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SPAR-R.813 ①

FEASIBILITY STUDY OF A
GENERAL PURPOSE BUS
FOR THE POTENTIAL MUSAT
COMMUNICATIONS SATELLITE PAYLOAD

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SPAR-R.813 ①

FEASIBILITY STUDY OF A GENERAL PURPOSE BUS FOR THE POTENTIAL MUSAT COMMUNICATIONS SATELLITE PAYLOAD

Prepared for:

Department of Supply and Services
and Department of Communications

File No. 01PC.36100-6-0601
Contract No. 0PC 76-00054

5/GC.1

MAY, 1977

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SPAR-R.813 **ISSUE** ☐

FEASIBILITY STUDY OF A GENERAL PURPOSE BUS FOR THE POTENTIAL MUSAT COMMUNICATIONS SATELLITE PAYLOADS

PREPARED BY Staff

REASON FOR REISSUE

DATE May, 1977

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SUMMARY

Having completed the study on the General Purpose Bus (GPB) with a SHF commercial payload, the Bus has been further examined to determine the changes which will be required to fly a second Canadian payload; namely, a UHF multipurpose satellite (MUSAT) launched on the Shuttle STS/SSUS, only.

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Four payload arrangements defined by the Communications Research Centre, CRC were investigated using the original design criteria for the GPB. These parameters included favourable moment of inertia during the spin phase, minimum launch costs, 7 year mission life, and pointing accuracy to meet the UHF requirements.

The preferred configuration recommended following a review of the pros and cons for each of the four arrangements is Configuration 2 shown in Figures 3-3 and 3-4. This employs an 84" SHF dish with dual horns, plus two each, receive and transmit, deployed helix UHF antennae with mechanisms. A derivative of this arrangement (Configuration 2A) is one with 27" UHF backplanes and 9" high rims at the base. This arrangement can be mounted to the periphery of the SHF dish without the need of a stowage and deployment mechanism for the UHF antenna support structure and only the UHF helices deploy. The final selection on which configuration to fly will require a trade-off study to show whether the cost of a deployment system for Configuration 2 is greater than the increased launch cost from shuttle for Configuration 2A.

The study shows that the GPB can fly any MUSAT configuration if active nutation control is acceptable. No major changes to the Bus are anticipated for MUSAT; expected modifications are mainly related to payload structural attachments and thermal considerations. Major subsystems such as Reaction Control and Attitude Control are not affected. In fact the CTS ACS can be flown as is with the North/South (N-S) stationkeeping modification incorporated.

The payload platform arrangement for this spacecraft utilizes both the north and south radiating panels with a heat pipe radiator for the UHF high dissipating components supplementing the otherwise passive design.

However, because none of the configurations fully utilize the weight and power available from the GPB, two suggestions are made in this report for enhanced MUSAT payloads to achieve a more productive mission. The first suggestion is to fly a dedicated MUSAT for a 10 year mission and examine what must be done to other subsystems to achieve this extended life. The second suggestion is to fly the MUSAT with an additional payload such as ANIK A replacements (assumed 12 channels at 4-6 GHz frequency) which is due to be operational in 1982.

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The implementation program plan recommended for this satellite is similar to that generated for the Bus described in the GPB, commercial SHF report, SPAR-R.810, Volume III, with the differences being that;

(a) the program quantities are reduced to one qualification and two flight spacecraft.

(b) An assumption is made that the Communications Antennae will be design developed and tested prior to the MUSAT program go-ahead.

(c) Delivery of the qualification and flight Bus or Payload will both be delayed 6 months to accomplish the antenna qualification test program and flight acceptance. This has not been fully examined since no detail design of the antenna has been made during this study.

The costs for this program will be similar to those identified for the commercial SHF system with the deletion of one flight unit. The costs stated do not include that associated with:

(i) Pre-contract development/design of the UHF deployed antenna.

(ii) Spacecraft integration, test and launch support activity.

1.0 INTRODUCTION

The General Purpose Bus (GPB) was initially configured during this study, for Department of Supplies and Services and Department of Communications, File Number 01PC.26100-6-0601, Contract Number PC 76-00054, to accommodate the commercial SHF payload defined in SPAR-R.810 Volume I as 24 channels of 6/4 or 14/12 GHz communications at 10 watts/channel RF output power. This spacecraft was designed to be launched by either the Delta 3910/PAM (Payload Assist Module) expendible launch vehicle or the Space Transportation System/PAM launch vehicles. A complete description of the GPB design, which successfully meets these requirements, along with the launch vehicle characteristics and requirements, may be found in the above-mentioned document.

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This report presents the work performed during this study to investigate the effect of the MUSAT payload configurations on the General Purpose Bus. The reader is encouraged to familiarize himself with the GPB baseline design presented in SPAR-R.810, Volume I, before proceeding, since this document discusses only the changes required or utilization of the GPB, and does not repeat a full description of the baseline Bus design. Volume II of SPAR-R.810 provides the Specifications and Requests for Quotation issued and Vendor Responses received in the course of the study. Volume III of that report shows the program implementation plan applicable to the commercial SHF payload.

To summarize the GPB, it is a BUS which is capable of accommodating:

o the commercial SHF payload (3 Options considered)

- o the dedicated MUSAT payload (4 Configurations examined during this study)
- o MUSAT extended life or MUSAT hybrid payloads (2 examples presented in this report)

This standard GPB, as designed to accommodate the commercial SHF payload (January, 1977 presentation) i.e. with

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- o 1900 watt hr. battery
- o 1100 watt EOL, 7 years, solar array
- o RCS and AKM fuel to support this hardware and provide 7 year life

is presented in SPAR-R.810, Volume I, Section 3. This GP Bus was configured for Option C with antenna feed horns at the aft end of the spacecraft. Consequently, the transponder equipment was mounted at this end of the north and south panels to minimize waveguide runs and the housekeeping components are therefore mounted forward.

Subsequent to completing the design of the GPB for the SHF payload, Configuration #1 (as described herein) of the Multipurpose UHF Satellite (MUSAT), which would be launched only on the STS/PAM, was defined and the effect of this payload on the GPB design was examined. It was found that this configuration:

- o utilized complicated communications antennas and
- o under utilized GP Bus available power and STS launch vehicle weight capability

As a consequence of this examination and also of international frequency allocation considerations which could affect allowable communications beamwidth and thus antenna configuration, a contract

?

amendment was authorized to examine 3 additional MUSAT payload (transponder + antenna) configurations for their effect on and applicability to the GPB.

In the case of the MUSAT application, the standard GP Bus, as presented in this report, differs in certain respects (not power or weight) from the design presented in SPAR-R.810, Volume I, Section 3, notably:

o a heat pipe is required for thermal dissipation from the UHF power amplifier, whereas the commercial SHF design utilizes thermal doublers only (with dedicated MUSAT, thermal control weight not increased compared to SPAR-R.810).

o with the MUSAT antennas and their feeds mounted to the forward platform of the GPB, it would be very beneficial to invert the housekeeping components to the aft end of the north and south panels and provide forward mounting of the transponder equiment, thereby minimizing waveguide run complexity and avoiding their interferences with the batteries, etc. This was the concept recommended at the study outset by DOC, see DOC MUSAT Panel Layout drawing No. U-10202 E included in Section 5. All mass properties computer runs performed for the MUSAT configurations have utilized this housekeeping layout inversion forward and aft.

Even with these changes to the GPB for MUSAT, because weight and power are unaffected, the term standard GPB per SPAR-R.810 is still applicable.

As will be presented in this report, none of the 4 dedicated MUSAT payload configurations requires the power (arrays and batteries) or weight capability of the Standard GPB. Consequently, the term <u>minimum</u> GP Bus is used in conjunction with the MUSAT payloads to define the adaptation of the standard GPB where:

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- the batteries (watt hrs.)
- the solar arrays (watts) and
- the expendibles

are tailored for the dedicated MUSAT configuration being examined.

The examination of hybrid and longer life MUSAT payloads, found in Section 8 of this report, is based on these two GPB complements.

The work in this volume was prepared prior to the receipt of GPB potential bought-out subassembly vendor quotations. The effect of the revised technical inputs discussed in Section 5 of SPAR-R.810, Volume I on the MUSAT design would have to be investigated during follow-on study.

The term <u>dedicated</u> MUSAT payload is used for the S/C complement where only MUSAT is present and the UHF and SHF transponder equipment is split onto the two north and south radiating panels. The first 4 sections of this report deal exclusively with the dedicated MUSAT payload.

Finally the report is divided into 4 parts, that is:

- The MUSAT Payloads and Their Installation Into the GPB (found in Sections 2, 3 & 5)
- Technical Effect of the Dedicated MUSAT Payloads on the GPB and the Installation in the Shuttle Orbiter (found in Sections 4 & 6)
- Dedicated MUSAT Program Plan (found in Section 7) and
- MUSAT Long Life & Hybrid Payloads Considerations and Recommendations for Follow-on Study (found in Section 8 & 9)

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A proposed implementation and program plan is included in this report with cost associated with the program submitted in a separate letter. The major difference between this plan and that presented in SPAR-R.810, Volume III is:

- only 2 flight spacecraft are required
- the qualification S/C will be delayed by 6 months because of antenna and heat pipe design/qualification
- Flight 1 spacecraft will be delivered for launch by month 39 and Flight 2-6 months later

As will be evident from Section 3, even the higher power Configuration #2, with a seven year mission, does not come close to making efficient use of the GP Bus. Consequently Section 8 has been included which outlines examples of GPB optimum MUSAT long life and hybrid configurations.

2.0 PAYLOAD REQUIREMENTS AND ASSUMPTIONS

The requirements which follow are for potential MUSAT payloads, provided by DOC. The weights given for the antenna support structures have, in most cases, been modified by Spar in the course of the conceptual design activity as presented in Section 6 of this report.

