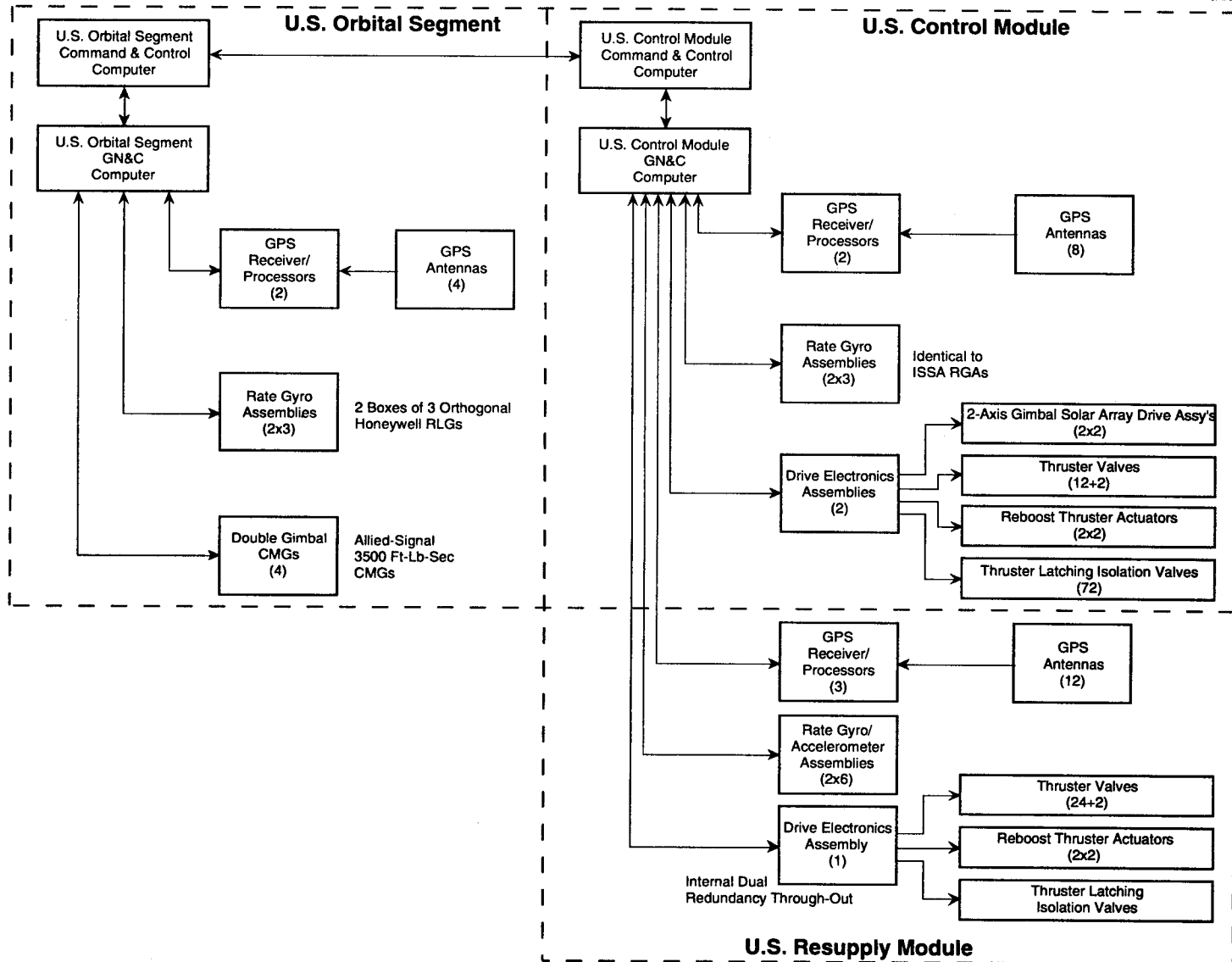
U.S. Resupply Module
