TABLE OF (



# [General purpose spacecraft bus : report]

SPAR

SPAR-R.672

TABLE OF CONTENTS

# SECTION 2

# PARAMETERS AND ASSUMPTIONS

## PARAMETERS & ASSUMPTIONS USED FOR "BUS" STUDY

1. Launch Vehicle

- Delta 3914
- Fairing dynamic envelope = 86" dia.
- NASA Delta Restraint Manual
- Adaptor 3731A

2. Orbit

- Geosynchronous
- Stationkeeping : N-S = ±.05° - .10°
  E-W = ±.05° - .10°
- Adjustment period no less than 21 days
- Transfer orbit :

| | | |
|---|---|---|
| Apogee | - | 19,525 n.mi. |
| Perigee | - | 100 n.mi. |
| Inclination | - | 28.3° |
| Delta V | - | 6,024 ft./sec. |

3. Spacecraft

Life

| | | |
|---|---|---|
| In orbit life time | = | 6 years |
| Storage | = | 3 years |

Weight

Lift-off weight = 1,925 lbs. (excludes adaptor weight)

## Stability

Transfer Orbit : spin stabilized
Synchronous Orbit : 3 axis stabilized

## Power

800 watts E.O.L. (does not include power for payload $e_2$ below).

## Payload Requirements

a) UHF + 12 channel (4-6 GHz)
b) UHF + 4 channel (12-14 GHz)
c) UHF + 1 channel (7-8 GHz)
d) UHF + L Band + 1 channel (7-8 GHz) + Exp.
$e_1$) 12 channel (12-14 GHz), 30 W TWT
$e_2$) 8 channel (12-14 GHz), 4-20 W TWT, 4-50 W TWT

$\frac{I}{Ip}$ greater than 1.1 during spin phase

## Eclipse

Full eclipse operation

## Payload Assumptions Used for Sizing Spacecraft

a) 4-6 GHz (12 channel)

- 5-6 watt TWTS (HAC)
- No transponder redundancy per channel
- Same transponder electrical configuration as ANIK Mk I including EPC multiplexers, filters, etc.
- 12 channels powered E.O.L., including eclipse
- Dissipations per channel as per ANIK

b) 12-14 GHz (4 channel)

- 20 watt TWT
- No redundancy per channel
- Similar transponder electrical configuration as CTS, including EPC's, etc.
- 4 channels powered E.O.L. including eclipse
- Dissipations per channel as per CTS

c) UHF

- Dissipations as supplied by DOC
- Panels sizing based on thermal doubler requirements

d) L Band and Experiments

- Assume they will fit on panel sizes derived from a), b) or c) above.

$e_1$) $e_2$) Assumptions same as d).

4. Subsystem Parameters

4.1 ACS

Operation

Not to require correction more than every five days

3 Axis Accuracy

| | | |
|---|---|---|
| Roll | : | $\pm .10^\circ - .15^\circ$ |
| Pitch | : | $\pm .10^\circ - .15^\circ$ |
| Yaw | : | $\pm .3^\circ - 1.0^\circ$ |

Spin Phase Accuracy

±.20° (inclination angle for apogee motor firing)

Alignment Accuracy

Same as CTS and ANIK

## 4.2 RCS

Fuel : Hydrazine
Life : 6 years, tanks sized for 8 years

Thruster size : .10 - 1.0

## 4.3 Solar Array

Power

| | | |
|---|---|---|
| End of Life, 6 years | : | 800 watts |
| Housekeeping | : | 140 watts |
| Payload | : | 640 watts |
| Tracking Accuracy | : | ±1° |
| Transfer Orbit Power | : | 80-100 watts |
| System voltage | : | 50V |

## 4.4 Structure

| | | |
|---|---|---|
| Life-Off Weight | : | 1,925 lbs. |
| Design for | : | 2,120 lbs. |
| Launch Loads | : | Delta Restraints Manual |

## 4.5 Thermal

System/Component Dissipations : as provided by DOC

## GP BUS PAYLOAD CHARACTERISTICS

| PAYLOAD OPTIONS | ANTENNAE | | | TRANSPONDER | | | DC POWER |
|---|---|---|---|---|---|---|---|
| | TYPE | NO. & SIZE | WEIGHT | SIZE | WEIGHT lbs. | DISSIPATION watts | |
| a) UHF/4-6 GHz Transponder (12 channel) (5-6W TWT) | Dep. parabola or parabola + quad helix | 13 ft. dia. or 82" dia. x 100" long | ≈ 55 lbs. | TBD | 218.4 | S 314.9<br>E 264.3 | S 414.9<br>E 339.3 |
| b) UHF/12-14 GHz Transponder (20W TWT) | Dep. parabola or parabola + quad helix | 13 ft. dia. or 82" dia. x 100" long | ≈ 55 lbs. | TBD | 180.5 | S 456.6<br>E 351.5 | S 624.6<br>E 463.5 |
| c) UHF/7-8 GHz Transponder with auxilary experimental payload | Dep. parabola | 13 ft. dia. | ≈ 55 lbs. | TBD | 221.9 | S 404.2<br>E 252.3 | S 505.2<br>E 305.3 |
| d) UHF/SHF/L Band Transponder | Dep. parabola | 13 ft. dia. | ≈ 60 lbs. | TBD | 190.4 | S 397.2<br>E 305.3 | S 513.2<br>E 373.3 |
| $e_1$) 12-14 GHz Transponder (12 channels) 30W TWT | | | | | | ? | S 430 |
| $e_2$) 12-14 GHz Transponder 4-20 watt TWT 4-50 watt TWT + 50% redundancy | | | | | | ? | S<br>E 732 |

## POWER REQUIREMENTS/ASSUMPTIONS

| | POWER REQUIREMENTS HOUSEKEEPING | POWER REQUIREMENTS COMMUNICATIONS PAYLOAD |
|---|---|---|
| a) UHF/4-6 GHz (12 channel transponder) | | S 414.9 watts<br>E 339.3 watts |
| b) UHF/12-14 GHz transponder | | S 624.6 watts<br>E 463.5 watts |
| c) UHF/7-8 GHz transponder with Exp. payload | | S 505.0 watts<br>E 305.0 watts |
| d) UHF/SHF/L Band transponder | | S 513.0 watts<br>E 373.0 watts |
| $e_1$) 12 (12-14) 30W TWT | | 636.0 watts |
| $e_2$) 8 (12-14) 4-20W TWT<br>4-50W TWT | | 732.0 watts |
| TTC<br>Power<br>ACS<br>DSA<br>Thermal<br>RCS | 30 watts<br>15 watts<br>40 watts<br>10 watts<br>30 watts<br>15 watts | |
| TOTAL | 140 watts | 732.0 watts |
| Maximum Requirement at End of Life : | i) excluding item $e_1$ and $e_2$<br>ii) includes $e_2$ requirement | 765.0 watts<br>872.0 watts |

# SECTION 3

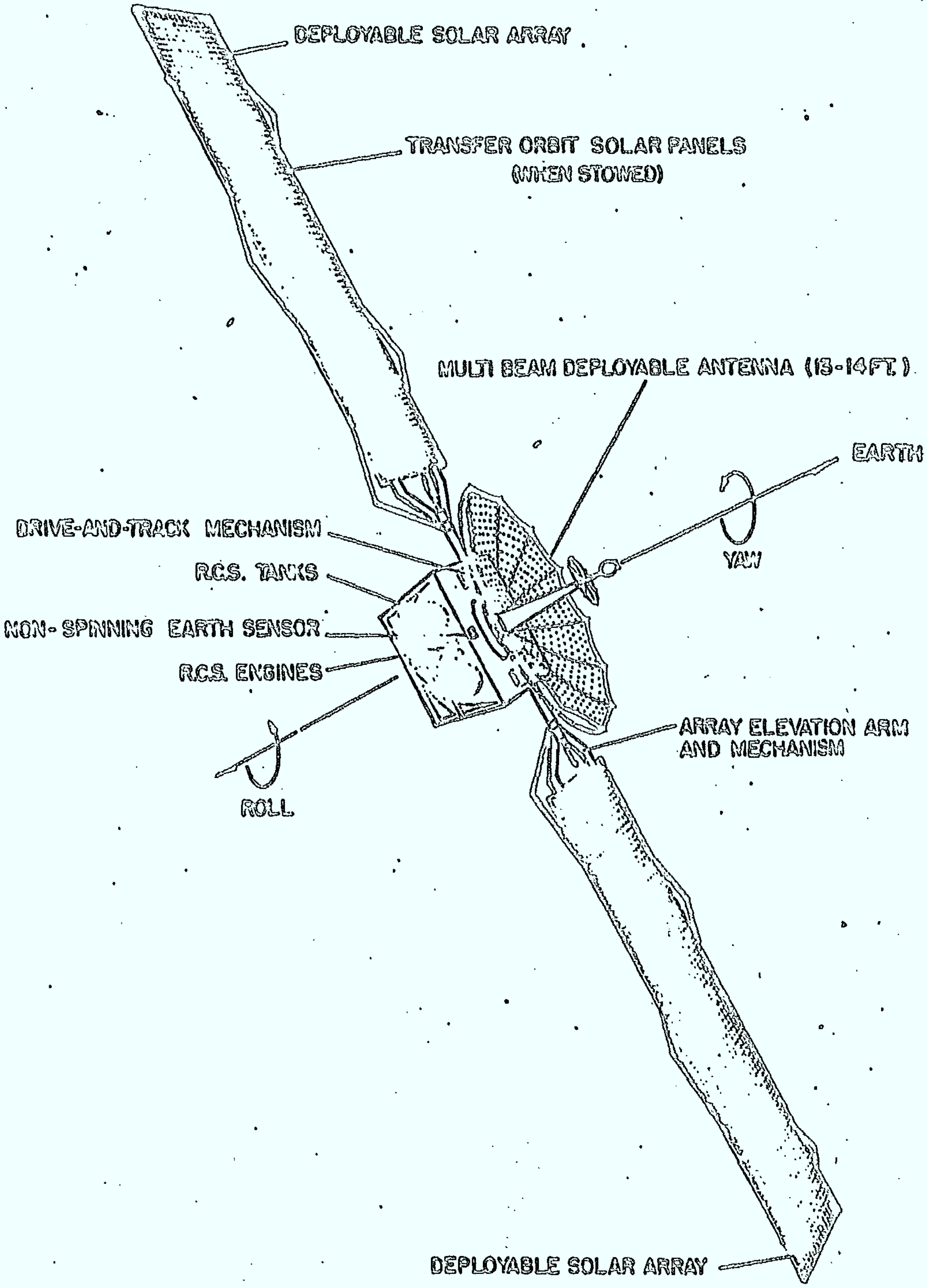
# CONFIGURATIONS/LAYOUTS

## SPACECRAFT CONFIGURATIONS

- Configuration I conventional 3 axis arrangement with antenna/forward platform, earth facing.

- Configuration II, similar to Configuration I, with antenna/east or west face earth facing.

- Configuration III, 3 axis stabilized, sun oriented spacecraft with despun antenna and earth sensor.



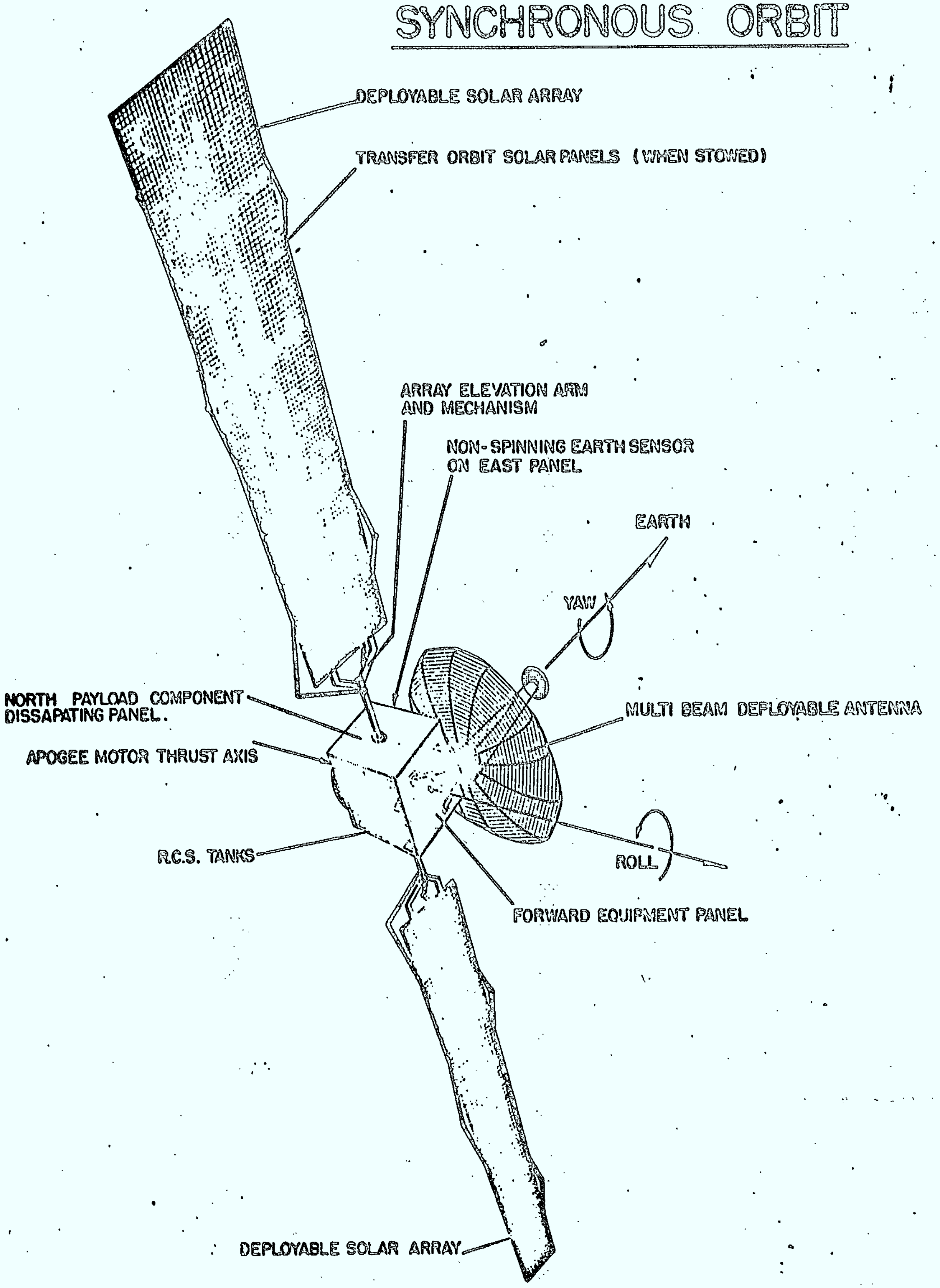

# SPACE CRAFT ARRANGEMENT I.
# IN
# SYNCHRONOUS ORBIT

# SPACECRAFT CONFIGURATION I

## MAJOR FEATURES

- Forward deck and antenna earth pointing
- Antenna requires cut outs to allow non-spinning earth sensor viewing
- N/S panels used for payload/housekeeping component with high dissipations
- Arrays stowed on N/S platform during transfer orbit
- Drive and tracking units mounted on forward platform
- Can achieve M.O.I. ratios with deployable antennae or quad helix

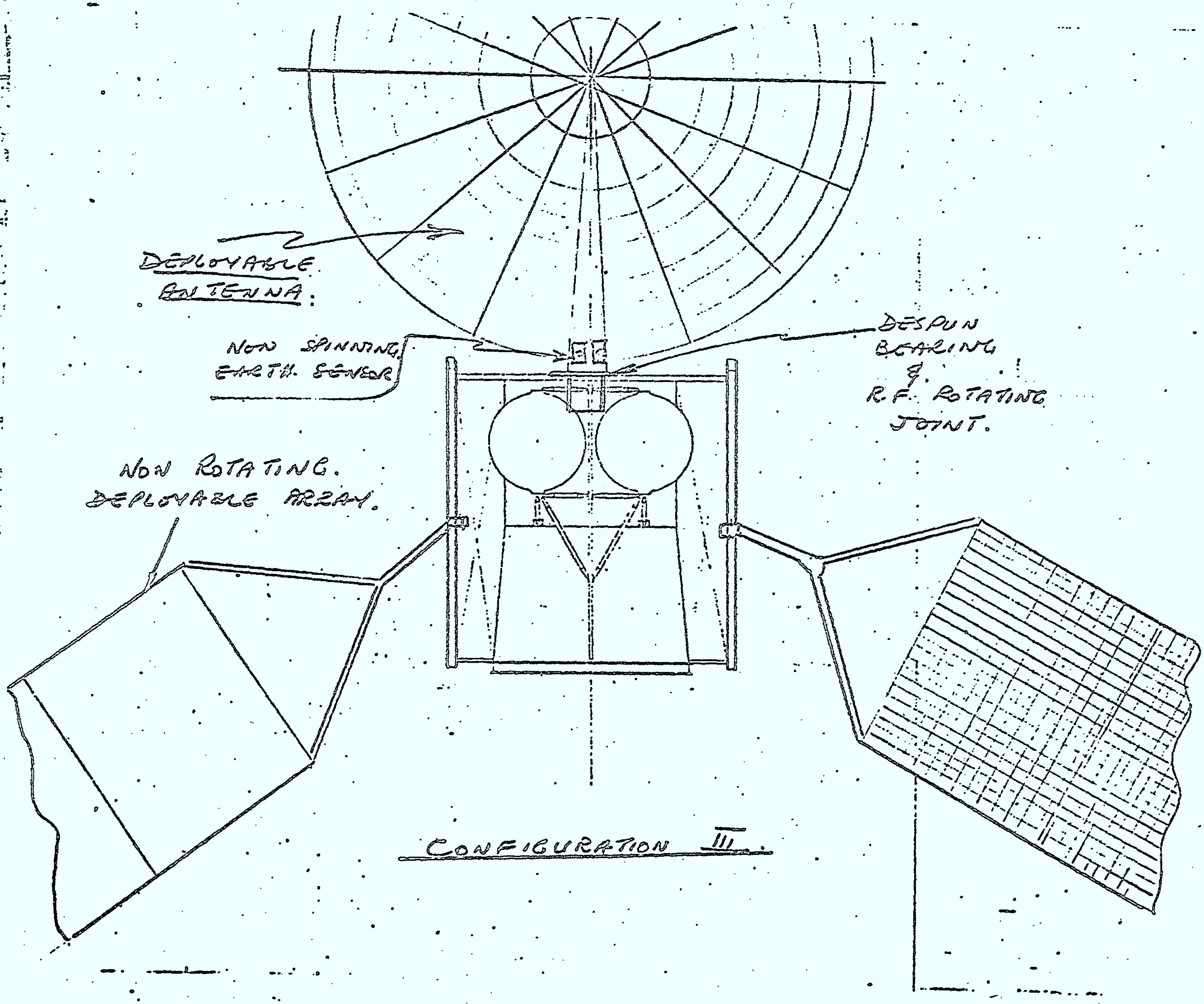
# SPACE CRAFT ARRANGEMENT II. IN SYNCHRONOUS ORBIT



## SPACECRAFT CONFIGURATION II

### MAJOR FEATURES

- SIMPLER ACQUISITION SEQUENCE
- SATELLITE ALWAYS LOCKED ON TO EARTH DURING SPIN AND 3 AXIS PHASE OF MISSION
- ACQUISITION AND ARRAY DEPLOYMENT CAN OCCUR IMMEDIATELY AFTER INJECTION INTO SYNCHRONOUS ORBIT WITH MINIMUM OF MANEOUVRES
- UTILIZES THE LENGTH OF THE FAIRING FOR EARTH POINTING COMPONENT, I.E. ANTENNAE SENSOR PLUS OTHERS
- CAN ACHIEVE M.O.I. RATIO WITH LOCKHEED DONUT ATENNA (CONSTRAINT)
- CAN ACCOMMODATE QUAD HELIX ANTENNA WITH 5 FOOT PARABOLIC DISH
- CONVENTIONAL DRIVE AND TRACKING MECHANISM, NO ROTATING JOINTS, FOR RF WAVEGUIDE

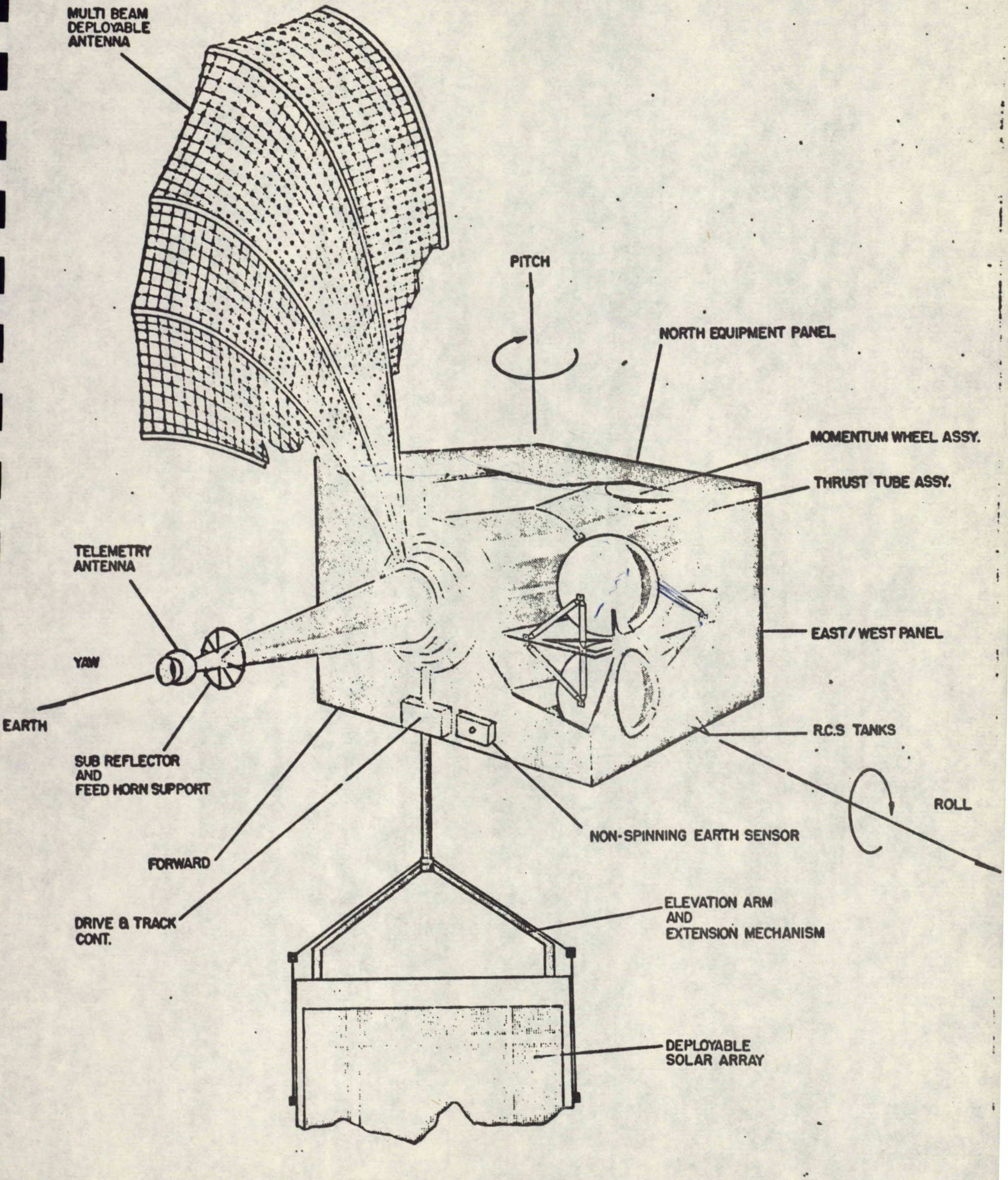


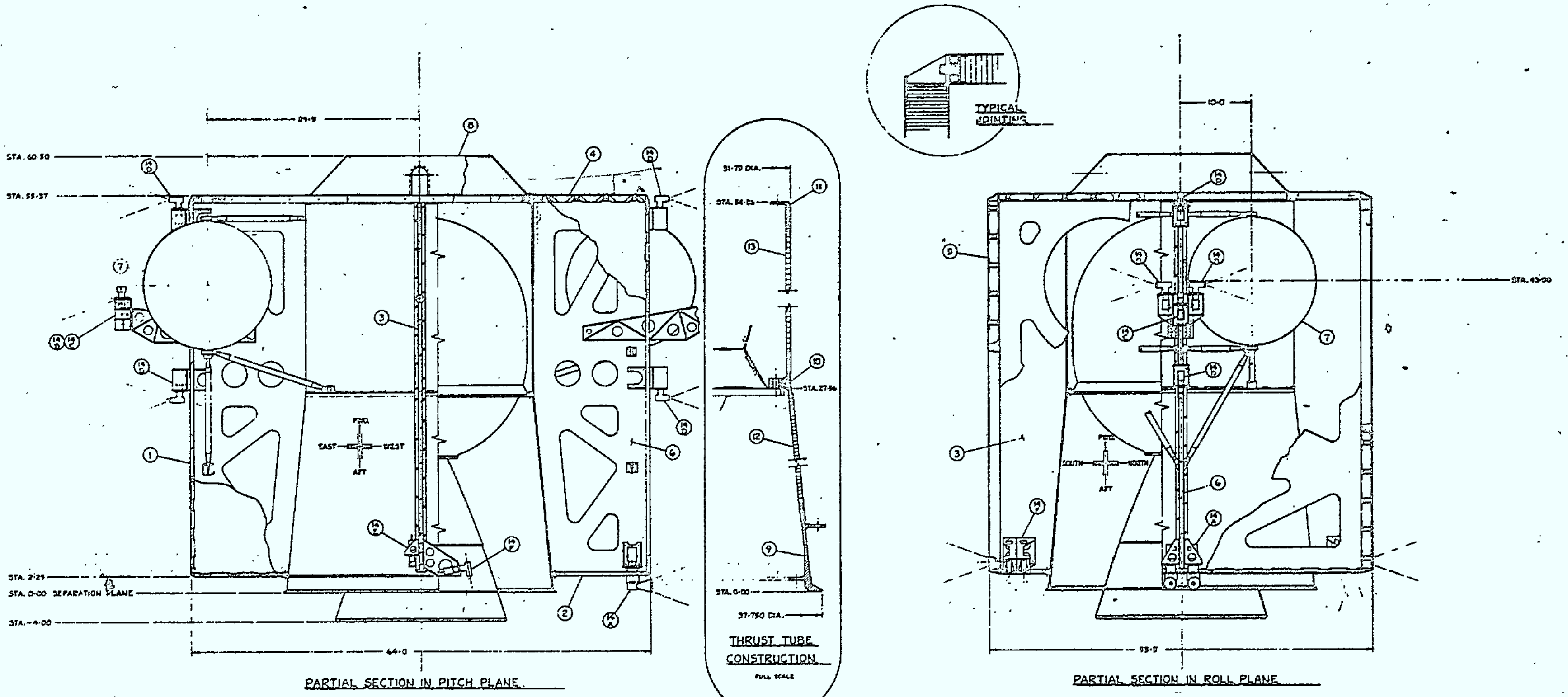

CONFIGURATION III.

## SPACECRAFT CONFIGURATION III

### MAJOR FEATURES/RESTRAINTS

- Spacecraft and panels sun oriented
- Antenna and non-spinning earth sensor despun and earth oriented, (1 RPD)
- RF Rotary joint required with special signal/supplies to earth sensor on despun unit
- Difficult to achieve M.O.I. ratio
- Restraint interference between antenna and solar panel
- Simplified acquisition
- Reduced solar torques
- No solar variation to be considered
- Additional surfaces available for mounting dissipating components


MULTI BEAM DEPLOYABLE ANTENNA
PITCH
NORTH EQUIPMENT PANEL
MOMENTUM WHEEL ASSY.
THRUST TUBE ASSY.
TELEMETRY ANTENNA
EAST/WEST PANEL
YAW
EARTH
R.C.S TANKS
SUB REFLECTOR AND FEED HORN SUPPORT
ROLL
NON-SPINNING EARTH SENSOR
FORWARD
DRIVE & TRACK CONT.
ELEVATION ARM AND EXTENSION MECHANISM
DEPLOYABLE SOLAR ARRAY




COMPONENTS :

1. EAST AND WEST CLOSURE PANELS
2. AFT LATERAL RESTRAINT PANEL
3. NORTH AND SOUTH BULKHEADS

} 0·5 THICK 2·0LB/FT³ ALUM. HONEYCOMB, ·006 ALUM. FACESHEETS

4. FORWARD EQUIPMENT PLATFORM — 1·0 THICK · · · · · ·
5. NORTH AND SOUTH EQUIP'T. PANELS — 1·5 THICK · · · · · ·
6. EAST AND WEST BULKHEADS — 0·62 THICK · · · · · ·
7. HYDRAZINE FUEL TANKS — TITANIUM
8. DISH ANTENNA MOUNT — 0·04 THICK ALUM. SPINNING

9. SEPARATION RING
10. APOGEE MOTOR RING

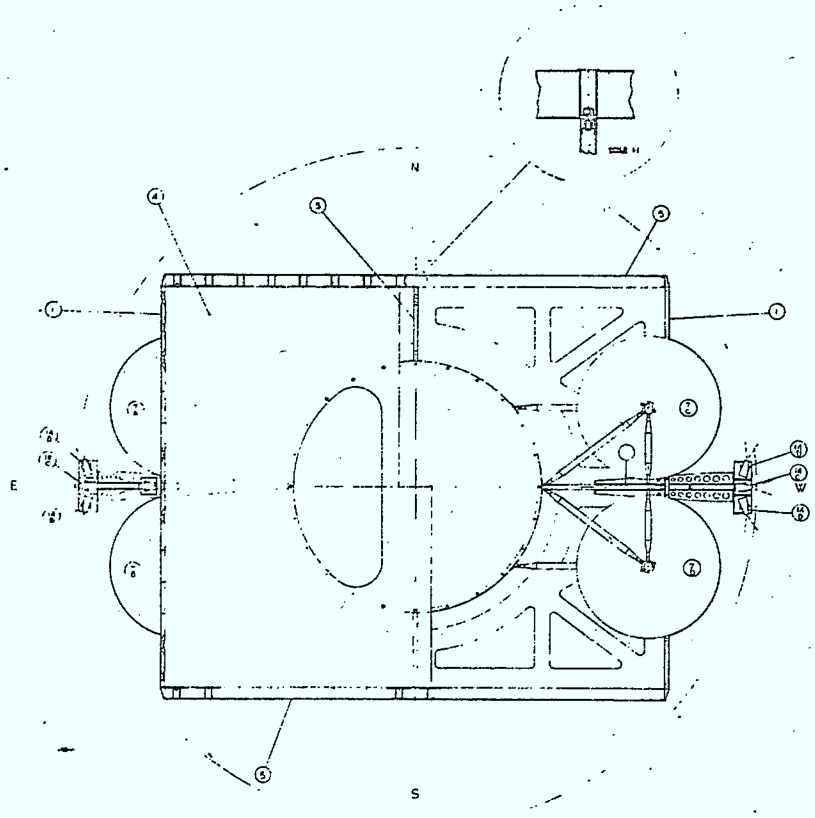
} MACHINED ALUMINUM

11. FORWARD RING — · MAGNESIUM
12. AFT THRUST TUBE — 0·125 THICK 3·1 LB/FT³ ALUM. HONEYCOMB, ·007 ALUM. FACESHEETS
13. FWD. THRUST TUBE — · · 2·0LB/FT³ · · , ·005 · ·
14. THRUSTERS : A = HIGH THRUST PRECESSION, B = NORTH/SOUTH STATION AND YAW ATTITUDE, C = EAST/WEST STATION, D = EAST/WEST STATION AND PITCH ATTITUDE, E = NORTH/SOUTH STATION AND ROLL ATTITUDE, F = OFFSET, ROLL/YAW ATTITUDE.

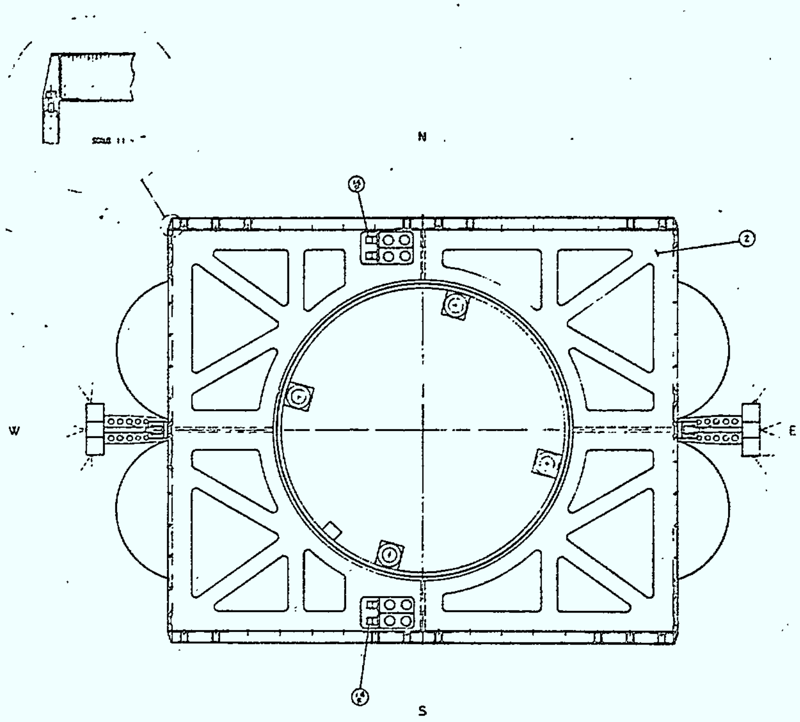
STRUCTURE AND R.C.S.