It is recognized that the values presented in these requirements for payload weights and powers are adequate for this feasibility study but are still considered soft.

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In this study, the interface between the Bus and the antennas (payload) has been defined such that the antenna supports attach points are part of the Bus except in the case of the TRW 16 foot deployable antenna.

2.1 Payload Requirements

Same as requirements for commercial SHF payload except as noted below:

2.1.1 General

Launch Vehicle:	Space Transportation System (STS) with Payload Assist Module (PAM)
Spacecraft:	3 axis stabilized; operational life 7 years; spin stabilized during transfer orbit.
Solar Array:	Provides Spin Phase power; deployable and sun-oriented during 3 axis operation.
Station-keeping of S/C:	±0.05° in North-South and East-West directions; correction update every 14 days, minimum.
Frequency Range:	SHF 7-8 GHz UHF 300-400 MHz

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Beamwidth:		SHF ± 0.5° UHF ± 4.0°
Pointing Accuracies:	SHF	±0.20 degrees, boresight, pitch and roll, (± 0.15 deg. in pitch and roll for the bus including forward platform plus ± 0.05 deg. for the antenna and feed)
		± 0.70 degrees yaw, boresight
	UHF:	± 0.5 degrees pitch & roll, boresight
		± 1.0 degrees yaw, boresight
Antenna Frequency (Deployed):		$f_n > 1.0$ Hz

UHF Antenna and Ground Plane Plate Tolerances

- o Ground plane plates to be coplanar within ±0.125 inches (this includes fabrication, assembly and deployment tolerances).
- o ground plane plates are to be forward of or coplanar with the aperture plane of the UHF dish in Configuration #3 and of the SHF dish in Configurations #1 and #2.

Environment As specified for STS/PAM per MDAC 3J1-86911

S/C Envelope:	Compatible with STS/SSUS mounting with PAM.
Safety Requirement:	STS requirement
Spacecraft Moment of Inertia Ratios:	Design goal $I_{spin}/I_{transverse} \geq 1.05$

2.1.2 Power

Table 2-1 below presents the power required by the payload in normal and eclipse operations (Values are in watts).

	Configuration			
	#1	#2	#3	#4
Normal	313	563	313	313
Eclipse	213	363	213	213

Table 2-1

Power Required During Normal & Eclipse Operations

2.1.3 Geometry

The geometry of the four configurations as provided by CRC are given in Figures 2-1 to 2-4.

Configuration #1 (Figure 2-1)

SHF Antenna & Feed

There is an 84 in. diameter solid paraboloidal dish directly fed by 2 identical horns. Aperature plane is parallel to the BUS forward platform. Aperture angle is 140 deg. Focal length F=30 in., depth H=14.7 in. Antenna is coaxial with the GPB yaw axis.

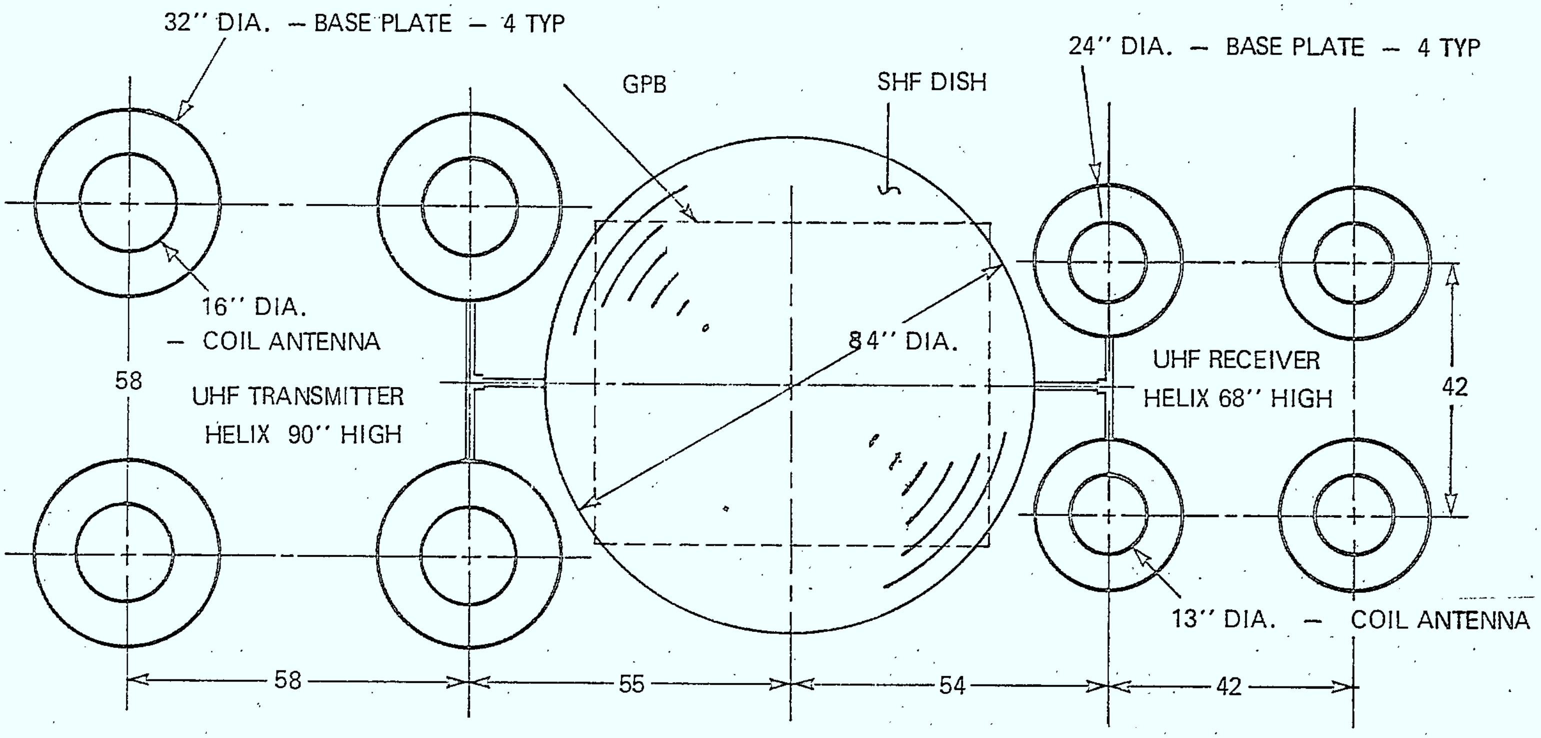


FIGURE 2-1

ANTENNA REQUIREMENTS – CONFIGURATION #1

UHF Antennas & Feed

Eight Spar Astro deployable helices are specified with dimensions and placement shown in Figure 2-1.

Configuration #2 (Figure 2-2)

SHF Antenna & Feed

Identical to that of Configuration #1.

UHF Antennas & Feeds

5/GC.14 Two identical helical antennas, each, on the West and East sides, having either flat 39 in. diameter circular groundplane plates which are 25 percent transparent (0.5 in. diameter holes 0.952 in. apart), or 27 in. diameter circular groundplanes each with a 9 in. high perpendicular rim around its circumference.

Fairchild deployable helices are specified (update). Feed is an aft pointing, 6 in. long, coaxial mast, parallel to axis of the helix and located at the 16 in. perimeter of the helix.

The centre-to-centre distance of the SHF antenna and any one of the UHF helices is not defined; however, the groundplane of the UHF antennas must not be behind the aperture plane of the SHF dish.

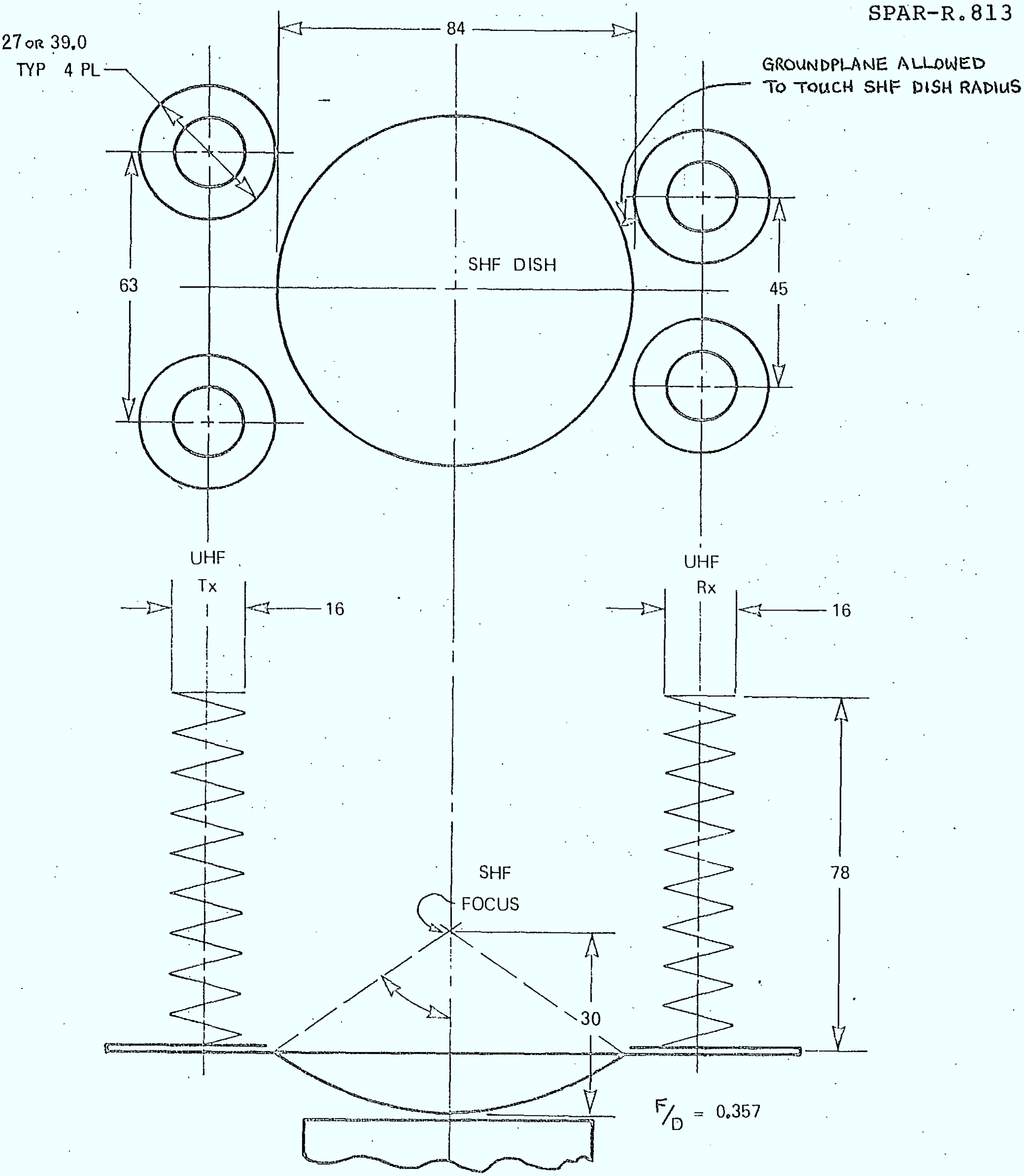
Configuration #3 (Figure 2-3)