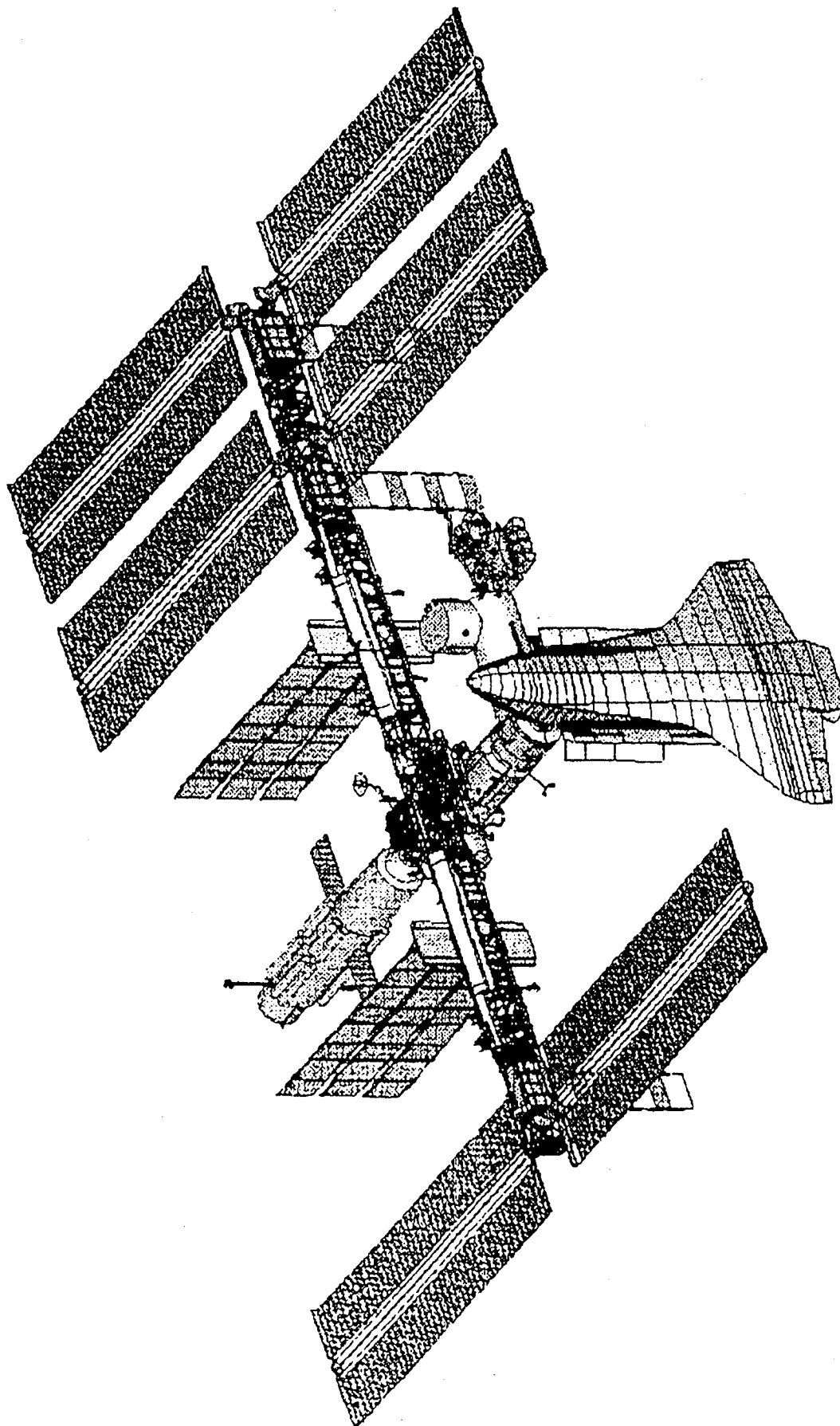
Figure 3. USOS/USCM GN&C hardware block diagram.