GENERAL PURPOSE SATELLITE BUS

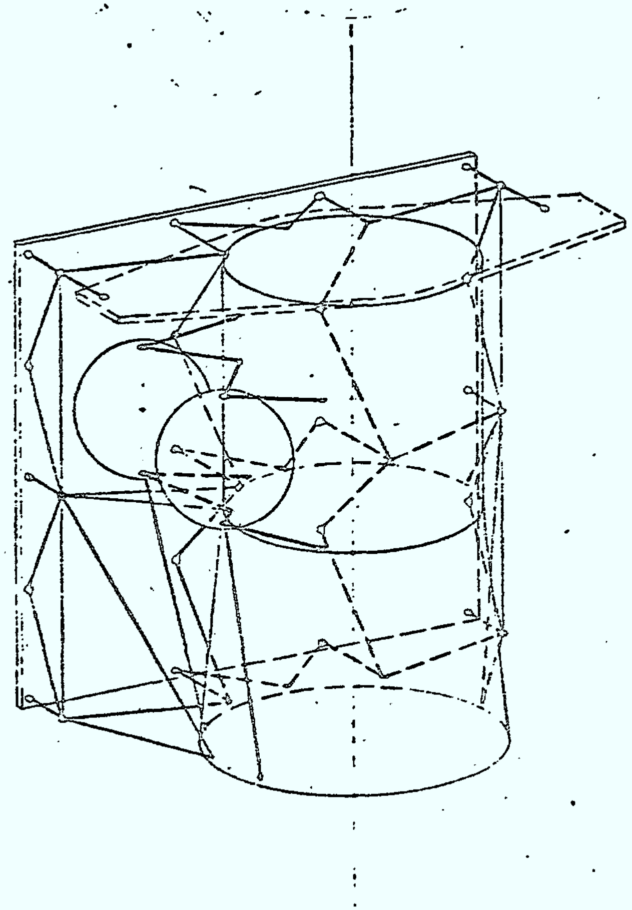
D 31138J1



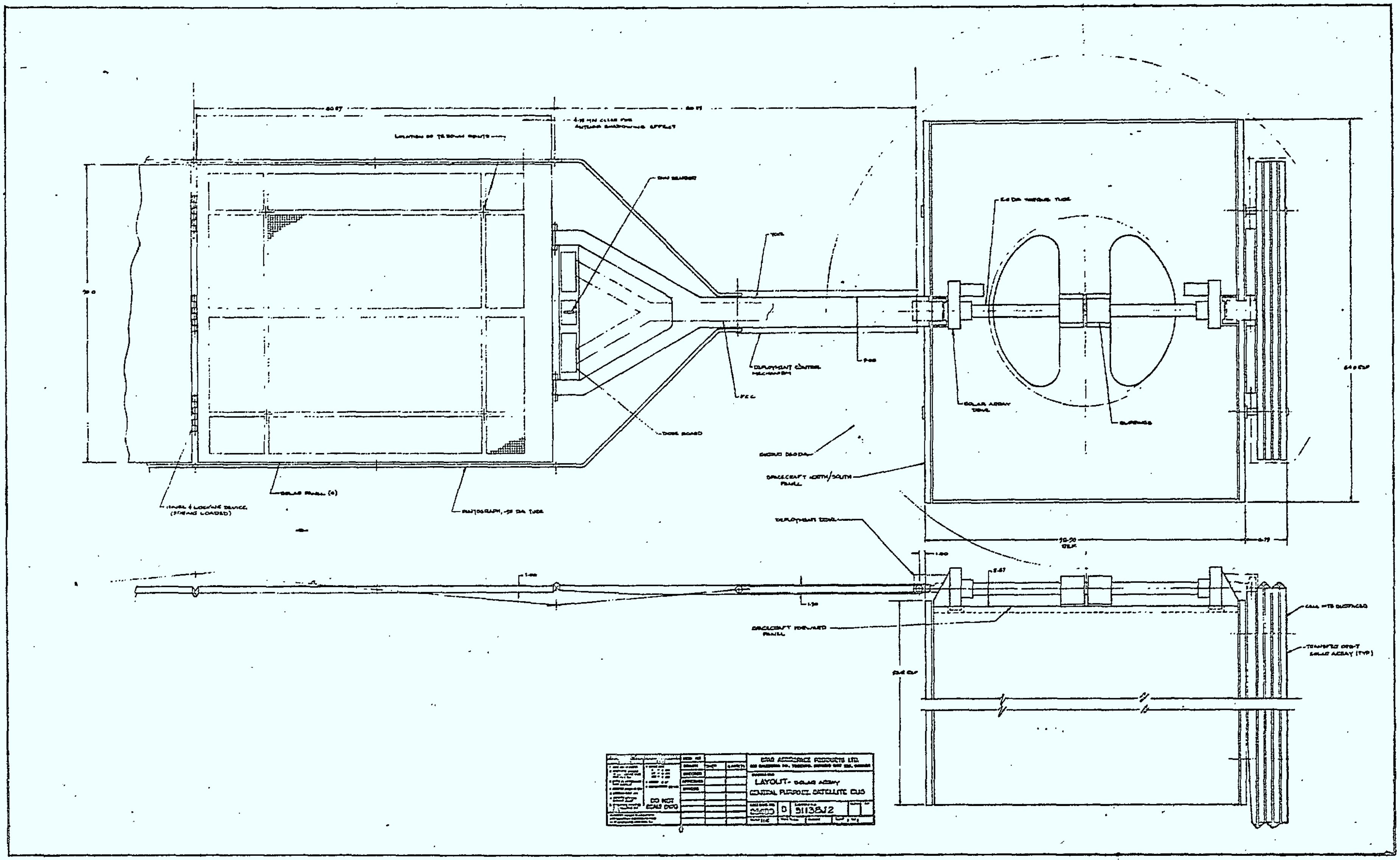

PARTIAL SECTION LOOKING AFT IN YAW PLANE

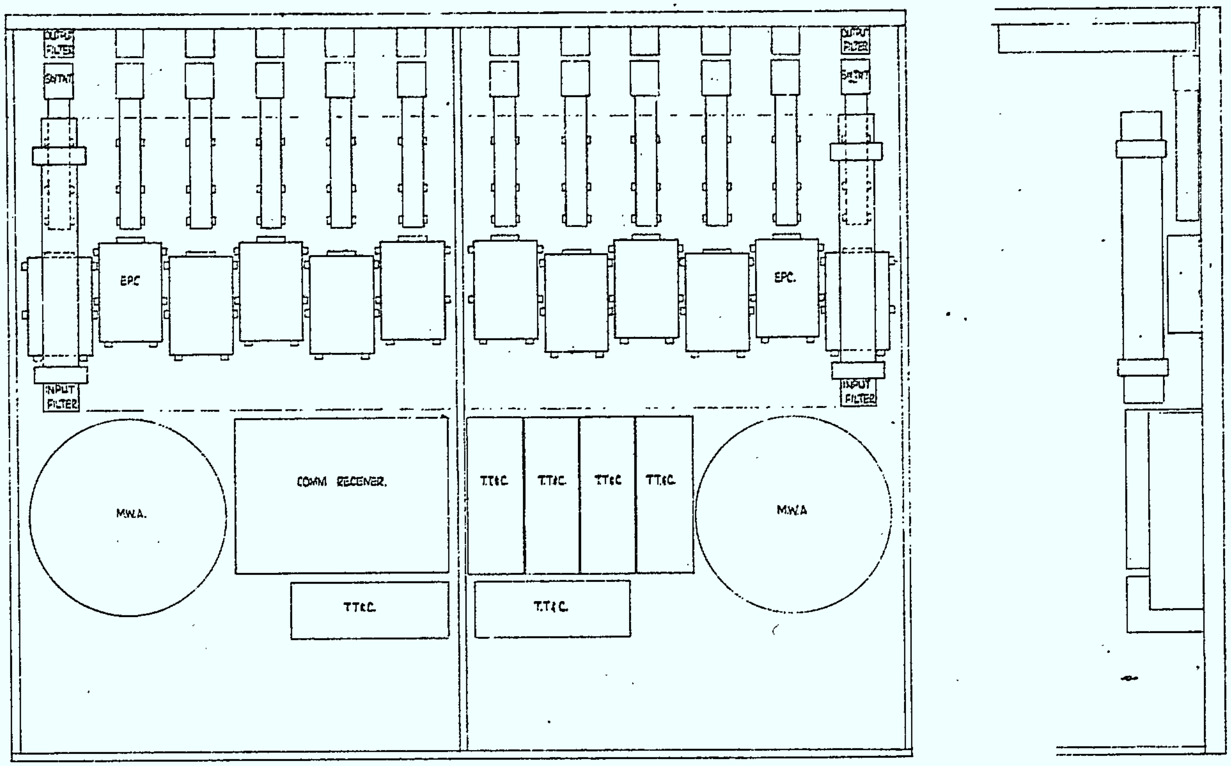



VIEW LOOKING FWD IN YAW PLANE



| | NO./S.C. |
|---|---|
| N/S PANEL SUPPORT | 100 |
| FUEL TANK SUPPORT | 20 |
| THRUST TUBE TERMINATION | 42 (76) |
| ◦ PANEL TERMINATION | 44 (68) |
| ◦ STRUT/STRUT TERMINATION | 12 (64) |
| ◦ | 8 (20) |


SPAR AEROSPACE PRODUCTS LTD.
LAYOUT - SOLAR ARRAY
GENERAL PURPOSE SATELLITE BUS
DO NOT SCALE DWG
0
51138J2



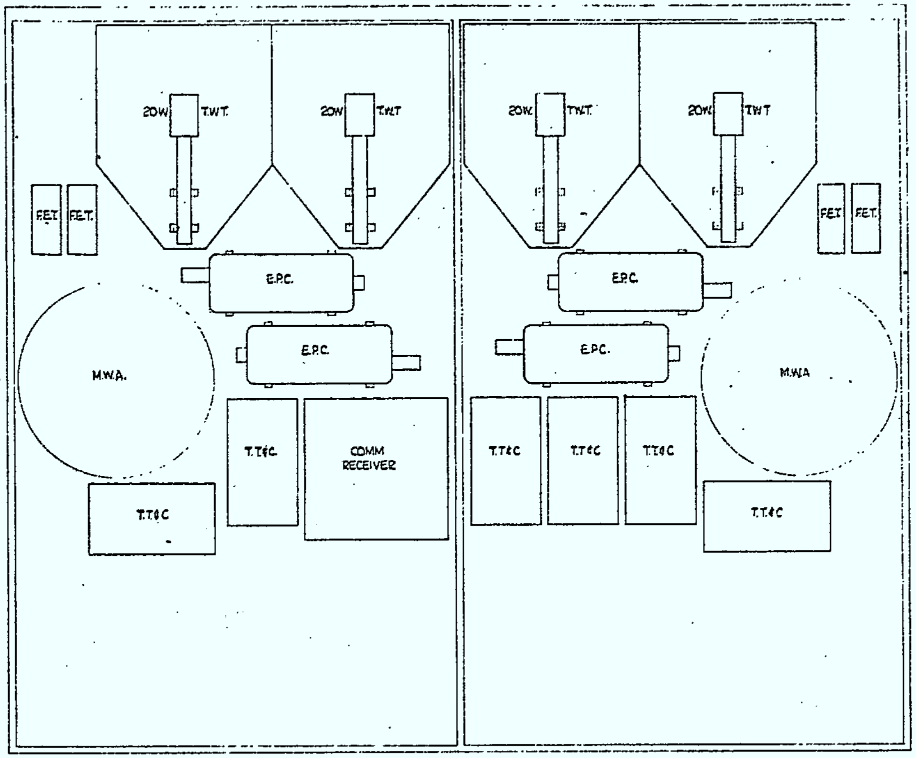

SPAR AEROSPACE PRODUCTS LTD.
TORONTO, ONTARIO, CANADA

| | | |
|---|---|---|
| MOD NO | | |
| DRAWN | | |
| CHECKED | | |
| APPROVED | | |
| STRESS | | |

DRAWING TITLE
12 CHANNEL 4-6 GHz PANEL
GENERAL PURPOSE SATELLITE BUS

| CODE IDENT. NO. | | DRAWING NO. |
|---|---|---|
| 36400 | D | 31138D3 |

SCALE 1/4 | WGT. CALC. | ACTUAL | SHEET 1 OF 1



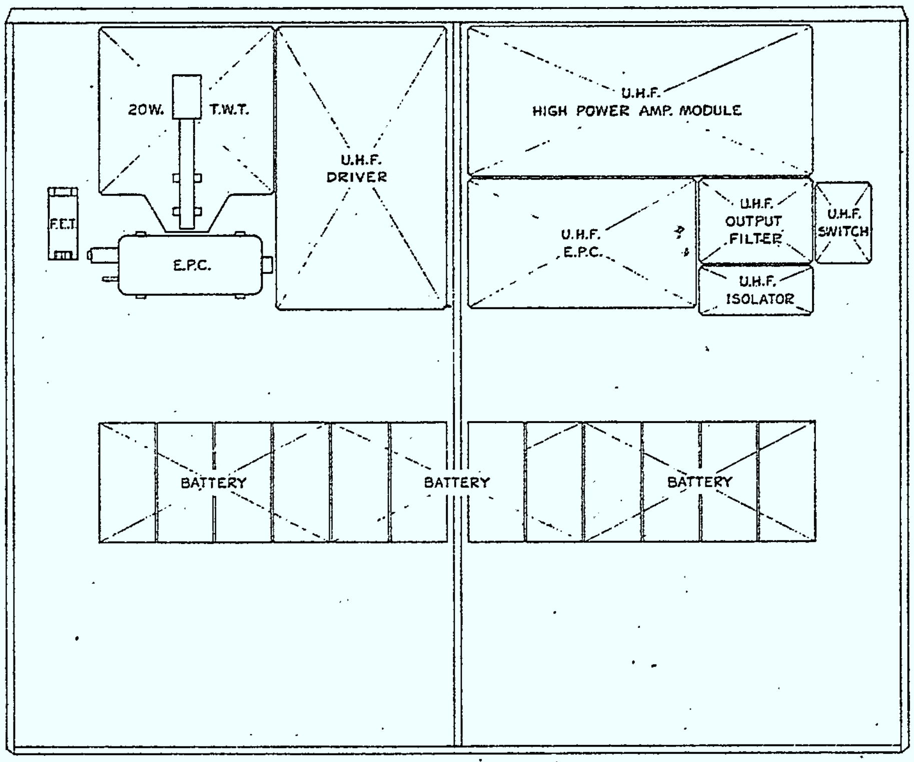

| MCO NO | | |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| APPROVED | | |
| STRESS | | |

SPAR AEROSPACE PRODUCTS LTD.
825 CALEDONIA RD., TORONTO, ONTARIO M6B 3X8, CANADA

DRAWING TITLE
4 CHANNEL 12-14 GHz PANEL
GENERAL PURPOSE SATELLITE BUS

CODE IDENT. NO. 36400 | DRAWING NO. 3I138D5

SCALE 1/4 | WGT. CALC. | ACTUAL | SHEET 1 OF 1




| | | |
|---|---|---|
| MOD NO | | |
| DRAWN | J.A. FRY | 75 |
| CHECKED | | |
| APPROVED | | |
| STRESS | | |

SPAR AEROSPACE PRODUCTS LTD.
[illegible] CALEDONIA RD., TORONTO, ONTARIO [illegible], CANADA

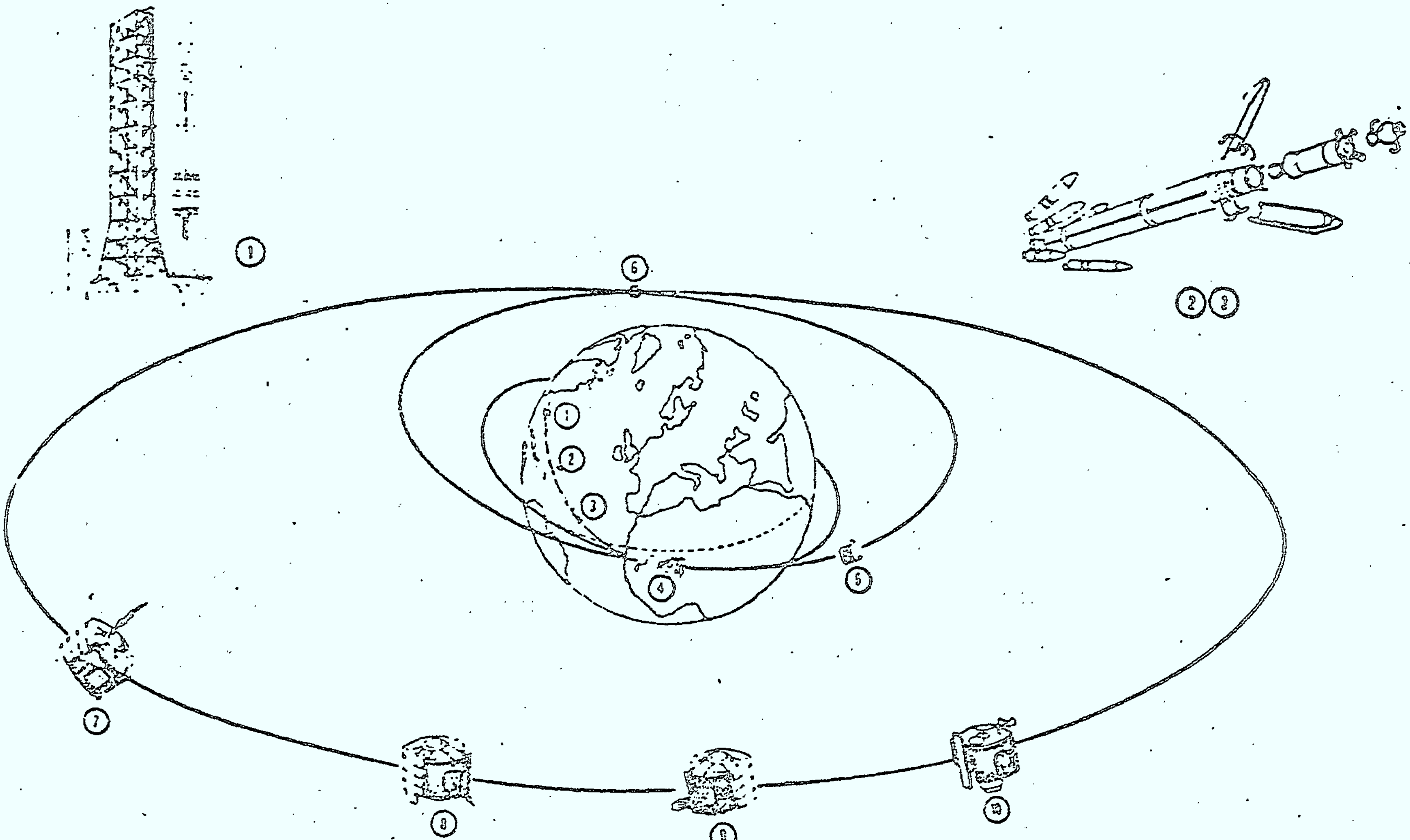
DRAWING TITLE
U.H.F. EQUIPMENT PANEL
GENERAL PURPOSE SATELLITE BUS

CODE IDENT. NO. 36400 | D | DRAWING NO. 8113804 | ISSUE | REV
SCALE 1/4 | WGT. CALC. | ACTUAL | SHEET 1 OF 1

# SECTION 4

# MISSION/LAUNCH VEHICLE

## COMMUNICATIONS TECHNOLOGY SATELLITE




1. LIFT OFF FROM EASTERN TEST RANGE (CAPE KENNEDY)
2. SECOND STAGE IGNITION
3. SPIN-UP TO 60 RPM
4. THIRD STAGE IGNITION
5. ALIGNMENT OF SPACECRAFT FOR APOGEE BURN
6. APOGEE MOTOR FIRING
7. ALIGNMENT OF SPACECRAFT FOR POSITIONING MANOEUVRES
8. POSITIONING OF SPACECRAFT ON STATION
9.
10. SPACECRAFT CORRECTLY ORIENTED

LAUNCH PROCEDURE

6 August, 1971

# DISPERSIONS AND STATION ACQUISITION FUEL

| | | |
|---|---|---|
| APOGEE HEIGHT | 300 NM | ) |
| | | ) |
| PERIGEE HEIGHT | 3.3 NM | ) 3914 - 99% |
| | | ) |
| INCLINATION | 0.25 DEG. | ) |
| APOGEE MOTOR TOTAL IMPULSE | 0.5% | |
| APOGEE MOTOR AVERAGE THRUST DIRECTION ERROR (INCL. ATT. DET.) | 0.4 DEG. | |

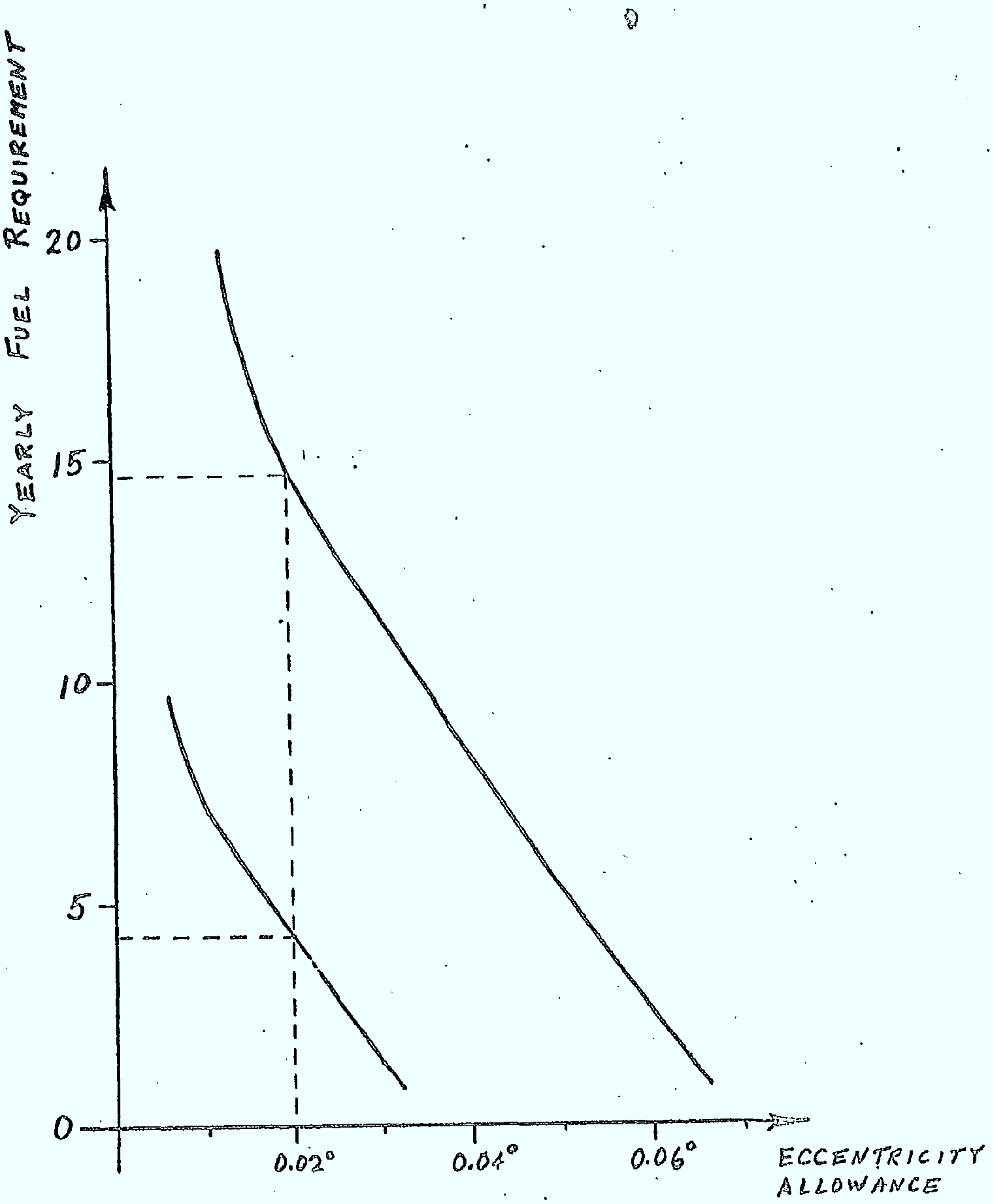
FUEL REQUIRED FOR DISPERSION REMOVAL AND STATION ACQUISITION (IN-PLANE, OUT-OF-PLANE, AND RADIAL) IS 160 FT./SEC.

---

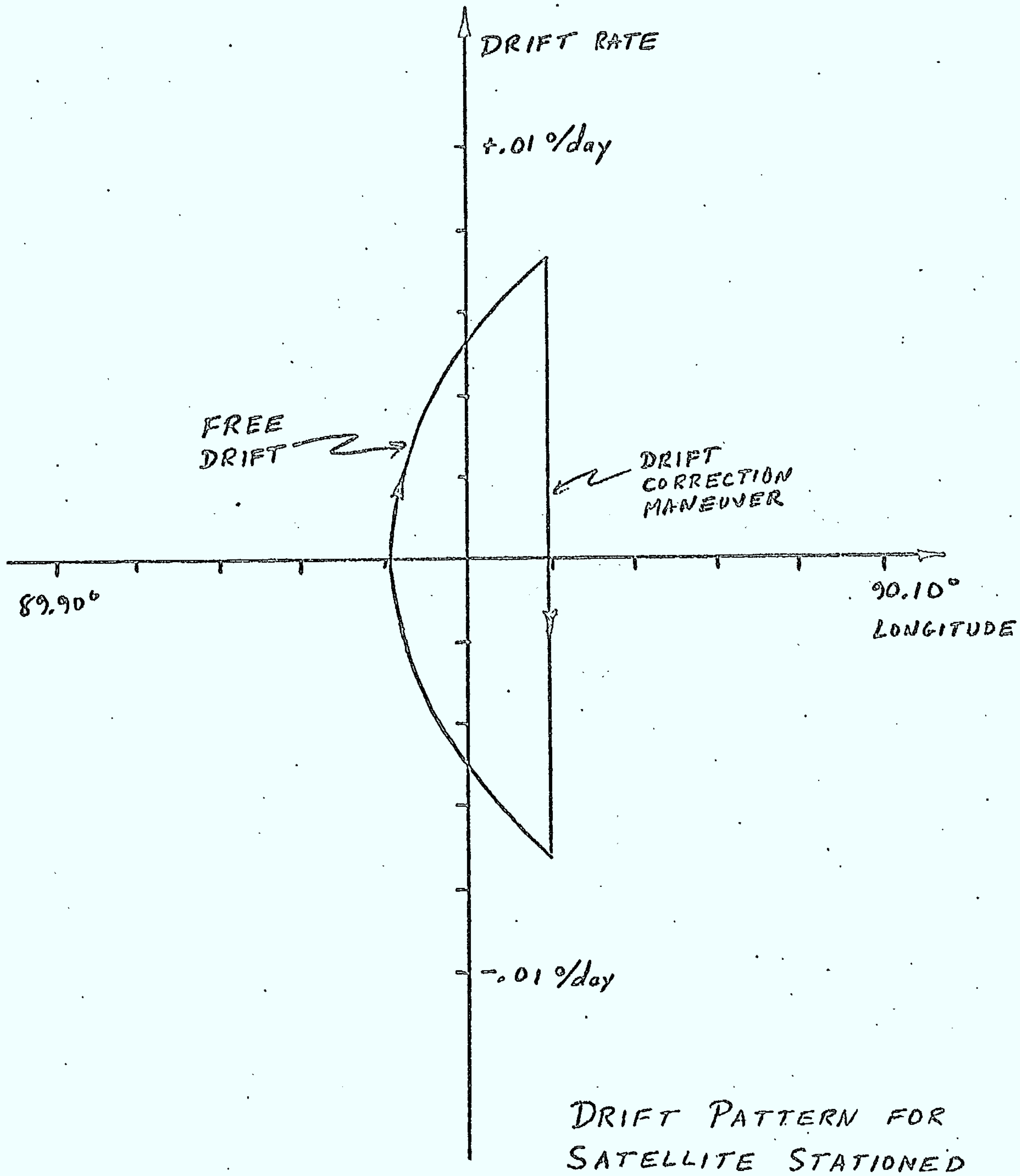
FUEL REQUIRED TO SHIFT LONGITUDE BY 10 DEGREES IN TWO WEEKS IS 13.4 FT./SEC.

# STATIONKEEPING PLAN SUMMARY

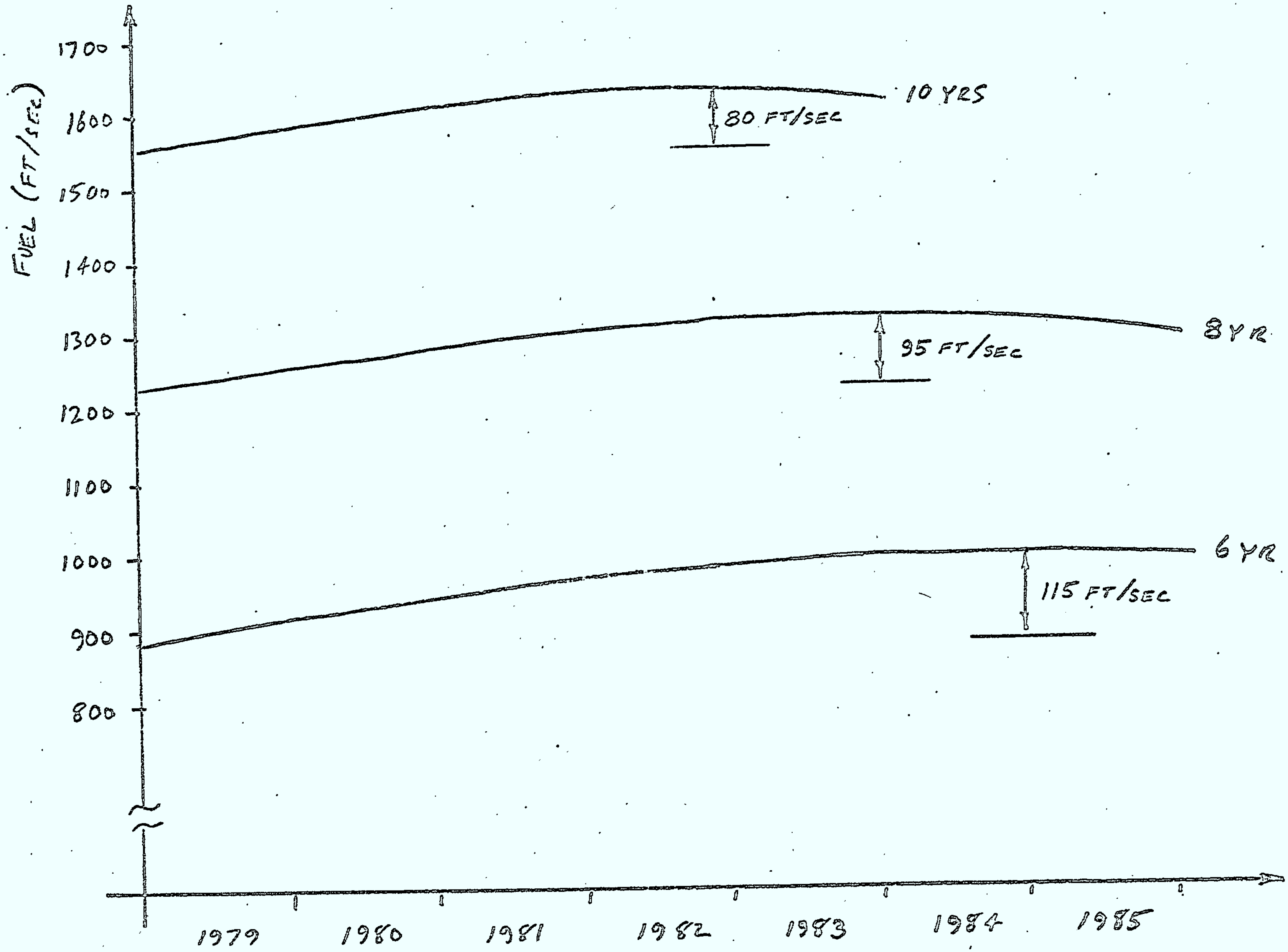
- 3 week cycle, ±0.05° nominal maximum north-south and east-west
- East-West Manoeuvre Pair on Day 0 - at 90° W longitude, manoeuvres are approximately 0.49 and 0.35 ft./sec.
- Optional East-West Manoeuvre Pair in mid-cycle to correct errors, manoeuvres are less than 0.01 ft./sec.
- Inclination Manoeuvre on Day 18 - maximum manoeuvre size is 9.7 ft./sec.
- Yearly east-west fuel is 14½ ft./sec.
- 6 year north-south fuel is 999 ft./sec. maximum
- 8 year north-south fuel is 1,320 ft./sec. maximum (for 1975 launch - 1,124 ft./sec.)



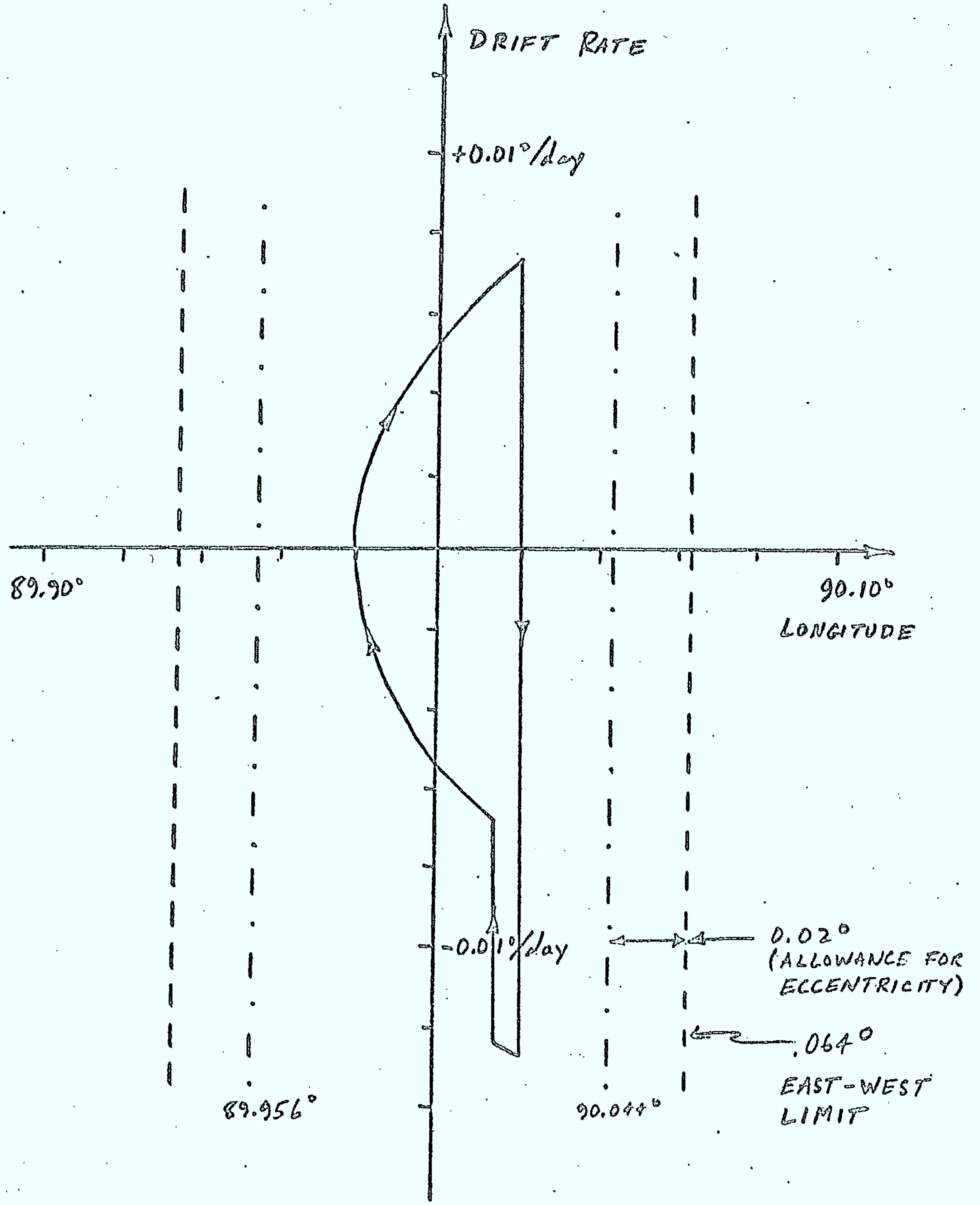

FUEL REQUIRED FOR CORRECTION OF ORBITAL ECCENTRICITY EFFECTS DUE TO SOLAR RADIATION PRESSURE



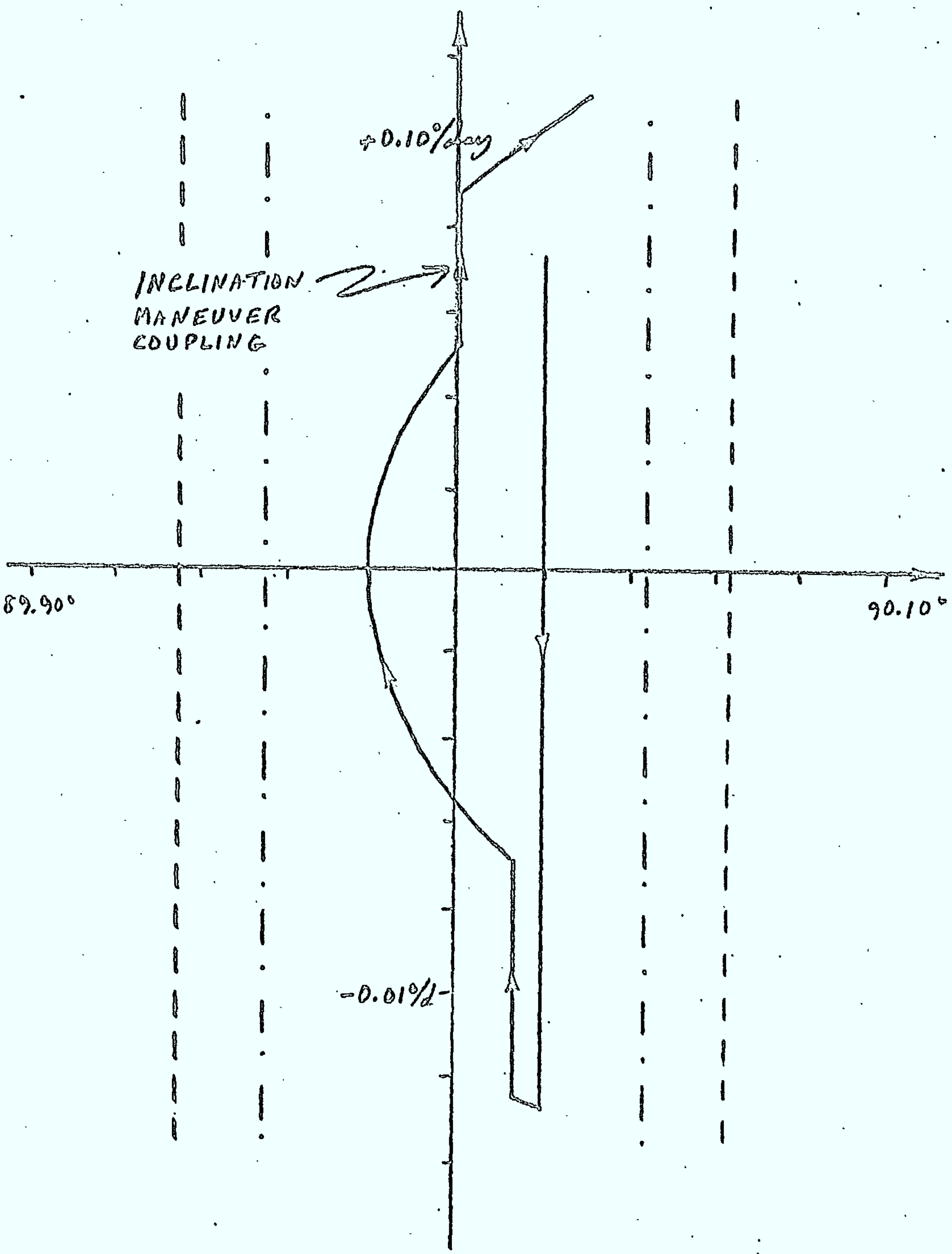

DRIFT PATTERN FOR SATELLITE STATIONED AT 90° W (21 DAY CYCLE)