SHF Antenna & Feed

Identical to that of Configuration #1 and #2 but integrated with the 16-foot deployable antenna.

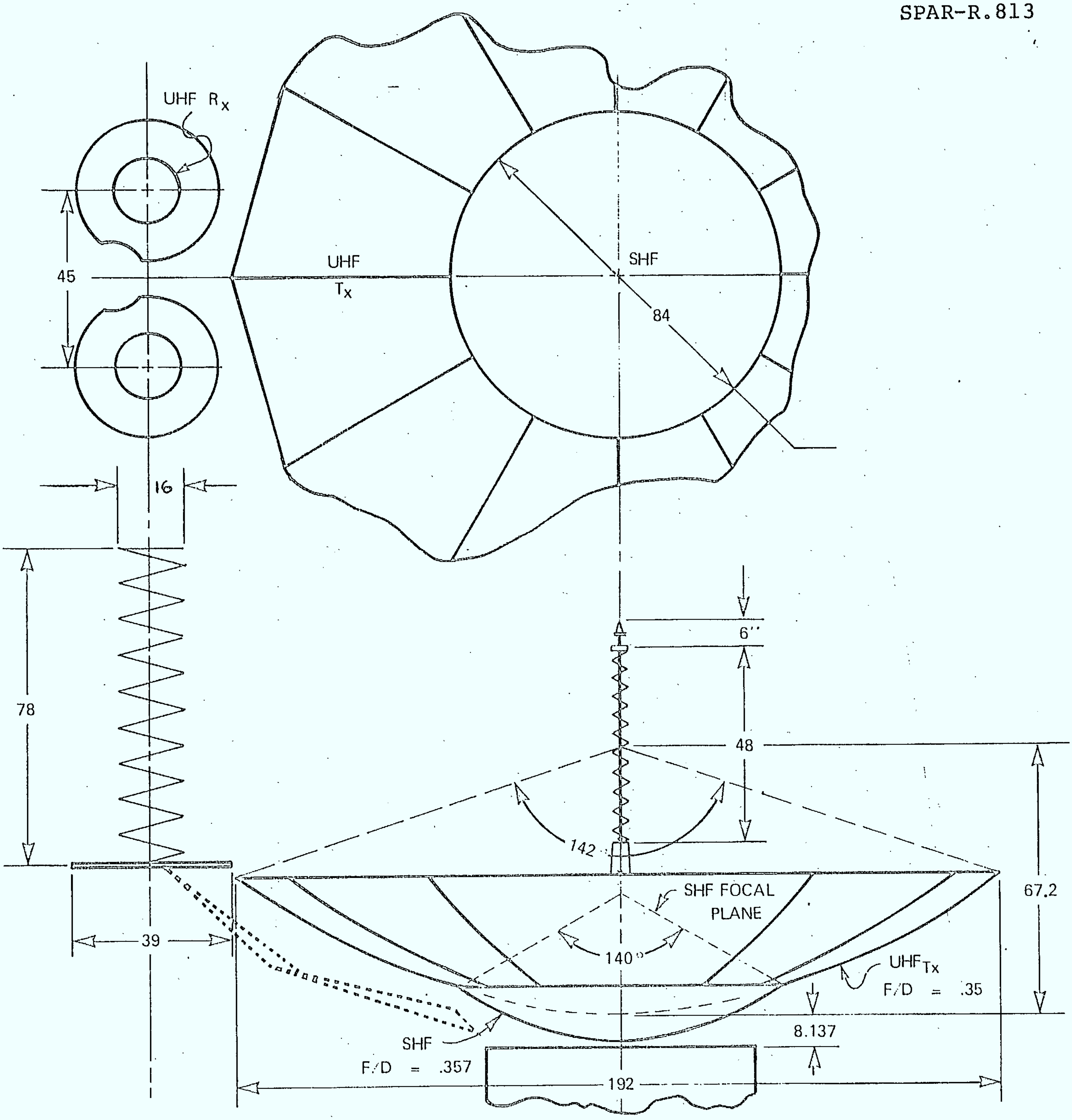
UHF Transmit (Tx) Antenna & Feed

Surface of revolution, D=192 in. mesh type paraboloidal antenna of approximately 50-75% transparency for light perpendicular to the aperture



ANTENNA REQUIREMENTS CONFIGURATION #2

FIGURE 2-2



ANTENNA REQUIREMENTS CONFIGURATION #3

FIGURE 2-3

plane. Antenna axis is coincident to the S/C yaw axis. The centre 84 in. diameter part is a mesh which is located forward of the SHF dish. This mesh is transparent to SHF radiation. The area outside the 84 in. diameter represents 81% of that of the nominal dish. The UHF axis antenna axis is coincident with that of the SHF dish. The perimeter of the dish is not strictly circular but closely resembles a regular dodecagon (12-sided) due to the geometrical constraints imposed by the deployment mechanisms. 5/GC.15

The feed is a "backfire" type, 48 in. long, 3 in. diameter helix mounted on a central support mast (coincident with the yaw axis). Its mid cross-section is on the focal plane.

UHF Rx Antennas & Feeds

Two helical antennas with distance from the centreline of S/C not being closely defined; its minimum value is 113.3 in. Both helices possess either a 39 in. diameter circular groundplane, or a 27 in. groundplane with 9 in. perpendicular rim, identical to that of Configuration #2.

The groundplane of these helices is not behind the aperture plane of the 192 in. UHF-Tx dish.

Fairchild deployable helices are specified (update). Feed is an aft pointing, 6" long, coaxial mast parallel to the axis of the coil and located at the 16" perimeter of the helix.

Configuration #4 (Figure 2-4)

SHF Antenna & Feed

Identical to that of Configuration 3.

UHF Antenna & Feed

Both Tx and Rx communications use the same 16-foot deployable antenna which is identical to that of the UHF, Tx antenna of Configuration #3.

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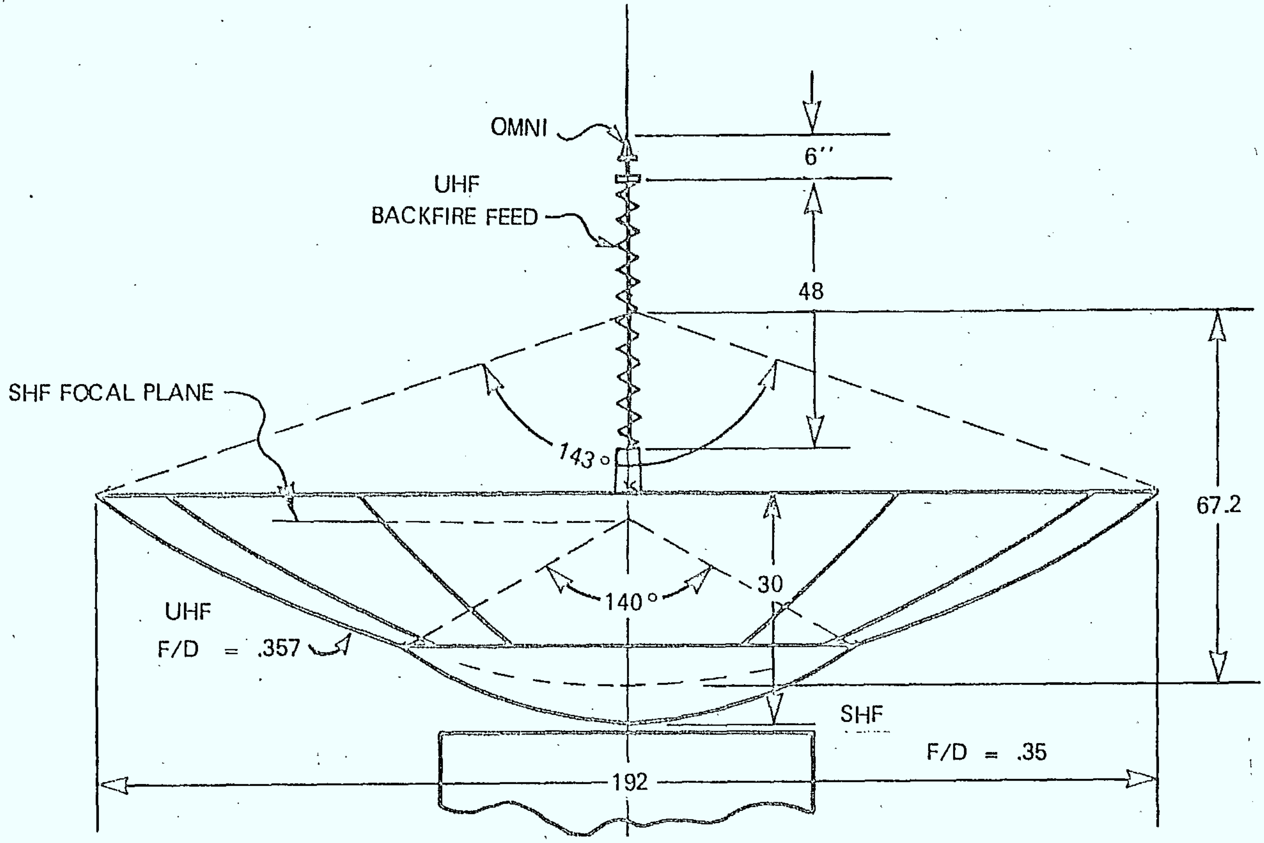
2.1.4 Weights