Figure 4. Stage 27 with orbiter.
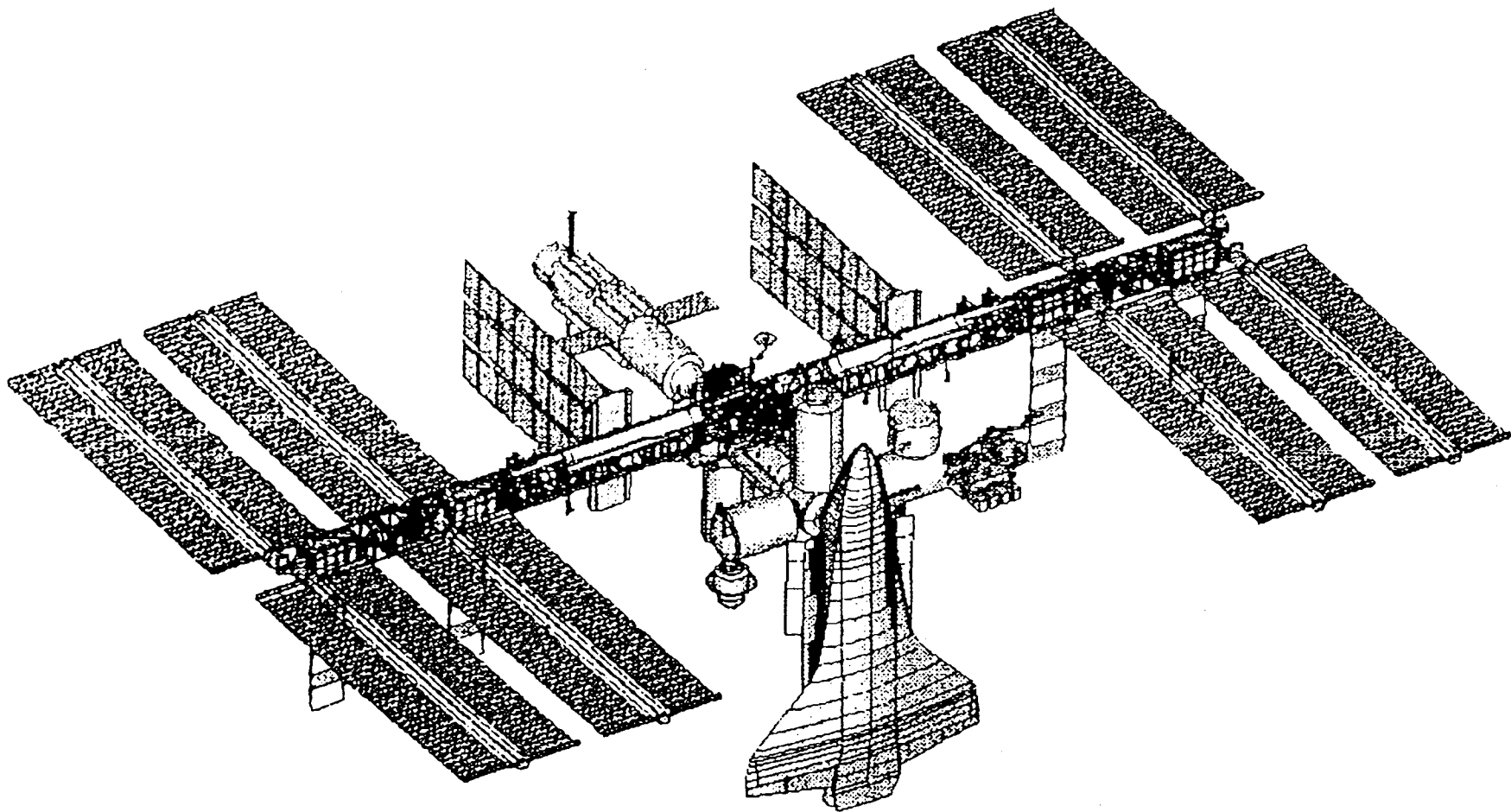
Figure 5. Assembly complete with orbiter.