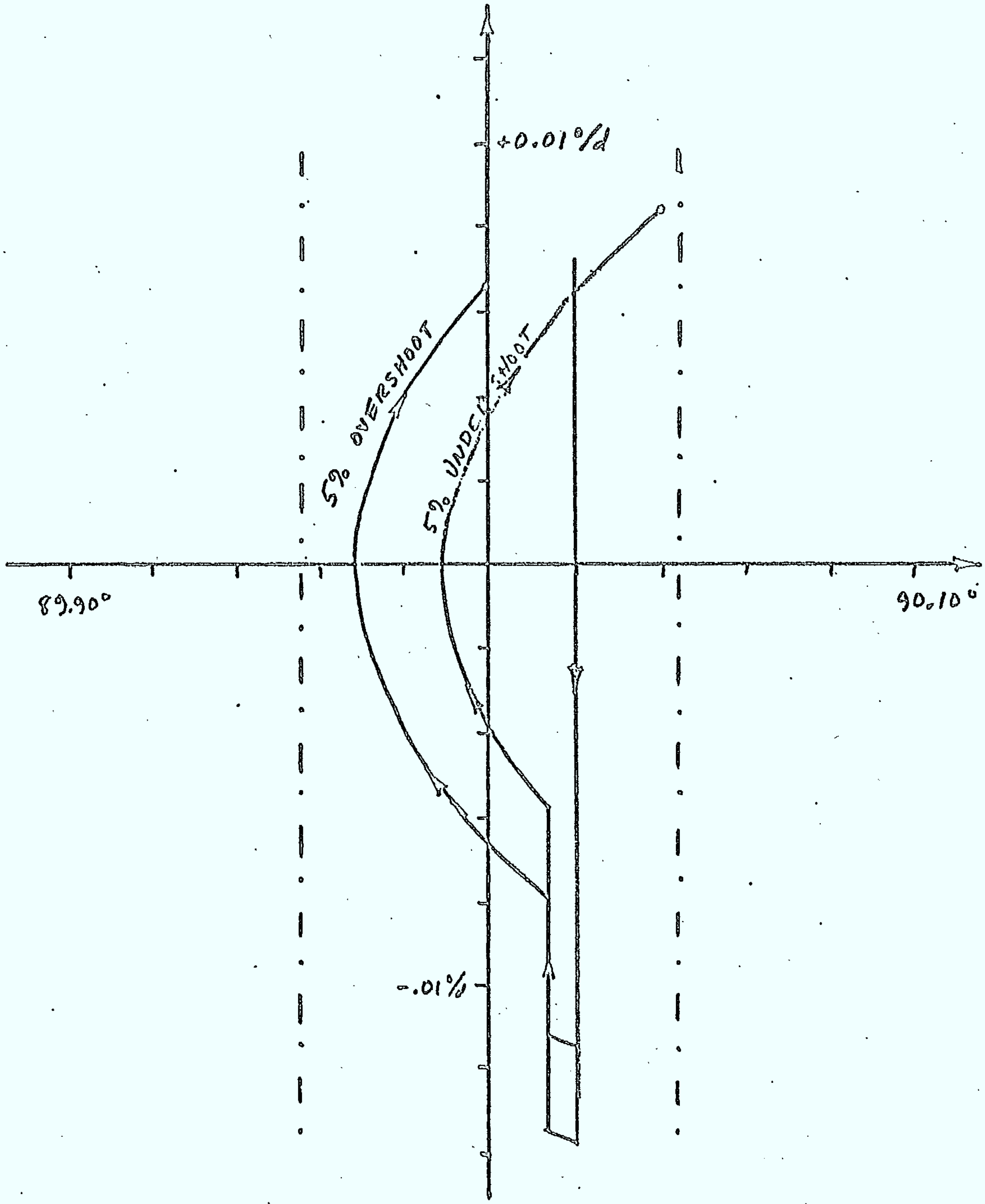

NORTH-SOUTH STATIONKEEPING FUEL



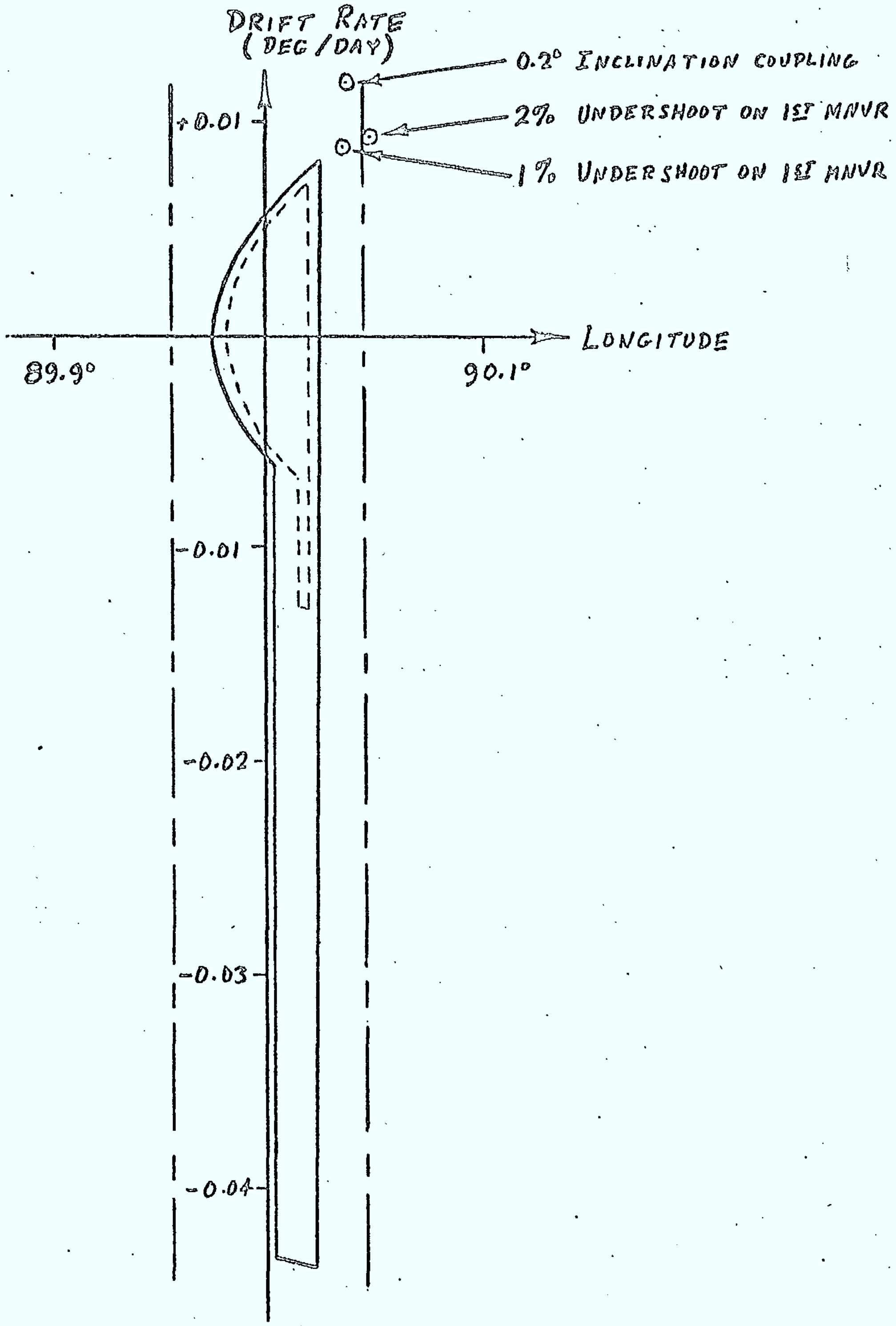

DRIFT PATTERN FOR COMBINED DRIFT AND ECCENTRICITY CORRECTIONS




DRIFT PATTERN FOR
WORST CASE INCLINATION
COUPLING




EFFECT OF DRIFT RATE ERRORS

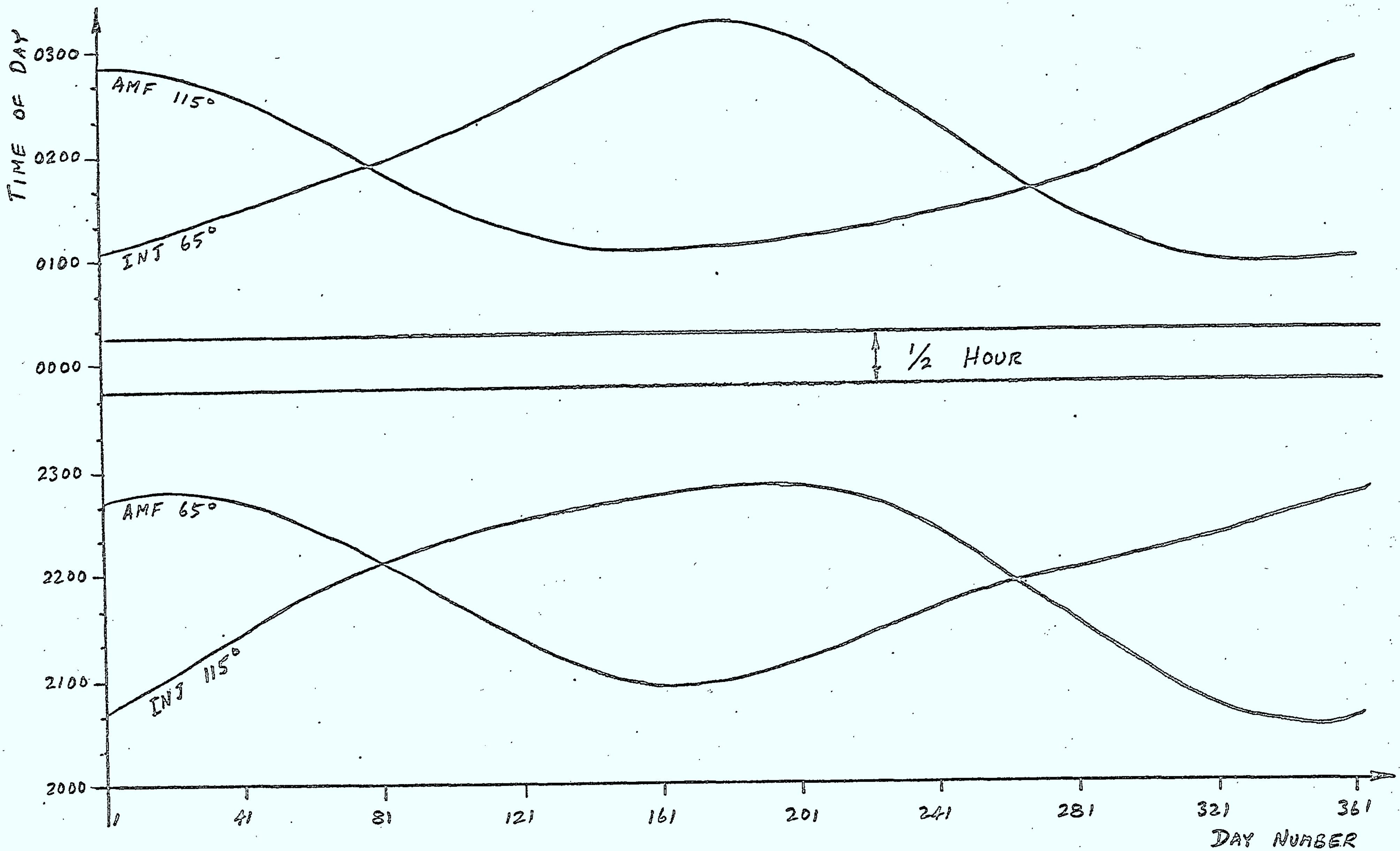



DRIFT PATTERN FOR
COMBINED DRIFT AND
ECCENTRICITY CORRECTIONS

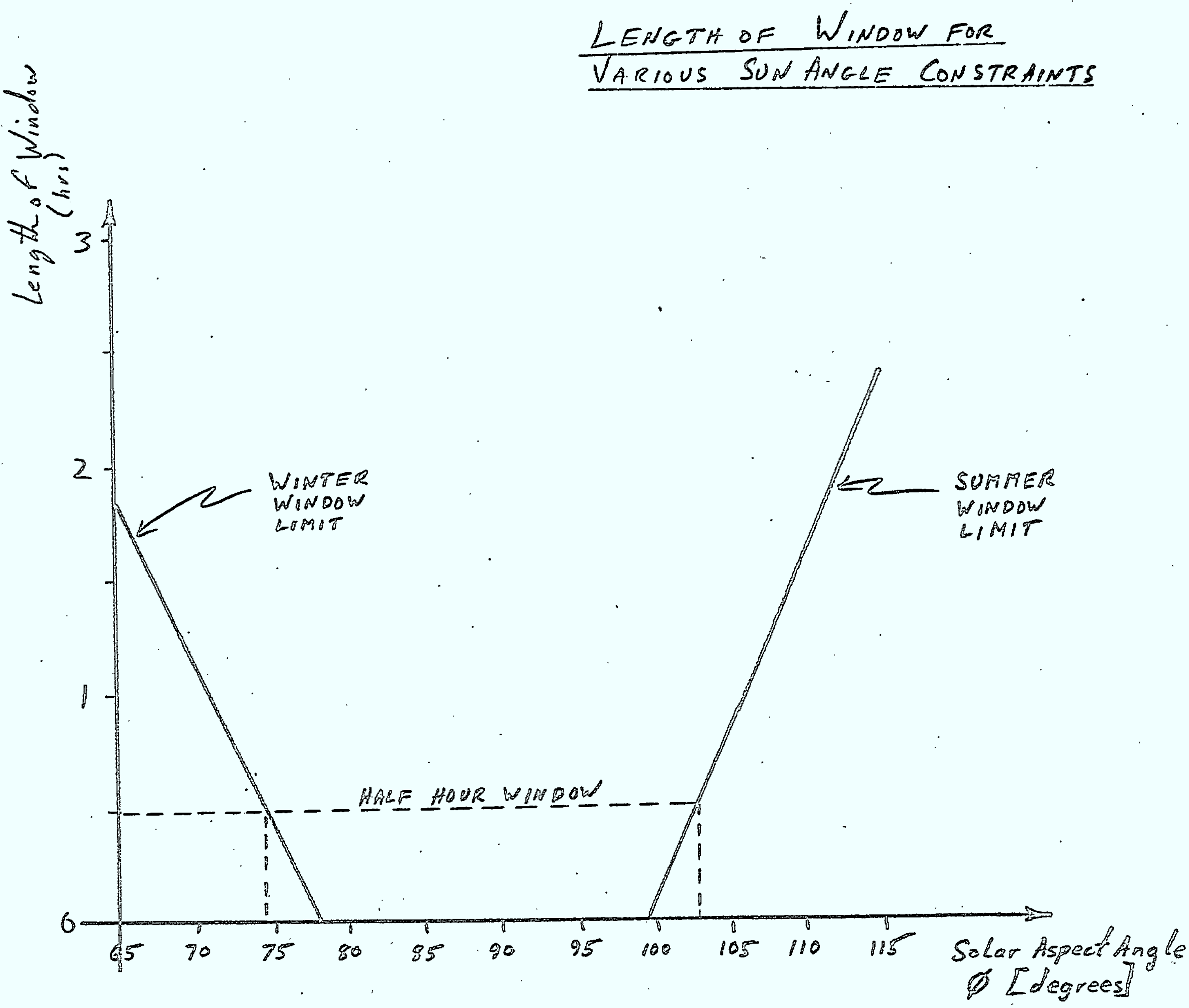
## FUEL BUDGET SUMMARY PAGE

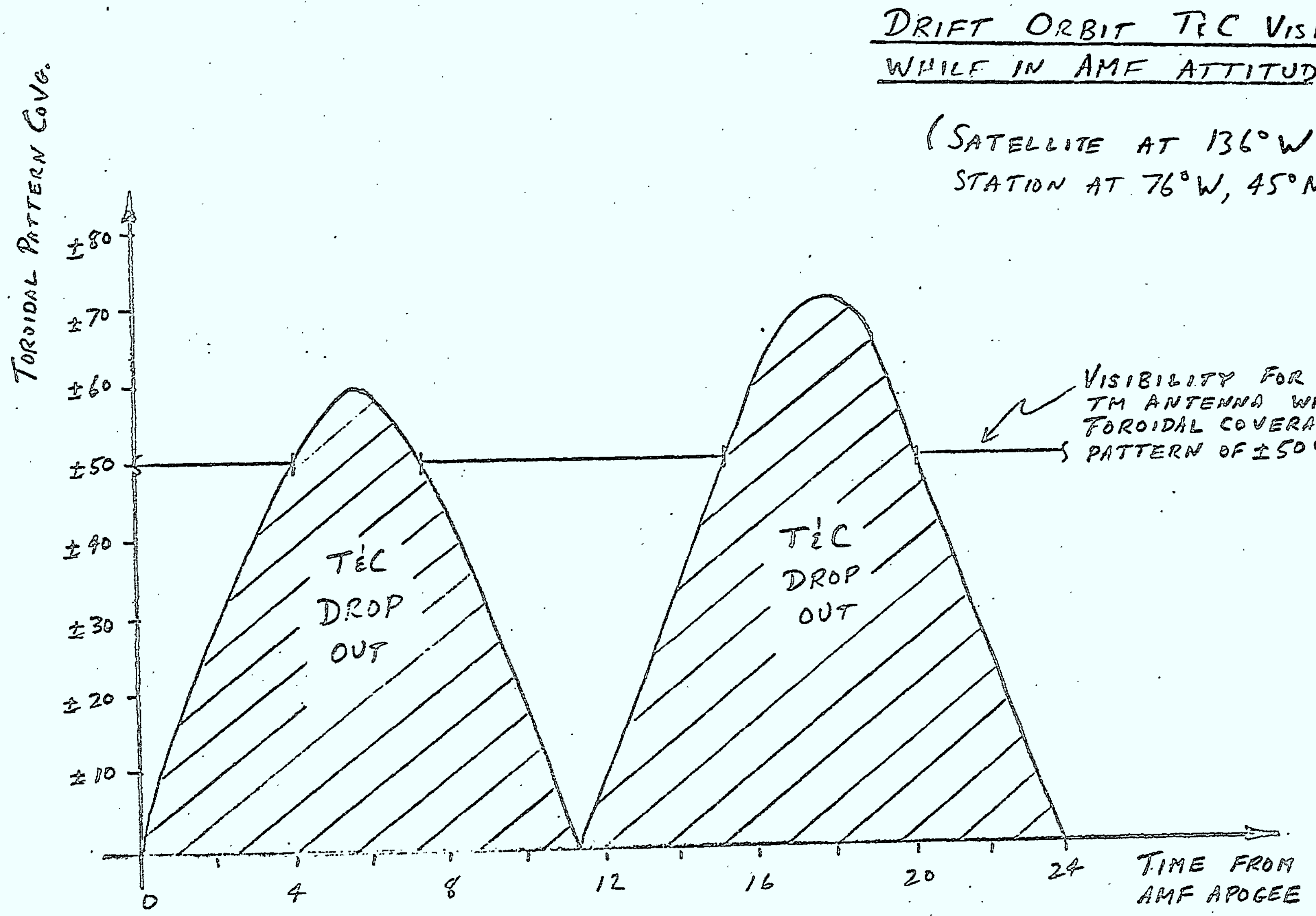
(UHF MULTIPURPOSE BUS)

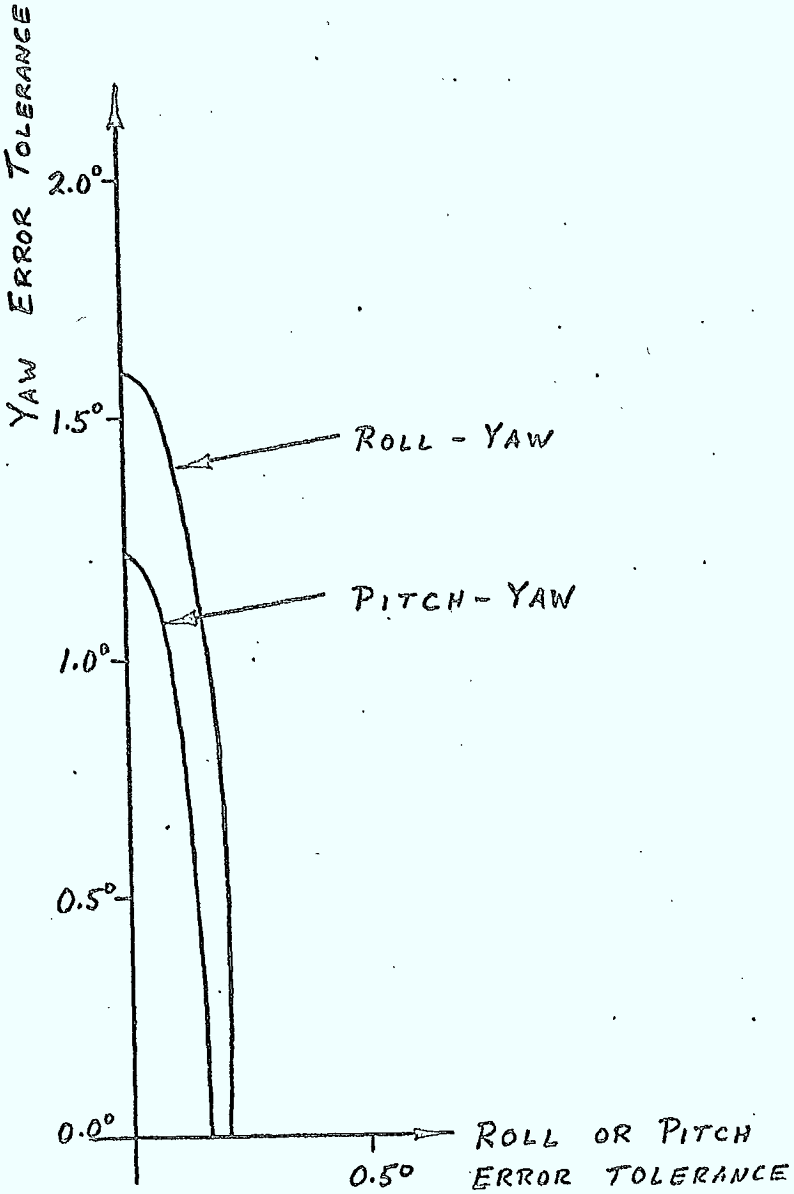
| MANOEUVRES | MISSION 6 Years | MISSION 8 Years | MISSION 10 Years |
|---|---|---|---|
| Pre-AMF Reor | 129.5° | 129.5° | 129.5° |
| Spin Down (from 50 RPM) | 5.235 $\frac{Ir}{r}$ | ← | ← lb.-sec. |
| Reor Post-AMF | 68.3° | 68.3° | 68.3° |
| Attitude Acquisition | | | |
| Station Acquisition and Launch Vehicle - AMF Dispersion Correction | 160 ft./sec. | 160 ft./sec. | 160 ft./sec. |
| East-West Stationkeeping | 87 ft./sec. | 116 ft./sec. | 145 ft./sec. |
| North-South Stationkeeping | 999 ft./sec. | 1,320 ft./sec. | 1,630 ft./sec. |




LAUNCH WINDOW FOR $\phi$ = 65° TO 115° (90° ± 25°)


LENGTH OF WINDOW FOR
VARIOUS SUN ANGLE CONSTRAINTS
Length of Window (hrs)
3
2
1
0
WINTER WINDOW LIMIT
SUMMER WINDOW LIMIT
HALF HOUR WINDOW
65
70
75
80
85
90
95
100
105
110
115
Solar Aspect Angle
Ø [degrees]


DRIFT ORBIT T&C VISIBILITY
WHILE IN AMF ATTITUDE
(SATELLITE AT 136°W
STATION AT 76°W, 45°N)
TOROIDAL PATTERN COVG.
±80
±70
±60
±50
±40
±30
±20
±10
T&C
DROP
OUT
T&C
DROP
OUT
VISIBILITY FOR
TM ANTENNA WITH
TOROIDAL COVERAGE
PATTERN OF ±50°
0
4
8
12
16
20
24
TIME FROM
AMF APOGEE




ROLL - YAW AND PITCH - YAW ERROR TOLERANCE TRADEOFFS

# SECTION 5

# GENERAL PURPOSE SATELLITE

# ATTITUDE CONTROL SYSTEM

## MAJOR DESIGN CONSIDERATIONS

- 8 year life

- Autonomous Attitude Acquisition

- Stationkeeping accuracy $\pm 0.1^{\circ}$ North-South and East-West with a design goal of $\pm 0.05^{\circ}$. Orbit adjust intervals of not less than 21 days as a design goal.

- Capable of pitch slew of up to $\pm 0.5^{\circ}$ to accommodate change of station longitude.

POINTING ACCURACY

| CONTROL AXIS | ACCURACY DURING ORBIT ADJUST THRUSTING | ACCURACY DESIGN GOAL |
|---|---|---|
| Pitch | $\pm 0.15^{\circ}$ | $\pm 0.1^{\circ}$ |
| Roll | $\pm 0.15^{\circ}$ | $\pm 0.1^{\circ}$ |
| Yaw | $\pm 1.0^{\circ}$ | $\pm 1.0^{\circ}$ |

# ATTITUDE CONTROL SYSTEM TRADE-OFFS

Two basic types considered:

- Biased Momentum
- Zero Momentum

Biased momentum system requires yaw sensing only during orbit adjust thrusting.

Zero momentum system requires continuous yaw sensing.

# SPACECRAFT CONFIGURATIONS

Two basic configurations considered:

- Through shaft solar array mounted forward of the centre of mass

- Split shaft solar array mounted along the centre of mass

Rigid solar arrays only have been considered.

# SOLAR DISTURBANCE TORQUES

## A THROUGH SHAFT ARRAY MOUNTED FORWARD OF CM

Pitch : $22 \times 10^{-6}$ ft.lb. Periodic

Roll/Yaw : $5.5 \times 10^{-6}$ ft. lb. Periodic (constant Roll Torque)

$+ 4.8 \times 10^{-6}$ ft. lb. Secular

## B SPLIT SHAFT ARRAY MOUNTED ON CM

Pitch : $0.3 \times 10^{-6}$ ft. lb. Periodic

Roll/Yaw : $4.8 \times 10^{-6}$ ft. lb. Secular

## SOLAR DISTURBANCE TORQUES

### A PITCH

| | | |
|---|---|---|
| $T_p =$ | $0.3 \times 10^{-6} \sin (2 W_o t)$ | Due to Antenna |
| | $+ 22 \times 10^{-6} \cos^2\theta_d \cos (W_o t)$ | Due to array offset |
| | $+0.3 \times 10^{-6} \cos \theta_d \sin (W_o t)$ | Due to array tracking error |

### B ROLL

| | | |
|---|---|---|
| $T_r =$ | $7.5 \times 10^{-6} \sin (2 \theta_d)$ | Due to array offset |
| | $+3.2 \times 10^{-6} \cos^2\theta_d \cos (W_o t)$ | Due to CP-CM mismatch |
| | $+0.7 \times 10^{-6} \cos\theta_d \sin (W_o t)$ | Due to Propeller Effect |
| | $+2.1 \times 10^{-6} \sin (2\theta_d) \cos (W_o t)$ | Due to Di-hedral Effect |

### C YAW

| | | |
|---|---|---|
| $T_y =$ | $-3.2 \times 10^{-6} \cos^2\theta_d \sin (W_o t)$ | Due to CP-CM mismatch |
| | $-0.7 \times 10^{-6} \cos\theta_d \cos (W_o t)$ | Due to Propeller Effect |
| | $-2.1 \times 10^{-6} \sin (2\theta_d) \sin (W_o t)$ | Due to Di-hedral Effect |

$\theta_d$ = Sun Declination Angle

$W_o$ = Orbit Rate ($7.29 \times 10^{-5}$ rad/sec.)

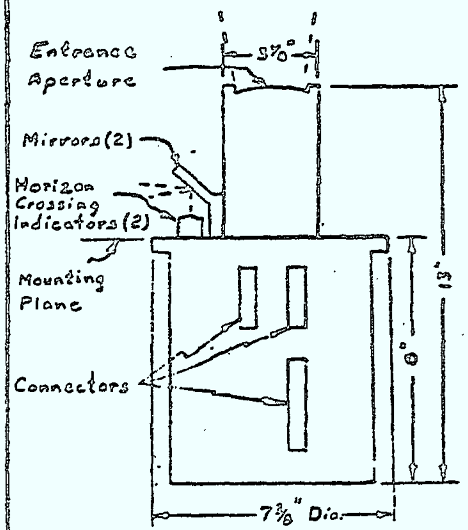
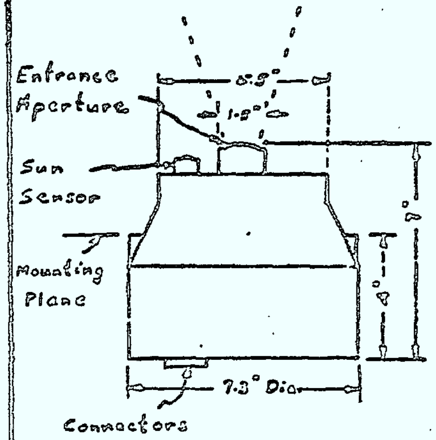
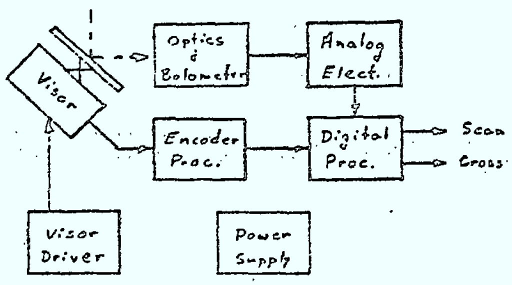
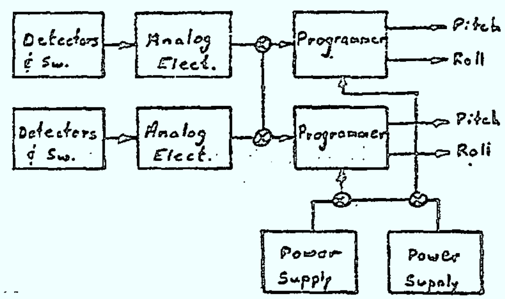
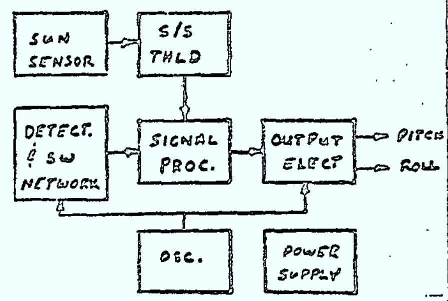
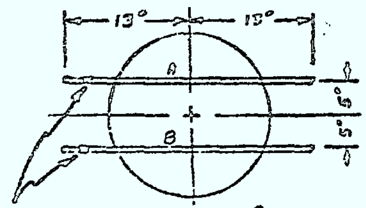
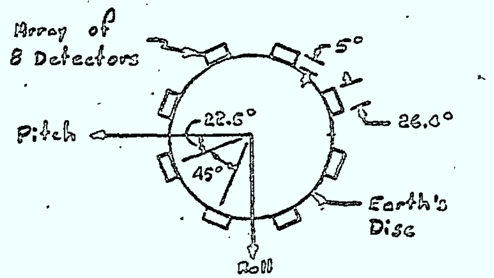
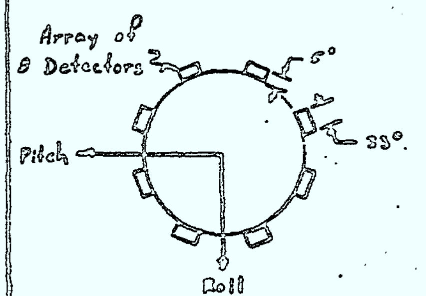
t = Time

| | | |
|---|---|---|
| Array tracking error | = | $\pm 1^o$ |
| CP-CM mismatch | = | 2" |
| Propeller angle | = | $\pm 0.2^o$ |
| Di-hedral tip deflection | = | 1" |

## MAJOR ON-ORBIT COMPONENTS

- Roll and Pitch Sensors
  - Thermal balance Infra-red Earth sensors
  - Scanning Infra-red Earth sensors
  - Micro-wave Attitude Sensor System
- Yaw Sensors
  - Sun Sensor
  - Sun Sensor plus Rate Integrating gyro
  - Micro-wave Attitude Sensor System plus Earth Sensor or POLANG
- Wheels
  - Momentum Wheels (Biased Momentum)
  - Reaction Wheels (Zero Momentum)
- Thrusters
- Control Electronics
  - Special Purpose Digital Controllers
  - General Purpose Digital Computers

FIGURE 5 - EARTH SENSOR STUDY - EQUIPMENT DEFINITION

| Characteristic | TRW | BEC | QUANTIC |
|---|---|---|---|
| Envelope | Envelope for 'Next Generation' sensor not yet established.<br><br>To minimize weight, consideration will be given to integrating the electronics unit with the optical head. |  |  |
| Block Diagram | <br>2 OFF REQD - CHANNEL A & B | <br>Cross Strapping provides 8 combinations |  |
| Field of View Pattern | <br>0.75° Square Field of View Scanned at 4.4 Hz rate |  |  |

## THERMAL BALANCE SENSORS

- Poor Accuracy (0.1° 3 σ, each Axis)
- Pitch slew requirement not feasible since accuracy degrades off-null (25% of pitch angle)
- Relatively expensive (500-600 K or more)
- Reliability and built-in redundancy good (.98-.99 for 8 years)
- Weight 10-11 lb.
- Power 4-5 watts
- Typical Applications - BSE, ERTS, GPS

## SCANNING INFRA-RED SENSORS

- Acceptable Accuracy (0.05° 3σ, each axis)
- Pitch slew requirement easily accommodated
- Least expensive
- Two independent sensors required for redundancy
- Weight 14 lb.
- Power 4-5 watts
- Typical Applications - CTS, SATCOM, FLTSATCOM, ATS

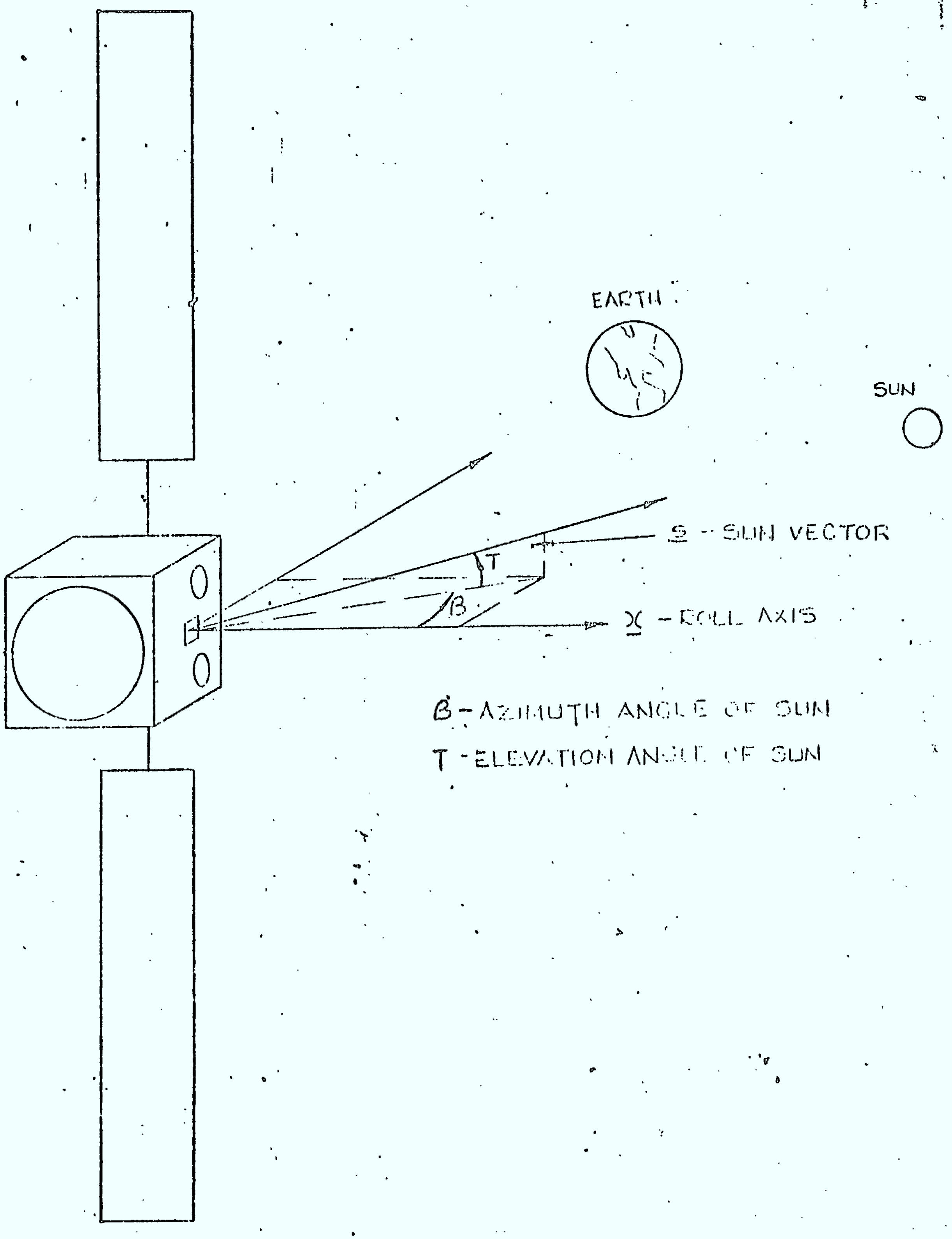
## MICRO-WAVE ATTITUDE SENSOR SYSTEM

- Excellent Accuracy in Roll and Pitch ($0.02^\circ$ $3\sigma$ RSS of Roll and Pitch)
- Pitch slew requirement automatic since sensor looks directly at relevant ground station
- Ground transmitter required
- Present developed model is non-redundant and does not include POLANG. Development costs likely incurred
- Weight of present non-redundant unit 8 lb.
- Power 10 watts
- Station acquisition likely required prior to Attitude Acquisition
- Possibly susceptible to jamming
- Typical Application - BSE

## YAW SENSING WITH ADCOLE T-B

## SUN SENSOR ONLY

- No yaw sensing ability within $\pm 30^{\circ}$ of noon and midnight
- Weight 2.8 lb. for redundant system
- Power 1 watt
- Reliability - high
- Accuracy $\approx 0.8^{\circ}$ at $60^{\circ}$ FOV limit
- On-board yaw angle computation requires approx. 250-300 words memory




SUN SENSOR GEOMETRY

## YAW ANGLE COMPUTATION

## USING SUN SENSOR

$$\psi = \frac{1}{\cos B}\left(T - T_o + \phi \sin B\right)$$

$\psi$ = Calculated Yaw Angle

$\phi$ = Roll Angle (from Earth Sensor)

$T$ = Sun Elevation (from Sun Sensor)

$T_o$ = Nominal Sun Elevation Angle

- Calculated on board

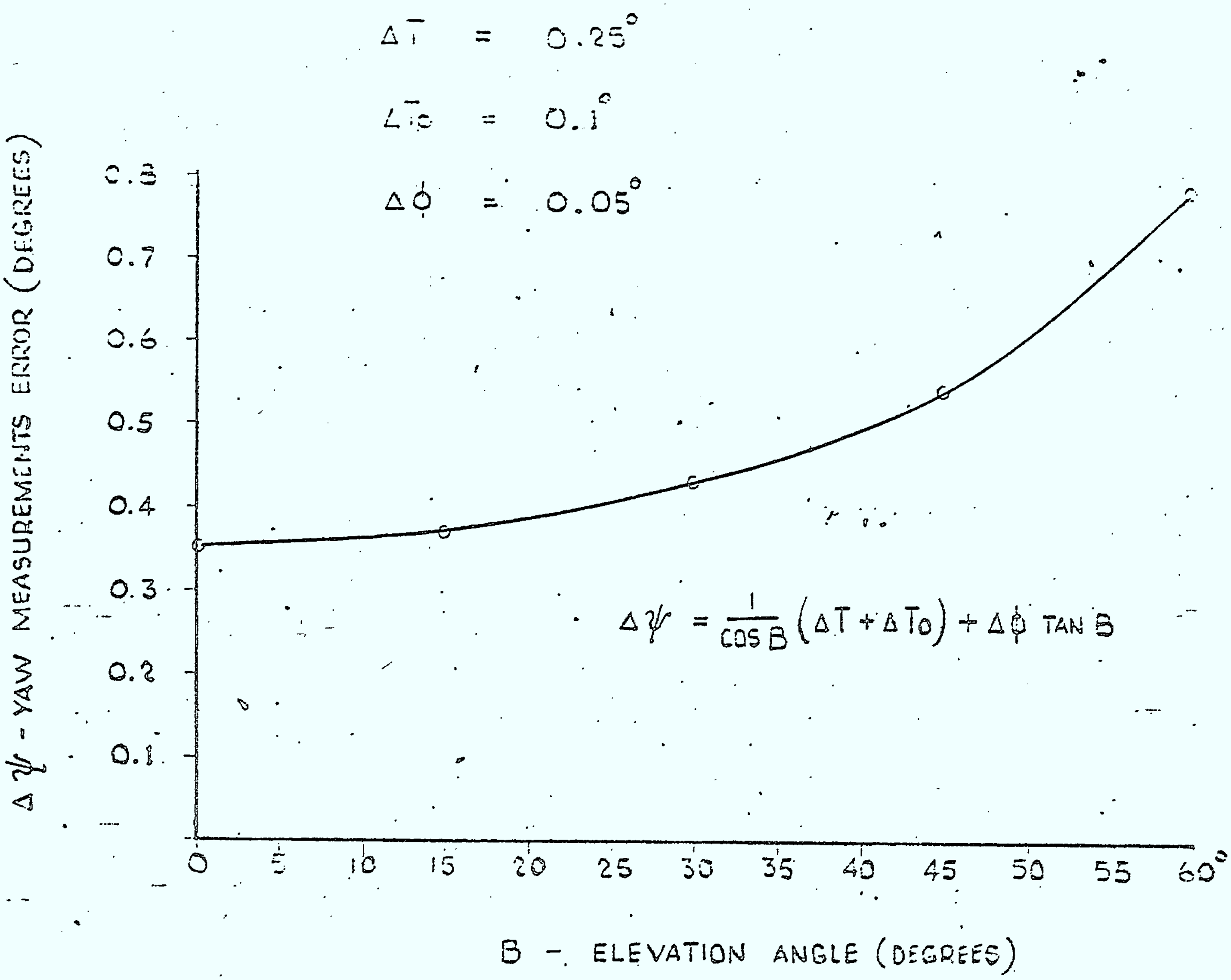
or

- Transmitted via Telemetry

$B$ = Sun Azimuth Angle

- From Sun Sensor with Cos B, Sin B calculated on board, or
- Cos B, Sin B Transmitted via telemetry

$\Delta\psi$ - ERROR IN YAW MEASUREMENT USING SUN SENSORS



## NORTH-SOUTH STATIONKEEPING USING SUN

## SENSOR FOR YAW SENSING

- No fuel penalty for $\pm 0.09^\circ$ inclination

- Fuel penalty less than 5 lb. for $\pm 0.05^\circ$ inclination control

Note:

For inclination control less than $.09^\circ$, off node correction required during solstice periods. A non-optimal sequence for $\pm 0.05^\circ$ control is:

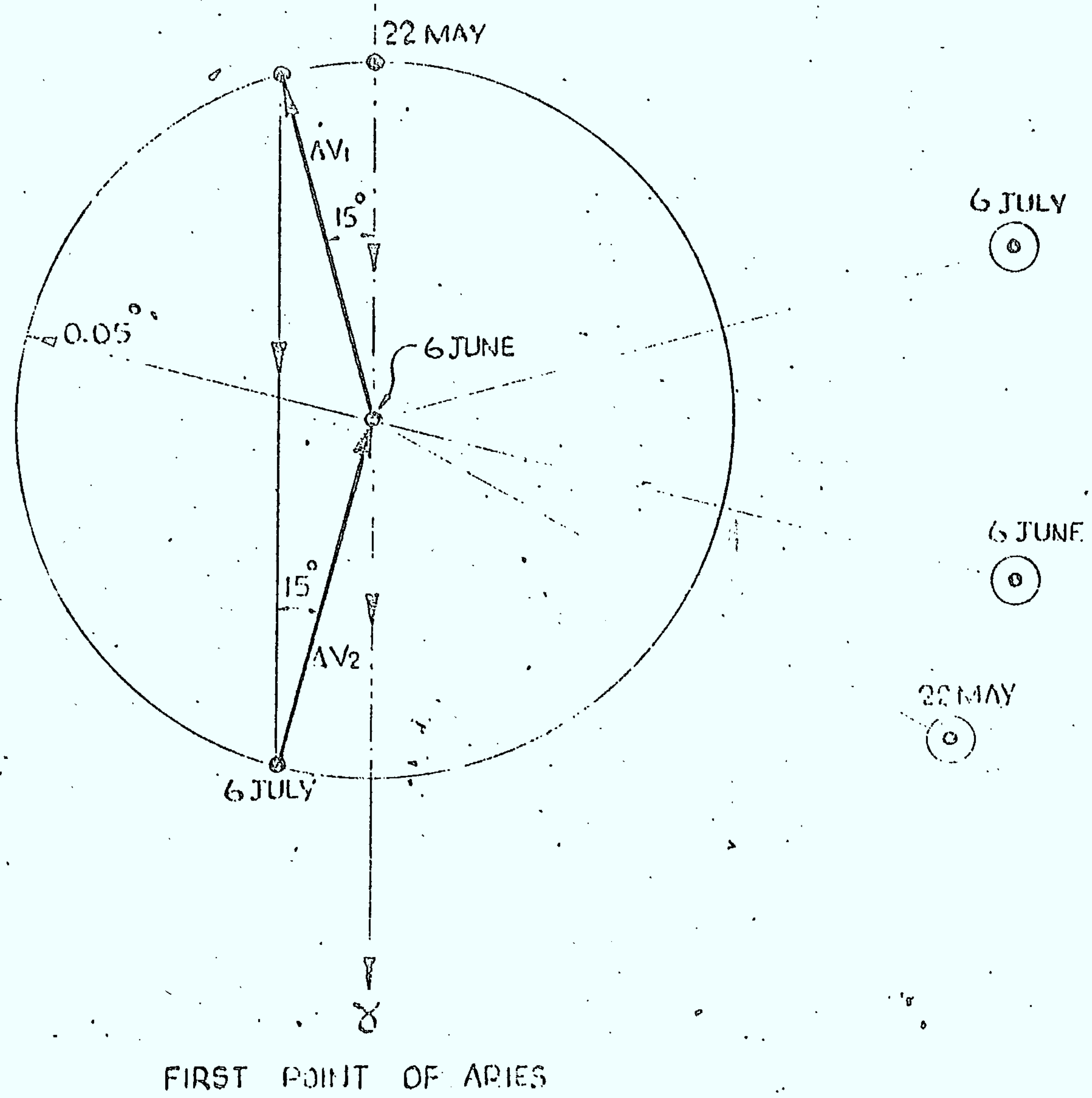
22 May - adjust inclination to $.05^\circ$

6 June - readjust inclination to $.05^\circ$ and rotate node by $15^\circ$

6 July - adjust inclination to $0^\circ$ and re-rotate node by $15^\circ$

This results in a fuel penalty of 5 lb. for 6 years.