The MUSAT payload weights (including SHF power regulators and the antennas), were initially specified by the customer (see Table 2-2, below).

Configuration	Transponder Equipment Including SHF Power Regulators & TT&C Security Box	Antennas Including Feeds, & Their Support Structures and Excluding TT&C Antennas	Total Payload
#1	115	80 lbs.	195
#2	137	37 lbs.	174
#3	115	60 lbs.	175
#4	121 incl. duplexer	44 lbs.	165

Table 2.2

Weight Requirements for the 4 MUSAT Configurations



ANTENNA REQUIREMENTS CONFIGURATION #4

FIGURE 2-4

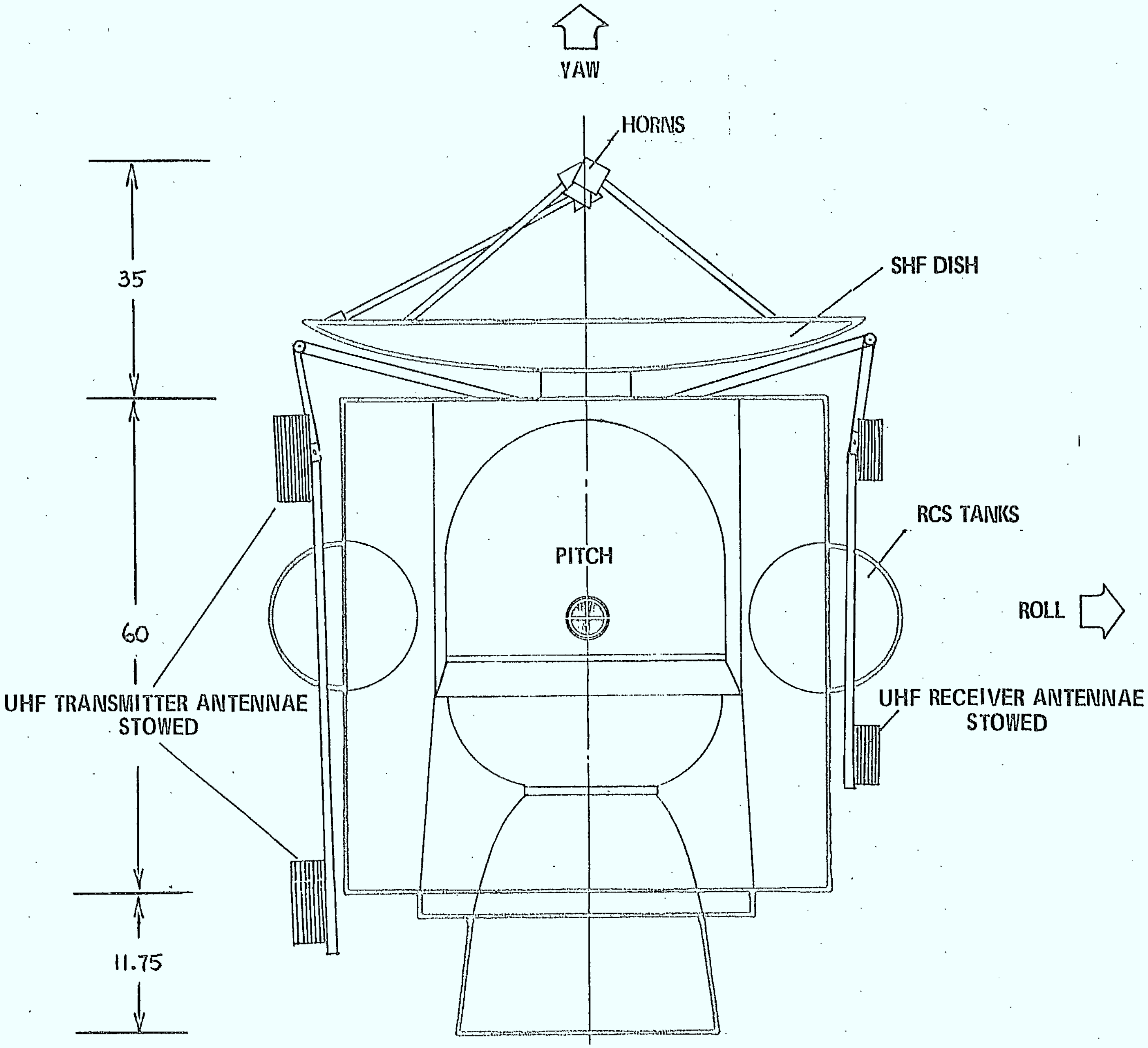
3.0 CONFIGURATIONS AND DISCUSSION

The four MUSAT payload configurations defined in Section 2 can be integrated with the General Purpose Bus and launched on the STS with PAM. This section summarizes the advantages and disadvantages of each dedicated configuration with respect to utility of the GPB. Although there are very significant differences in complexity of the payloads and their antenna mounting, as well as in their stowage volume, see Sections 4 and 5, effects on the design of the GPB itself are minimal as discussed in Section 6.

3.1 Configuration #1

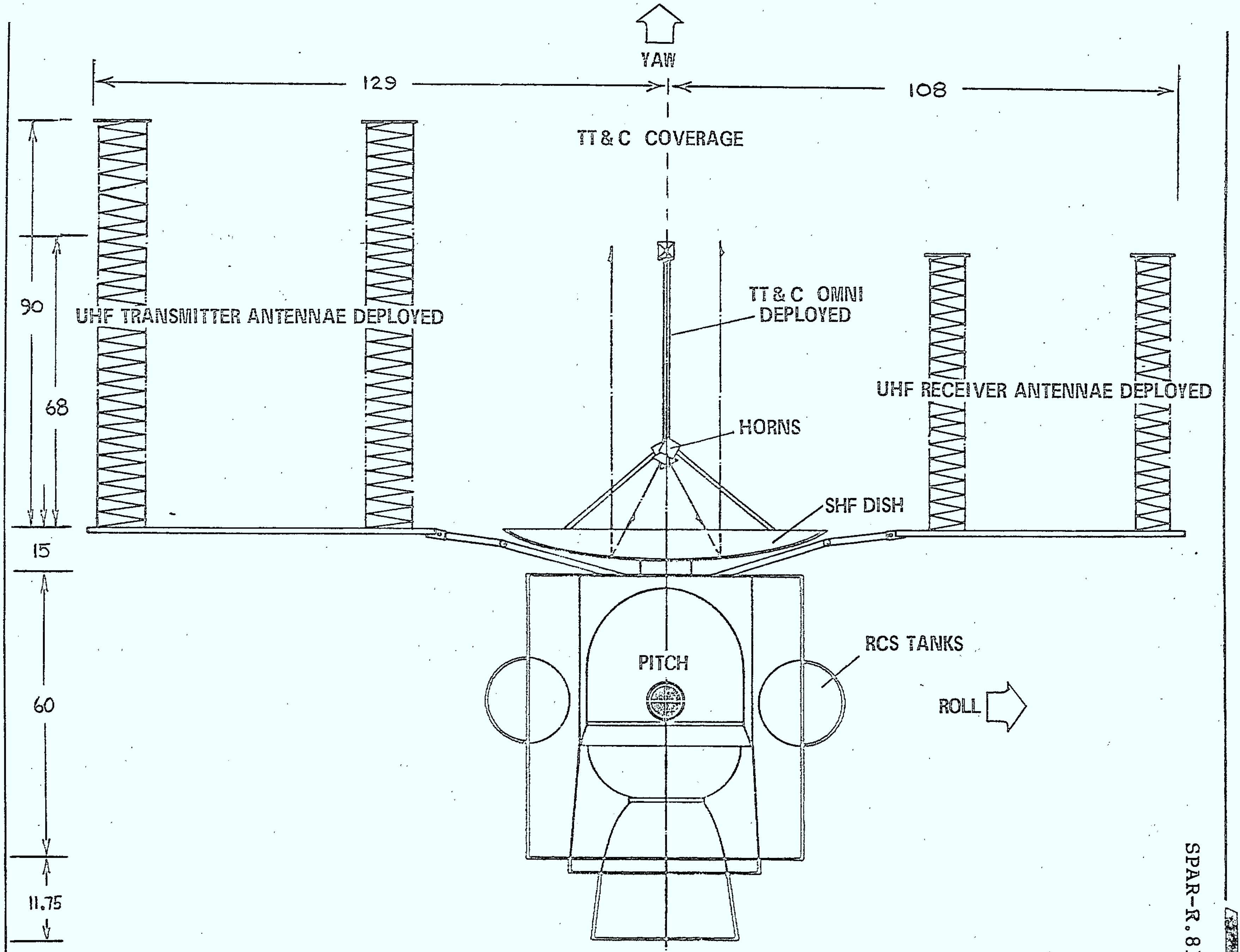
Figures 3-1 and 3-2 illustrate MUSAT configuration #1 with its eight UHF antennas stowed and deployed. From the GPB point of view, the major advantageous feature of this configuration is that, with the UHF antennas stowed on the east and west sides of the GPB, favourable spinning to transverse axis moment of inertia ratios can be attained which precludes the need for active nutation control during the spinning mission phases. As with all configurations, this payload can be integrated without major redesign of the GPB and, along with configuration #2, requires only 149 inches of Shuttle Bay Length during launch, thereby minimizing launch cost.