Control Module Starboard & Port Engines (S1 thru S9):
Pitch Gimbal Angle Range: -1.4 deg. (S2)
                               9.5 deg. (S4)
Nominal Pitch Gimbal Angle: 5.2 deg.

Reboost Engine Pitch Gimbal Angles &
CG Migration Chart: Y Axis View

Note: Stage 10 is latest USRM
could be delivered & could then
do reboost.

Stage 9

Stage 4

Stage 1

Engine Thrust C$_L$

15°

X

Z

Control Module Reboost
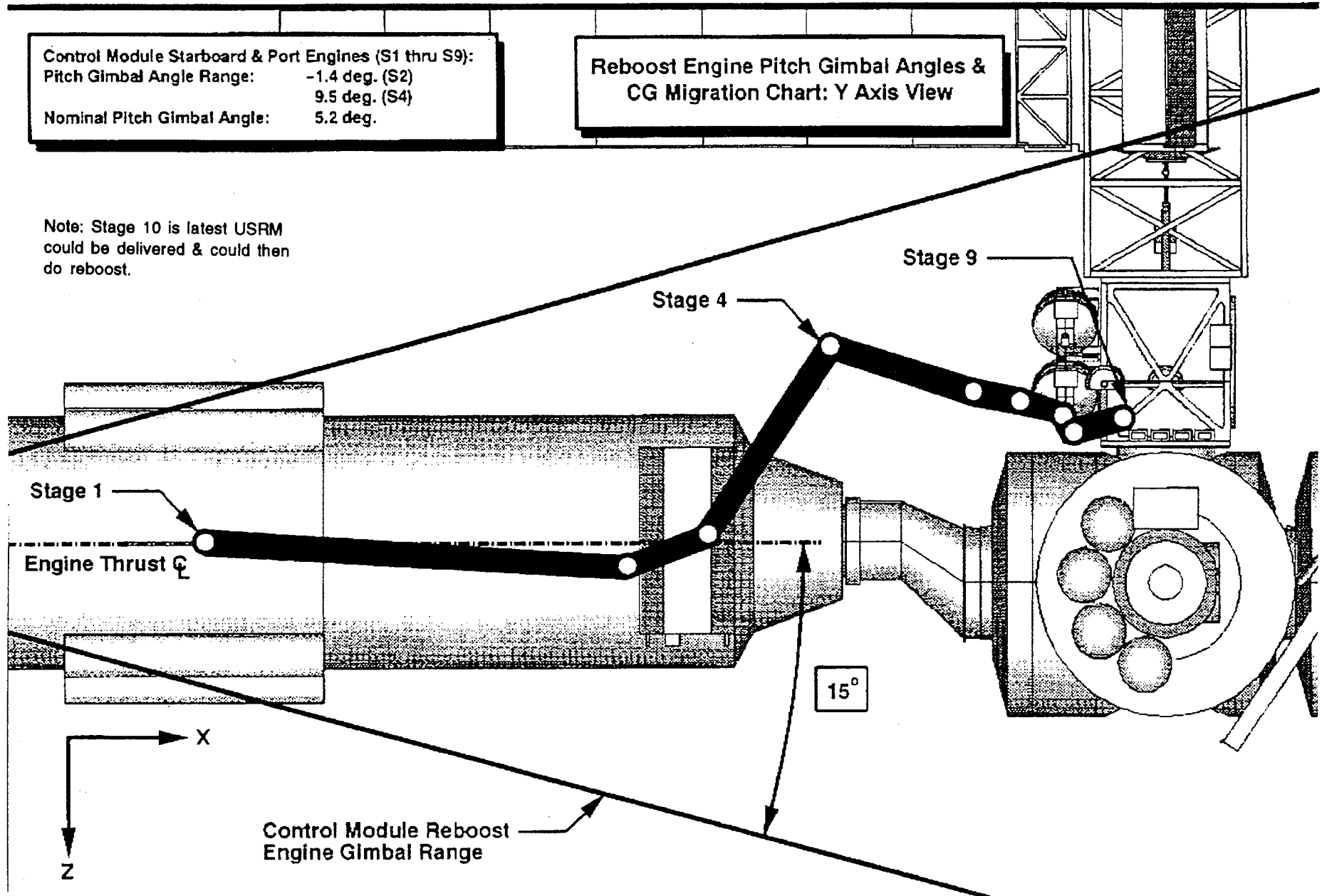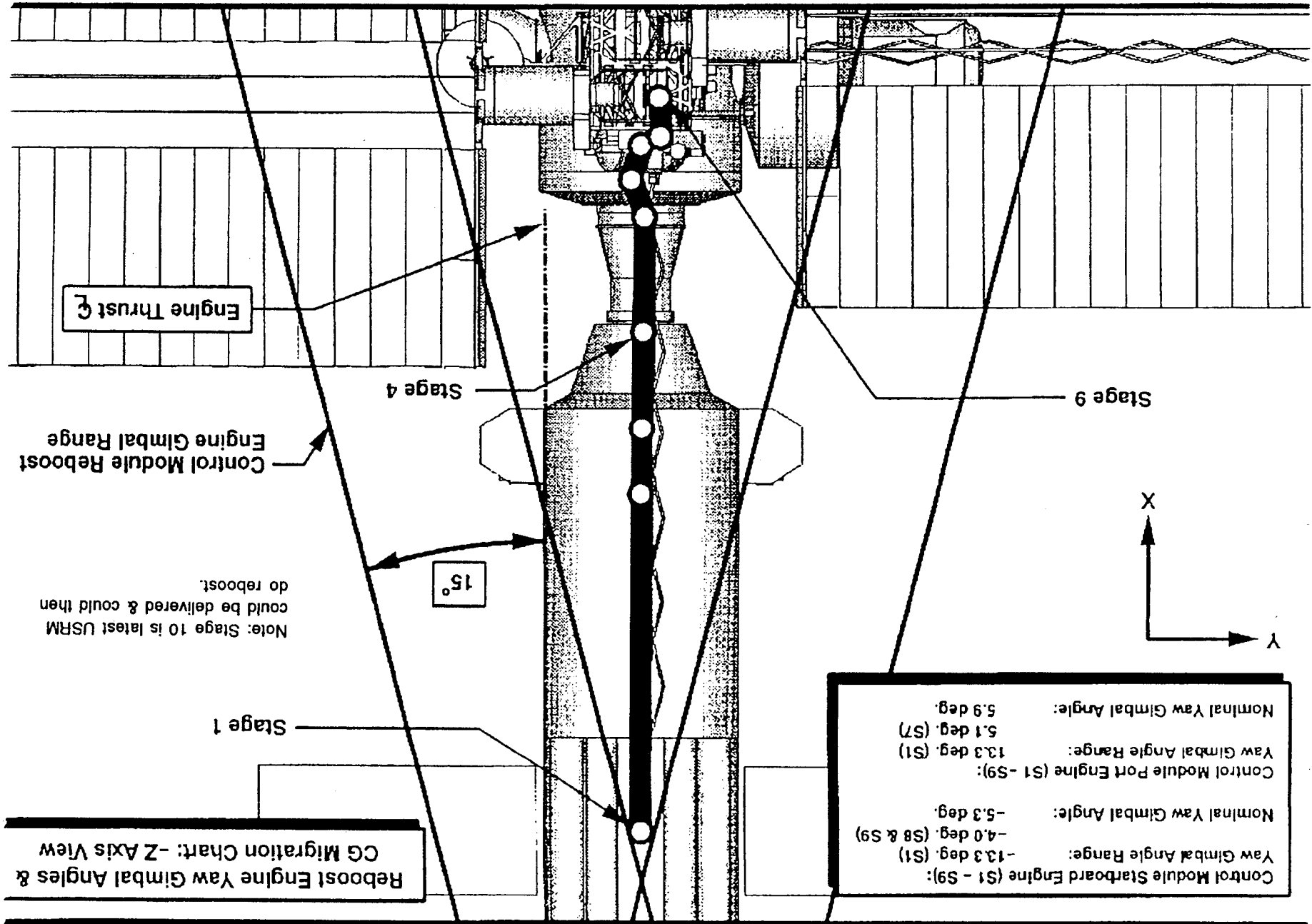Engine Gimbal Range