DRIFT RATE = .003° PER DAY TOWARD ♈




NON OPTIMAL STATION KEEPING PLAN FOR ±.05°

USING ±60° FOV SUN SENSOR

## RATE INTEGRATING GYRO PLUS SUN SENSOR

- Continuous Yaw sensing
- Sun sensor used to update gyro every 12 hours
- System accuracy 0.35°
- Weight

| | | |
|---|---|---|
| | 3 gyros | 9.0 lb. |
| | 2 sun sensors | 2.8 lb. |
| | | 11.8 lb. |

- Power 36 watts
- Reliability .968 for 8 years

## MICRO-WAVE ATTITUDE SENSING SYSTEM

- Provides continuous Yaw sensing

- Accuracy with two station method (MASS + Earth Sensor) approx. 0.7° for transmitter at 61° latitude. Total weight of redundant MASS plus redundant earth sensors approx. 30 lb.

- Accuracy with POLANG yaw measurement technique (no earth sensor needed) approx. 0.4° using 14 GHz reference. Weight of redundant Mass approx. 17 lb.

- No sun sensor required

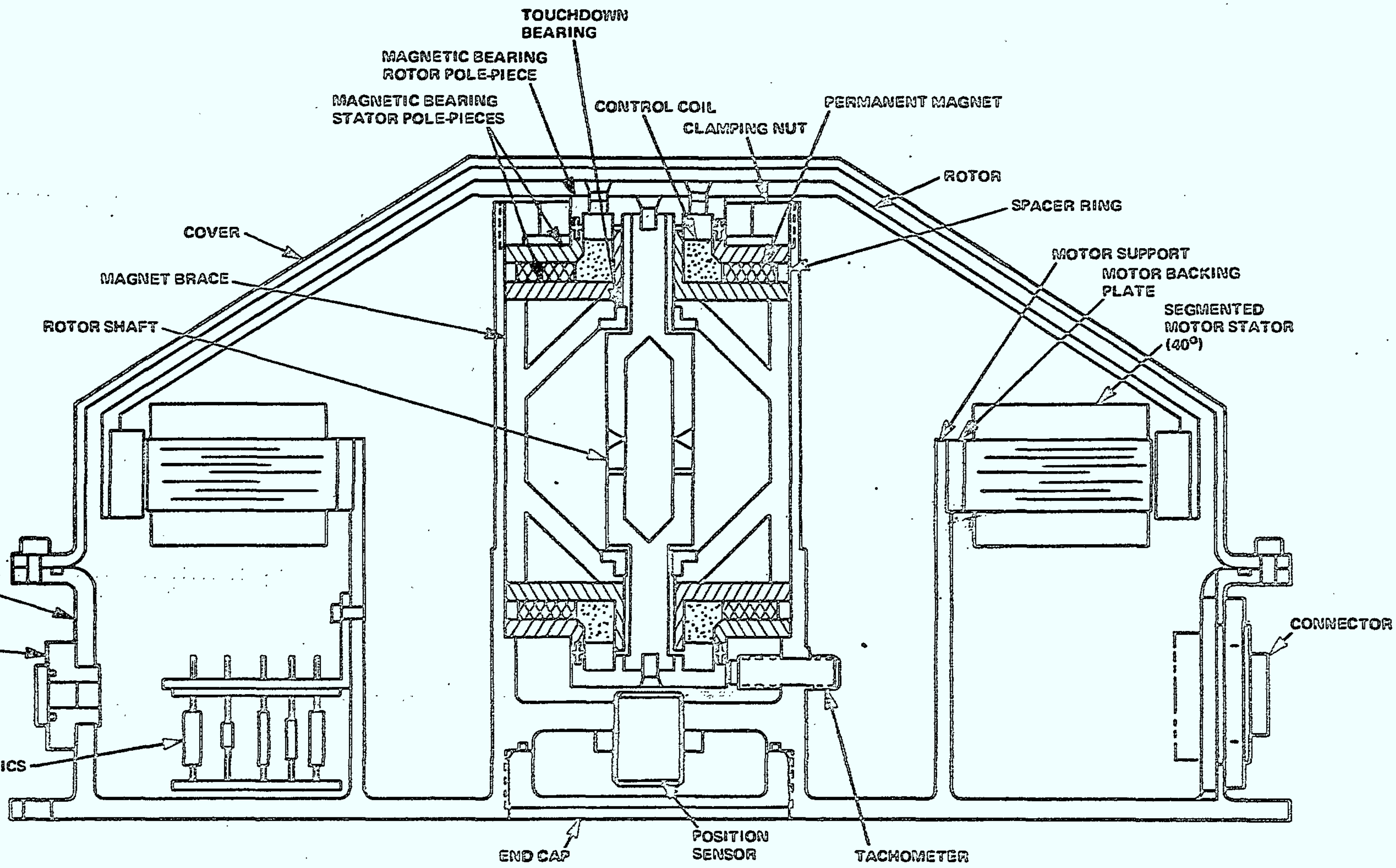
## MOMENTUM WHEELS

- Conventional ball bearing wheels require complete redundancy. Concern in some quarters that conventional bearing wheels cannot meet long life requirements of next generation satellites.

- Magnetic bearing wheels under development. Single wheel only required since magnetic suspension eliminates wear-out mechanism. To be flight tested within 2 years. Potential yaw sensor available through radial displacement measurement of wheel axis. This technology development bears monitoring.

- Conventional bearing wheels assumed for present trade-off.

# PRELIMINARY RWA LAYOUT




SPERRY FLIGHT SYSTEMS

44-5100-2-029-26

## MOMENTUM/REACTION WHEELS

## ADVANTAGES OF MAGNETIC VS BALL BEARINGS

- Higher reliability (can achieve "no single point failure" criteria in a single wheel)

- Lower weight (no need for redundant wheels)

- Lower power (negligible levitation power in orbit, no windage or friction losses)

- Better environment tolerance (hermetic seal not required, thermal/lubrication problems avoided, no brinelling due to shock)

- Fabrication/assembly easier (broad tolerances, less susceptible to contamination)

- Cost (slightly less as ball bearings require ball selection and lubrication)

# DESIGN STUDY RESULTS

| PARAMETER | DESIGN OBJECTIVE | ATTAINED VALUE |
|---|---|---|
| ANGULAR MOMENTUM | ±.5 FT-LB-SEC | ±.5 FT-LB-SEC |
| WEIGHT | 8 LB | 6.62 LB |
| VOLUME | 250 $IN.^3$ | 220 $IN.^3$ |
| CROSS AXIS RATE (MAX) | .017 RAD/SEC | .83 RAD/SEC |
| OUTPUT TORQUE | .01 FT-LB | .01 FT-LB |
| DRAG TORQUE | — | .015 OZ-IN. |
| MOTOR POWER (MAX) | 8 WATTS | 8 WATTS |
| BEARING SYSTEM POWER | — | |
| MAX | 8 WATTS | 8 WATTS (AT LIFT OFF) |
| AVERAGE | 1 WATT | .5 WATT |
| RELIABILITY | | .913 (10 YEARS) |

SPERRY FLIGHT SYSTEMS

44-5100-2-029-19

## YAW GYRO CONCEPT

A change in yaw angle ($\dot{\psi}$) interacts with the MWA momentum (H) causing a torque $\tau = H\dot{\psi}$. on the wheel. The angular compliance of the magnetic bearings ($K_{ANG}$) along with position sensors and integrator provides a yaw angular error signal.

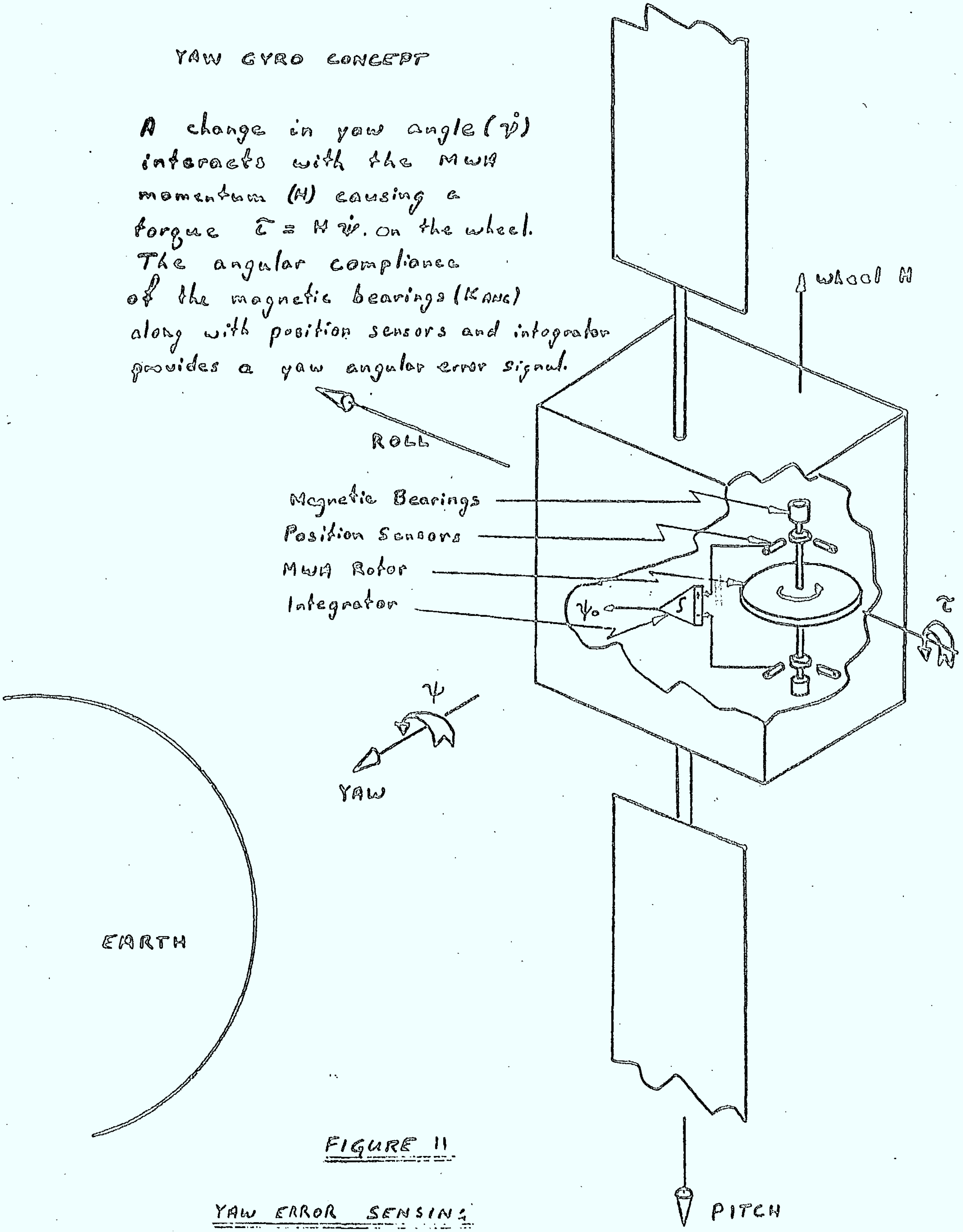



FIGURE 11

YAW ERROR SENSING USING A MBMWA

# LIFE CHARACTERISTICS-
# MAGNETIC SUSPENSION

- NO WEAR SURFACES – CONTACTLESS SUPPORT
- NO LUBRICANT – DEPLETION, CHEMICAL CHANGES, CONTAMINATION
- NOT CYCLE LIMITED
- RELIABILITY OF ELECTRONICS

| | |
|---|---|
| RWA + ELECTRONICS | .913 (10 YRS) |
| RWA + 2 ELECTRONICS | .994 (10 YRS) |
| RWA + 2 ELECTRONICS + REDUNDANT SPIN MOTOR | .995 (10 YRS) |

- ELIMINATES SINGLE POINT FAILURE SOURCES (WITH REDUNDANT ELECTRONICS) IN A SINGLE MECHANICAL ASSEMBLY

## MOMENTUM WHEEL SIZING

$$H = \frac{57.3\ T}{W_o \psi}$$

T = Disturbance Torque

$W_o$ = Orbit Rate = $7.29 \times 10^{-5}$ rad/sec.

$\psi$ = Allowed yaw error = $1^{\circ}$

### A THROUGH SHAFT CONFIGURATION

H = 8.1 ft.lb.sec. calculated

With contingency, momentum in the range 13-17 ft.lb.sec. is recommended

Nominal H = 15 ft.lb.sec.

Weight = 32 lbs. (2 wheels)

### B SPLIT SHAFT CONFIGURATION

H = 3.8 ft.lb. sec. calculated

With contingency, momentum in the range 6-8 ft.lb.sec. is recommended

Nominal H = 7 ft.lb.sec.

Weight = 28 lb. (2 wheels)

## REACTION WHEELS

- Conventional ball bearing wheels have proven reliability for 2-3 year mission. As with momentum wheels, there is concern over long life. At least 4 wheels required for redundancy.

- Magnetic suspension reaction wheels under development. Same comments apply as for momentum wheels.

## REACTION WHEEL SIZING

Wheel momenta in ft.lb.sec.

Pitch = 0.3 cos $(W_o t)$

Roll = 0.42 N cos $(W_o t)$

Yaw = 0.08 - 0.42 N sin $(W_o t)$

N = No. of days

With contingency, 1-2 ft.lb.sec. reaction wheels are recommended

Nominal = 1.5 ft.lb.sec.

Weight = 8 lb. each

## CONTROL ELECTRONICS

- Special purpose digital controllers using TTL are heavy, inflexible and require very early definition of control laws.

- General purpose computers using micro-processors are weight effective and highly flexible. Careful reliability engineering required due to large parts count. Special memory bypass and error correction techniques may be necessary.

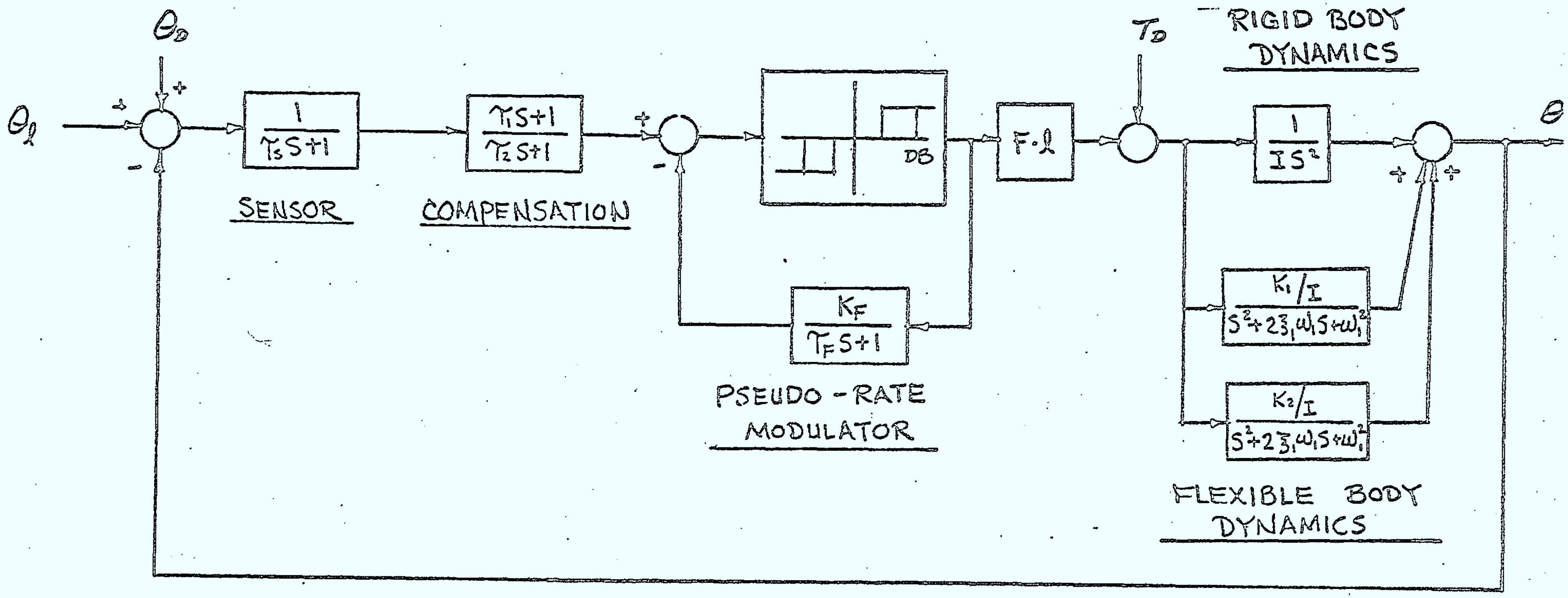



FIGURE. ATTITUDE CONTROL SYSTEM FOR STATIONKEEPING

# TABLE ROLL AND YAW CONTROL LOOP PARAMETERS

| | ROLL | YAW |
|---|---|---|
| SENSOR LAG. ($\tau_S$) in sec. | 1.5 | 1.5 |
| COMPENSATION | | |
| o LEAD TIME CONSTANT ($\tau_1$) in sec. | 1.5 | 1.5 |
| o LAG TIME CONSTANT ($\tau_2$) in sec. | .3 | .3 |
| PSEUDO RATE MODULATOR | | |
| o DEAD BAND (DB) in deg. | .03 | .03 |
| o HYSTERESIS (H) in % of DB | 10% | 10% |
| o FEEDBACK LOOP GAIN ($K_F$) | 1.72 | 1.72 |
| o ON TIME CONSTANT ($\tau_N$) in sec. | 0.172 | 0.172 |
| o OFF TIME CONSTANT ($\tau_F$) in sec. | 5.4 | 5.4 |
| o MIN. PULSE WIDTH ($PW_{min}$) in sec | .01 | .01 |
| DYNAMICS | | |
| o MOMENT OF INERTIA (I) in slug-ft$^2$ | 730 | 770 |
| o UNCONSTRAIN 1st MODAL GAIN ($K_1$) | 8 | 5.6 |
| o UNCONSTRAIN 1st MODE FREQUENCY ($\omega_1$) in Hz. | 0.1 | 0.1 |
| o DAMPING RATIO ($\zeta_1$) | 0.001 | 0.001 |
| CONTROL TORQUE ($T_c$) in ft-lb | 0.5 | 0.5 |

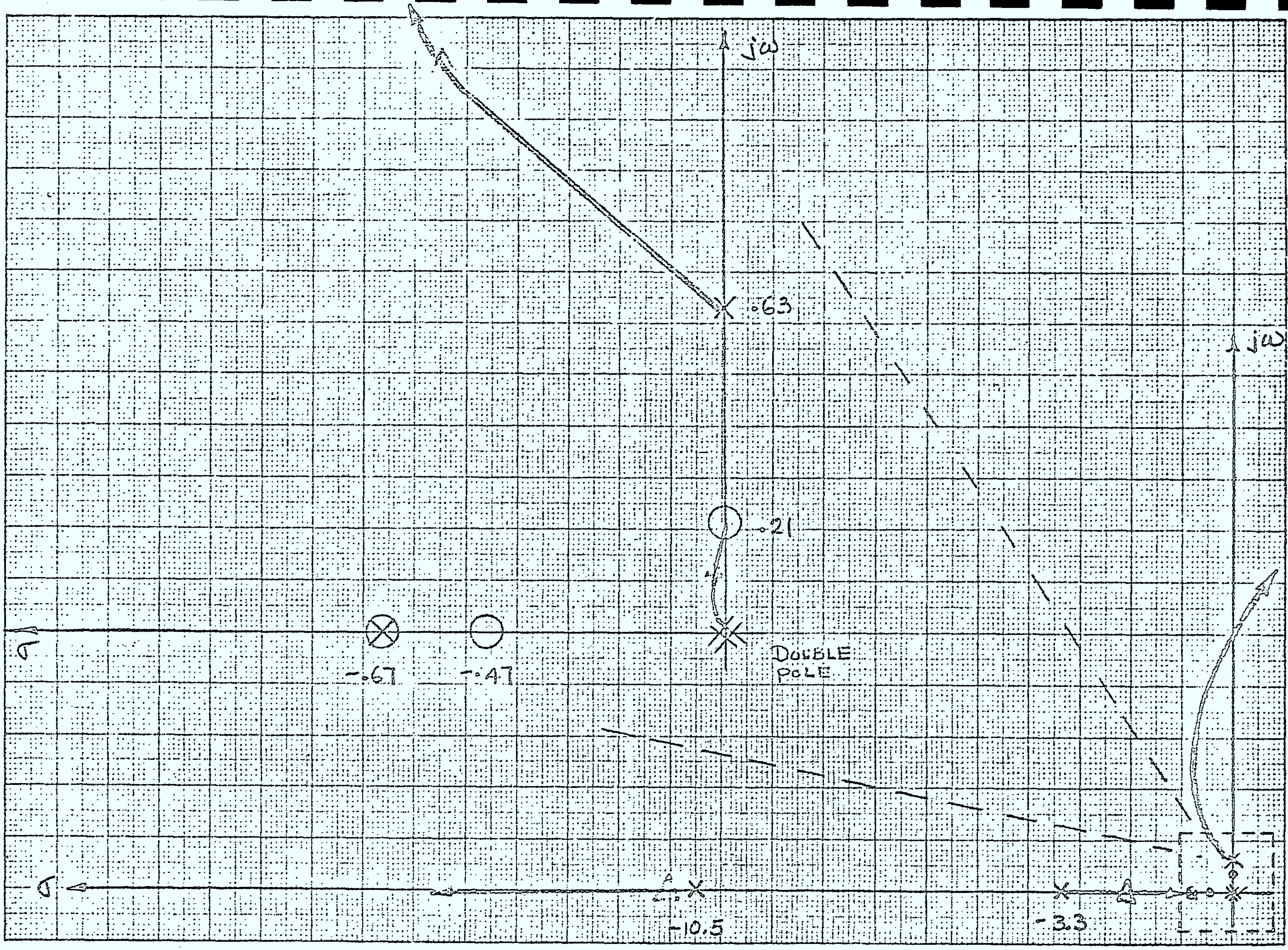
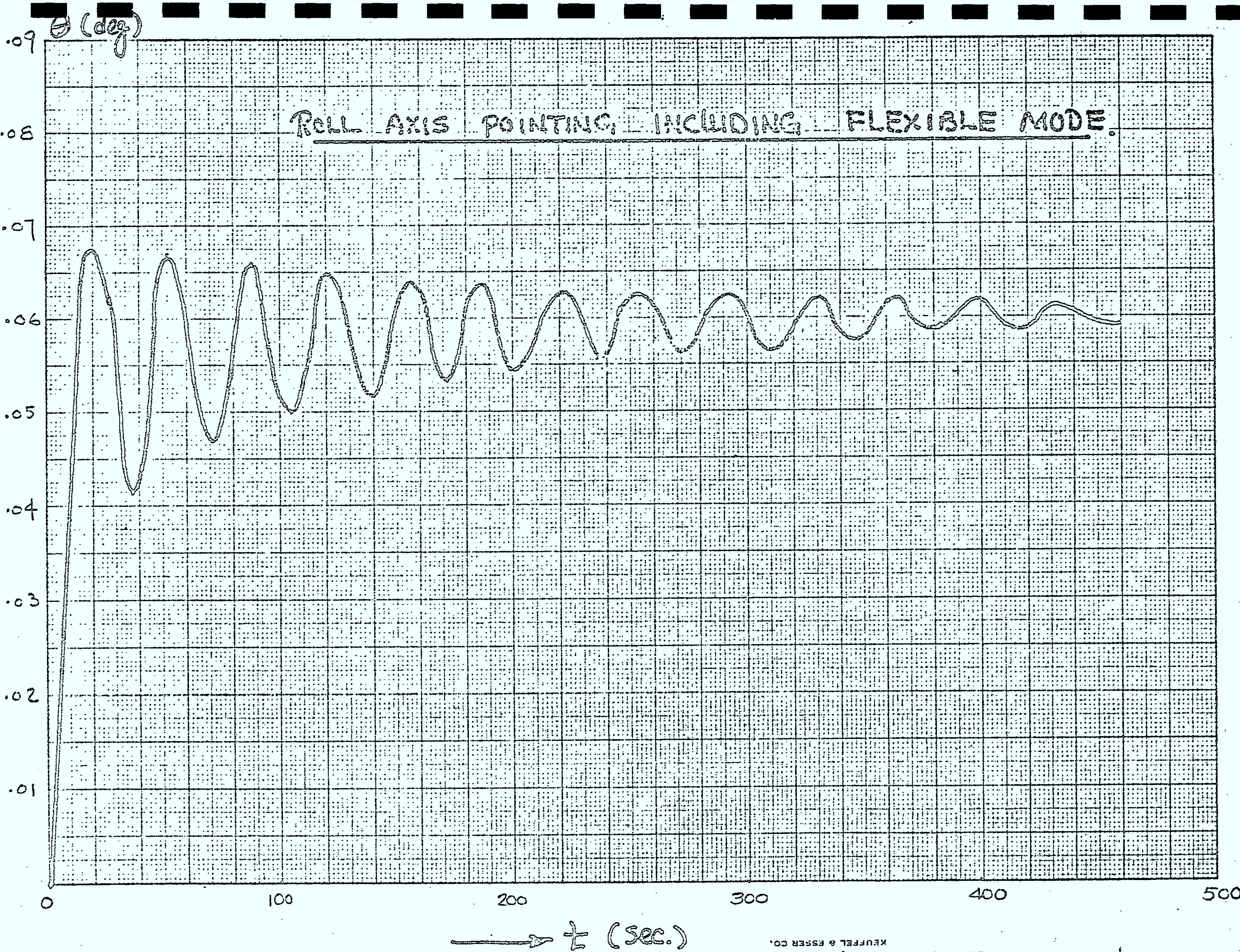
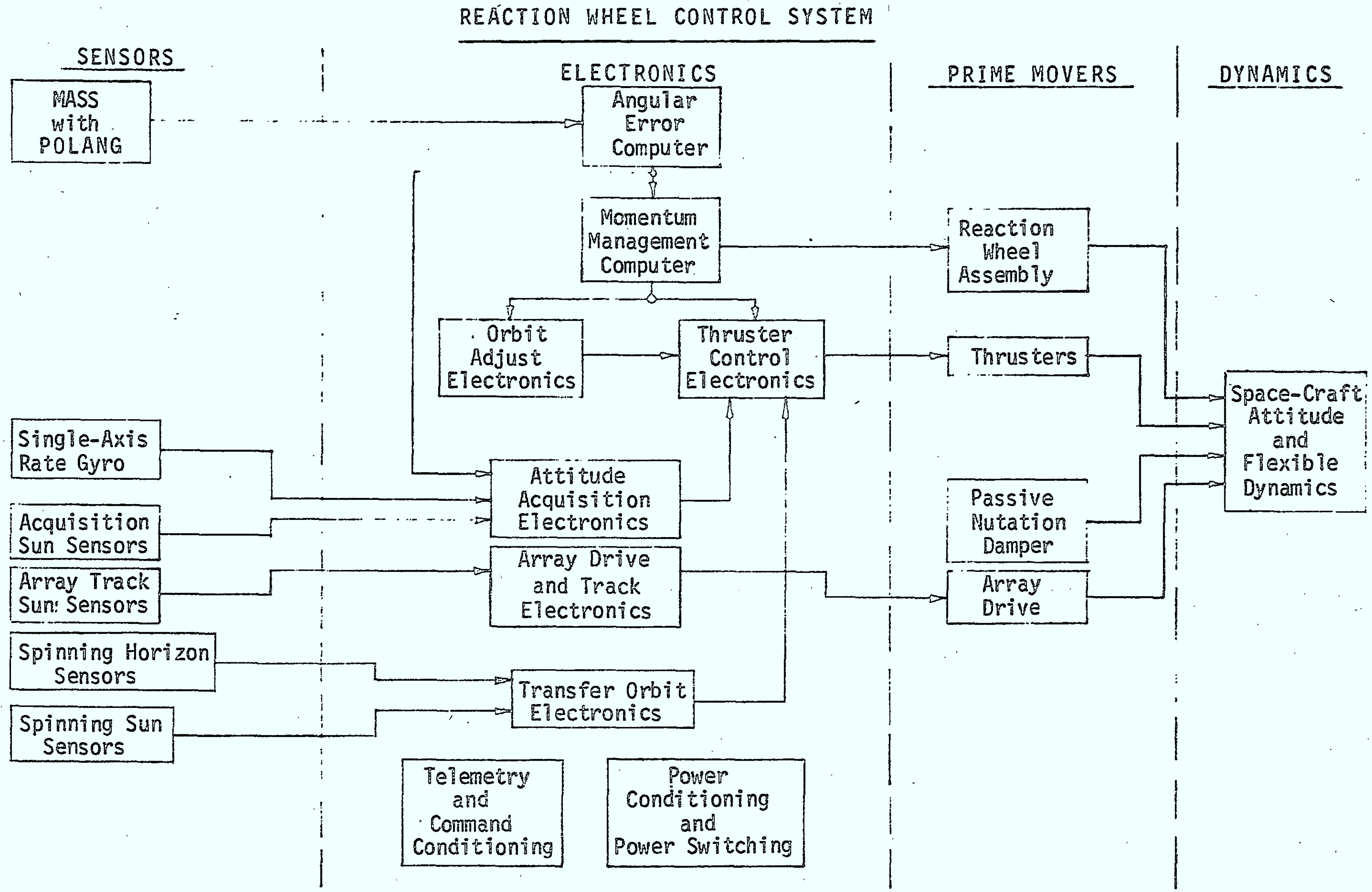



FIG. ROLL AXIS ROOT LOCUS PLOT INCLUDING FLEXIBLE MODE



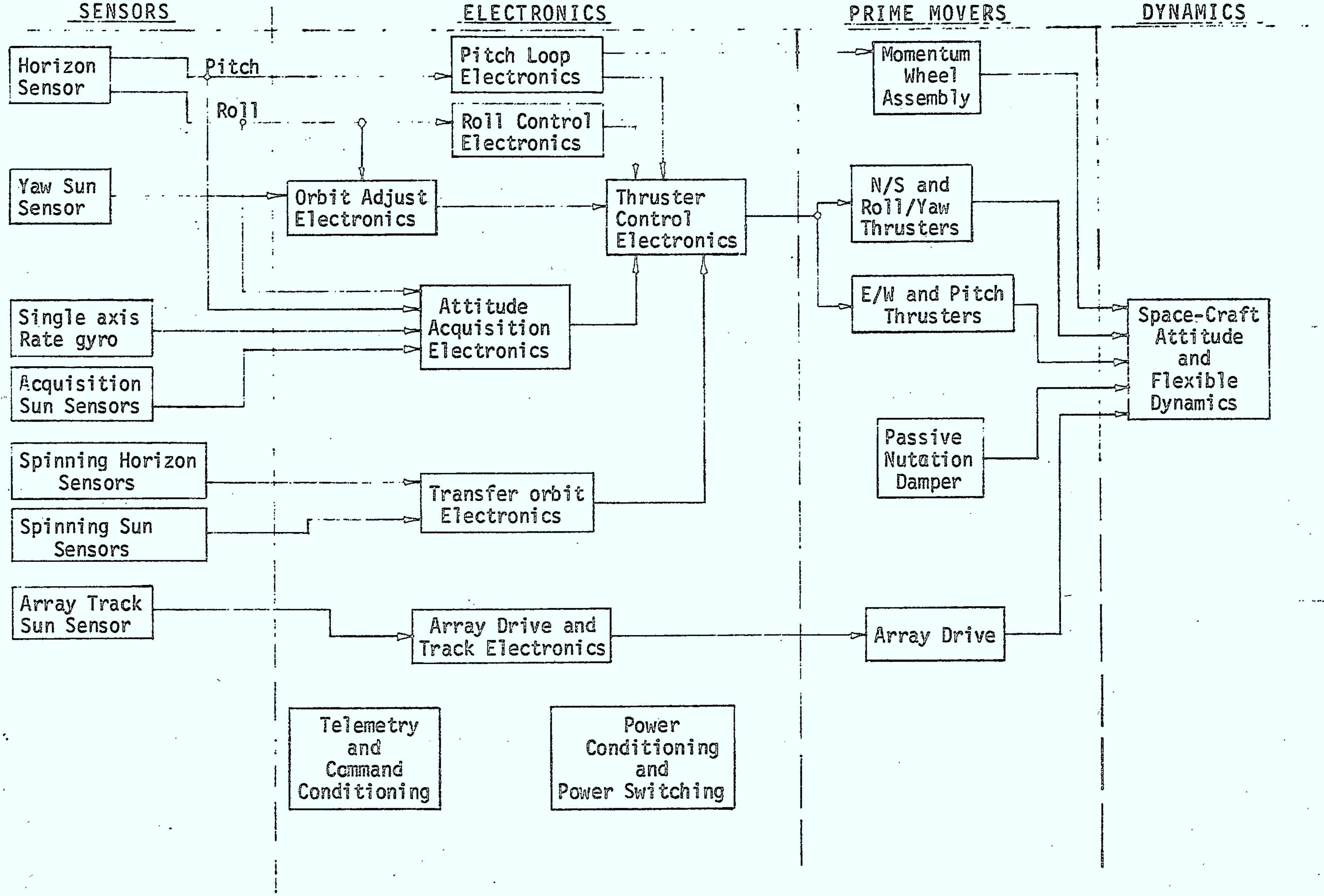
θ (deg)
ROLL AXIS POINTING INCLUDING FLEXIBLE MODE.
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
100
200
300
400
500
t (sec.)