Configuration #1 has several disadvantageous features, due to the large, unsymmetrical and complex UHF antenna farms. These appendages created a significant GPB lateral C of G shift as a consequence of their deployment; they cause solar array shadowing of up to 50 inches and their deployed locations cause the greatest potential RCS plume impingement hazard of any of the configurations. Their stowage



CONFIGURATION #1 MUSAT STOWAGE AND DEPLOYMENT CONFIGURATION

FIGURE 3-1



CONFIGURATION #1 MUSAT STOWAGE AND DEPLOYMENT CONFIGURATION

FIGURE 3-2

would be complex with at least 10 pyrotechnic circuits likely required, and natural frequencies of the assemblies in all mission phases, particularly when deployed, would be a major design factor of the payload. Finally, as with all configurations, the GPB capabilities of weight and power, are not efficiently utilized.

Table 3-1 presents the pros and cons of this configuration in more detail.

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MUSAT CONFIGURATION #1

PROS	CONS
o SIMILAR TO SHF OPTION 'C' CONFIGURATION GPB	o POOR UTILIZATION OF GP BUS AVAILABLE POWER, AND STS/PAM LAUNCH CAPABILITY
o ACHIEVES FAVOURABLE M OF I RATIO DURING SPIN PHASE	o WILL NOT FIT WITHIN DELTA 3910 SHROUD DIMENSION
o FITS INTO SHUTTLE WITH NO MAJOR MODIFICATION	o LARGE IMBALANCE AND CG SHIFT WHEN UHF HELIX DEPLOYED. WILL AFFECT ACS (11 LBS. BALLAST REQUIRED)
o MINIMUM SHUTTLE LENGTH REQUIRED (MIN. LAUNCH COST)	o ACS SENSOR (NESA) BLOCKED, NEED SEPARATE APPENDAGE
	o GREATER SOLAR ARRAY SHADOWING
	o NEEDS HEAT PIPE - INTERFERENCE NOT KNOWN
	o WORST CONFIGURATION FOR E-W. PLUME IMPINGEMENT
	o NUMEROUS PYRO FIRING CIRCUITS
	o FREE-FREE VS. CONTROLLED DEPLOYMENT NOT INVESTIGATED

TABLE 3-1

3.2 Configuration #2

Figures 3-3 and 3-4 illustrate MUSAT configuration #2 with its 4 UHF antennas stowed within the SHF dish for launch and then deployed when 3 axis stabilized. From the point of view of the GPB and its launch vehicle, configuration #2 is the most advantageous option. Its major positive features, retaining minimum Shuttle Bay length and favourable moment of inertia ratio while eliminating most of the antenna problems discussed above for configuration #1, are presented in Section 3.5 where it is compared subjectively with the other configurations.

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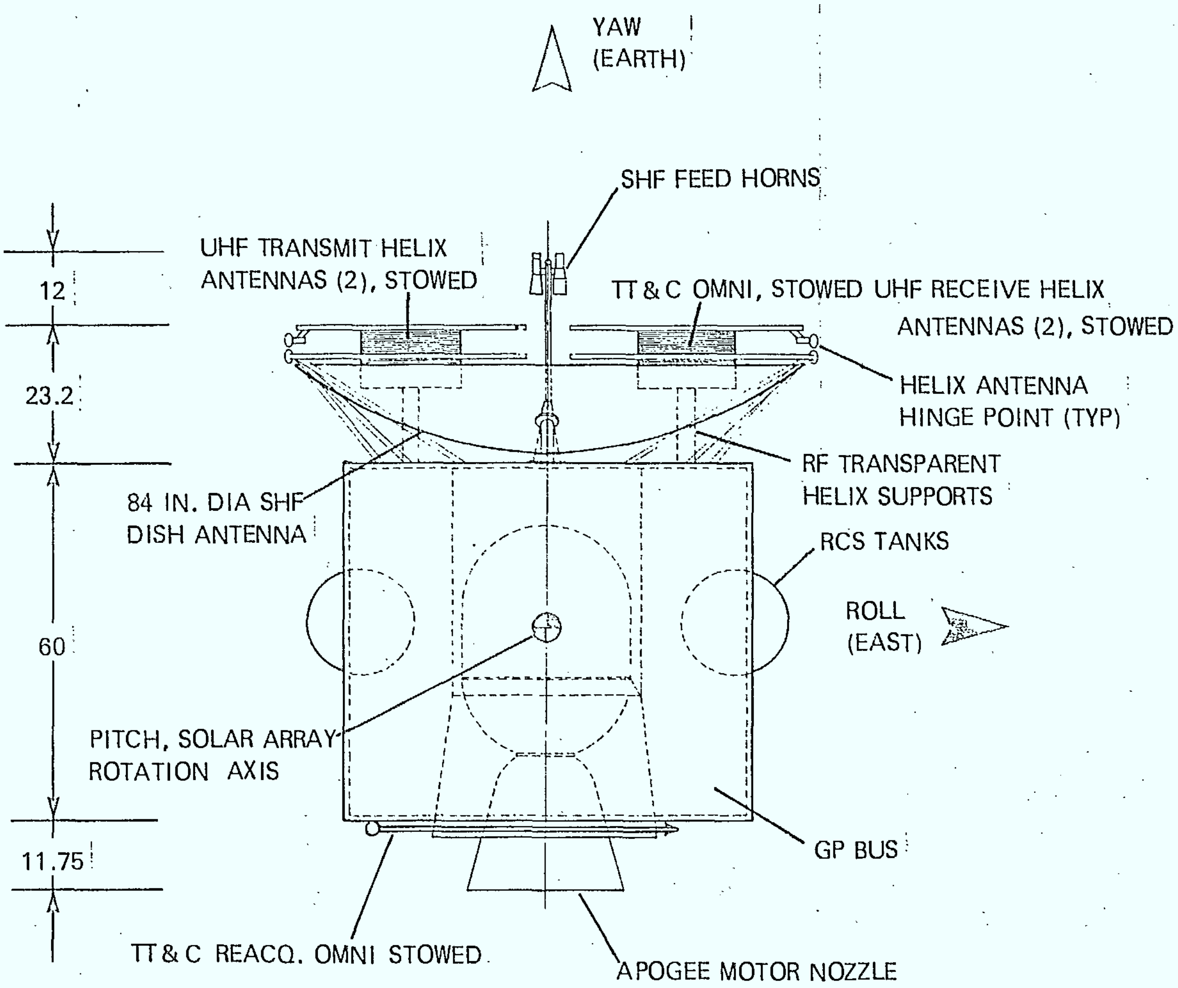
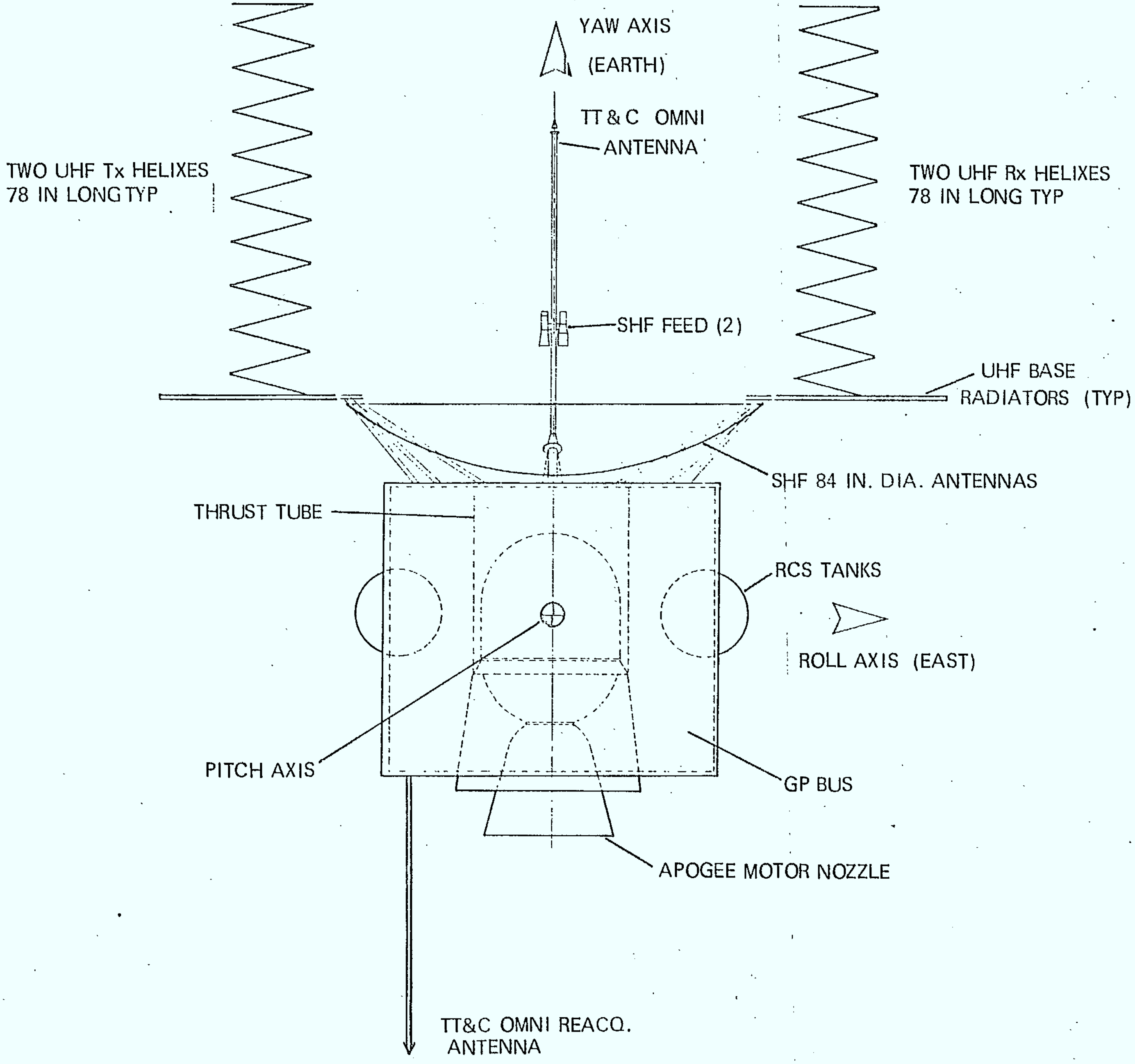
Although the UHF antennas (with 39" diameter flat ground planes) stowage and deployment is relatively straightforward with only 2 tie down cables through the support posts and short antenna support arms, a further option of configuration #2 is possible which eliminates any deployment of the supports at the expense of a significantly larger spacecraft radius and higher Shuttle costs. With this configuration #2a, the helices structures are rigidly mounted in the operational location and the 27" diameter ground planes with 9" high circumferential rims are employed and positioned radially as close as possible to the perimeter of the 84" SHF dish. Total radius of this configuration would be approximately 140 inches.