Figure 6. USCM reboost thruster pitch gimbal angles.

Figure 7. USCM reboost thruster yaw gimbal angles.

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Engine Thrust C̄

Stage 4

Stage 9

Control Module Reboost Engine Gimbal Range

15°

Note: Stage 10 is latest USRM could be delivered & could then do reboost.

Stage 1

Reboost Engine Yaw Gimbal Angles & CG Migration Chart: -Z Axis View

X

Y

Control Module Starboard Engine (S1 - S9):
Yaw Gimbal Angle Range: -13.3 deg. (S1)
-4.0 deg. (S8 & S9)
Nominal Yaw Gimbal Angle: -5.3 deg.

Control Module Port Engine (S1 -S9):
Yaw Gimbal Angle Range: 13.3 deg. (S1)
5.1 deg. (S7)
Nominal Yaw Gimbal Angle: 5.9 deg.

Reboost Engine Gimbal Angles for Stage 27 (Maximum Y Center of Gravity Offset Configuration)

Resupply Module Engines:

Starboard Yaw, Pitch Gimbal Angles: –7.8, 2.8 (deg.)

Port Yaw, Pitch Gimbal Angles: –6.7, 2.8 (deg.)
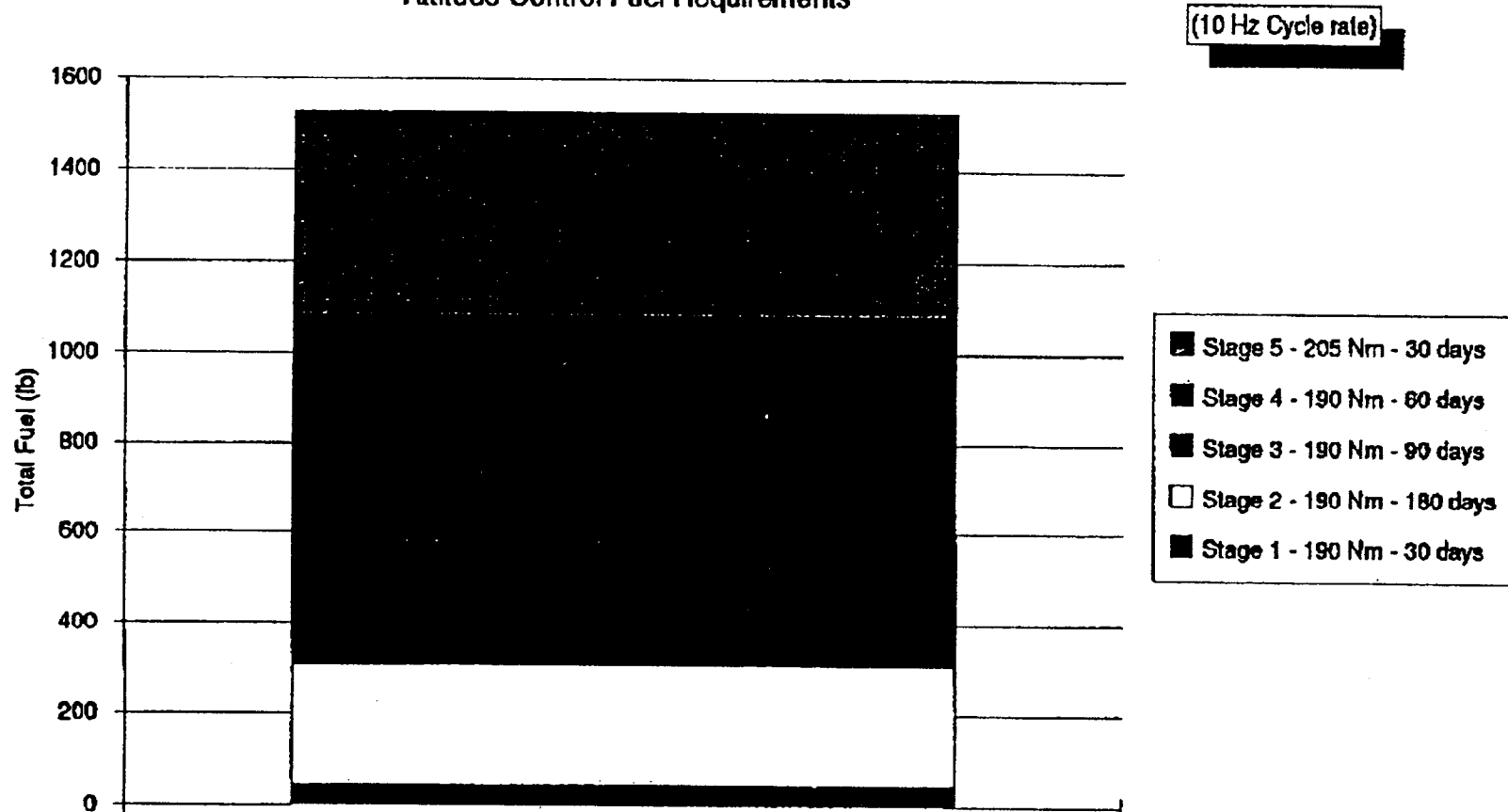

Control Module Engines:

Starboard Yaw, Pitch Gimbal Angles: –12.2, 3.1 (deg.)

Port Yaw, Pitch Gimbal Angles: –3.8, 3.1 (deg.)

Stage 27 CG Location (x,y,z): –1.47, –4.03, 2.59 (m)

Figure 8. USCM reboost thruster gimbal angles for stage 27.

Attitude Control Fuel Requirements

(10 Hz Cycle rate)

Legend:
- ▨ Stage 5 - 205 Nm - 30 days
- ▧ Stage 4 - 190 Nm - 60 days
- ▦ Stage 3 - 190 Nm - 90 days
- ☐ Stage 2 - 190 Nm - 180 days
- ■ Stage 1 - 190 Nm - 30 days

Simulation conditions:
1. 15 ft diameter USCM
2. Attitude thrusters on 10 ft booms
3. Only thrusters for attitude control
4. USCM flies torque equilibrium attitude

Figure 9. USCM propellant for attitude control until USOS CMG's arrive.