REACTION WHEEL CONTROL SYSTEM
SENSORS
ELECTRONICS
PRIME MOVERS
DYNAMICS
MASS with POLANG
Angular Error Computer
Momentum Management Computer
Reaction Wheel Assembly
Orbit Adjust Electronics
Thruster Control Electronics
Thrusters
Space-Craft Attitude and Flexible Dynamics
Single-Axis Rate Gyro
Attitude Acquisition Electronics
Acquisition Sun Sensors
Passive Nutation Damper
Array Track Sun Sensors
Array Drive and Track Electronics
Array Drive
Spinning Horizon Sensors
Transfer Orbit Electronics
Spinning Sun Sensors
Telemetry and Command Conditioning
Power Conditioning and Power Switching

## REACTION WHEEL CONTROL SYSTEM

| COMPONENT | (lb.) WEIGHT | (watts) POWER |
|---|---|---|
| MASS | (16) | (12) |
| Rate Gyro | 2.2 | 14 |
| Acquisition Sun Sensors | 0.36 | - |
| Array Track Sun Sensors | 0.52 | 0.1 |
| Spinning Horizon Sensor | 3.0 | 2.6 |
| Spinning Sun Sensor | 1.84 | 0.4 |
| Electronics | 18.0 | 15 |
| Reaction Wheels | 32.0 | 13.3 |
| Nutation Damper | 0.9 | - |
| Bracketry | 1.5 | - |
| | 76.32 | 55.4 |
| RCS Fuel | 4.0 | |
| | 80.32 | |

# WHECON ATTITUDE CONTROL SYSTEM



## WHECON ATTITUDE CONTROL SYSTEM

| COMPONENT | WEIGHT Through Shaft | WEIGHT Split Drive | POWER |
|---|---|---|---|
| Horizon Sensor | 14 | | 4.5 |
| Rate Gyro | 2.2 | | 14.0 |
| Yaw Sun Sensor | 2.8 | | 1.0 |
| Acquisition Sun Sensor | 0.36 | | - |
| Array Track Sun Sensor | 0.52 | | 0.1 |
| Spinning Horizon Sensor | 3.0 | | 2.6 |
| Spinning Sun Sensor | 1.84 | | 0.4 |
| Electronics | 18.0 | | 15 |
| Momentum Wheels | 32.0 | 28.0 | 10 |
| Bracketry | 1.5 | | |
| Nutation Damper | 0.9 | | |
| | 77.12 | 73.12 | 45.6 |
| Offset Thrusters | 3.0 | 3.0 | |
| RCS Fuel | 9.0 | 10.0 | |
| | 89.12 | 86.12 | |

## SYSTEM TRADE MATRIX

| TRADE PARAMETER | REACTION WHEELS | WHECON THROUGH SHAFT | SPLIT SHAFT |
|---|---|---|---|
| 1. Weight | 80.3 | 89.1 | 86.1 |
| 2. Accuracy | | | |
| a) during thrusting | | | |
| Pitch/Roll | $0.15^{o}$ | $0.15^{o}$ | $0.15^{o}$ |
| Yaw | $0.4^{o}$ | $1.0^{o}$ | $1.0^{o}$ |
| 3. Power | 55.4 | 45.6 | 45.6 |
| 4. Development Problems | MASS Development Microprocessor Development | Microprocessor Development | Micro-processor Development |

SPAR-R.672

SECTION 6

# MULTI PURPOSE BUS (MPB) STUDY

# REACTION CONTROL SUBSYSTEM

# DESIGN STATUS PRESENTATION

18 APRIL, 1975

S. F. ARCHER
PROPULSION/SYSTEMS

# RCS MPB PRESENTATION OUTLINE

* SIGNIFICANT DESIGN REQUIREMENTS

* STUDY SCHEDULE

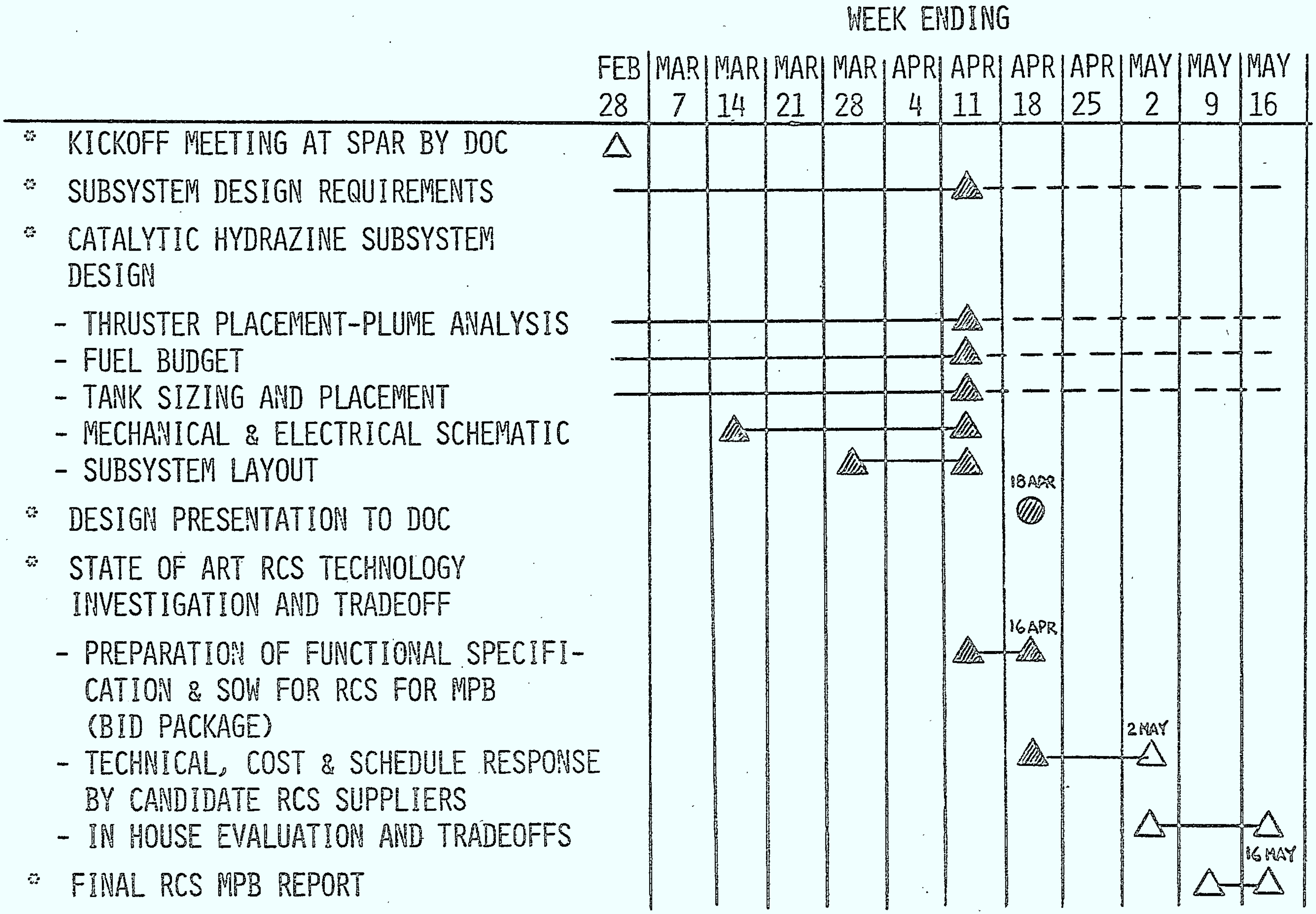
* CATALYTIC HYDRAZINE SUBSYSTEM DESIGN

* STATE OF THE ART RCS TECHNOLOGY INVESTIGATION & TRADEOFF

# SIGNIFICANT RCS MPB DESIGN REQUIREMENTS

- 8 YEAR HARDWARE SPACE LIFE AND 6 YEAR EXPENDABLES MISSION LIFE
- ATTITUDE ACQUISITION PRIOR TO STATION ACQUISITION
- NORTH SOUTH STATIONKEEPING TO $\pm .1°$ FOR MISSION LIFE $-\Delta V = 1320$ FPS. FOR EIGHT YEARS WORST CASE
- FIXED PITCH WHEEL WITH ROLL-YAW, OFFSET THRUSTER ATTITUDE CONTROL SUBSYSTEM ON-ORBIT
- VERY LOW TORQUE IMPULSE BIT OF $4 \times 10^{-3}$ FT. LBF. SEC. MAXIMUM, NEEDED FOR ON-ORBIT ROLL-YAW ATTITUDE CONTROL
- OFFSET SOLAR ARRAY AND ITS STOWAGE CONFIGURATION
- PAYLOAD PRECLUDES THRUSTERS ON NORTH OR SOUTH PANELS NEAR CENTRE OF MASS
- OPERATE ELECTRICALLY GIVEN A SINGLE VOLTAGE POWER RAIL
- MINIMIZE TELEMETRY AND COMMAND COMPLEXITY
- SPACECRAFT LAUNCH PAD WEIGHT OF 1925 LBM.
- OVERALL SPACECRAFT HOUSEKEEPING RELIABILITY OF 0.9
- POTENTIAL MOTION OF SPACECRAFT CENTRE OF MASS DURING LIFE
- NO PURE JET 3-AXIS BACKUP ATTITUDE CONTROL DESIGNED IN APRIORI

# RCS MPB STUDY SCHEDULE



# CATALYTIC HYDRAZINE RCS MPB SUBSYSTEM DESIGN

- RCS MISSION REQUIREMENTS
- TANKAGE LOCATION & CENTRE OF MASS SHIFTS DUE TO PROPELLANT EXPULSION
- PLUME IMPINGEMENT ANALYSIS AND THRUSTER CONFIGURATION
- FEATURES OF THE DESIGN
  - RCS MECHANICAL SCHEMATIC
    - BLOWDOWN MASS EXPULSION, CTS TECHNOLOGY
    - 2 HTEs, 1. TO 5.5 LBF STEADY STATE THRUST, FOR PRECESSION
    - 16 LTEs, .1 TO .3 LBF STEADY STATE THRUST, FOR ROLL, PITCH, YAW, DESPIN, N-S AND E-W STATIONKEEPING AND ROLL-YAW (OFFSET) OPERATION CONFIGURED WITH 8 LATCHING VALVES TO PROVIDE SINGLE POINT THRUSTER FAILURE PROTECTION
    - 4 EPT-10 DIAPHRAGM, SPHERICAL, BOSS-MOUNTED, 6AL4V TITANIUM TANKS, 17.3 INCHES ID, DIAGONALLY CROSS STRAPPED
  - THERMAL INTERFACE - RCS RESPONSIBLE FOR THERMAL CONTROL OF THRUSTER CHAMBERS ONLY
  - RCS ELECTRICAL SCHEMATIC
- RCS WEIGHT BUDGET
  - PROPELLANT WEIGHT BUDGET
    - PROPELLANT WEIGHT BUDGET PER MANOEUVRE - DESIGN WORST CASE (6 YEARS)
    - PROPELLANT WEIGHT BUDGET VS LIFE AND LAUNCH DATE
  - RCS HARDWARE AND TOTAL WEIGHT BUDGET
- POSSIBLE SIGNIFICANT WEIGHT SAVINGS WITHIN CATALYTIC DESIGN
    - SURFACE TENSION TANKAGE-13 LBM (RCA SATCOM QUALIFIED TANK DESIGN)
    - SPLIT ARRAY DESIGN- 13 LBM
    - REDUCTION OF MINIMUM LINEAR IMPULSE BIT BY A FACTOR OF THREE - 12 LBM

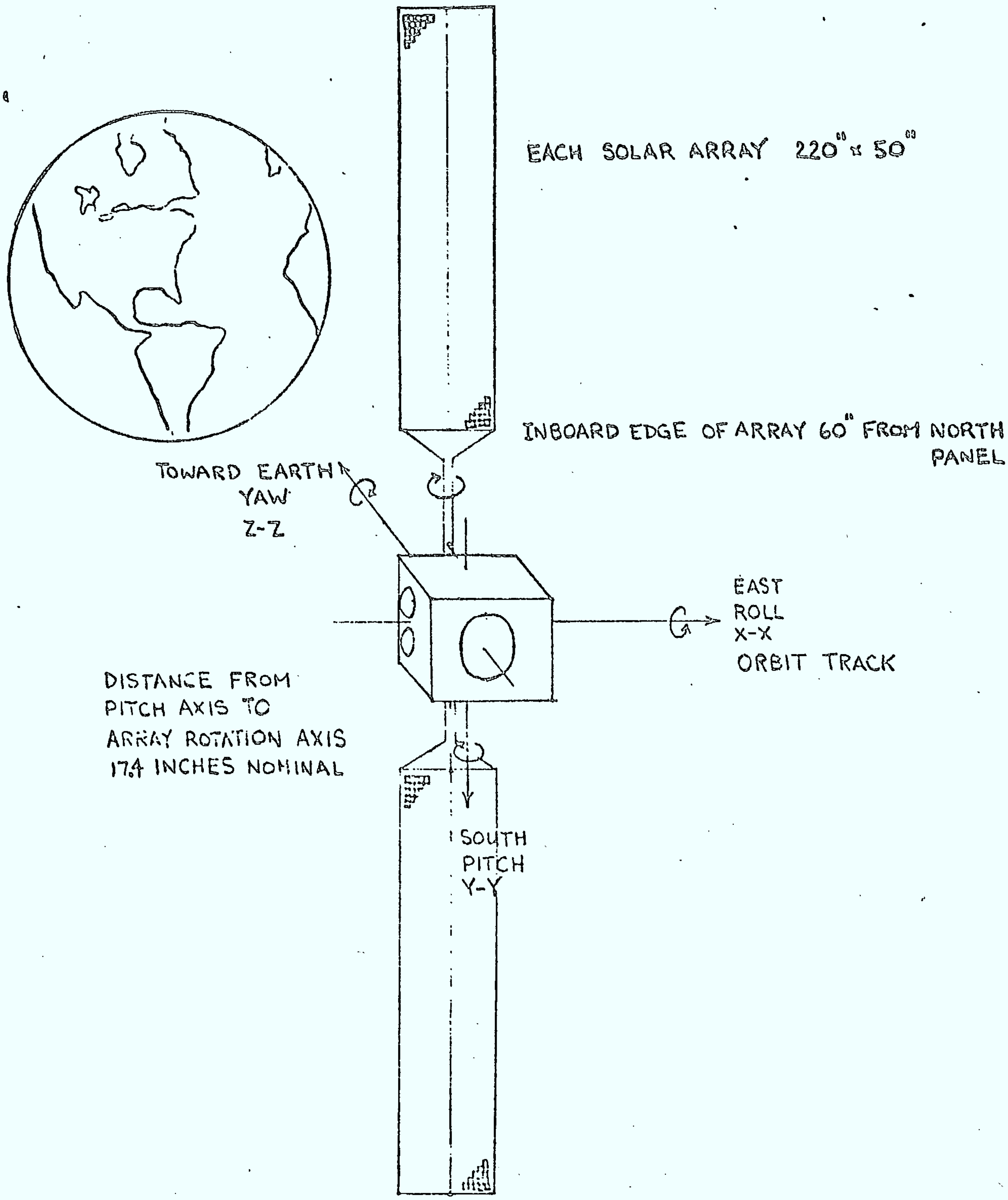



FIGURE 3 SPACECRAFT 3-AXIS STABILIZED CONFIGURATION

| Manoeuvre | Total Impulse Or Delta Velocity | Maximum Thrust/ Torque Bit | Minimum Thrust/ Torque Bit | Duty Cycle | Maximum Starts | Maximum Pulses |
|---|---|---|---|---|---|---|
| 1. Pre Apogee Precession | 2,807 ~~2,200~~ ft.lbf.sec. | 5.5 lbf | 1.0 lbf | .135 sec. on, .835 sec. off ±10% | 10 | Function of Thrust Level |
| 2. Post Apogee Precession | 1337 ~~1,137~~ ft.lbf.sec. | 5.5 lbf | 1.0 lbf | .135 sec. on, .835 sec. off ±10% | 10 | Function of Thrust Level |
| 3. Despin | 954 ft.lbf.sec. | .3 lbf | .01 lbf | Continuous Burn | 3 per engine | 3 per engine |
| 4. Attitude Acquisition | | | | | | |
| a) pitch wheel spinup | 60 ft.lbf.sec. | $7.5\times10^{-3}$ ft.lbf.sec. | TBD ft.lbf.sec | Average Torque during manoeuvre = $6\times10^{-3}$ ft.lbf. | 1 | Function of Torque Bit Level |
| b) 3 axis limit cycle | 80 ft.lbf.sec. | | Very Low Duty Cycle - TBD | | | |
| c) on-board capture with offset engines | 40 ft.lbf.sec. | | Very Low Duty Cycle - TBD | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5. Station Acquisition<br>- in plane<br>- out of plane | <br><br>80 ft./sec.<br>80 ft./sec. | <br><br>.3 lbf. | <br><br>.01 lbf. | <br><br>Continuous Burn (inverse pulse width modulation) | <br><br>40 Orbit Manoeuvres<br><br>per engine | <br><br>TBD |
| 6. On-Board Roll-Yaw Attitude Control | 1885 ft.lbf.sec. (6 years)<br>2515 ft.lbf.sec. (8 years) | $8.0 \times 10^{-3}$ ft.lbf.sec. | $5 \times 10^{-4}$ ft.lbf.sec. | Continuous pulsing, 20 sec. to .5 day off time between pulses | Function of IBIT Level | Function of Torque Bit Level |
| 7. Pitch Momentum Dumping | 104 ft.lbf.sec. (6 years)<br>139 ft.lbf.sec. (8 years) | $7.5 \times 10^{-3}$ ft.lbf.sec. | TBD ft.lbf.sec. | Manoeuvre every 21 days, average torque bit during manoeuvre $= 4 \times 10^{-3}$ ft.lbf. | 150 | Function of Torque bit level |
| 8. East-West Stationkeeping | 84 ft./sec. (6 years)<br>112 ft./sec. (8 years)<br><br>Split between E&W TBD | .3 lbf. | .01 lbf. | Manoeuvre every 21 days, continuous burn (inverse pulse width modulation) | 150 | TBD |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9. North-South Stationkeeping (North or South only permissible operating mode) | 999 ft.sec. (6 years) 1,320 ft. sec. (9 years) | .3 lbf. | .01 lbf. | Manoeuvre every 21 days, continuous burn (inverse pulse width modulation) | 150 | TBD |

NOTES: 1. Manoeuvres 6, 7, 8 and 9 comprise the on-orbit mission and are interspersed over the mission life.

2. The spacecraft mass prior to commencing manoeuvre 2 shall be 1,017 lbm.

3. Vehicle effective total impulse stated for manoeuvres 1 and 2.

4. Figure 4 shows offset engines 13, 14, 15 and 16 lying in a projection of the roll yaw plane.

5. Vehicle effective delta velocity stated for manoeuvre 9.

6. Although manoeuvre 6 allows a torque bit of 8 x $10^{-3}$ ft.lbf.sec. there will be a spacecraft weight penalty (momentum wheel) for values $\geq$ 4 x $10^{-3}$ ft.lbf.sec. assume that this penalty is linear to a maximum of 10 lbm. at 8.0 x $10^{-3}$ ft.lbf.sec.

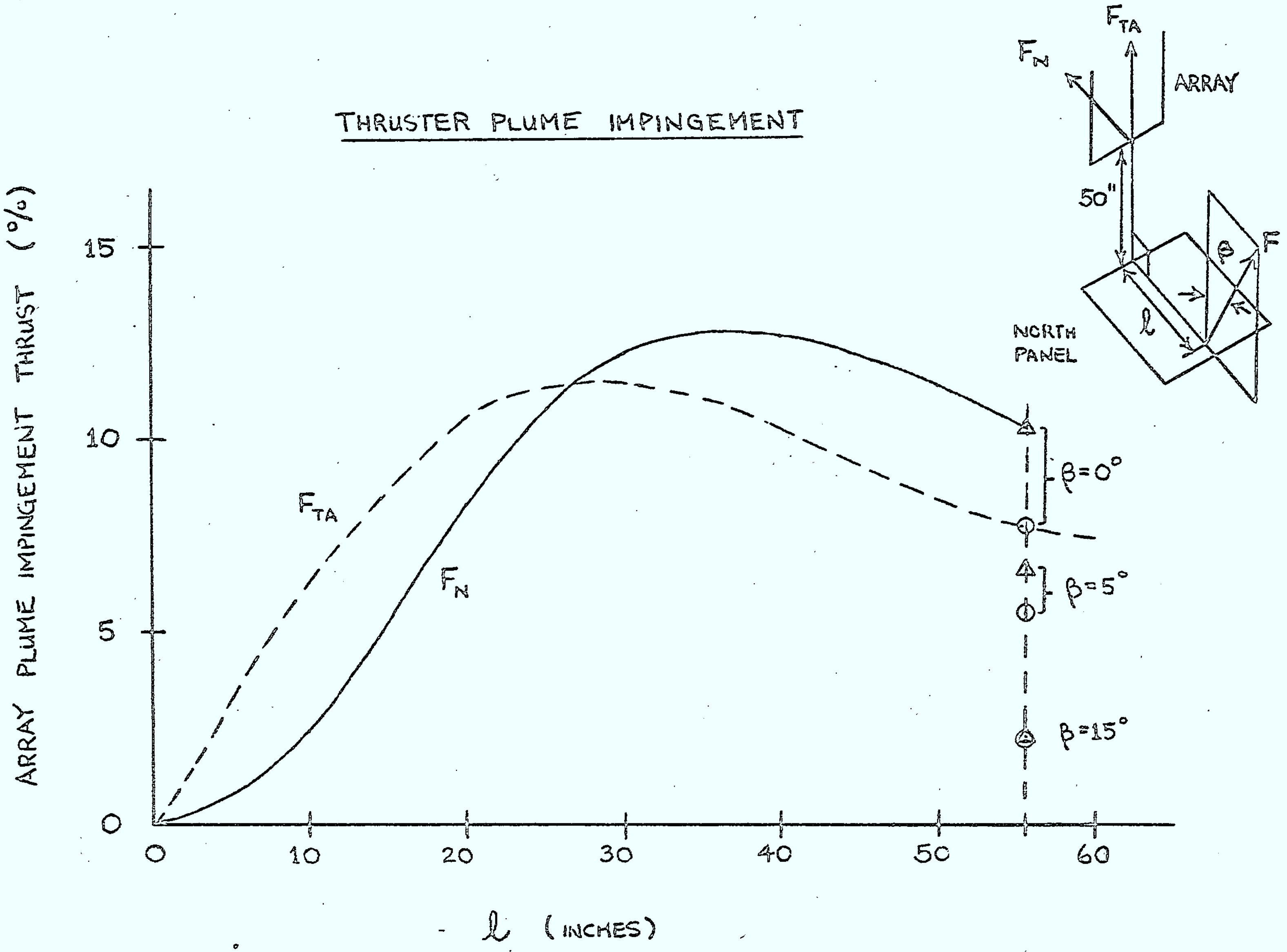
7. Tankage shall be sized and fuel shall be allotted for 5% growth propellant.

# RCS MPB TANK LOCATION AND SPACECRAFT NOMINAL CENTRE OF MASS SHIFTS ALONG Z-Z AXIS DURING LIFE

- TANKAGE EXPULSION IS IN THE DIRECTION OF THE Z-Z AXIS
- TANK CENTRES ARE PLACED AT STATION 43.0 INCHES ABOVE SEPARATION PLANE SO THAT:

| SPACECRAFT C OF M LOCATION AT STATION | POINT IN THE MISSION |
|---|---|
| 37.7 INCHES | PRIOR TO AMF |
| 38.3 INCHES | JUST AFTER AMF |
| 40.7 INCHES | JUST AFTER ARRAY DEPLOYMENT (TANK ULLAGE OF 33%) |
| 40.7 INCHES | END OF LIFE (TANK ULLAGE 100%) |

- MAXIMUM EXCURSION OF CENTRE OF MASS ALONG Z-Z AXIS DUE TO PROPELLANT DEPLETION IS LESS THAN .2 INCHES.


THRUSTER PLUME IMPINGEMENT
ARRAY PLUME IMPINGEMENT THRUST (%)
15
10
5
0
0
10
20
30
40
50
60
ℓ (INCHES)
$F_{TA}$
$F_N$
β=0°
β=5°
β=15°
$F_{TA}$
$F_N$
ARRAY
50"
F
β
ℓ
NORTH PANEL

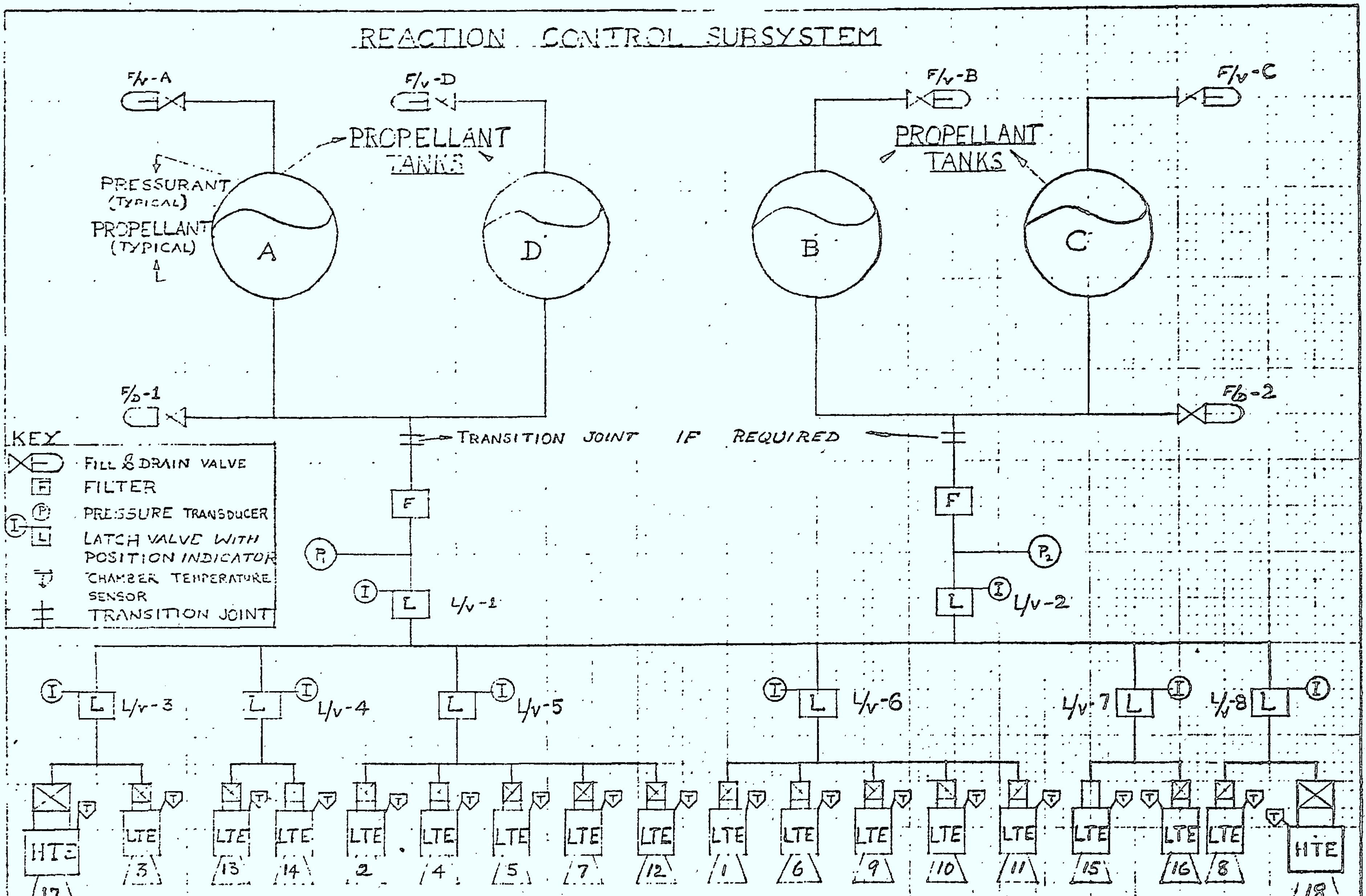



FIGURE 1 MECHANICAL SCHEMATIC DIAGRAM

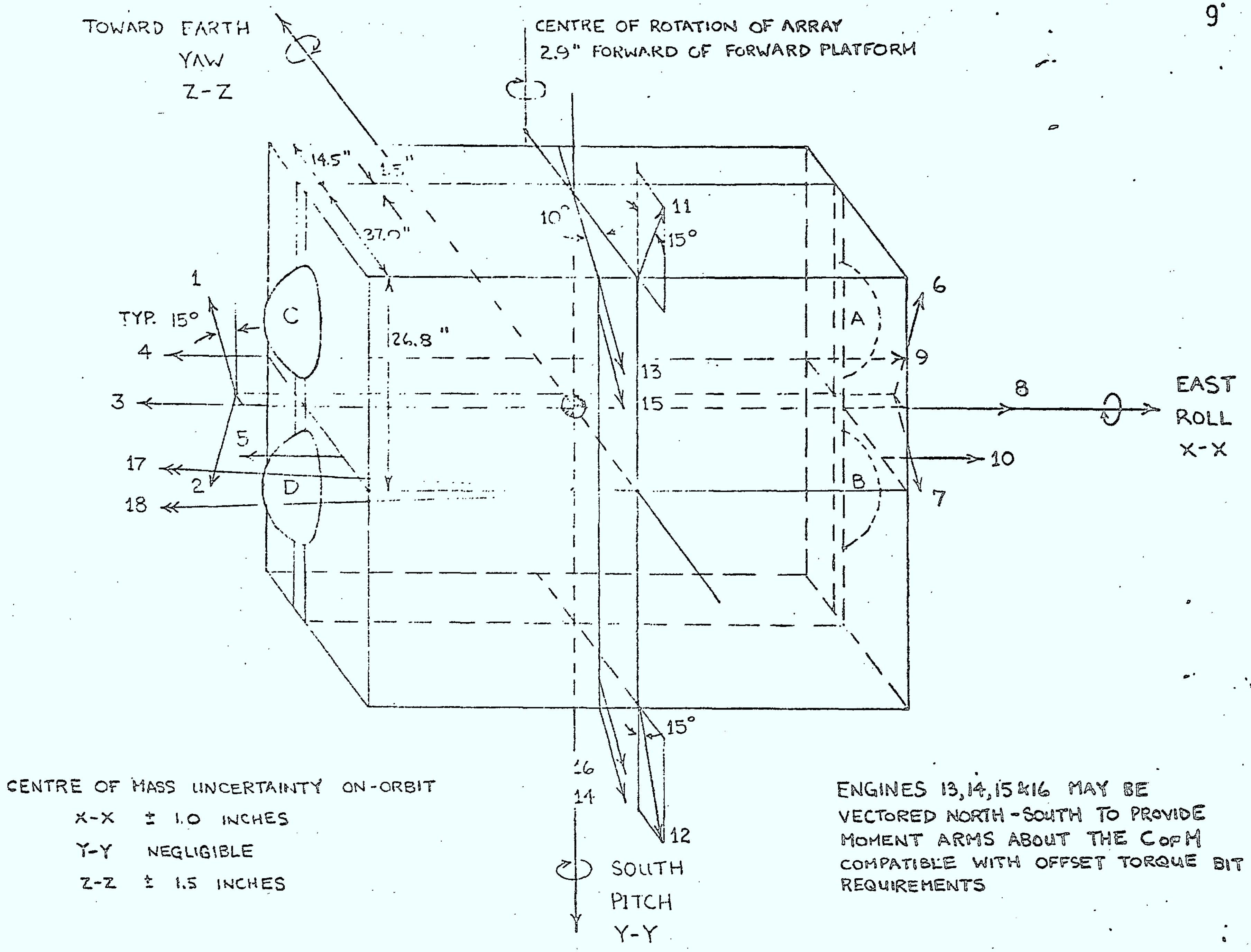



FIGURE 4. RCS THRUSTER LOCATIONS & DIRECTIONS

PRELIMINARY

# TABLE IV - PRELIMINARY

## RCS THRUSTER FUNCTIONS - NOMINAL C OF M LOCATION

| THRUSTER | +P | -P | +R | -R | +Y | -Y | N | S | E | W | +O | -O | PR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | △ | | | △ | | (II) | (III) | | | [VII] | | | |
| 2 | △ | | △ | | (I) | | | (IV) | | [VII] | | | |
| 3 | | | | | | | | | | ◇P | | | |
| 4 | ◇P | | | | | | | | | (VIII) | | | □ |
| 5 | | ◇P | | | | | | | | (VIII) | | | □ |
| 6 | | △ | | △ | (I) | | (III) | | [V] | | | | |
| 7 | | △ | △ | | | (II) | | (IV) | [V] | | | | |
| 8 | | | | | | | | | ◇P | | | | |
| 9 | | ◇S | | | | | | | (VI) | | | | □ |
| 10 | ◇S | | | | | | | | (VI) | | | | □ |
| 11 | | | ◇P | | | | (III) | | | | | | |
| 12 | | | | ◇P | | | | (IV) | | | | | |
| 13 | | | | □ | | | | | | | | ◇P | |
| 14 | | | □ | | | | | | | | ◇P | | |
| 15 | | | | □ | | | | | | | | ◇S | |
| 16 | | | □ | | | | | | | | ◇S | | |
| 17 | | | | | | | | | | | | | ◇P |
| 18 | | | | | | | | | | | | | ◇S |

KEY

◇A PERFORMS INTENDED FUNCTION BY ITSELF: "A"=P, PRIMARY; "A"=S, SECONDARY

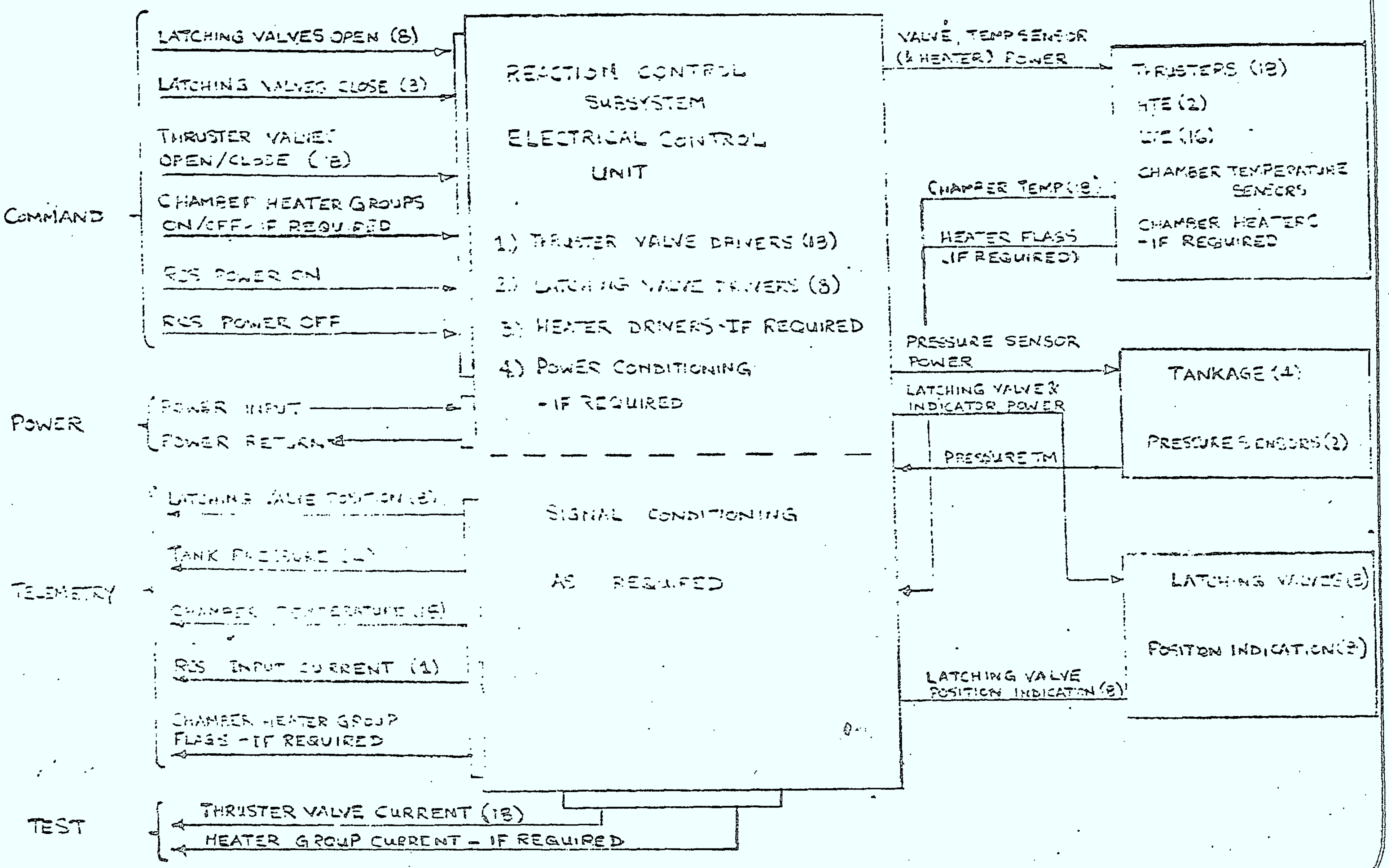
(A) PERFORMS INTENDED FUNCTION WITH OTHER ENGINE(S) NUMBERED "A"

□ PERFORMS SECONDARY FUNCTION WITH PROPELLANT INEFFICIENCY

△ HAS UNWANTED SIDE EFFECT WHEN FIRED BY ITSELF

NOTE: THRUSTERS 11 & 12 CANNOT PERFORM PRECESSION BECAUSE THEY ARE COVERED UNTIL THE ARRAYS ARE DEPLOYED DURING ATTITUDE ACQUISITION