Table 3-2 presents the pros and cons of configuration #2 in more detail.



MUSAT – CONFIGURATION 2 – STOWED

FIGURE 3-3



MUSAT — CONFIGURATION #2 — DEPLOYED

FIGURE 3-4

MUSAT CONFIGURATION #2

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PROS	CONS
o SIMILAR TO SHF OPTION 'C' CONFIGURATION. GPB IS USABLE WITH MINIMAL MODIFICATIONS	o DOES NOT FULLY UTILIZE AVAILABLE GPB POWER. HOWEVER, IMPROVED WEIGHT UTILIZATION.
o BETTER UTILIZATION OF AVAILABLE POWER FROM GPB WHEN COMPARED o WITH CONFIGURATION 1	o ACS SENSOR (NESA) BLOCKAGE STILL A PROBLEM. NEEDS OPENING IN THE ANTENNA OR SEPARATE APPENDAGE.
o CONFIGURATION MAY FIT WITHIN 3910 DELTA FAIRING AND SHUTTLE WITH TT&C OMNI FOLDED	o HEAT PIPE SYSTEM REQUIRES LARGEST RADIATOR. o HELIX FREE-FREE DEPLOYMENT NOT ANALYZED
o NO CG SHIFT. CG IS ALONG THRUST AXIS (YAW) FOR BOTH SPIN AND DEPLOYED	o 6 PYRO FIRING CIRCUITS MAY BE REQUIRED TO DEPLOY THE SYSTEM.
o OBSTRUCTIONS TO E-W & N-S THRUSTER OPERATION MINIMIZED	o NATURAL FREQUENCY OF FAIRCHILD HELICAL ANTENNAS < 1.0 Hz, NOT INVESTIGATED AND EFFECT ON GPB ACS NOT KNOWN
o TIE DOWN AND DEPLOYMENT MECHANISM NOT CONSIDERED COMPLEX	
o MINIMUM SHUTTLE LENGTH REQUIRED (MIN. LAUNCH COST)	
o ARRAY SHADOWING DUE ANTENNAS NOT SIGNIFICANT	
o CAN ACHIEVE FAVOURABLE M OF I DURING SPIN PHASE (IF BATTERIES MOUNTED FORWARD)	

TABLE 3-2

3.3 Configuration #3

Figures 3-5 and 3-6 illustrate MUSAT configuration #3 with its 16-foot deployable transmit UHF antenna and its 2 offset helical receive UHF antennas stowed and deployed. The only significant advantage of this configuration, other than the development status of the 16-foot antenna, is the convenient central support structure for mounting the TT&C omni antenna to attain wide angle coverage.

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The 16-foot TRW designed deployable antenna causes several problems. Its high centre of mass both precludes favourable moment of inertia ratios, even with the batteries forward, and may cause significantly higher thrust tube loading. This long stowed length significantly increases Shuttle Bay length required. Solar pressure torques are increased, array shadowing is significant (up to 50 inches), NESA blockage problems are compounded by having two antennas to view through, etc. Additionally, the offset deployed helical antennas with long-arm mounting structure create many of the problems already presented by configuration #1, (for example; centre of gravity shifts, plume impingement in (both the stowed and) deployed state, natural frequency and stowage complexity.)

Table 3-3 presents the pros and cons of this configuration in more detail.

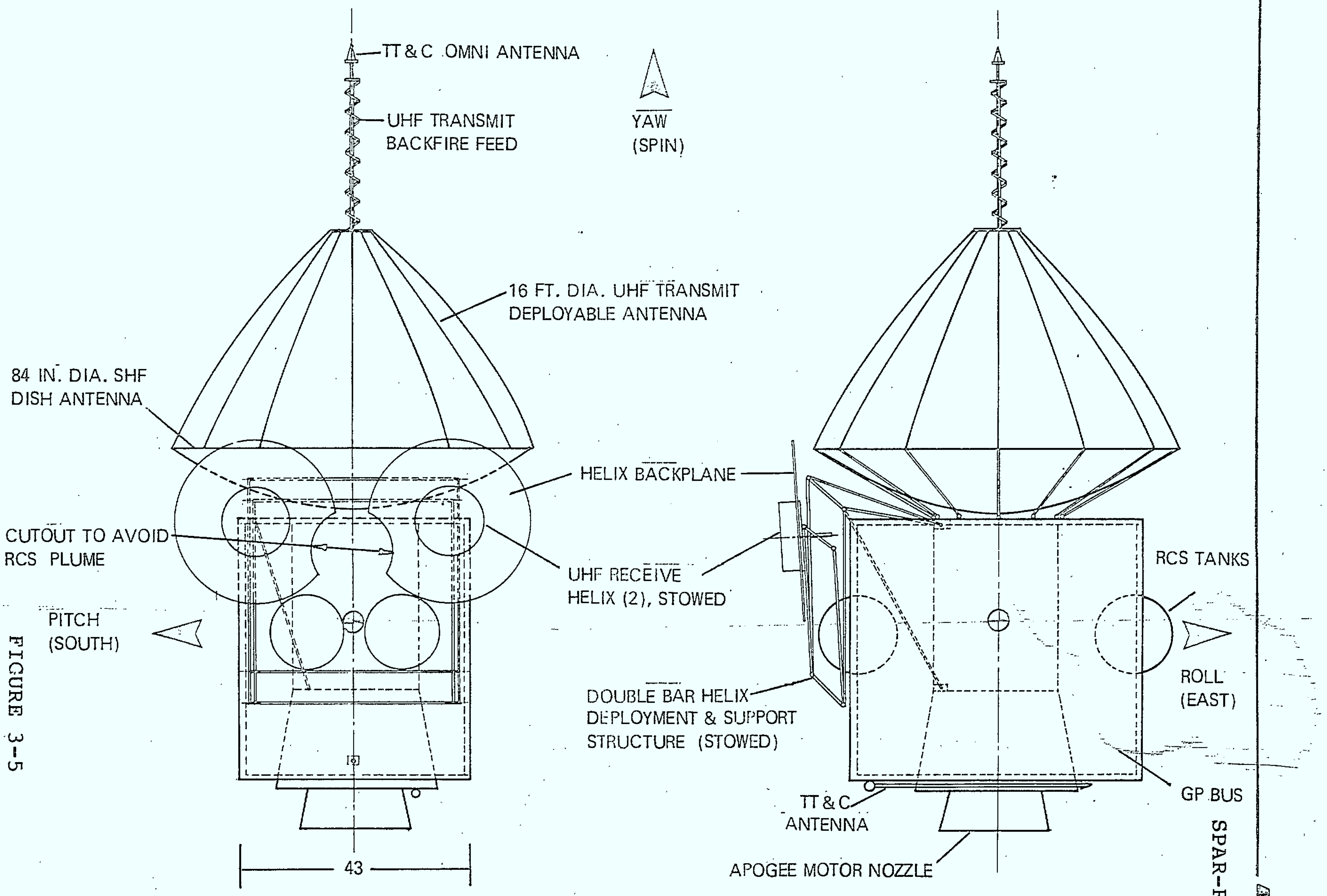
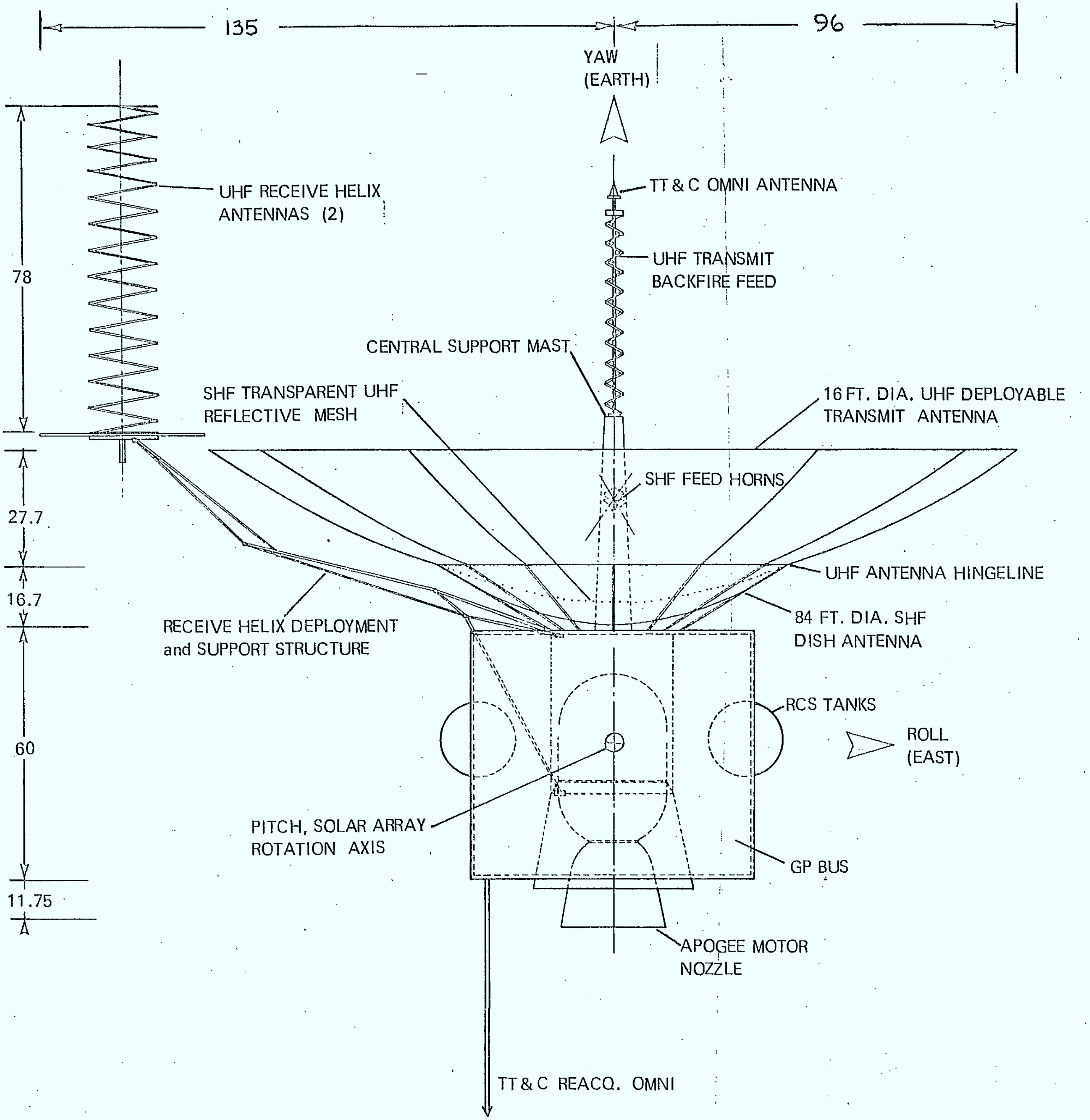