Table 1. USCM GN&C subsystem requirements.

Functional Requirement	Performance Requirement	Selected Design Approach
Determine USCM attitude wrt ECI & LVLH axes for USCM attitude control, USRM AR&C & ISSA users.	0.5 deg/axis (3 sigma)	USCM/USRM GPS hardware & RGAs
Determine USCM angular velocity in USCM axes for USCM attitude control, USRM AR&C & ISSA users.	0.01 deg/s/axis (3 sigma)	USCM/USRM RGAs
Determine USCM state vector for USCM orbit reboost, USRM AR&C & ISSA users.	500 ft (1 sigma) for position & 0.5 ft/s (1 sigma) for velocity	USCM/USRM GPS hardware
Determine USCM orbital parameters for USCM orbit reboost.	Determine USCM orbit semi-major axis to 500 ft (3 sigma).	USCM/USRM GPS hardware
Determine USCM optimum solar array orientation & point solar arrays.	6 deg (3 sigma)	USCM onboard knowledge of attitude, computer model of sun ephemeris & two-axis solar array drive assemblies.
Control USCM/ISSA to commanded LVLH, inertial, or TEA attitude.	+/- 1.0 deg/axis & +/- 0.1 deg/s/axis wrt commanded attitude; < 10 deg/axis/orbit attitude variation during TEA control.	USCM/USRM attitude thrusters under USCM control.
Perform USCM/ISSA angular slews. control.	> 0.1 deg/s/axis	USCM/USRM attitude thrusters under USCM
Stabilize USCM/ISSA during USRM AR&C & orbiter proximity operations.	+/- 1.0 deg/axis & +/- 0.1 deg/s/axis wrt commanded attitude.	USCM/USRM attitude thrusters under USCM control.
Provide angular impulse for USOS CMG momentum desaturation.	Control USOS CMG momentum to +/- 100 ft-lb-s/axis.	USCM/USRM attitude thrusters under USCM control.
Provide translational thrust for USCM/ISSA · orbit reboost. Control USCM/ISSA attitude during thrusting.	Control USCM/ISSA orbit semi-major axis to 1000 ft (3 sigma) at end of reboost. Control USCM/ISSA attitude to +/- 1.0 deg/axis during thrusting.	USCM/USRM gimballed reboost thrusters & attitude thrusters under USCM control.

Refs: 1. Shireman & Sunkel, "Functional Description of the GN&C System for ISSA," AAS paper no. 95-015, Feb 1995.
2. "Russian Segment Specification, International Space Station Alpha," NASA JSC doc. no. SSP-41163, Sept 27, 1994.
3. "Prox Ops-Imposed ISS Controllability Requirements," fax from Kirk Shireman, NASA/ Johnson Space Center, June 1995.

Table 2. USCM GN&C subsystem equipment list.