FIGURE 2 RCS ELECTRICAL SCHEMATIC



# TABLE VI

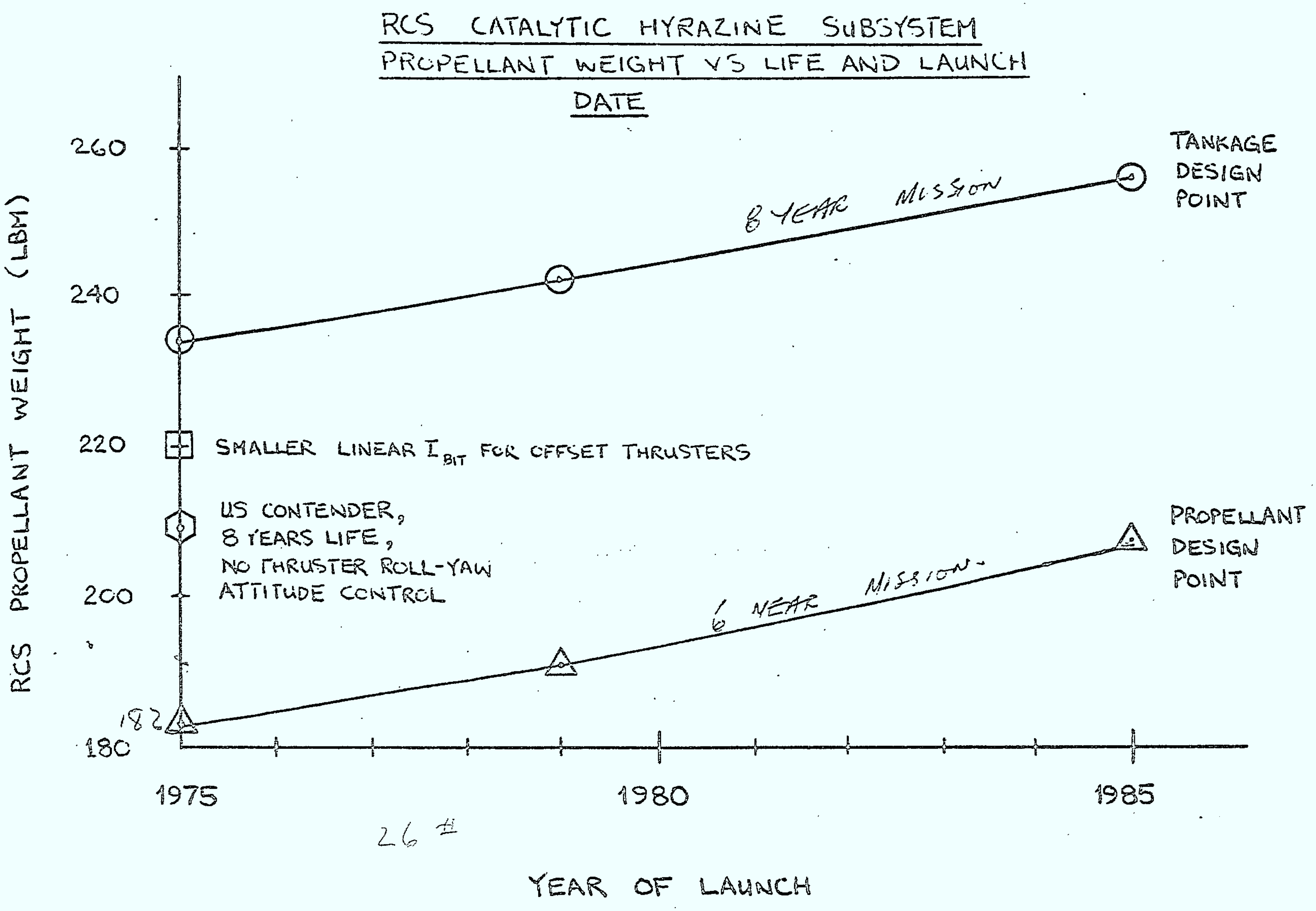
## RCS COMMAND AND TELEMETRY REQUIREMENTS

| CHANNEL NUMBER | COMMAND CHANNEL | COMMAND DURATION | TELEMETRY CHANNEL |
|---|---|---|---|
| 1 | THRUSTER 1 VALVE | AS LONG AS VALVE OPEN | THRUSTER 1 CHAMBER TEMP. |
| 2 | " 2 " | " | " 2 " |
| 3 | " 3 " | " | " 3 " |
| 4 | " 4 " | " | " 4 " |
| 5 | " 5 " | " | " 5 " |
| 6 | " 6 " | " | " 6 " |
| 7 | " 7 " | " | " 7 " |
| 8 | " 8 " | " | " 8 " |
| 9 | " 9 " | " | " 9 " |
| 10 | " 10 " | " | " 10 " |
| 11 | " 11 " | " | " 11 " |
| 12 | " 12 " | " | " 12 " |
| 13 | " 13 " | " | " 13 " |
| 14 | " 14 " | " | " 14 " |
| 15 | " 15 " | " | " 15 " |
| 16 | " 16 " | " | " 16 " |
| 17 | " 17 " | " | " 17 " |
| 18 | " 18 " | " | " 18 " |
| 19 | LV 1 OPEN | 50 msec | TANK PRESSURE 1 |
| 20 | LV 1 CLOSE | " | TANK PRESSURE 2 |
| 21 | LV 2 OPEN | " | LV 1 POSITION |
| 22 | LV 2 CLOSE | " | LV 2 " |
| 23 | LV 3 OPEN | " | LV 3 " |
| 24 | LV 3 CLOSE | " | LV 4 " |
| 25 | LV 4 OPEN | " | LV 5 " |
| 26 | LV 4 CLOSE | " | LV 6 " |
| 27 | LV 5 OPEN | " | LV 7 " |
| 28 | LV 5 CLOSE | " | LV 8 " |
| 29 | LV 6 OPEN | " | RCS INPUT CURRENT (ANALOG) |
| 30 | LV 6 CLOSE | " | CHAMBER HEATER GROUP ON/OFF FLAGS, IF HEATERS REQUIRED. |
| 31 | LV 7 OPEN | " | |
| 32 | LV 7 CLOSE | " | |
| 33 | LV 8 OPEN | " | |
| 34 | LV 8 CLOSE | " | |
| 35 | RCS POWER ON | | |
| 36 | RCS POWER OFF | | |
| 37 ETC. | CHAMBER HEATER GROUPS, IF REQUIRED, ON/OFF, TBD | AS LONG AS HEATER GROUP TO BE ACTIVATED | |

## RCS MPB CATALYTIC SUBSYSTEM PROPELLANT WEIGHT BREAKDOWN

### - 6 YEAR 1985 LAUNCH -

| MANOEUVRE | SPECIFIC IMPULSE (LBF.SEC./LBM) | PROPELLANT WEIGHT (LBM) |
|---|---|---|
| PRE APOGEE PRECESSION | 225 | 3.94 |
| POST APOGEE PRECESSION | 225 | 1.87 |
| DESPIN | 232 | 1.46 |
| ATTITUDE ACQUISITION | | |
| - WHEEL SPINUP | 153 | .34 |
| - 3 AXIS LIMIT CYCLE | 103 | .34 |
| - WHECON ENABLE | 103 | .39 |
| STATION ACQUISITION | 232 | 22.13 |
| ON-ORBIT ROLL-YAW ATTITUDE CONTROL | 103 | 18.31 |
| PITCH MOMENTUM DUMPING | 153 | .58 |
| EAST-WEST STATIONKEEPING | 225 | 10.53 |
| NORTH-SOUTH STATIONKEEPING | 225 | 135.97 |
| MISALIGNMENT | - | .58 |
| RESIDUALS & LOADING TOLERANCE | - | .90 |
| TANK EXPULSION IN EFFICIENCY | - | .99 |
| SUB-TOTAL | | 198.33 |
| 5% GROWTH PROPELLANT | - | 9.92 |
| TOTALS | | 208.25 LBM |


RCS CATALYTIC HYRAZINE SUBSYSTEM
PROPELLANT WEIGHT VS LIFE AND LAUNCH DATE
RCS PROPELLANT WEIGHT (LBM)
260
240
220
200
180
182
8 YEAR MISSION
TANKAGE DESIGN POINT
SMALLER LINEAR $I_{BIT}$ FOR OFFSET THRUSTERS
US CONTENDER, 8 YEARS LIFE, NO THRUSTER ROLL-YAW ATTITUDE CONTROL
6 YEAR MISSION
PROPELLANT DESIGN POINT
1975
1980
1985
26 #
YEAR OF LAUNCH

# RCS MPB CATALYTIC SUBSYSTEM HARDWARE WEIGHT BREAKDOWN

| COMPONENT | MPB | | U.S. CONTENDER[1] | |
|---|---|---|---|---|
| | QUANTITY | WEIGHT (LBM) | QUANTITY | WEIGHT (LBM) |
| TANK | 4 @ 9.25 | 37.00[2] | 4 @ 5.2 | 20.80 |
| F & D VALVES | 6 | .87 | 6 | .80 |
| PRESSURE SENSOR | 2 | .32 | 2 | .50 |
| FILTER | 2 | .44 | 2 | .80 |
| LTE | 16 @ .45 | 7.20 | 12 @ .5 | 6.00 |
| HTE | 2 @ .81 | 1.62 | - | - |
| LATCHING VALVES | 8 @ .53 | 4.25 | 4 @ .5 | 2.00 |
| TUBING | A/R | ~ 2.5 | | ~ 2.5 |
| WIRING | A/R | ~ 4.0 | | ~ 4.0 |
| ECU - EXCEPT PC. | | 7.0 | - | - |
| - POWER CONDITIONING | | ~ 1.0 | - | - |
| MISCELLANEOUS HARDWARE (P CLAMPS, ETC.) | | ~ 1.5 | - | - |
| REM BRACKETS | A/R | ~ 3.0 | - | - |
| TOTAL | | 70.70 LBM[2] | | 37.4 LBM[3] |

NOTES:

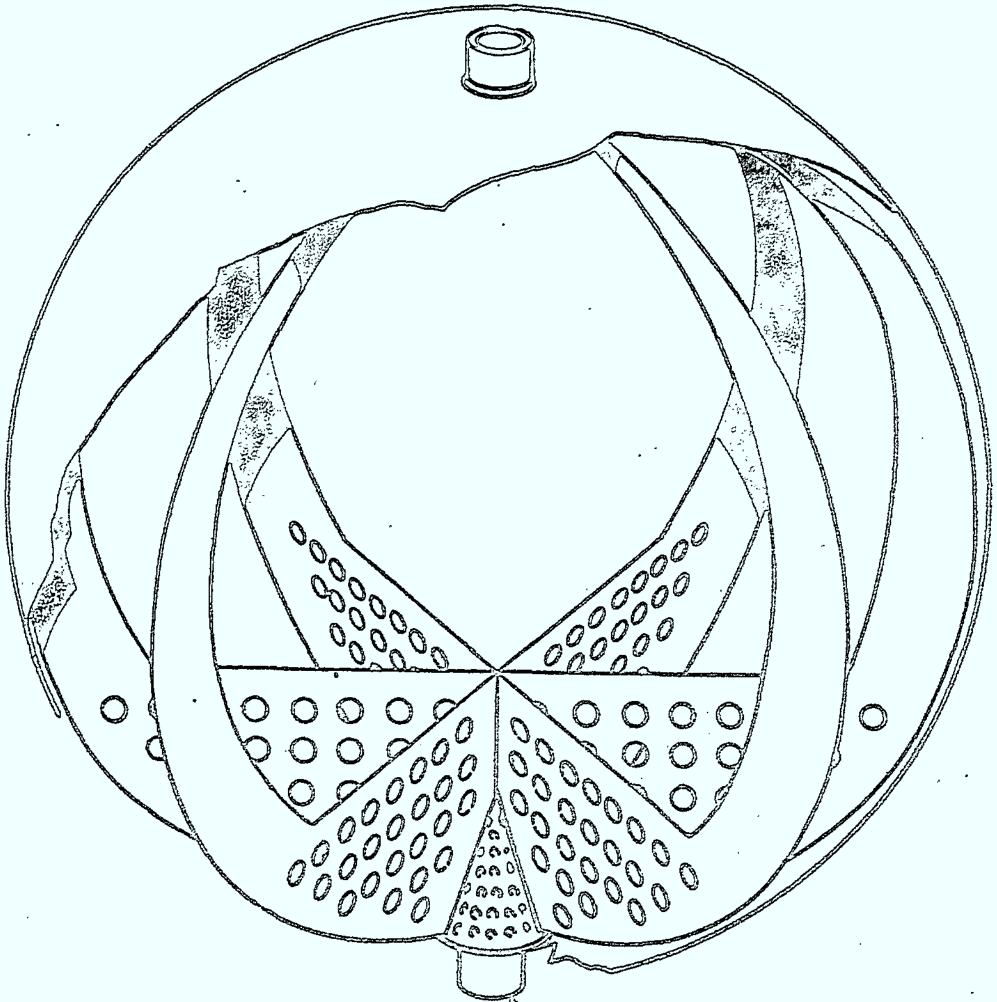
1. HALF SYSTEM DESIGN WITH 12 ENGINE CONFIGURATION EMPLOYING LTEs FOR PRECESSION MANOEUVRES WILL NOT MEET RELIABILITY REQUIREMENTS FOR MPB.
2. IF SURFACE TENSION TANKAGE OF THE RCA SATCOM CONFIGURATION WERE EMPLOYED, TANK WEIGHT WOULD BE APPROXIMATELY 6.0 X 4 = 24.0 LBM AND RCS TOTAL HARDWARE WEIGHT WOULD BE APPROXIMATELY 57.7 LBM.
3. U.S. CONTENDER'S WEIGHT DOES NOT APPEAR TO INCLUDE ELECTRONICS, BRACKETRY OR MISCELLANEOUS HARDWARE WHICH MUST BE ACCOUNTED FOR IN OTHER SUBSYSTEMS.
4. MPB DESIGN IS HARDWARE WEIGHT COMPETITIVE TAKING INTO ACCOUNT 1 ABOVE, EXCEPT FOR TANKAGE.

# RCS MPB CATALYTIC TOTAL WEIGHT SUMMARY

## - 6 YEAR MISSION 1985 LAUNCH -

| | |
|---|---|
| PROPELLANT | 208.25 LBM. |
| HARDWARE (TANKAGE FOR 8 YEARS) | 70.70 LBM. |
| PRESSURANT | 1.27 LBM. |
| TOTAL WEIGHT | 280.22 LBM. |

## SURFACE TENSION TANKAGE




### FEATURES

SIMPLE STRUCTURAL DESIGN

COMPLETELY PASSIVE

LOW COST

LIGHT WEIGHT

FEW FAILURE MODES
AUTOMATIC OPERATIONAL RECOVERY

LIFE EQUIVALENT TO TANK SHELL

SINGLE MATERIAL FOR TANK & DEVICE

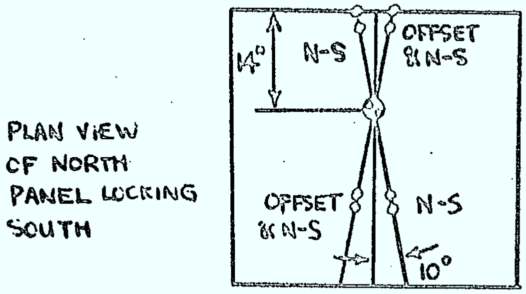
### DISADVANTAGES

DIFFICULT TO TEST IN A 1 G ENVIRONMENT

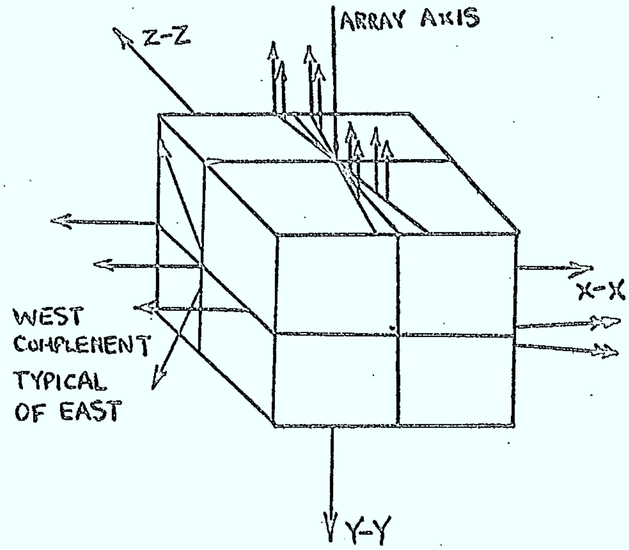
- NEED FOR SEGMENTED TESTING (DROP TOWER, NEUTRAL BUOYANCY & 1 G BENCH) TO VERIFY: CORRECT STATIC INTERFACE UNDER ENVIRONMENTAL LOADING AND ZERO G; REQUIRED EXPULSION EFFICIENCY; THAT NO GAS INGESTION OCCURS DUE TO ENTRAINED VAPOUR BUBBLES

RADIAL-TO-SPIN-AXIS ORIENTATION OF PROPELLANT OUTLET REQUIRED FOR THE SPINNING MISSION PHASES (HORIZONTAL IN LAUNCH CONFIGURATION)-MAKES GROUND FILLING & DRAINING OPERATIONS MORE COMPLICATED THAN WITH A GRAVITY DRAIN. PRESSURANT INLET SHOULD BE LOCATED IN THE QUADRANT WHERE GAS RESIDES IN THE ONE G ENVIRONMENT.

# SPLIT ARRAY - CATALYTIC HYDRAZINE DESIGN



ARRAY AXIS THROUGH C OF M




CONFIGURATION:

- 2 HTEs, 18 LTEs, 8 LATCHING VALVES

ADVANTAGES:

- PROPELLANT WEIGHT SAVING OF APPROXIMATELY 13 LBM DUE TO REDUCED SOLAR TORQUES OF 4.3 X $10^{-6}$ FT.LBF COMPARED TO 7.8 X $10^{-6}$ FT.LBF FOR OFFSET ARRAY (8 LBM) AND NO CANTING OF N-S STATIONKEEPING ENGINES I.E. 2% THRUST DEGRADATION COMPARED TO 6% FOR OFFSET ARRAY (5 LBM)
- GREATER REDUNDANCY OF THRUSTERS FOR N-S STATIONKEEPING IF HAVE CAPABILITY TO USE SAME THRUSTERS FOR ROLL-YAW ATTITUDE, OFFSET CONTROL
- REDUCED SPACECRAFT SOLAR TORQUES DURING N-S STATIONKEEPING
- ABILITY TO CHOOSE ENGINES TO MINIMIZE C OF M SHIFTS
- SLIGHT NET HARDWARE WEIGHT SAVING ( 1 LBM) EVEN THOUGH 20 THRUSTER SUBSYSTEM BECAUSE OF REDUCTION IN TANKAGE WEIGHT
- SPLIT ARRAY WEIGHT SAVING?

DISADVANTAGES:

- SPLIT ARRAY OPERATIONAL & STOWAGE COMPLEXITY
- NEED TO ROTATE THE ARRAY TO LIE IN YAW/PITCH PLANE DURING N-S STATIONKEEPING - ADDITIONAL BATTERY LOAD
- USE OF VALUABLE NORTH OR SOUTH PANEL REAL ESTATE FOR MOUNTING RCS THRUSTERS

# STATE OF THE ART RCS TECHNOLOGY INVESTIGATION & TRADEOFF

## - PRELIMINARY REPORT -

- CATALYTIC HYDRAZINE/CATALYTIC PLENUM GAS ELECTROTHERMAL HYDRAZINE SUBSYSTEM
- BIPROPELLANT MMH/$N_2O_4$ SUBSYSTEM
- CATALYTIC HYDRAZINE/ELECTROTHERMAL HYDRAZINE SUBSYSTEM
- ION ENGINE FOR NORTH SOUTH STATIONKEEPING

## CATALYTIC HYDRAZINE/CATALYTIC PLENUM GAS ELECTROTHERMAL HYDRAZINE SUBSYSTEM

### CONFIGURATION:

* BLOWDOWN MASS EXPULSION SUBSYSTEM EXCEPT FOR ROLL-YAW ATTITUDE, OFFSET OPERATION
* CATALYTIC HYDRAZINE HTEs, 1 TO 5.5 LBF STEADY STATE THRUST, FOR PRECESSION
* CATALYTIC HYDRAZINE, .1 TO .3 LFB STEADY STATE THRUST, LTEs FOR ROLL, PITCH, YAW, DESPIN, N-S AND E-W STATIONKEEPING
* CATALYTIC, PRESSURE REGULATED PLENUM ASSEMBLY & GAS ELECTROTHERMAL THRUSTERS PROVIDING WARM GAS, IN RANGE .001 TO .020 LBF STEADY STATE THRUST, (ISP=150 LBF SEC/LBM) FOR ROLL-YAW ATTITUDE OFFSET CONTROL

### ADVANTAGES:

* SMALLER SPACECRAFT PERTURBATION TORQUES THAN WITH CATALYTIC THRUSTERS
* LINEAR IMPULSE BIT PROVIDED FOR OFFSET CONTROL, AS LOW AS IS OPTIMUM ($< 1 \times 10^{-3}$ LBF SEC IF REQUIRED) AND CONSTANT OVER LIFE
* NET WEIGHT SAVINGS COMPARED TO ALL CATALYTIC SUBSYSTEM OF APPROXIMATELY 7 LBM FOR WORST CASE 6 YEAR MISSION WITH TANKAGE SIZED FOR 8 YEARS FUEL
* PLENUM SYSTEM HAS FLOWN

### DISADVANTAGES:

* REDUCED RELIABILITY DUE TO INCREASED COMPLEXITY OF PRESSURE REGULATED PLENUM ASSEMBLY
* POSSIBLE LONG TERM GAS LEAKAGE WITH OFFSET THRUSTERS
* INCREASED COST - NOT QUANTITATIVELY ASSESSED
* PLENUM IS DUTY CYCLE LIMITED
* 3 WATT THRUSTER CHAMBER HEATERS REQUIRED FOR OFFSET OPERATION

# BIPROPELLANT MMH/$N_2O_4$ SUBSYSTEM

## CONFIGURATION:

* PRESSURE REGULATED SUBSYSTEM
  REGULATED PRESSURANT MANAGEMENT ASSEMBLY INCLUDING HIGH PRESSURE TANK (~4000 PSIA), PRESSURE TRANSDUCER, REGULATOR, SLAM SUPPRESSOR, ISOLATION VALVE - APPROXIMATELY 23 LBM ADDED HARDWARE WEIGHT
* BIPROPELLANT HTEs, 1. TO 5.5 LBF STEADY STATE THRUST, FOR PRECESSION
* BIPROPELLANT, TIROC LTEs, .3 LBF STEADY STATE THRUST, REGULATED, FOR ALL OTHER FUNCTIONS
* EQUAL VOLUME PROPELLANT & OXIDIZER TANKAGE (MR 1.6)

## MAJOR ADVANTAGES:

* NET WEIGHT SAVING COMPARED TO ALL CATALYTIC SUBSYSTEM OF APPROXIMATELY 4 LBM FOR WORST CASE 6 YEAR LIFE WITH TANKAGE SIZED FOR 8 YEARS FUEL. (COULD BE APPROXIMATELY 21 LBM GREATER IF TIROC ENGINE WERE ALLOWED TO OPERATE AT ITS DESIGN POINT OF .5 LBF STEADY STATE THRUST)
* THERMAL CONTROL OF FUELS UNNECESSARY (FREEZING POINT ~ -30°C) AND NO THRUSTER CHAMBER HEATER REQUIRED - OPERATIONAL SIMPLIFICATION
* SIMPLIFIED TEST PROGRAM - PERFORMANCE TESTING AT SEA LEVEL PRESSURE
* DELIVERED TORQUE IMPULSE BIT NOT DEPENDENT UPON DUTY CYCLE AND SQUARE PULSE SHAPE DOWN TO 5 M SEC PULSES
* TIROC THRUSTER OPERATED FOR 10 M PULSES AND 1 M SEC STEADY STATE SUBSEQUENT TO VIBRATION TESTING

## BIPROPELLANT MMH/$N_2O_4$ SUBSYSTEM (CONT'D.)

MAJOR DISADVANTAGES:

* NO FLIGHT EXPERIENCE WITH LTE, TIROC. (7 YEARS DEVELOPMENT ACCOMPLISHED)
* REDUCED RELIABILITY DUE TO PRESSURE REGULATION AND DUAL ENGINE AND LATCHING VALVES
* POSSIBLE PLUME CONTAMINATION OF UNBURNED FUELS - AT LOW PULSE WIDTHS
* HTE MANUFACTURED BY U.S. FIRM, TIROC, LTE, BY GERMAN FIRM - COMPLICATED TEAMING ARRANGEMENT
* METALLIC OR TEFLON OXIDIZER EXPULSION DEVICE REQUIRED
* LONG TERM,8 YEARS, COMPATIBILITY OF OXIDIZER WITH HARDWARE, ESPECIALLY VALVE COMPONENTS, UNCERTAIN

# CATALYTIC HYDRAZINE/ELECTROTHERMAL HYDRAZINE SUBSYSTEM

## CONFIGURATION:

* BLOWDOWN MASS EXPULSION SUBSYSTEM
* CATALYTIC HYDRAZINE HTEs, 1 TO 5.5 LBF STEADY STATE THRUST, FOR PRECESSION
* ELECTROTHERMAL HYDRAZINE LTEs (EHT), IN RANGE .01 TO .04 LBF STEADY STATE THRUST WITH CHAMBER HEATERS, FOR ALL OTHER FUNCTIONS

## MAJOR ADVANTAGES:

* OVERALL WEIGHT SAVINGS COMPARED TO ALL CATALYTIC SUBSYSTEM OF APPROXIMATELY 21 LBM FOR WORST CASE 6 YEAR LIFE WITH TANKAGE SIZED FOR 8 YEARS FUEL, EPT-10 DIAPHRAGM TANK
* EHT THRUSTER DESIGN DEVELOPED UNDER NASA FUNDING (>5 YEARS DEVELOPMENT), LIFE TEST COMPLETED OF 1M PULSES, ALSO 30 HR STEADY STATE AND 300 K PULSES ON SAME ENGINE, SHOULD BE QUALIFIED THIS YEAR
* CAPABILITY OF DELIVERING SMALLER LINEAR IMPULSE BITS THAN CATALYTIC FOR ROLL-YAW ATTITUDE, OFFSET CONTROL ($<1 \times 10^{-3}$ LBF SEC IF REQUIRED) AT SIGNIFICANTLY HIGHER SPECIFIC IMPULSE (ISP = 165 LBF SEC/LBM)
* SMALLER S/C PERTURBATION TORQUES THAN WITH CATALYTIC THRUSTERS
* POSSIBILITY OF ENHANCED PERFORMANCE IN THE FUTURE

## MAJOR DISADVANTAGES:

* POWER REQUIRED FOR BED HEATERS (3. TO 5. WATTS PER THRUSTER), HIGHER THAN FOR CATALYTIC THRUSTERS (1 WATT PER THRUSTER)
* TOTAL STEADY STATE OPERATING LIFE FOR NS STATIONKEEPING THRUSTERS GREATER BY A FACTOR OF APPROXIMATELY 7 THAN FOR CATALYTIC THRUSTERS

INSTRUCTIONS

MODE D'EMPLOI

ION ENGINE

AUXILIARY PROPULSION SYSTEM

| ADVANTAGES | DISADVANTAGES |
| --- | --- |
| o ONE-TENTH AS MUCH PROPELLANT REQUIRED FOR SAME TOTAL IMPULSE | o NEEDS ELECTRICAL POWER |
| o CAN ADJUST SPACECRAFT POTENTIAL DURING MAGNETIC STORMS | o REQUIRES POWER PROCESSING |
| o OFFSET TORQUES ARE LOW | o DOES NOT HAVE COMMONALITY WITH HIGH THRUST ENGINE PROPELLANT |
| o CAN BE THRUST VECTORED ( MOMENTUM DUMPING) | o NOT UNEQUIVOCALLY DEMONSTRATED BY SPACE FLIGHT |
| o MERCURY IS A SAFER PROPELLANT TO HANDLE THAN HYDRAZINE | o SUBSYSTEM MORE EXPENSIVE |
| o EAST-WEST STATIONKEEPING CAN BE ACCOMPLISHED ALSO | o SPACECRAFT CONFIGURATION MUST PERMIT ION BEAM CLEAR EXHAUST PATH |
| o CAN USE SPACECRAFT BATTERY WHEN NOT REQUIRED BY COMMUNICATIONS EQUIPMENT | |

TABLE I

| NO. | DATE | LAUNCH VEHICLE | ION ENGINE | MANUFACTURER | AGENCY | RESULT |
|---|---|---|---|---|---|---|
| 1. | 18 Dec 62 | Ballistic (Scout) | Cs - Contact | EOS | Air Force | - failed - battery vapour caused P.C. arcs |
| 2. | 20 Jul 64 | Ballistic (Scout) SERT I | a) Cs- Contact<br>b) Hg - Bombardment | HRL<br>LeRC | NASA<br>NASA | - a) failed - arc in high voltage connector<br>- b) successful |
| 3. | 29 Oct 64 | Ballistic (Scout) | Cs - Contact | EOS | A.F. | - successful |
| 4. | 21 Dec 64 | Ballistic (Scout) | Cs - Contact | EOS | A.F. | - successful |
| 5. | 3 Apr 64 | Orbital Snap 10-A | Cs - Contact | EOS | A.F. | - telemetry failed, ion engine test prematurely terminated |
| 6. | 10 Aug 68 | Synch Orbit ATS-4 (Atlas-Centaur) | a) CS - Contact<br>b) CS - Contact | EOS<br>EOS | NASA | - successful for two month S/C life |
| 7. | 12 Aug 69 | Synch Orbit ATS-5 (Atlas-Centaur) | a) Cs - Contact<br>b) Cs - Contact | EOS<br>EOS | NASA | - S/C in flat spin, meutralizer only operated |
| 8. | 3 Feb 70 | Orbital SERT II (Thorad/Agena) | a) Hg - Bombardment<br>b) Hg - Bombardment | LeRC<br>LeRC | NASA | - a) 3781 hrs then shorted<br>b) 2011 hrs then shorted*<br>*restarted 16 Aug 74 |
| 9. | 30 May 74 | Synch Orbit ATS-6 (Titan 3E-Centaur) | a) Cs - Bombardment<br>b) CS - Bombardment | EOS<br>EOS | NASA | - 1 hr on one thruster<br>92 hr on second |

TABLE III

AVAILABLE THRUSTER SYSTEM

| Developer/Manufacturer | Propellant | Description | Thrust mN | Thrust mlb | Isp sec | Grid Diameter cm | Thruster Power (Watts) | PPS Eff. % | Total Power | MASS Kg Less Propellant |
|---|---|---|---|---|---|---|---|---|---|---|
| LeRC/Hughes | Hg-B | SIT 8 | 4.45 | 1 | 2900 | 8 | 120 | 87 | 141 | 9.05 |
| Giesson/MBB | Hg-RF | RIT-10 | 5 | 1.12 | 3000 | 10 | 145 | 72 | 200 | 8.5 |
| RAE,Cullam/ Mullard, Marconi | Hg-B | T-4 | 7 | 1.57 | 2620 | 10 | 175 | 87 | 200 | 8.0 (Est.) |
| TRW/TRW | Colloid | ADP | 4.4 | 1 | 1400 | 20 (square) | 50.6 | 72 | 70 | 11.5 |
| EOS/EOS | Cs-B | ATS-6 | 4.45 | 1 | 2600 | 8 | 123 | 85 | 150 | 12.33 |

Appendix II

Baseline Design

The SIT 8 thruster is used as an example for a baseline design.

Assumptions

| | |
|---|---|
| Spacecraft mass | 448 Kg ( 985 lb) |
| Thrust of ion engine | 4.45 mN ( 1m lb ) |
| Specific impulse | 2900 sec. |

Configuration Is as shown in the attached figure. The two power processors are completely crosstrapped. Thrusters are gimballed through $\pm 10^{0}$ in two orthogonal directions.

Mass Properties

| | | | Kg | | Kg |
|---|---|---|---|---|---|
| Thrusters | 4 | @ | 1.69 | = | 6.76 |
| Gimbals | 4 | @ | 0.68 | = | 2.72 |
| Power Processors | 2 | @ | 6.49 | = | 12.98 |
| Tanks (8 yr size) | 2 | @ | 0.92 | = | 1.84 |
| Switches | 4 | @ | .8 | = | 3.20 |
| Harnesses | 2 | @ | .4 | + | .80 |
| | | | | | 28.30 |
| 6 yrs propellant | | | | | 8.78 |
| | | | | | 37.08 |
| 150 watts array allocation at 30 [illegible] (if no battery allocation) w/kg | | | | | 4.5 |
| | | | | | 41.58 Kg = (91.47 lb) |

.../29

Operation

Thrusting time per orbit - 6.09 hrs

Total thrusting time* - 13,362 hrs

Total preheat time (6 yrs) - 547 hrs

Propellant required (6 yrs) - 8.78 Kg

Propellant required (8 yrs) - 11.70 Kg

*Note that the firing time is divided approximately equally between a thruster on each of the east and west faces. As each unit is redundant, the average operating time required is 13,362/4 = 3340 hrs.

Power Requirement

150 watts (assuming vectoring gimbals are operated during thrust periods).

INSTRUCTIONS

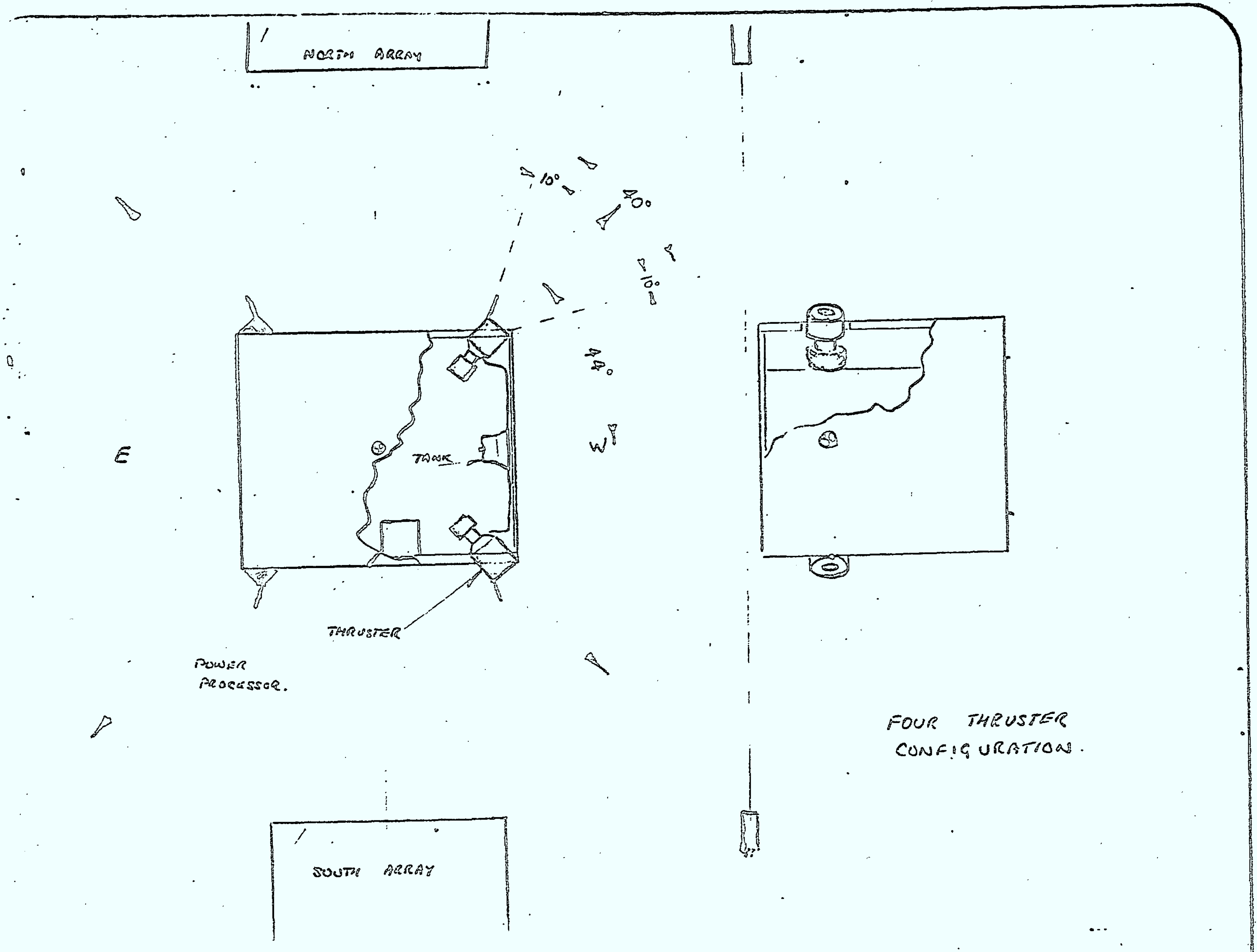
TABLE II

GROUND LIFE TESTS

| | |
|---|---|
| - SIT 8 - Hq - Bombardment | - 10,700 hrs. 317 cycles |
| - 30 cm - Hq - Bombardment | - 8,900 hrs. |
| - SIT 5 - Cathode, isolator vapourizer | - 20,000 hrs. |
| - T-4 - Hq - Bombardment | - 1,050 hrs. no failures |
| - EOS 8 cm - Cs - Bombardment | - 4,348 hrs (including 2,614 hrs full thrust 471 cycles) |
| - RIT 10 Hq - Bombardment duration test | - 1,000 hrs. |

MODE D'EMPLOI

.../15




MODE D'EMPLOI

INSTRUCTIONS

# SECTION 7

# DEPLOYABLE SOLAR ARRAY

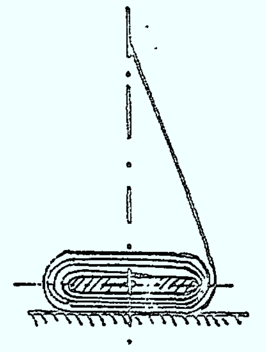
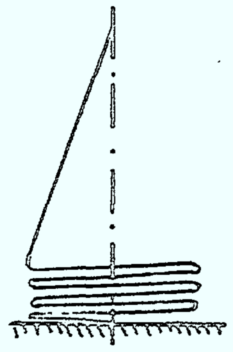
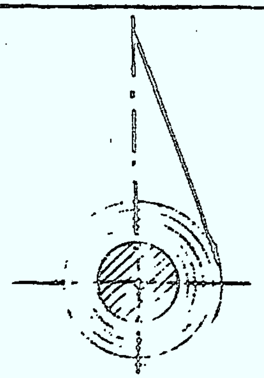
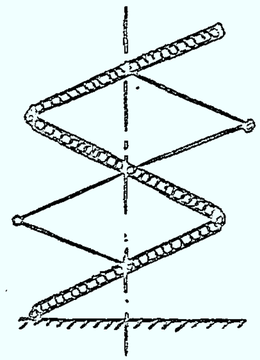
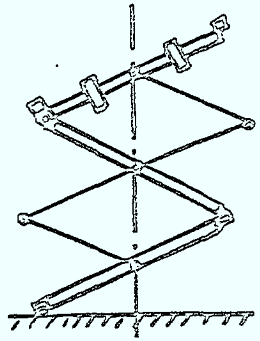
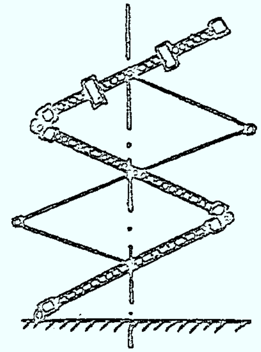
## REQUIREMENTS - DEPLOYABLE

### SOLAR ARRAY SUBSYSTEM - G.P. SAT. BUS

1. Provide 500-800 watts, end of life 6-8 years, 35 to 40 V.
2. Minimum weight, tailor to particular mission requirements.
3. Survive Launch Vibration - Thor Delta 3914.
4. Provide sufficient exposed solar cells in launch configuration for 70 watts transfer and drift orbit power.
5. Minimized thermal deformations and fabrication tolerances to reduce solar torquing effects.
6. Deploy in a controlled manner to the fully deployed condition.
7. Deployed array stiffness consistent with requirements of ACS.
8. Stowed array must provide thermal protection to the S/C North and South Panels.
9. Stowed array must clear those RCS thrusters which operate in transfer and drift orbit.
10. Lower end of array must be elevated to minimize shadowing by the antenna and to achieve the desired thermal field-of-view.
11. Deployed arrays should track the sun with an accuracy of $\pm 1^{\circ}$.

| POWER REQUIREMENTS - G.P. SATELLITE BUS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SUBSYSTEM | PAYLOAD A | | PAYLOAD B | | PAYLOAD C | | PAYLOAD D | | PAYLOAD E | |
| | T.O POWER-W | SYNCH POWER-W | T.O (W) | SYNCH (W) | T.O (W) | SYNCH (W) | T.O (W) | SYNCH (W) | T.O (W) | SYNCH (W) |
| COMMUNICATIONS | | 415 | | 625 | | 505 | | 513 | | |
| TELEMETRY AND COMMAND | | 30 | | 30 | | 30 | | 30 | | |
| POWER | | 15 | | 15 | | 15 | | 15 | | |
| DSA (TRACKING) | | 10 | | 10 | | 10 | | 10 | | |
| ACS | | 40 | | 40 | | 40 | | 40 | | |
| RCS | | 15 | | 15 | | 15 | | 15 | | |
| THERMAL HEATERS | | 30 | | 30 | | 30 | | 30 | | |
| TOTAL | | 555 | | 765 | | 645 | | 653 | | |
| CONTINGENCY | | 35 | | 35 | | 35 | | 35 | | |
| DESIGN TOTAL | | 590 | | 800 | | 680 | | 688 | | |