FIGURE 3-5

MUSAT – CONFIGURATION 3 – STOWED



MUSAT – CONFIGURATION 3 – DEPLOYED

FIGURE 3-6

MUSAT CONFIGURATION #3

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PROS	CONS
o GPB MAY BE USED WITH MINIMAL MODIFICATIONS	o FAVOURABLE M OF I NOT ACHEIVED $I_s/I_t = .94$ ACTIVE CONTROL REQUIRED)
o TRW FLEET SATCOM ANTENNA DEVELOPED/ QUALIFIED FOR ATLAS CENTAUR	o IMBALANCE DUE TO CG SHIFT WHEN HELIX DEPLOYED 1.0 INCH
o WIDE ANGLE TT&C COVERAGE AVAILABLE DURING SPIN PHASE	o STRUCTURE SENSTIVE TO MISALIGNMENT
	o GREATER SOLAR PRESSURE TORQUES
	o WILL NOT FIT WITHIN DELTA FAIRING
	o INTERFERENCE WITH RCS. TO AVOID PLUME IMPINGEMENT, WHEN STOWED CUT OUTS REQUIRED IN HELIX GROUNDPLANES.
	o FREE-FREE DEPLOYMENT NOT INVESTIGATED RE: TRW ANTENNA & HELIX ANTENNA
	o EXPENSIVE SHUTTLE LAUNCH DUE TO OVERALL LENGTH
	o REQUIRES HEAT PIPES
	o GREATER ARRAY SHADOWING DUE TO 192" DIAMETER
	o NESA BLOCKAGE STILL EXISTS MAY NEED SEPARATE APPENDAGE
	o SENSITIVE UHF FEED AND TT&C OMNI SUPPORT STRUCTURE
	o DOES NOT FULLY UTILIZE AVAILABLE POWER AND WEIGHT OF GPB/STS LAUNCH

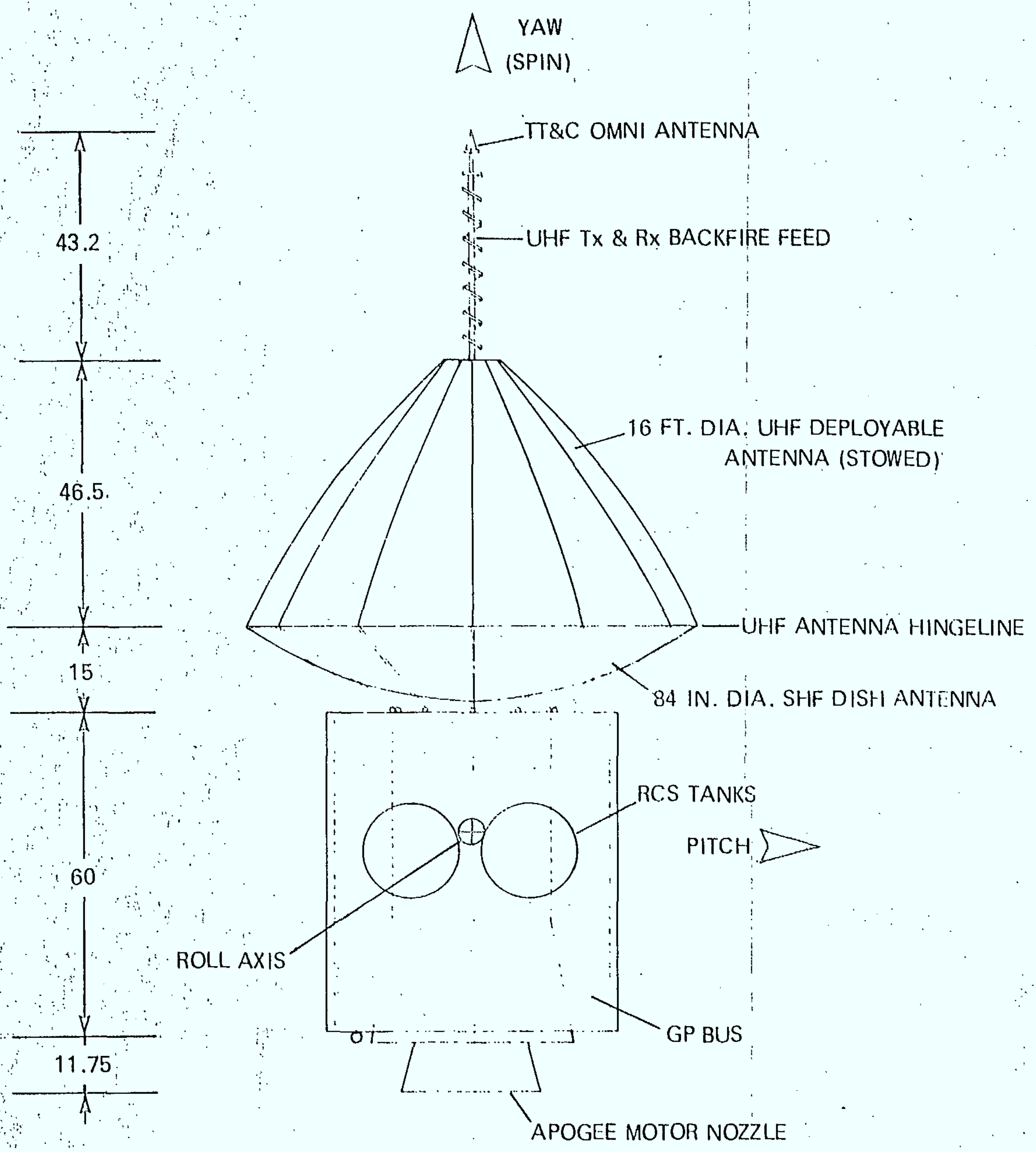
TABLE 3-3

3.4 Configuration #4

Figures 3-7 and 3-8 illustrate MUSAT configuration #4, which is identical to configuration #3 stowed and deployed, except the offset helical antennas are removed. Its major advantage is its antenna mechanical design simplicity. It suffers from the same disadvantages as configuration #3 regarding the 16-foot deployable antenna.