Component	Vendor & Model	# Units on S/C + # of Spares	Characteristics	Data Rate	Size	Mass	Power	Operating Temp (°F)	On-Orbit Lifetime	Design Status
GPS Antenna/ Preamp Assembly	Space Systems/ Loral ; GPS Tensor	8 + 2	4 antennas with hemispherical coverage per receiver for att. & state vector determination	Not applicable	4" x 4" x 1" per assembly	1 lb per assembly	0 W	-67 to +185 for antenna	> 10 years	U.S. Orbital Segment Off-the-shelf
GPS Receiver/ Processor Unit	Space Systems/ Loral ; GPS Tensor	2 + 1	Accuracy: 100 m in pos., 0.1 m/s in vel., 0.1° rms in att.	Read processors @ 1 Hz	5" x 11" x 4" per receiver/ processor unit	4 lb per receiver/ processor unit	10 W per receiver/ processor unit	-40 to +160	> 10 years	U.S. Orbital Segment Off-the-shelf
Rate Gyro Assembly	Honeywell; 3 orthogonal GG1320AE RLGs in each assy	2 + 1	+/- 50°/s range; 1.5 arcsec/s acc.; 0.03°/hr drift	Read RLGs @ 5 Hz	8" x 11.04" x 12.7" per assembly	24 lb per assembly	20 W per assembly	-45 to +100	10 years	U.S. Orbital Segment Off-the-shelf
Two Axis Gimbal Solar Array Drive Assembly	Shaeffer Biax Type 55	2 + 1	Unlimited freedom azimuth drive + ±90° elevation drive. Each drive has red. winding stepper mtr & resolver, + harm. drive; max rate = 2.25°/s/axis	Read resolver & update stepper mtr cmds @ 1 Hz	9" long x 5" dia. azimuth drive + 7" long x 5" dia. elevation drive per assembly	45 lb per assembly	24 W per assembly	+14 to +122	10 years	Off-the-shelf from XTE Program with possible mods to meet ISSA specs
Drive Electronics Assembly	TRW	2 + 1	2 assy's req'd to drive 12 attitude thrusters' valves, 2 reboost thrusters' valves, 72 isovalves, & to drive & control TAG SADA's & TVC actuators.	Read measure-ments & update cmds @ 1 Hz	20" x 11" x 8"	50 lb per assembly	10 W max dissipated per assembly	-11 to +120	10 years	Modified AXAF-I Drive Electronics Assembly
Thrust Vector Control Linear Actuator	NASA/MSFC	4 (2 reboost engines with 2 actuators per engine) + 1	Each actuator has roller screw + DC mtr & resolver with redund. windings	Read resolvers & update actuator cmds @ 1 Hz	16" long & 3" dia. per actuator	8 lb per actuator	30 W per actuator during Δ in gmbl pos. & 33 W during reboost; 0 W otherwise	+ 15 to +250	10 years	Build inhouse using off-the-shelf components

Totals: Mass = 286 lb, Avg Pwr = 128 W

Table 3. USCM propellant consumed versus attitude thruster boom length.

Configuration	Thruster	Attitude Hold/Maneuver	Fuel Usage (lb)
Stage 36 w/o STS	RM thrusters	Attitude hold	17.9 lb/orbit
Stage 36 w/o STS	10-ft boom thrusters	Attitude hold	7.4 lb/orbit
Stage 36 w/o STS	20-ft boom thrusters	Attitude hold	5.5 lb/orbit
Stage 36 with STS	RM thrusters	180° yaw maneuver	280 lb over 2 orbits
Stage 36 with STS	10-ft boom thrusters	180° yaw maneuver	112 lb over 2 orbits
Stage 36 with STS	20-ft boom thrusters	180° yaw maneuver	79 lb over 2 orbits
Stage 27 with STS	RM thrusters	180° yaw maneuver	251 lb over 2 orbits
Stage 27 with STS	10-ft boom thrusters	180° yaw maneuver	106 lb over 2 orbits

Notes: 1. Stage 27 has worst case c.g. properties.

2. Stage 36 has assembly complete.

3. Attitude control thrusters:

a. Thrust = 15 lbf

b. Isp = 260 s.

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13. ABSTRACT *(Maximum 200 words)*

Should the Russian Space Agency (RSA) not participate in the *International Space Station* (*ISS*) program, then the United States (U.S.) National Aeronautics and Space Administration (NASA) may choose to execute the *ISS* mission. However, in order to do this, NASA must build two new space vehicles, which must perform the functions that the Russian vehicles and hardware were to perform. These functions include periodic *ISS* orbit reboost, initial *ISS* attitude control, and U.S. On-Orbit Segment (USOS) control moment gyroscope (CMG) momentum desaturation. The two new NASA vehicles that must perform these functions are called the U.S. control module (USCM) and the U.S. resupply module.

This paper presents a design concept for the USCM GN&C subsystem, which must play a major role in *ISS* orbit reboost and initial attitude control, plus USOS CMG momentum desaturation. The proposed concept is structured similar to the USOS GN&C subsystem, by design. It is very robust, in that it allows the USCM to assume a variety of vehicle attitudes and stay power-positive. It has a storage/safe mode that places the USCM in a gravity-gradient orientation and keeps it there for extended periods of time without consuming a great deal of propellant. Simulation results are presented and discussed that show the soundness of the design approach. An equipment list is included that gives detailed information on the baselined GN&C components.

14. SUBJECT TERMS

attitude control, control module, global positioning system, guidance, *International Space Station*, navigation, orbit reboost, propulsion system, rate gyros, reaction control system, resupply module

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