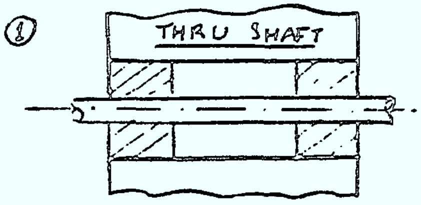
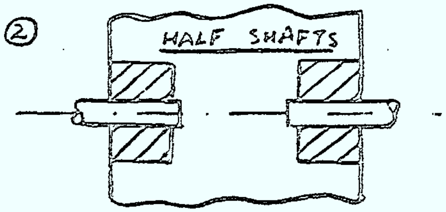
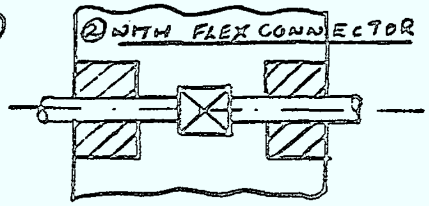
# ALTERNATE DSA STOWAGE & DEPLOYMENT CONCEPTS

| FLEXIBLE | | | RIGID | | |
|---|---|---|---|---|---|
| FLAT SPINDLE | FLAT PACK | ROLL UP | RIGID SUBSTRATE | RIGID FRAME/ FLEX. SUBSTRATE | RIGID FRAME/ 'RIGID' SUBSTRATE |
|  |  |  |  |  |  |
| o UNUSED CORNERS VOLUME > FLAT PACK<br>o TRANSLATION OF PIVOT CENTER REQD<br>o ADDITIONAL SPINDLE DRIVE REQD.<br>o ROTARY POWER TRANSFER REQD<br>o CELL PROTECTION BY INTERLEAFS REQD<br>o IRREGULAR EXTENSION<br>o LOW DEPLOYED $f_n$<br>o WEIGHT > FLAT PACK | o WEIGHT EFFECTIVE SMALLEST VOLUME<br>o RETRACTION IS DIFFICULT<br>o SIMPLE DEPLOYMENT<br>o NO ROTARY POWER TRANSFER REQD.<br>o CELL PROTECTION BY INTERLEAFS REQD<br>o IRREGULAR EXTENSION<br>o LOW DEPLOYED $f_n$<br>o LOWEST WEIGHT | o UNUSED DRUM VOLUME ≫ FLAT PACK<br>o EXTENSION & RETRACTION POSSIBLE<br>o ADDITIONAL DRUM DRIVE REQUIRED<br>o ROTARY POWER TRANSFER REQD.<br>o CELL PROTECTION BY INTERLEAFS REQD<br>o REGULAR EXTENSION<br>o LOW DEPLOYED $f_n$<br>o WEIGHT > FLAT PACK | o HIGH SOLAR CELL DENSITY POSSIBLE VOLUME > FLEX FLATPACK<br>o RETRACTION IS DIFFICULT<br>o SIMPLE DEPLOYMENT PANTOGRAPH OR CABLE.<br>o NO ROTARY POWER TRANSFER REQD.<br>o NO CELL PROTECTION REQD.<br>o REGULAR EXTENSION<br>o DEPLOYED $f_n$ > OTHERS<br>o WEIGHT > OTHERS | o SOLAR CELL LAYOUT SLIGHTLY AFFECTED BY CROSS BEAMS<br>o RETRACTION IS DIFFICULT<br>o SIMPLE DEPLOYMENT PANTOGRAPH OR CABLE<br>o NO ROTARY POWER TRANSFER REQD<br>o INTER PANEL 'BUTTONS' PREVENT CELL DAMAGE<br>o REGULAR EXTENSION<br>o DEPLOYED $f_n$ < RIGID SUBSTRATE<br>o WEIGHT < RIGID SUBSTRATE & FLEX FOR ~ LEN | o SOLAR CELL LAYOUT SLIGHTLY AFFECTED BY CROSS BEAMS<br>o RETRACTION IS DIFFICULT<br>o SIMPLE DEPLOYMENT PANTOGRAPH OR CABLE<br>o NO ROTARY POWER TRANSFER REQD<br>o NO CELL PROTECTION REQD<br>o REGULAR EXTENSION<br>o DEPLOYED $f_n$ ≤ RIGID FRAME/FLEX S/ST.<br>o WEIGHT > RIGID FRAME/FLEX S/STRATE |

| CONSTRUCTION TECHNIQUES - RIGID ARRAYS | | |
|---|---|---|
| 1) RIGID SUBSTRATE | 2) RIGID FRAME/FLEXIBLE SUBSTRATE | 3) RIGID FRAME/'RIGID' SUBSTRATE |
| 1. Aluminum honeycomb with facesheets of any one of the following:<br><br>- fibreglass<br>- aluminum<br>- carbon fibre<br><br>Depth and density of honeycomb core can be varied to achieve desired stiffness. Rear face sheets can have holes to reduce operating temperature.<br><br>2. Light metal (magnesium or aluminum alloy) milled in triangular or rectangular grid with bonded aluminum or kapton skin. | Kapton or kapton/fibreglass substrate typically about .003" (.08 mm) thick, stretched between a framework of rectangular tubular construction. The materials used for the framework can be any one or a combination of the following:<br><br>- aluminum<br>- carbon fibre<br>- beryllium<br><br>Depth and thickness of tubes can be varied to achieve desired stiffness.<br><br>Substrate/cells on adjacent panels are prevented from contacting each other during stowed vibration by the use of short columns termed buttons distributed across the panels. | Aluminum honeycomb with kapton facesheets typically .0015" (.04 mm) thick on the solar cell side and .003" (.08 mm) thick with 50% holes on the rear, supported between a framework of rectangular tubular construction similar to 2).<br><br>This design may not need as much support within the panel as 2) to prevent contact during vibration. |

| MAJOR TRADE-OFF PARAMETERS - RIGID ARRAYS | | | |
|---|---|---|---|
| PARAMETER | 1) RIGID SUBSTRATE | 2) RIGID FRAME/FLEXIBLE SUBSTRATE | 3) RIGID FRAME/'RIGID' SUBSTRATE |
| 1. Size - Deployed | Typically 4 panels per side, each panel 59.25" (150.5 cm) long and 50" (127 cm) wide, for 800 watt EOL, assuming $1x10^{15}$ eq. 1 mev electrons total deployed length including elevation yoke = 301.25" (765 cm). | Typically 4 panels per side, each panel 72" (183 cm) long and 50" (127 cm) wide, for 800 watt EOL, assuming $2x10^{15}$ eq. 1 mev electrons to allow for backside radiation. Total length = 365" (927 cm). | Same as (2).<br><br>Increased operating temperature may be compensated by additional rearside radiation shielding. Detail study not done. |
| 2. Size - Stowed | 60.5" x 51" x 7" (154 cm x 130 cm x 18cm) | 73" x 51" x 7.75" (185 cm x 130 cm x 20 cm) | Same as (2). |
| 3. Weight | About 50.2 lb. per side or 100.4 lb. per spacecraft. | About 40.7 lb. per side or 81.4 lb. per spacecraft. | About 45.3 lb. per side or 90.6 lb. per spacecraft. |
| 4. Natural frequency - deployed | 0.31 Hz using 1", 1 lb/cu.ft. Al. H/C core, .0035" al. skin - cell side, .014" al. skin - rear, 50% holes. | 0.46 Hz using beryllium tubes, 0.32 Hz using carbon fibre tubes. | 0.44 Hz using beryllium tubes, 0.30 Hz using carbon fibre tubes. |
| 5. Operating temperature - | | | |
| a) summer solstic | 52.2°C | ~52°C end panels, 46°C intermediate | ~61.4°C end panels, 55.3°C intermediate |
| b) equinox | 64.4°C | ~64°C end panels, 57.7°C intermediate | ~75.7°C end panels, 68.2°C intermediate |
| 6. Development Status | Honeycomb rigid substrate construction most commonly used - well proven. | This concept is in preliminary design stage at SPAR. Vibration test to prove the concept is planned. | Preliminary static load and acoustic noise tests have been carried out by TRW of this concept. |

## ARRAY ORIENTATION & POWER TRANSFER – ALTERNATE CONFIGURATIONS

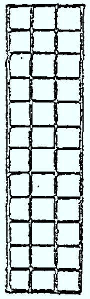
| | | | |
|---|---|---|---|
| CONFIGURATION | ①   | ②   | ③   |
| ADVANTAGES | ○ COMPLETE SYNCHRONIZATION OF ARRAYS<br>○ ENTIRE DEVICE CAN BE BUILT & TESTED AS AN ASSY.<br>○ BEARING PRELOAD CAN BE ACCURATELY ADJUSTED AT ASSY<br>○ GIVES BEST ARRAY ROOT STIFFNESS<br>○ PERMITS MAX. POWER TRANSFER VOLUME<br>○ PROBABLY MOST RELIABLE | ○ TEMPERATURE COMPENSATION MINIMUM.<br>○ SEIZURE OF ONE END DOES NOT AFFECT THE OTHER<br>○ EACH ASSY. OF SMALLER VOLUME THAN ①<br>○ POTENTIALLY LIGHTEST | ○ COMPLETE SYNCHRONIZATION<br>○ FLEX – CONNECTOR PERMITS FLEXURE DUE TO TEMPERATURE EFFECTS<br>○ ONE DRIVE COULD BE OPERATIVE IF OTHER FAILED. |
| DISADVANTAGES | ○ GREATEST VOLUME<br>○ SEIZURE OF MAIN BEARINGS AT EITHER END CAUSES SYSTEM FAILURE<br>○ INDEPENDENT OPERATION OF ARRAYS NOT POSSIBLE<br>○ PROBABLY HEAVIEST<br>○ CENTRE OF ROTATION OFFSET FROM S/C C. OF.M CAUSES SOLAR TORQUES. | ○ SYNCHRONIZATION BETWEEN ARRAYS MORE DIFFICULT<br>○ GIVES LESS ARRAY ROOT STIFFNESS THAN ①<br>○ MAY REQUIRE HANDED CONFIGURATIONS<br>○ EACH MODULE HAS SIMILAR RELIABILITY TO ① BUT OVERALL RELIABILITY MAY BE LOWER | ○ POWER TRANSFER SIZE LIMITED<br>○ LESS ARRAY ROOT STIFFNESS THAN ①<br>○ MAY REQUIRE HANDED CONFIGURATIONS<br>○ SLIGHTLY HEAVIER THAN ②<br>○ RELIABILITY SIMILAR TO ②<br>○ OFFSET CENTRE OF ROTATION - SIMILAR TO ① |

| TYPICAL AEG - CTS TYPE SOLAR CELL PERFORMANCE - mW/Cell - | | | | |
|---|---|---|---|---|
| NO. | STATUS | FOR RIGID SUBSTRATE | FOR FLEXIBLE SUBSTRATE | REMARKS |
| 1 | Beginning of Life @ 25°C, A.M.O, Max. Power Point | 65.00 | 65.00 | Based on CTS Housekeeping Array - Cell selection used |
| 2 | After radiation dosage | 45.48 | 37.90 | $1 \times 10^{15}$ eq. 1 MeV electrons for rigid<br>$2 \times 10^{15}$ eq. 1 MeV electrons for flex. |
| 3 | At summer solstice temperature | 40.37 | 34.07 | 52°C for rigid substrate<br>48°C average for flexible |
| 4 | Cell mismatch | 39.56 | 33.39 | 2 % loss |
| 5 | Cover glass darkening | 39.17 | 33.05 | 1 % loss |
| 6 | Cell breakage | 38.38 | 32.39 | 2 % loss |
| 7 | Calibration uncertainty | 38.00 | 32.07 | 1 % loss |
| 8 | Summer solstice sun intensity | 36.48 | 30.79 | 4 % loss |
| 9 | Solstice angle effect | 33.45 | 28.23 | 8.3% loss (cos 23.5 = 0.917) |
| | End of Life power/cell - normalized due to effects 4 to 9 | 33.45 mW | 28.23 mW | Max. power point occurs at approx. 0.401V, for rigid at E.O.L. and at approx. 0.390 V for flex, E.O.L. (This applies at Status 3) |

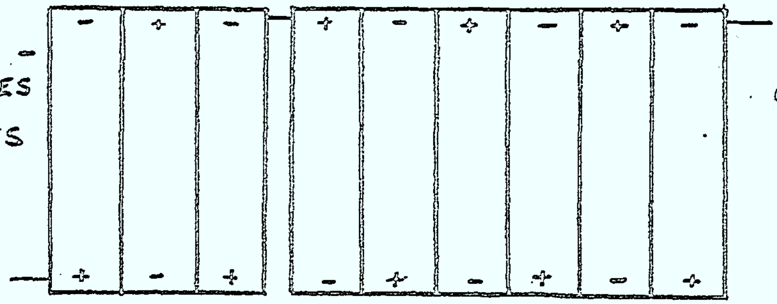
| PRELIMINARY ARRAY SIZING | | | |
|---|---|---|---|
| NO. | FACTOR | RIGID SUBSTRATE | FLEXIBLE SUBSTRATE |
| 1 | Minimum No. of cells required for 800 W end of life | 23,917 cells | 28,339 cells |
| 2 | Area required - using<br>1.1 x CTS packing factor for rigid<br>1.125 x CTS packing factor for rigid<br>frame/flex. substrate to allow for frames | 23,678 sq.in. | 28,693 sq.in. |
| 3 | Length of each panel for a 4 panel per side, 50" wide array | 59.2 in. | 71.7 in. |
| 4 | Minimum No. of cells required per panel | 2,990 cells | 3,543 cells |
| 5 | For 40 volt array operation, minimum No. of cells in a series string (allowing for average 0.4V drop in wiring and 0.8V drop in diodes) | 103 cells | 106 cells |

# PRELIMINARY CELL LAYOUT - RIGID SUBSTRATE

**MODULE** - 12 CELLS IN SERIES, 3 CELLS IN PARALLEL

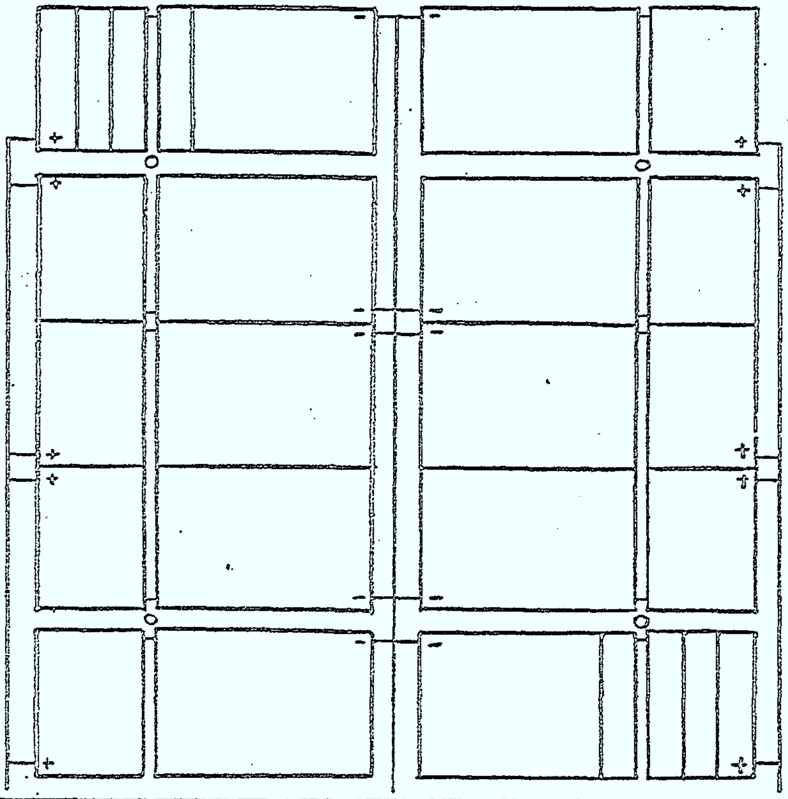


**MATRIX** - 9 MODULES IN SERIES



PROVIDES - 108 CELLS IN SERIES, 10.84 WATTS AT 43.3 VOLTS AT E.O.L

**PANEL** - 10 MATRICES IN PARALLEL



**FEATURES** -

- 108.4 WATTS AT 43.3 VOLTS, E.O.L
- CENTRAL GROUND RETURN FEATURE GIVES ZERO MAGNETIC MOMENT.
- ALLOWS 6" WIDTH FOR FCC'S
- ALLOWS 6" IN LENGTH DIRECTION FOR TIE DOWN POINTS, HINGES.
- 8 PANELS PER SPACECRAFT, PARALLEL CONNECTED PROVIDE 867 WATTS AT 43.3 VOLTS AT CELL STRINGS, OR 835 WATTS AT 40 VOLTS ON SPACECRAFT SIDE OF DIODES..
- TO COMPLETELY AVOID PARABOLIC UHF ANTENNA SHADOWING, INBOARD-MOST STRING CAN BE 18, 6x3 MODULES IN SERIES, GIVING 1.25% POWER REDUCTION OR 825 WATTS AT 40 VOLTS.

# TRANSFER ORBIT CONSIDERATIONS

BASED ON CTS. THE OPERATING TEMPERATURE RANGE WILL BE 3°C TO 24°C TAKING INTO ACCOUNT SEASONAL VARIATIONS AND SUN ANGLE TO NORMAL (OF s/c SPIN AXIS) OF ± 25°

POWER OUTPUT OF THE 65 mW/ B.O.L CELL @ 25°C WILL BE AFFECTED AS FOLLOWS:

| PARAMETER | DEGRADATION FACTOR |
|---|---|
| MISMATCH & ASSEMBLY | 0.98 |
| BREAKAGE & U-V DEGRADATION | 0.98 |
| CALIBRATION UNCERTAINTY | 0.99 |
| SOLSTICE INTENSITY | 0.96 |
| RADIATION DEGRADATION ($3.5 \times 10^{13}$ EQ. 1 MEV ELECTRONS) | 0.97 |
| SUN ANGLE EFFECT (cos 25°) | 0.906 |
| TEMPERATURE EFFECT (3°C) | 1.088 |
| OVERALL DEGRADATION | 0.873 |

POWER PER CELL = 56.75 mW @ THE MAX. POWER POINT, AT 0.491 VOLTS (53 V. @ STRING)

TO OPERATE AT A VOLTAGE OF 40 V

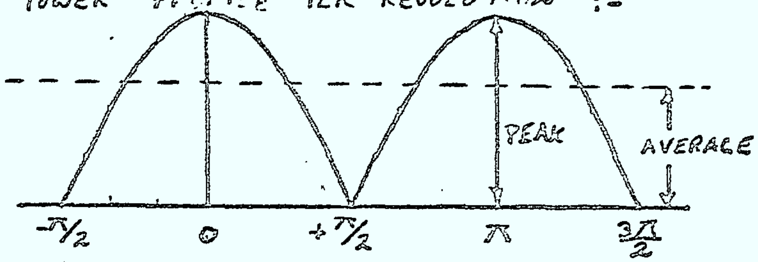
POWER PER CELL ≃ 52.4 mW, B.O.L.

≃ 45.75 mW, E.O.L

NUMBER OF CELLS = 3240 PER PANEL

PEAK POWER/PANEL = 148 W

POWER PROFILE PER REVOLUTION :-

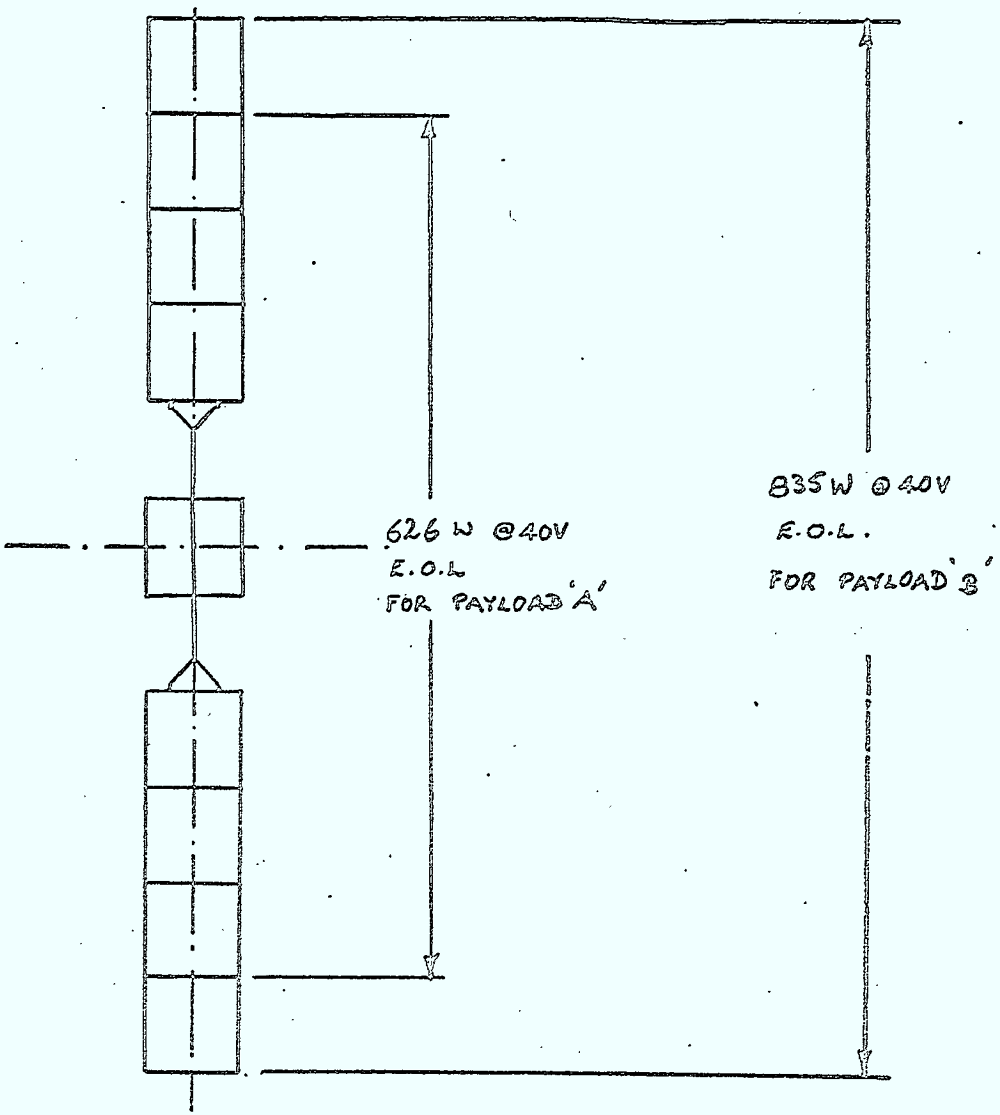



AREA UNDER EACH CURVE = $\int_{-\pi/2}^{\pi/2} \cos\theta \, d\theta = 2$

AVERAGE HEIGHT = $2/\pi$

∴ AVERAGE POWER = $148 \times \frac{2}{\pi}$ = 94 W @ 40V

# ADAPTABILITY TO PAYLOADS




FOR PAYLOADS C & D :-

OPTION 1 - UTILIZE ONLY 3½ PANELS / SIDE GIVING:- 731 W E.O.L

OPTION 2 - REDUCE PANEL LENGTHS BY 12.5% TO 52" EACH. NEW CELL LAYOUT & CELL MODULES REQUIRED. TRANSFER ORBIT POWER WILL BE REDUCED TO 82 WATTS.

# SECTION 8

# THERMAL SUBSYSTEM

GP BUS PAYLOAD CHARACTERISTICS

| PAYLOAD OPTIONS | ANTENNAE | | | TRANSPONDER | | | DC POWER |
|---|---|---|---|---|---|---|---|
| | TYPE | NO. & SIZE | WEIGHT | SIZE | WEIGHT lbs. | DISSIPATION watts | |
| a) UHF/4-6 GHz Transponder (12 channel) (5-6W TWT) | Dep. parabola or parabola + quad helix | 13 ft. dia. or 82" dia. x 100" long | ≈ 55 lbs. | TBD | 218.4 | S 314.9<br>E 264.3 | S 414.9<br>E 339.3 |
| b) UHF/12-14 GHz Transponder (20W TWT) | Dep. parabola or parabola + quad helix | 13 ft. dia. or 82" dia. x 100" long | ≈ 55 lbs. | TBD | 180.5 | S 456.6<br>E 351.5 | S 624.6<br>E 463.5 |
| c) UHF/7-8 GHz Transponder with auxilary experimental payload | Dep. parabola | 13 ft. dia. | ≈ 55 lbs. | TBD | 221.9 | S 404.2<br>E 252.3 | S 505.2<br>E 305.3 |
| d) UHF/SHF/L Band Transponder | Dep. parabola | 13 ft. dia. | ≈ 60 lbs. | TBD | 190.4 | S 397.2<br>E 305.3 | S 513.2<br>E 373.3 |
| $e_1$) 12-14 GHz Transponder (12 channels) 30W TWT | | | | | | ? | S 636 |
| $e_2$) 12-14 GHz Transponder 4-20 watt TWT 4-50 watt TWT + 50% redundancy | | | | | | ? | S<br>E 732 |

GENERATE ...

## 1. TRANSPONDER OPTIONS.

| COMPONENT | PWR DISSIP^N (WATTS) MAX | MIN | TEMP LIMITS (°C) OPERATING | NON-OP | * REQD | WT (lbs) | DIMENSIONS (ins) | REQD. THERMAL MOUNTING AREA (SQ INS) |
|---|---|---|---|---|---|---|---|---|
| **UHF TRANSPONDER [PAYLOADS (A) (B) (C) (D)]** | | | | | | | | |
| EPC | 29.1 | | 45 -5 | -40 | 1 | | | 150 |
| UHF DRIVER | 69.6 | | 70 -5 | -40 | 1 | | | 244 |
| UHF HPA MODULE | 75. | | 70 -5 | -40 | 1 | | | 263 |
| ISOLATOR | 5.7 | | 45 -5 | -40 | 1 | | | 29 |
| UHF SWITCH | 4.4 | | 45 -5 | -40 | 1 | | | 23 |
| UHF O/P FILTER | 9.8 | | 45 -5 | -40 | 1 | | | 50 |
| CABLING TO ANT. | 8.2 | | 45 -5 | -40 | 1 | | | 42 |
| **SHF 4-6 ghz TRANSPONDER [PAYLOAD (A)]** | | | | | | | | |
| 5 watt TWT | 14.25 | 9.25 | 55 - 15 | -40 | 12 | | | 63 |
| EPC | 3.7 | | 45 -5 | -30 | 12 | | | 19 |
| COMM. RECVR | 9.0 | | 35 20 | | 1 | | | |
| **SHF 12-14 ghz TRANSPONDER [PAYLOAD (B)]** | | | | | | | | |
| 20 watt TWT | 49 | | 70 -5 | -40 | 4 | | | 172 |
| EPC | 10.5 | | 45 -5 | -40 | 4 | | | 54 |
| PWR ADAPTOR | 2.38 | | 45 -5 | -40 | 4 | | | 12 |
| RECEIVER | 3.4 | | 40 0 | -40 | 1 | | | 18 |

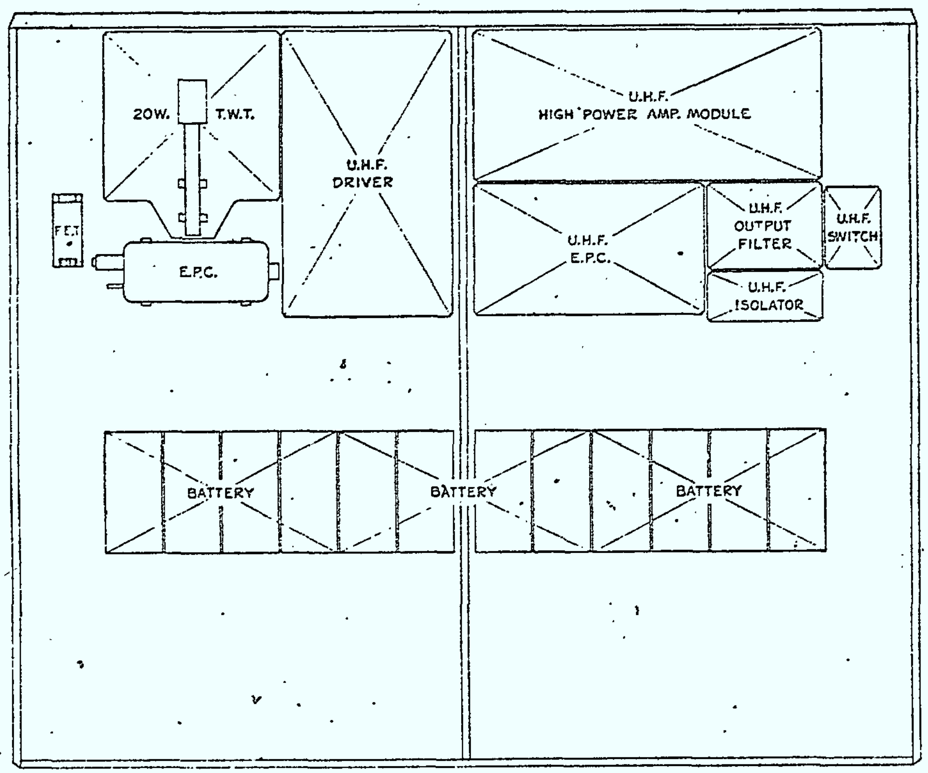
(1) [bracket spanning the UHF transponder operating temperature limits]

## 2. Housekeeping Components.

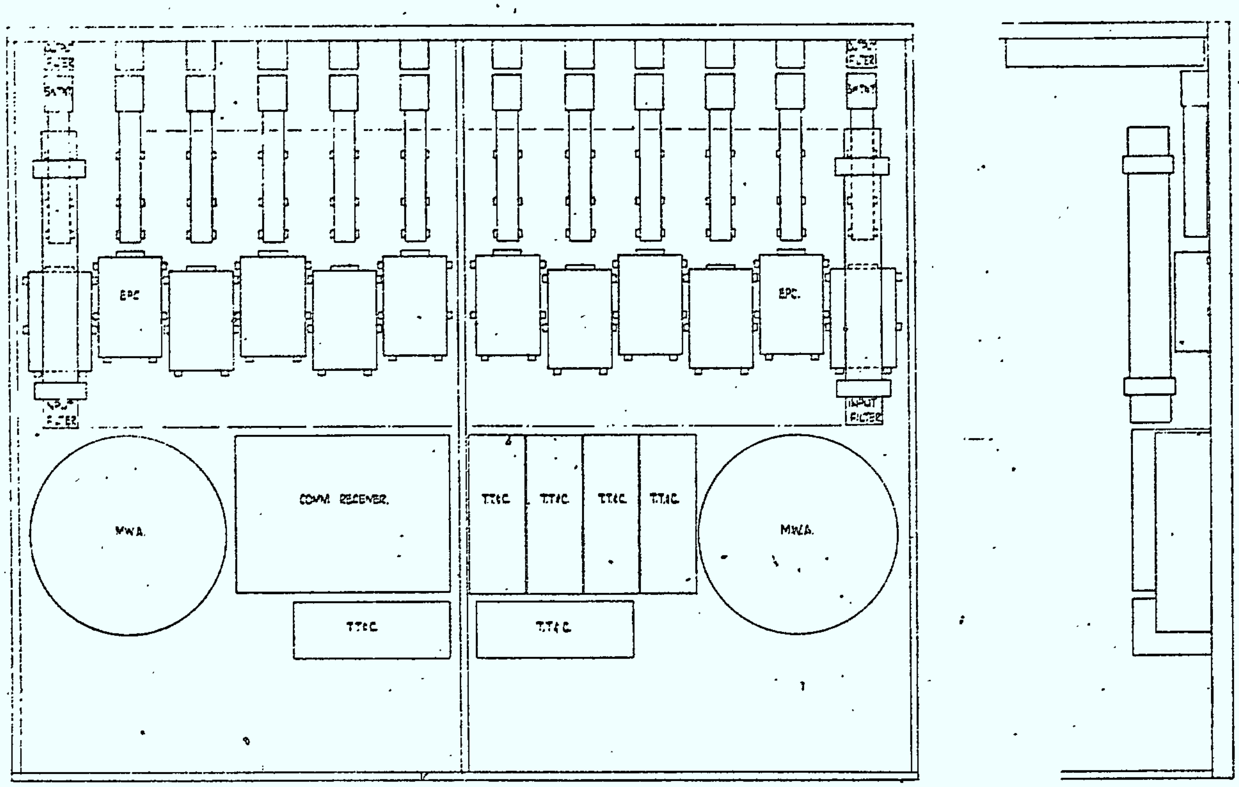
| Component | Pwr Dissip'd (Watts) Max | Min | Temp Limits (°C) Operating | | Non-Op | # Reqd | Wt. (lbs) | Dimensions (ins) | Reqd Thermal Mounting Area (sq. ins) |
|---|---|---|---|---|---|---|---|---|---|
| **Power Subsystem** | | | | | | | | | |
| Battery | 8.3 | 0 | 10 (2) | 0 | | 3 | | | |
| Power Supply Electronics | 21 | 0 | 50 | 5 | -20 | 1 | | | |
| ACS Sec Converter | | | 55 | 0 | -20 | 1 | | | |
| DSA Sec. Converter | | | 55 | 0 | -20 | 1 | | | |
| [illegible]CS Sec. Converter | | | 55 | 0 | -20 | 1 | | | |
| **TT&C Subsystem.** | | | | | | | | | |
| Typical Component | 5 | | 50 | 5 | -20 | 6 | 6.7 | | |
| **Attitude Control Subsystem** | | | | | | | | | |
| Momentum Wheel | | | 55. | 10 | -10 | 2 | | | |
| ACEA | | | 50 | 5 | -25 | 1 | | | |
| Earth Sensor N/S | | | 40 | 5 | -25 | 2 | | | |
| Earth Sensor Elec. | | | 45 | 0 | -25 | 1 | | | |
| Earth Sensor S.P. | | | 45 | 0 | -25 | 2 | | | |
| Sun Sensor S.P. | | | 65 | -50 | -65 | 2 | | | |
| Sun Sensor Elect. | | | 50 | -5 | -20 | 2 | | | |
| Sun Sensor N/S. | | | 65 | -50 | -65 | | | | |
| **Reaction Control Subsystem** | | | | | | | | | |
| E.J.B. | | | 50 | 5 | N/A | 1 | | | |
| Latching Valve Module | | | 50 | 5 | N/A | 1 | | | |

# THERMAL DESIGN GUIDE LINES.

- TRANSPONDERS TO BE LOCATED ON NORTH & SOUTH PANELS
  - UHF ON NORTH PANEL
  - SHF ON SOUTH PANEL
- DEPLOYED SOLAR ARRAYS TO BE ADEQUATELY SEPARATED FROM THE NORTH & SOUTH PANELS.
- BATTERIES MOUNTED ON THE NORTH PANEL.
- TT & C & MOMENTUM WHEELS MOUNTED ON SOUTH PANEL
- ANTENNAS, ACS SENSORS MOUNTED ON FWD PLATFORM
- NO RESTRICTION ON LOCATION OF RCS TANKS.
- SHUNT REGULATORS ON EXTERNAL FACE SHEETS OF EAST & WEST PANELS AND DECOUPLED FROM S/C.
- ALL NON-RADIATING AREAS TO BE COVERED WITH MULTILAYER INSULATION BLANKETS
- SPACECRAFT RADIATING AREAS TO BE COVERED DURING THE 'SPIN' PHASE
- MINIMUM 'SPIN' PHASE POWER REQUIREMENT — 80 WATTS.




| | | | |
|---|---|---|---|
| MOD NO | | | SPAR AEROSPACE PRODUCTS LTD. 825 CALEDONIA RD., TORONTO ONTARIO M6B 3X8, CANADA |
| DRAWN | J.A. FRY | 75 | DRAWING TITLE: U.H.F. EQUIPMENT PANEL GENERAL PURPOSE SATELLITE BUS |
| CHECKED | | | |
| APPROVED | | | |
| STRESS | | | |
| | | | CODE IDENT NO 36480 — D — DRAWING NO 3113824 |
| | | | SCALE 1/4 — WGT CALC — ACTUAL — SHEET 1 OF 1 |




| | | |
|---|---|---|
| MOD NO | | |
| DRAWN | | |
| CHECKED | | |
| APPROVED | | |
| STRESS | | |

SPAR AEROSPACE PRODUCTS LTD

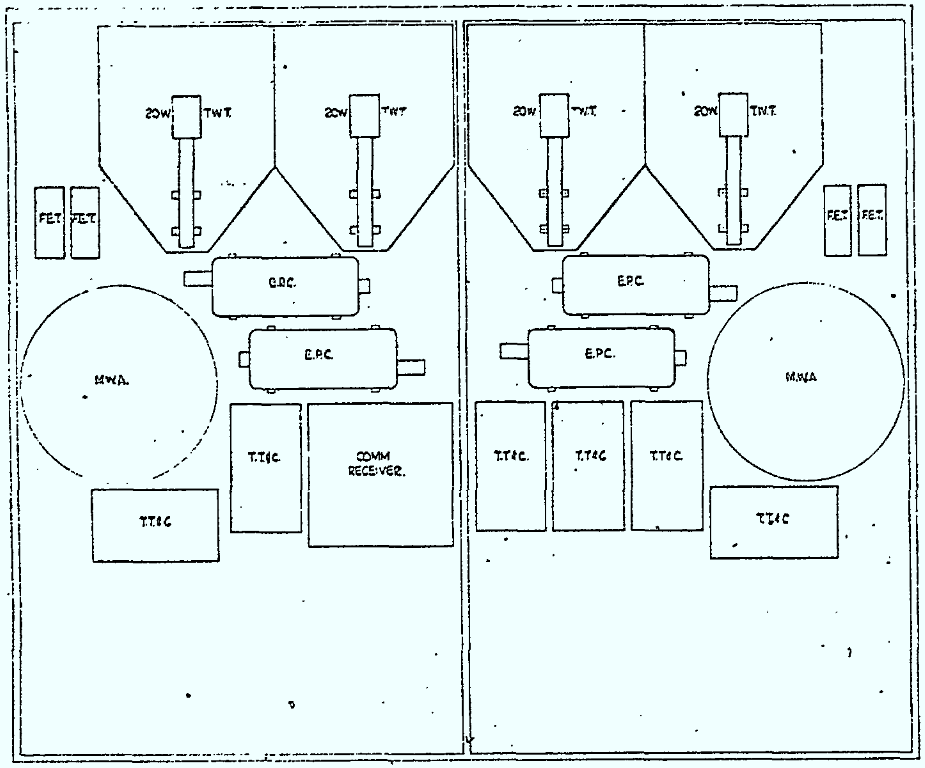
DRAWING TITLE

12 CHANNEL 4-6 GHz PANEL

GENERAL PURPOSE SATELLITE BUS

| CODE IDENT NO | | DRAWING NO |
|---|---|---|
| 36480 | D | 3113BD3 |

SCALE 1/4




| | | |
|---|---|---|
| MOD NO | | |
| DRAWN | | |
| CHECKED | | |
| APPROVED | | |
| STRESS | | |

SPAR AEROSPACE PRODUCTS LTD.
825 CALEDONIA RD., TORONTO, ONTARIO M6B 3X8, CANADA

DRAWING TITLE
4 CHANNEL 12:14 GHz PANEL
GENERAL PURPOSE SATELLITE BUS

CODE IDENT NO 36480 — DRAWING NO 3113805
SCALE 1:4 — WGT CALC — ACTUAL — SHEET 1 OF 1

# GENERAL PURPOSE BUS

## THERMAL SUBSYSTEM WEIGHT BREAKDOWN.

### A. MULTILAYER INSULATION BLANKETS.

| | | |
|---|---|---|
| FWD PLATFORM - 20 LAYER | 1.96 | lbs |
| AFT FACE - 22 LAYER | 2.55 | " |
| EAST & WEST PANELS - 5 LAYER | 1.04 | " |
| NORTH & SOUTH PANELS - 5 LAYER | .34 | " |
| APOGEE MOTOR - 7 LAYER | 2.26 | " |
| | 8.15 | lbs |

### B. PANEL SURFACE FINISHES.

| | | |
|---|---|---|
| EXTERNAL FACE OF N/S PANELS - S.S.M. | 4.42 | lbs. |
| INTERNAL FACE OF EQUIPMENT PLATFORMS - ANODIZED | — | |

### C. THERMAL CONDUCTORS.

| | | |
|---|---|---|
| HEAT PIPES IN SOUTH PANEL | 6.00 | lbs. |
| [THERMAL DOUBLERS AS ALTERNATIVE 17.5 lbs] | — | |

| | | |
|---|---|---|
| D. 10% FOR MISCELLANEOUS | 1.86 | lbs |
| | 20.43 | lbs. |

# SECTION 9

# STRUCTURE

# DESIGN REQUIREMENTS FOR STRUCTURE

1. SAFETY FACTORS

   1.10 for yield

   1.25 for failure (ultimate level loads)

2. MARGINS OF SAFETY (MS)

   Must be positive

$$MS = \frac{\text{Allowable load or stress}}{\text{Applied load or stress}} - 1$$

- The axial load and bending moment in the thrust tube near the separation ring were conservatively used to evaluate the Margin of Safety with respect to aft thrust tube buckling

- A total apogee motor weight of 1,065 lbs. was assumed, with its Centre of Mass 36.3 inches above the separation plane

## MAJOR ASSUMPTIONS MADE FOR STRESS ANALYSIS OF STRUCTURE

- For lateral spacecraft sinusoidal response, the design case was taken as:

  3 g qual. at the spacecraft centre of mass

  0.5 g qual. at the base of the spacecraft adapter linear distribution of acceleration over the length of the spacecraft

- A uniform distribution of equipment was assumed for the North and South panels

- No moment transfer assumed between connected panels: all joints have been treated as simple supports

- A maximum North-South panel vibration response of 30 g qual. has been assumed in a normal to panel direction

- The aft thrust tube was analysed as a cylinder with its diameter equal to the thrust tube diameter near the separation ring

## MAJOR SPACECRAFT VIBRATION MODES*

1. MAGNESIUM ALLOY THRUST TUBES

.040 inch thick forward thrust tube
.080 inch thick aft thrust tube

1st spacecraft lateral mode : 25.5 Hz
1st spacecraft axial mode : 63.9 Hz

2. HONEYCOMB THRUST TUBES

1/8 inch thick Al. alloy core, density of 3.1 lb./ft.$^3$

a) .006 inch Thick Facesheets (Al. Alloy)

1st spacecraft lateral mode : 16.1 Hz
1st spacecraft axial mode : 50.9 Hz

b) .008 inch Thick Facesheets on Forward Thrust Tube) Al. Alloy
.010 inch Thick Facesheets on Aft Thrust Tube )

1st spacecraft lateral mode : 19.0 Hz
1st spacecraft axial mode : 56.0 Hz

*All modes without spacecraft adapter

## 2. STIFFNESS REQUIREMENTS

When spacecraft hard-mounted (no adapter) :-

1st spacecraft lateral resonance $\geqslant$ 15 Hz

1st spacecraft axial resonance $\geqslant$ 35 Hz

The above restraints are for overall spacecraft modes

3. TOTAL SPACECRAFT WEIGHT

Structure designed for 2,200 lb. total spacecraft weight, excluding spacecraft adapter

## MAJOR DESIGN CONSTRAINTS FOR SPACECRAFT STRUCTURE

1. LAUNCH ENVIRONMENT

a) Quasi-Static Loads

| | | |
|---|---|---|
| POGO + MECO | : | 16 g qual. axial (thrust) |
| | | ±1 g qual. lateral (X or Y axis) |
| Maximum Lift-Off | : | 3.9 g qual. axial (thrust) |
| | | ±2.8 g qual. lateral (X or Y axis) |

b) Sinusoidal Vibration Loads

Qualification level inputs at base of spacecraft adapter:

| Input Axis | Frequency (Hz) | Input Acceleration (g's) |
|---|---|---|
| Thrust | 5 - 10 | 2.3 |
| | 10 - 15 | 2.3 |
| | 15 - 21 | 6.8 |
| | 21 - 250 | 2.3 |
| | 250 - 400 | 4.5 |
| | 400 - 2000 | 7.5 |
| Lateral (X or Y) | 5 - 10 | 2.0 |
| | 10 - 14 | 2.0 |
| | 14 - 250 | 1.5 |
| | 250 - 400 | 4.5 |
| | 400 - 2000 | 7.5 |

- Notching to Quasi-static levels allowed at:

  1st spacecraft lateral mode (3g at Centre of Mass)
  1st spacecraft axial mode (16 g max. response)

  The above must be overall spacecraft modes

# SECTION 10

# APOGEE MOTOR

STAR 30

ROCKET MOTOR

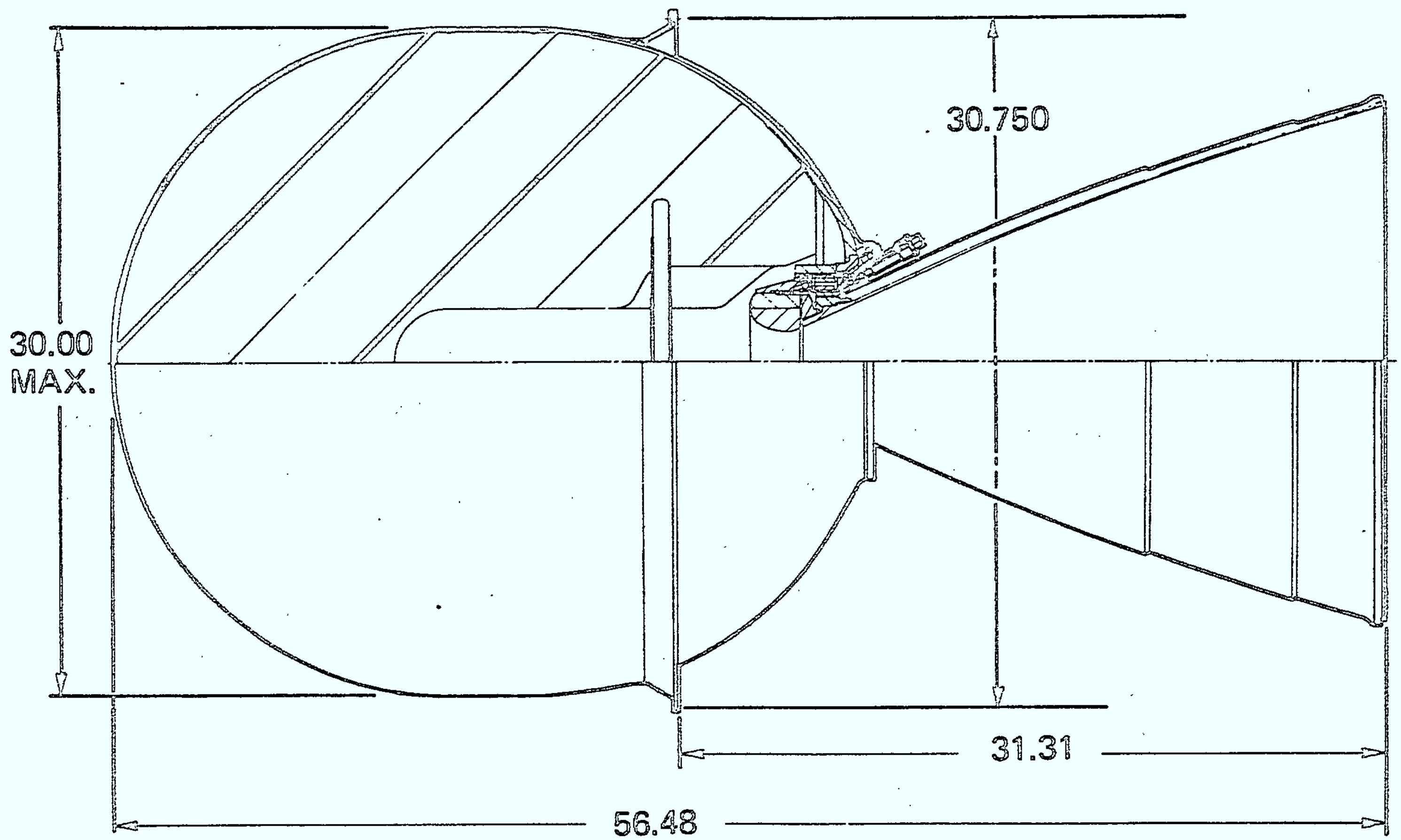
FOR

DELTA 3914

H974068

Thiokol / ELKTON DIVISION

## STAR 30 ROCKET MOTOR




Y974069

Thiokol / ELKTON DIVISION

## STAR 30 CHARACTERISTICS
## (NOMINAL, 65°F)

| | |
|---|---|
| TOTAL IMPULSE | 301,200 LBF-SEC |
| AVERAGE THRUST | 5,930 LBF |
| MAXIMUM THRUST | 7,000 LBF |
| BURN TIME | 50.2 SEC |
| PROPELLANT SPECIFIC IMPULSE | 297 LBF-SEC/LBM |
| EFFECTIVE SPECIFIC IMPULSE | 295 LBF-SEC/LBM |

## STAR 30 DESIGN CONDITIONS

| | |
|---|---|
| EXTERNAL TEMPERATURE: | CASE – 700°F MAX SOAK<br>NOZZLE – 1,000°F MAX SOAK |
| OPERATIONAL TEMPERATURE: | +20°F TO +110°F |
| STORAGE TEMPERATURE: | +60°F TO +80°F |
| AGING: | 5-YEAR SHELF LIFE GOAL |

# STAR 30 IGNITER

| | |
|---|---|
| DESIGN: | AFT END |
| | TOROIDAL |
| | DUAL INITIATORS |
| EXPERIENCE: | STATE OF THE ART |
| | SIMULATOR TESTS |
| ATTRIBUTES: | SYMMETRICAL |
| | LIGHTWEIGHT |
| | EASY ACCESS |
| | VERSATILE |

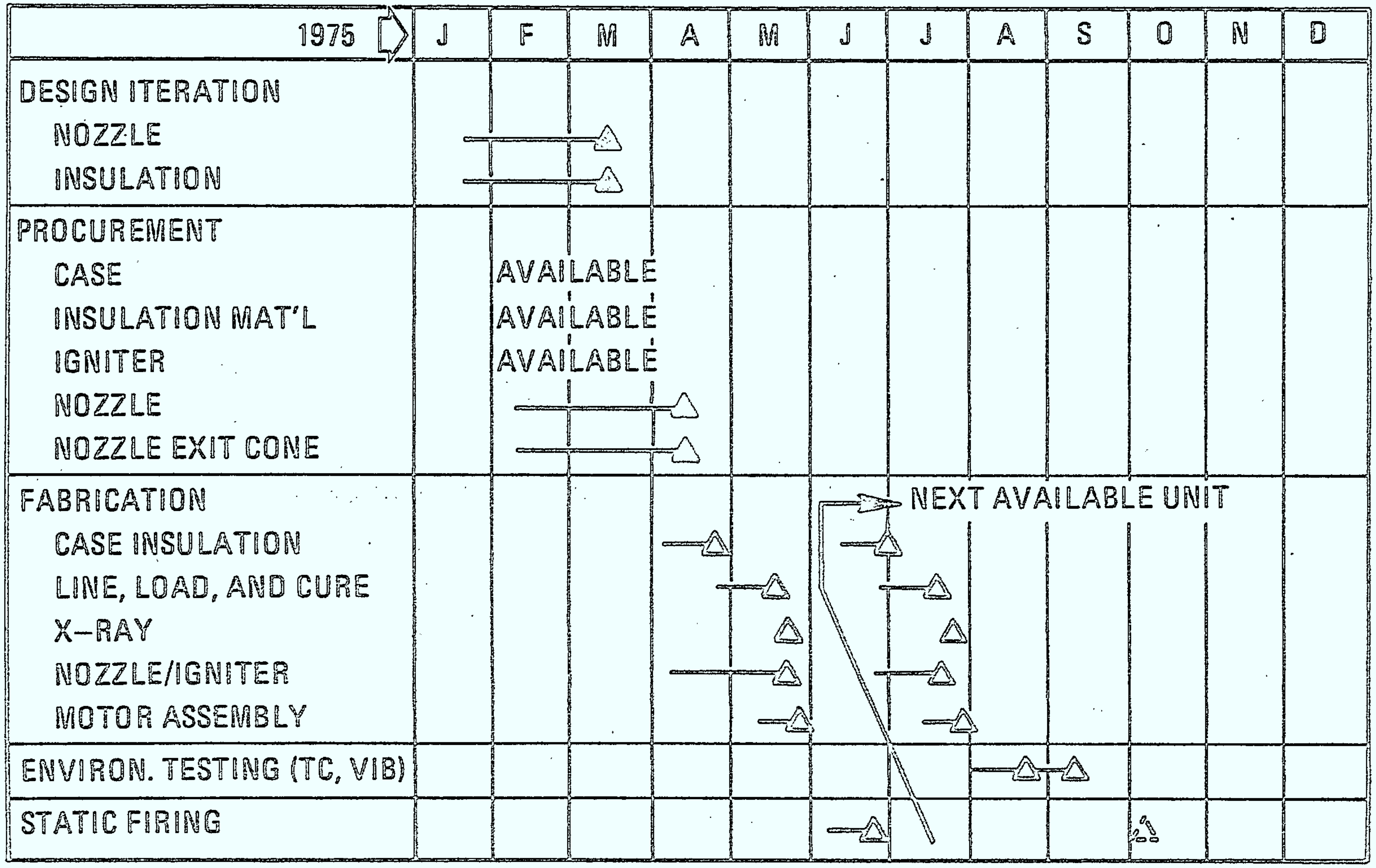
# STAR 30 NOZZLE

| | | |
|---|---|---|
| DESIGN: | CARBON–CARBON EXIT CONE<br>CARBON FELT EXTERNAL INSULATION<br>6Al-4V TITANIUM CLOSURE<br>G-90 GRAPHITE THROAT | |
| EXPERIENCE: | CARBON—CARBON | – 6 STATIC FIRINGS |
| | CLOSURE | – 8 STAR MOTORS (STAR 27 – STAR 37) |
| | G-90 | – ALL STAR MOTORS |
| ATTRIBUTES: | LIGHTWEIGHT<br>SYMMETRICAL EROSION<br>EXCELLENT ALIGNMENT | |

# STAR 30 WEIGHT SUMMARY

| ITEM | NOMINAL WT, LBS |
|---|---|
| PROPELLANT | 1014.0 |
| INERTS | 61.0 |
| LOADED MOTOR | 1075.0 |
| INERTS CONSUMED | 7.0 |
| FIRED MOTOR | 54.0 |

# STAR 30 DEVELOPMENT




Y475034

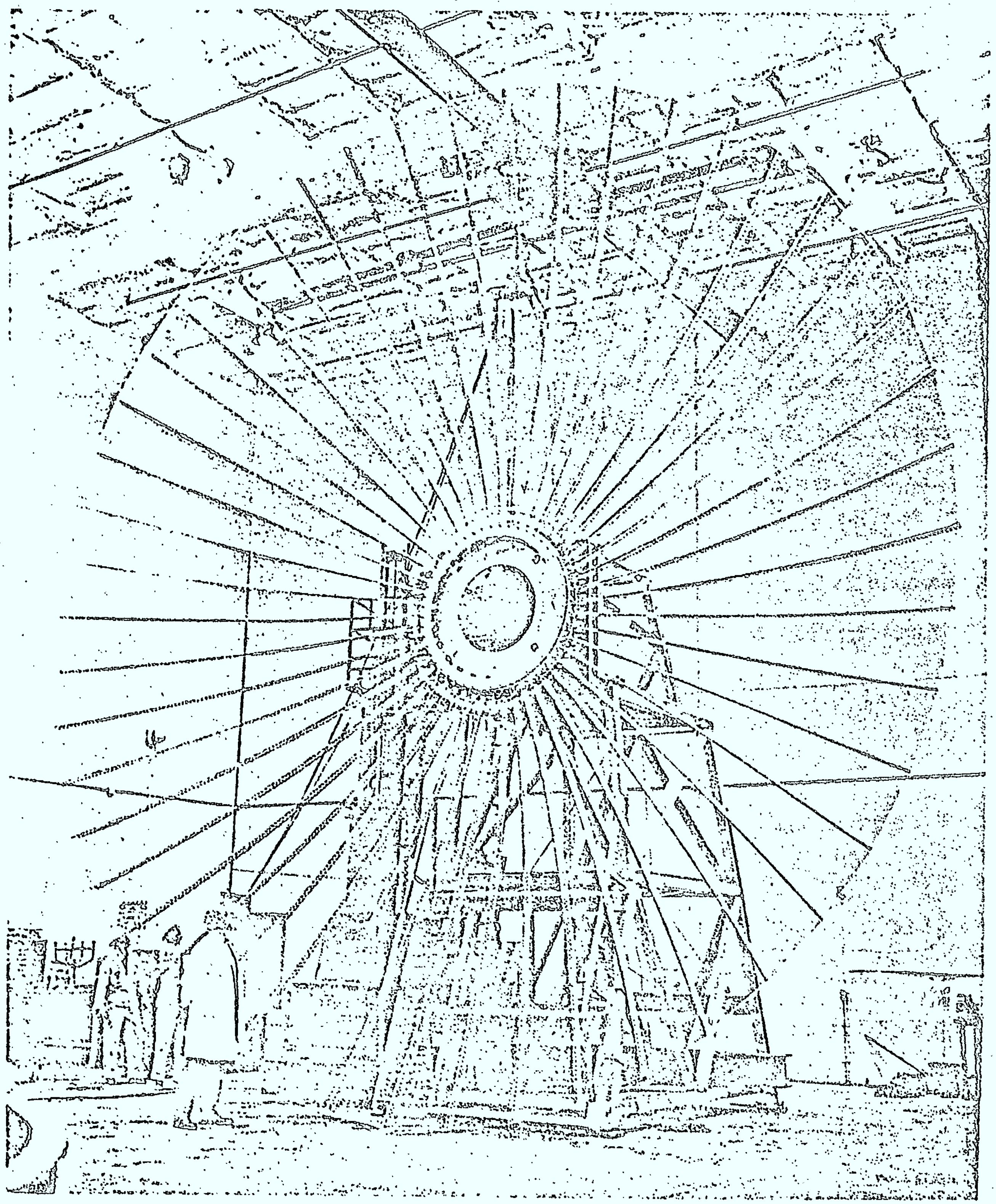
Thiokol / ELKTON DIVISION

# PERFORMANCE COMPARISON

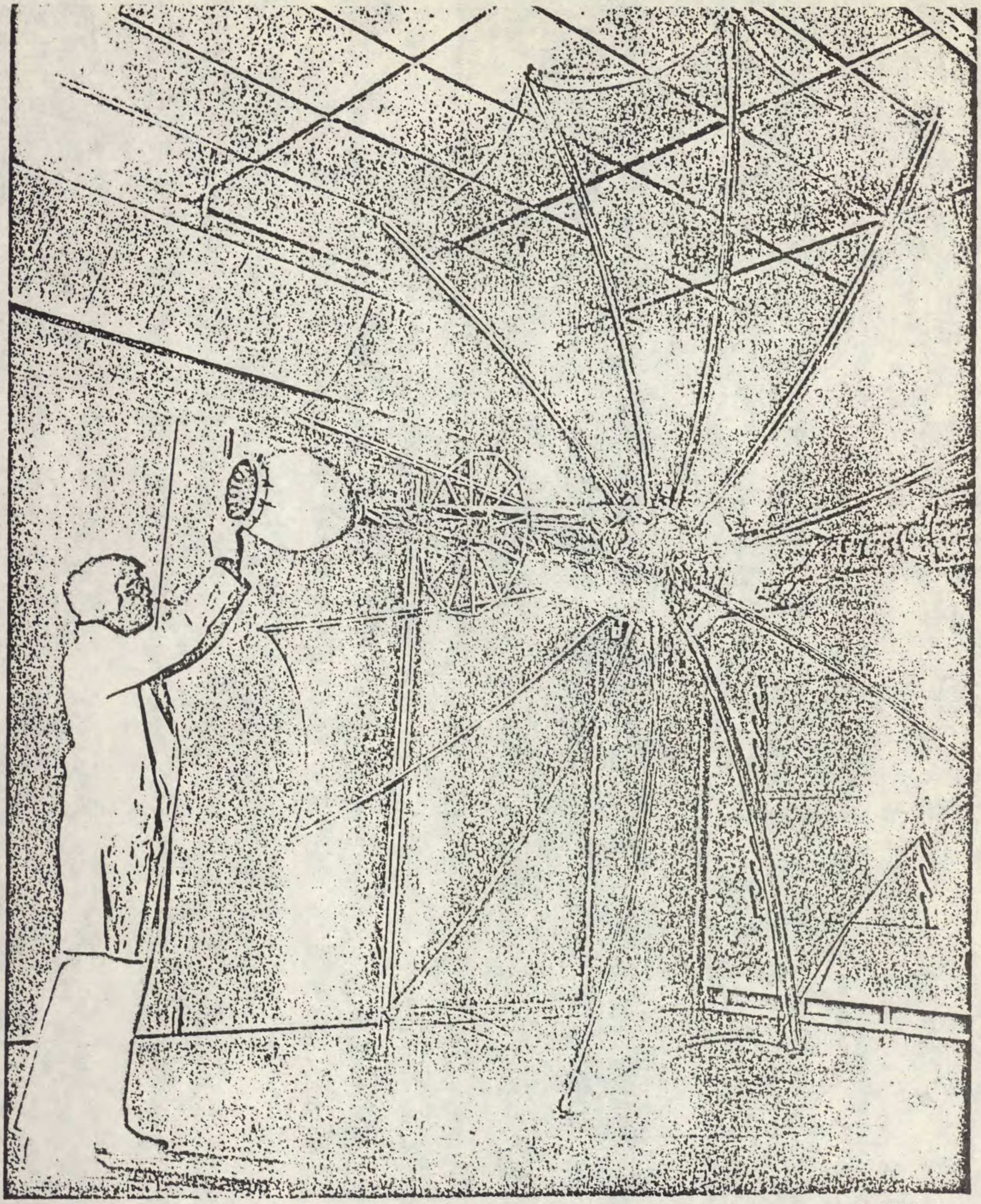
| | SATCOM | STAR 30 OFF-LOAD | STAR 30 NOMINAL |
|---|---|---|---|
| ΔV, FT/SEC | 6024 | 6024 | 6024 |
| STAGE WEIGHT, LBS | 1916 | 1916 | 2154 |
| PAYLOAD, LBS | 958 | 964 | 1089 |

# SECTION 11

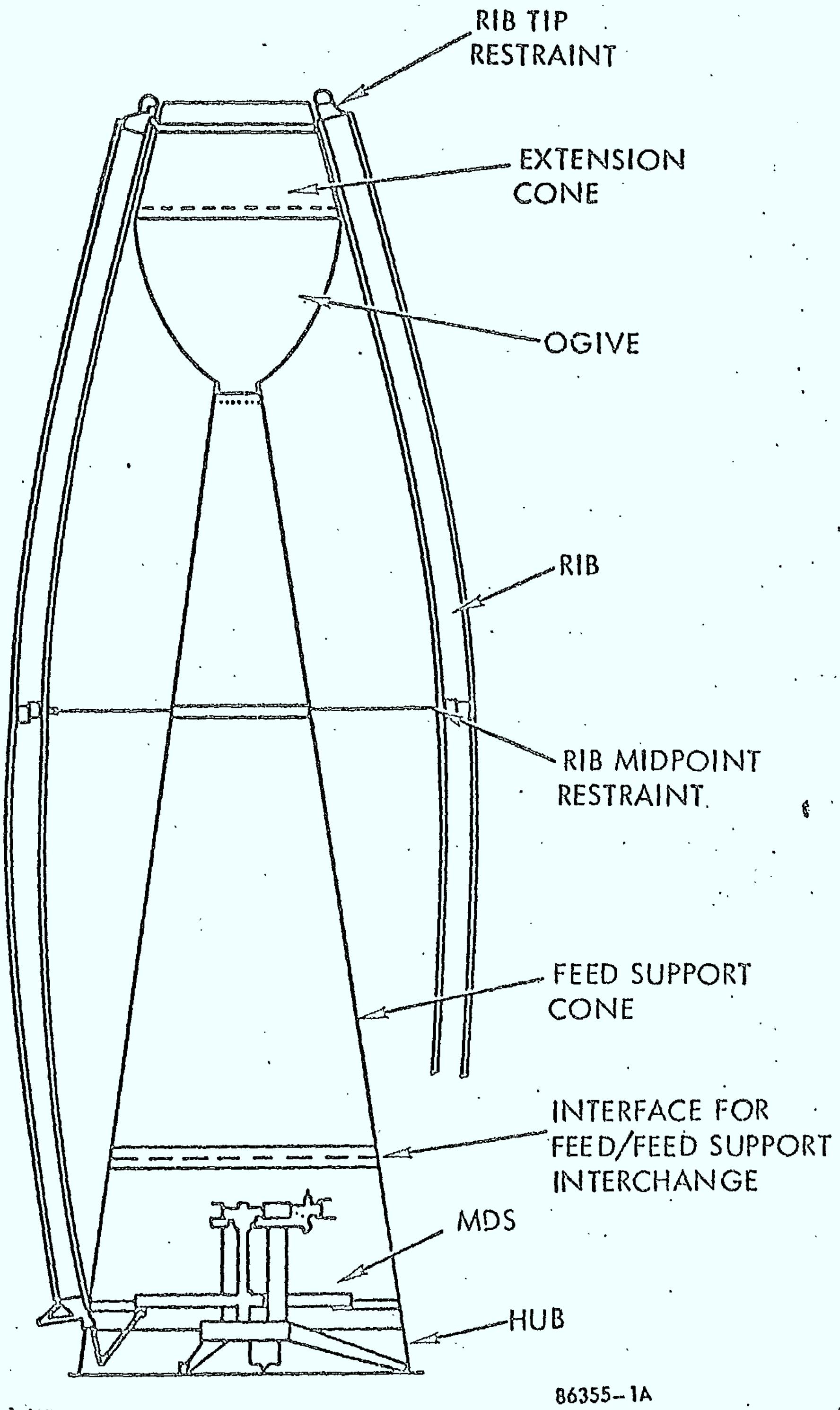
# DEPLOYED ANTENNA

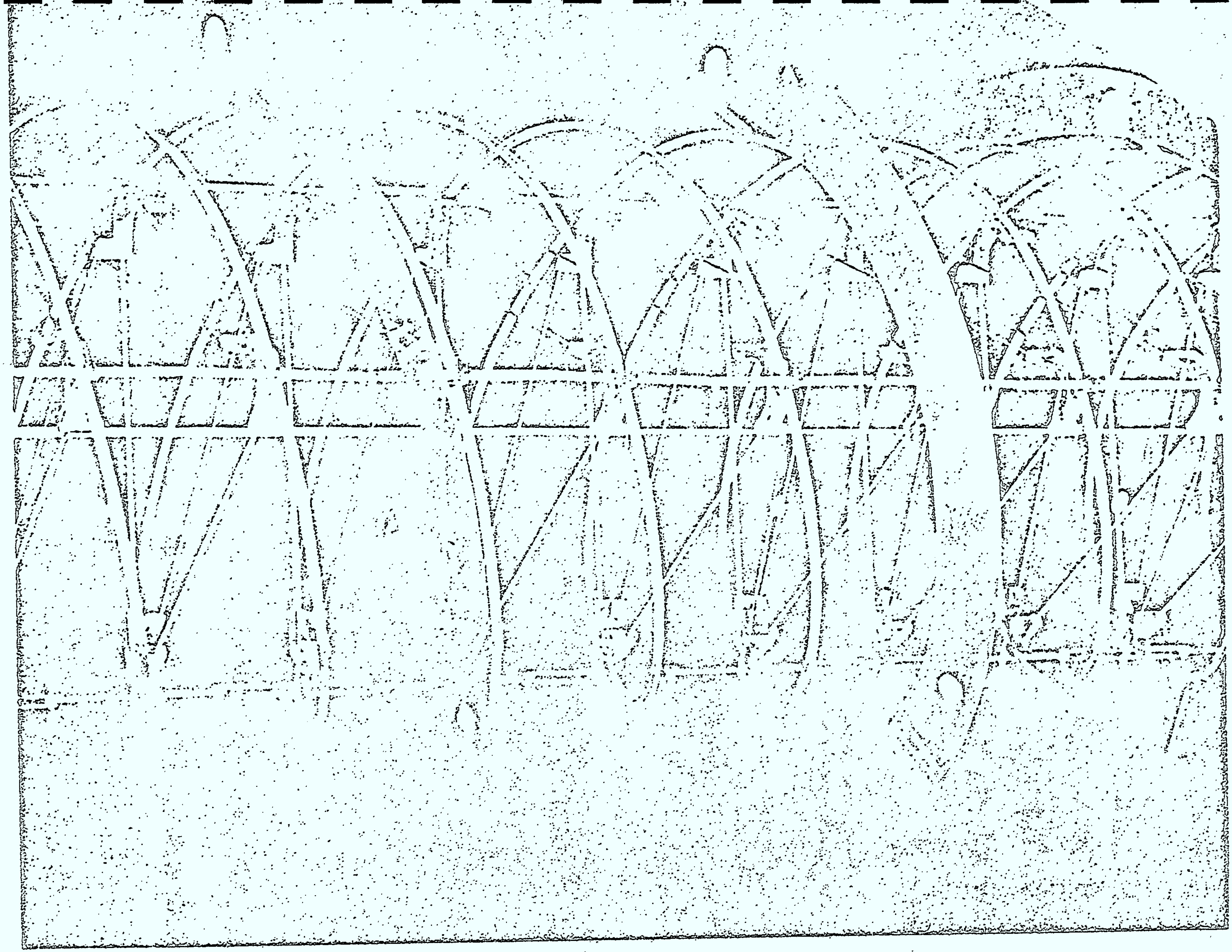


ATS F&G Thirty-Foot Parabolic Spacecraft Antenna for Excellent Performance up to 10 GHz: Weighs 180 lbs, Stows in 58-Inch ID by 78-Inch OD by 8-Inch Thick Torus



73–1354C


RIB TIP
RESTRAINT
EXTENSION
CONE
OGIVE
RIB
RIB MIDPOINT
RESTRAINT
FEED SUPPORT
CONE
INTERFACE FOR
FEED/FEED SUPPORT
INTERCHANGE
MDS
HUB
86355-1A



# SECTION 12

# MASS PROPERTIES

| | | |
|---|---|---|
| TT&C & ANT., NO SECURITY BOX | | 35 |
| ACS (WHECON) | | 71 |
| RCS (Tanks & Pressurant, no struts<br>(Fuel - 6 years | 69)<br>193) | 262 |
| STRUCTURE (Mag. Thrust Tube) | | 106 |
| THERMAL | | 33 |
| APOGEE MOTOR (Motor Fired<br>(Propellant & Inerts | 54)<br>903) | 957 |
| ARRAY (Housekeeping Portion .14 x 140<br>(D&TM | = 20)<br>= 20) | 40 |
| BATTERY & PC (Houseeping Portion .22 x 140) | | 31 |
| HARNESS | | 35 |
| SAFE & ARM | | 3 |
| Y TOTAL BUS | | 1,573 |

## WEIGHT SUMMARY : PAYLOAD OPTION DETAILS

| | PAYLOAD DEFINITION | 4-6 GHz a | 12-14 GHz b | 7-8 GHz c | L BAND d | 12/12-14 GHz $e_1$ | 8/12-14 GHz $e_2$ |
|---|---|---|---|---|---|---|---|
| A | PAYLOAD - TRANSPONDER & ANT. | 218.4 | 180.5 | 221.9 | 190.4 | 235 | 235 |
| | LESS - ANTENNA | -55 | -55 | -55 | -60 | | |
| | PLUS - AAFE ANT. 12.5' DIA. | 31.5 | 31.5 | 31.5 | 31.5 | | |
| B | ARRAY WEIGHT TO POWER A | 58.1 | 87.5 | 70.7 | 71.82 | 60 | 102 |
| C | BATTERY & PC TO OPER. A | 74.8 | 102.08 | 67.1 | 82.06 | 95 | 161 |
| D | SECURITY BOX MIL. VER. | 10 | 10 | 10 | 10 | 0 | 0 |
| X | TOTAL (A + B + C + D) | 337.8 | 356.58 | 346.2 | 325.78 | 390 | 498 |
| Y | TOTAL (BUS) | 1,573 | 1,573 | 1,573 | 1,573 | 1,573 | 1,573 |
| | TOTAL (X + Y) | 1,910.8 | 1,929.58 | 1,919.2 | 1,898.78 | 1,963 | 2,071 |
| | CONTINGENCY | 14 | - 5 | 6 | 26 | - 38 | - 146 |
| | TOTAL ARRAY (20 + 20 + B) | 98.1 | 127.5 | 110.7 | 111.82 | 100 | 142 |
| | TOTAL BATTERY & PC (31 + C) | 105.8 | 133.08 | 98.1 | 113.06 | 126 | 192 |

## UHF BUS PAYLOAD OPTION A

| ITEM | WT | X | Y | Z | $Wx^2$ | $Wy^2$ | $Wz^2$ | Ixp | Iyp | Izp |
|---|---|---|---|---|---|---|---|---|---|---|
| TT&C (S) | 34 | 5.67 | 22.55 | 18.23 | 1,093 | 17,289 | 11,299 | 493 | 8,670 | 8,347 |
| TT&C ANT. | 1 | 0 | 0 | 118.0 | 0 | 0 | 13,924 | 494 | 494 | 0 |
| UHF/SHF DISH | 31.5 | 0 | 0 | 88.21 | 0 | 0 | 245,102 | 17,895 | 17,895 | 3,024 |
| PAYLOAD S | 107.6 | 0 | 22.55 | 40.00 | 0 | 54,715 | 172,160 | 3,667 | 39,175 | 35,669 |
| PAYLOAD N | 55.8 | 0 | -22.55 | 40.00 | 0 | 28,374 | 89,280 | 1,902 | 20,316 | 18,498 |
| BATTERY & PCN | 105.8 | 0 | -22.55 | 21.4 | 0 | 53,800 | 48,952 | 954 | 24,477 | 24,158 |
| MW S | 20.0 | -23.5<br>+23.5 | 22.55 | 19.5 | 11,045 | 10,170 | 7,605 | 342 | 653 | 342 |
| ACS MW | 51 | 0 | 0 | 52.4 | 0 | 0 | 140,034 | 10,693 | 15,368 | 25,925 |
| ARRAY - D&TM | 20 | 0 | 0 | 57.9 | 0 | 0 | 67,048 | 708 | 708 | 1,333 |
| - SOLAR PANEL | 78.1 | 0 | ±30 | 28.81 | 0 | 70,290 | 64,824 | 22,974 | 38,926 | 16,590 |
| HARNESS ELEC. | 35 | 0 | 0 | 30.6 | 0 | 0 | 32,773 | 4,713 | 7,338 | 11,958 |
| SAFE & ARM | 3 | 0 | 0 | 24.0 | 0 | 0 | 1,728 | 0 | 0 | 0 |
| SECURITY BOX | 10 | 0 | ±22.55 | 18.23 | | 5,085 | 3,323 | 0 | 0 | 0 |
| THRUST TUBE STRUCT. | 36 | 0 | 0 | 20.47 | 0 | 0 | 15,085 | 13,745 | 13,745 | 10,130 |
| NORTH PANEL | 14 | 0 | -26 | 28 | 0 | 9,464 | 10,976 | 3,277 | 8,056 | 4,779 |
| SOUTH PANEL | 14 | 0 | 26 | 28 | 0 | 9,464 | 10,976 | 3,277 | 8,056 | 4,779 |
| EAST PANEL | 5 | 32 | 0 | 28 | 5,120 | 0 | 3,920 | 2,147 | 1,105 | 1,042 |
| WEST PANEL | 5 | -32 | 0 | 28 | 5,120 | 0 | 3,920 | 2,147 | 1,105 | 1,042 |
| FORWARD PLATFORM | 10 | 0 | 0 | 54.4 | 0 | 0 | 29,594 | 2,083 | 3,413 | 5,497 |
| SEP. PLATFORM | 5 | 0 | 0 | 1 | 0 | 0 | 5 | 1,707 | 1,042 | 2,728 |
| E/W PARTITION | 5 | 0 | ±23 | 28 | 0 | 2,645 | 3,920 | 1,127 | 1,220 | 94 |
| N/S PARTITION | 4 | ±20 | 0 | 28 | 1,600 | 0 | 3,136 | 928 | 901 | 27 |
| RCS STRUCT. | 4 | ±30 | ±10 | 43 | 3,600 | 400 | 7,396 | 0 | 0 | 0 |
| MISC. HARDWARE | 4 | 0 | 0 | 28 | 0 | 0 | 3,136 | 1,717 | 2,249 | 2,199 |
| RCS TANK & PRESS | 69 | ±30 | ±10 | 43 | 62,100 | 6,900 | 127,581 | 2,236 | 2,236 | 2,236 |
| RCS FUEL | 193 | ±30 | ±10 | 40.8 | 173,700 | 19,300 | 321,276 | 6,253 | 6,253 | 6,253 |
| THERMAL CONTROL | 33 | 0 | 0 | 40.0 | 0 | 0 | 52,800 | 9,911 | 13,739 | 18,700 |
| APOGEE MOTOR | 54 | 0 | 0 | 24.0 | 0 | 0 | 31,104 | 17,150 | 17,150 | 6,075 |
| PROPELLANT & INERTS | 903 | 0 | 0 | 37.0 | 0 | 0 | 1236,207 | 91,104 | 91,104 | 80,870 |
| TOTAL | 1,910.8 | 0 | 0 | 36.56 | 213,378 | 287,891 | 2758,584 | 223,644 | 345,394 | 292,295 |

$$Ixx = W(y^2 + z^2) + Ixp - Wt(y^{-2} + z^{-2})$$

$$= 287896 + 2758584 \quad 223644 - 1910.8 \times 26.56^2$$

$$= \underline{716085} \text{ lb.in.}^2$$

$$Iyy = W(x^2 + z^2) + Iyp - Wt(x^{-2} + z^{-2})$$

$$= 263378 + 2758584 + 345394 - 1910.8 \times 36.56^2$$

$$= \underline{813317} \text{ lb.in.}^2$$

$$Izz = W(x^2 + y^2) + Izp - Wt(x^{-2} \times y^{-2})$$

$$= 263378 + 287896 + 292295 - 0$$

$$= \underline{843569} \text{ lb.in.}^2$$

$$\text{M. of I. Ratio} = \frac{Izz}{\sqrt{Ixx\ Iyp}} = \frac{843569}{\sqrt{716085 \times 813313}} = 1.11$$