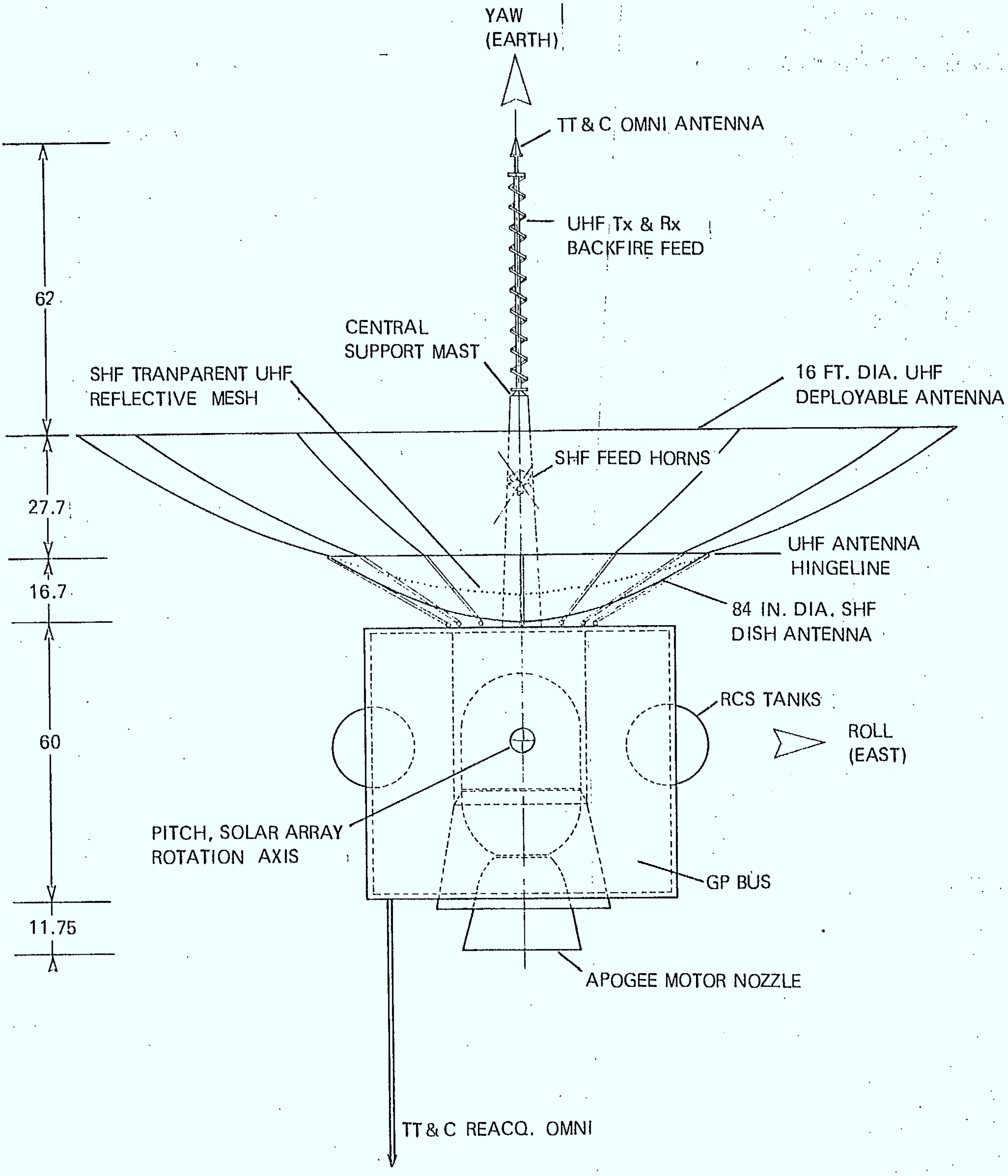
5/GC.24

Table 3-4 presents the pros and cons of this configuration in more detail.



MUSAT – CONFIGURATION 4 – STOWED

FIGURE 3-7



MUSAT – CONFIGURATION 4 – DEPLOYED

FIGURE 3-8

MUSAT CONFIGURATION #4

PROS

- SYSTEM QUALIFIED ON FLT. SATCOM NO MODIFICATIONS REQUIRED
- NO ADDITIONAL DEPLOYABLE STRUCTURES FOR UHF
- NO IMBALANCE CONDITION OCCURS WHEN IN OPERATIONAL DEPLOYED CONFIGURATION
- MINIMAL CHANGES TO GPB. MAY BE FITTED WITH NO MAJOR MODIFICATIONS
- LIGHTEST OF ALL CONFIGURATIONS

CONS

- FAVOURABLE M OF I NOT ACHEIVED $Is/I_t = .93$ (ACTIVE CONTROL REQUIRED)
- SENSITIVE UHF FEED STRUCTURE
- NESA BLOCKAGE EXISTS WILL NEED A WINDOW OR SEPARATE APPENDAGE
- EXPENSIVE SHUTTLE LAUNCH DUE TO OVERALL LENGTH
- ARRAY SHADOWING SIMILAR TO CONFIGURATION #3
- DOES NOT FULLY UTILIZE AVAILABLE POWER AND WEIGHT AVAILABLE ON GPB/STS LAUNCH
- HEAT PIPE REQUIRED

TABLE 3-4

3.5 Configuration Comparison and Conclusions

A subjective evaluation of the applicability of the standard GPB to each of the four MUSAT payload configurations is presented in Table 3-5. This evaluation was based on design complexity (which would directly relate to cost) and development risks. To each characteristic was first assigned a weighting factor between 1 and 10 with the highest weighting allocated to the characteristic of Shuttle Bay length used (and thus launch cost). Each of the configurations was rated for each characteristic on a scale of 0 to 5 and the total scores were tallied.

5/GC.26

As can be seen from the Table, configuration #2 with its:

- o minimum shuttle length
- o best utilization of GPB power and weight capabilities
- o likely acceptable moment of inertia ratio (no active nutation control) if batteries are relocated forward
- o no significant solar array shadowing
- o relatively simple tiedown and deployment mechanisms
- o symmetry resulting in minimal C of M shifts as a result of deployment
- o minimal RCS plume impingement on antennas

has the highest rating, 3.45 figure of merit, with a wide margin over the second preference of configuration #4, 2.80 figure of merit. This latter configuration suffers from:

- o higher Shuttle launch costs
- o poorer utilization of available GPB power and weight
- o unfavourable M of I ratio resulting in a need for active nutation control
- o more difficult attitude sensor placement

Table 3-5

Evaluation of MUSAT Configuration for Standard GPB

Characteristic	Weighting	Configuration 1 Rating	Configuration 1 Score	Configuration 2 Rating	Configuration 2 Score	Configuration 3 Rating	Configuration 3 Score	Configuration 4 Rating	Configuration 4 Score
Shuttle Length - Cost	10	5	50	5	50	1	10	1	10
Antennas Tiedown & Deploy. Mechanism Complexity	8	0	0	2	16	0	0	4	32
Natural Freq. of Antennas - ACS Analysis	7	1	7	1	7	0	0	3	21
Deployment Dynamics-ACS Interaction	7	1	7	3	21	0	0	3	21
M of I Ratio - Active Nutation Control	7	5	35	4	28	1	7	1	7
ACS Sensor Coverage-Sun	6	3	18	4	24	1	6	2	12
-Earth	6	3	18	3	18	1	6	1	6
Heat Pipe Req't-HSKPG Rearrangement	6	4	24	2	12	4	24	4	24
Reinforcement of Structure	5	4	20	4	20	1	5	1	5
Antenna Feed Accommodation	5	1	5	2	10	2	10	4	20
Pyrotechnic Complexity & TT&C Requirements	4	1	4	3	12	3	12	5	20
Plume (RCS) Impingement on Antennas	4	1	4	5	20	2	8	3	12
Solar Array Shadowing, Power (& Solar Torques)	4	2	8	5	20	2	8	2	8
Solar Torque Due to Antennas Directly	4	1	4	5	20	0	0	4	16
C of M Shift Due to Antenna Deployment	4	0	0	4	16	0	0	5	20
Power Req't (Utilization)	3	2	6	4	12	2	6	2	6
Weight Req't (Utilization)	3	4	12	5	15	3	9	2	6
TT&C Antenna Mechanism Complexity	3	2	6	2	6	4	12	4	12
Antenna Development Status	3	1	3	3	9	2	6	4	12
Payload Placement	2	5	10	4	8	5	10	5	10
Delta 3910/PAM Compatibility	2	0	0	5	10	0	0	4	8
Antenna Masking N-S Panel Thermal Radiation	1	5	5	5	5	3	3	3	3
Total	104		246		359		142		291

	1	2	3	4
Figure of Merit, Weighted Average	2.37	3.45	1.37	2.80

– but a different
VHF feed will
reduce length of
3 & 4

= Is this fair?

5/GC.27

- increased array shadowing, potentially resulting in increased solar torque
- high structural loading into the thrust tube during launch vibration

Configurations #1 and #3 are the least preferable from the point of view of the BUS and its launch vehicle.

The comparative characteristics and subjective evaluation deal with GPB features only.

It is understood that the final decision on a preferred configuration would necessarily include a systems level tradeoff including the communications equipment performance and might even be decided on non-technical and non-cost grounds. For example, configuration #2, with only 2 receive and 2 transmit helices has smaller receiver gain than other configurations. Also, it is understood, as a result of the 22 March presentation to DOC, that configurations 1, 2 and 3, all non-duplexed systems, are considered equally effective in minimizing passive intermodulation (PIM) products problems with the UHF system. With the duplexed configuration #4, it is apparently not possible to evaluate whether PIM products will cause problems until such time as a full scale 16 ft. dia. antenna is built and tested. In light of the FLTSATCOM experience in this area, configuration #4 is considered to involve significant antenna electrical design and cost risks.

4.0 MOUNTING OF MUSAT IN THE SHUTTLE ORBITER BAY

4.1 General

A more complete description of the Payload Assist Module (PAM) being designed by McDonnell Douglas for launching geosynchronous Delta class payloads out of the Shuttle orbiter bay and into the transfer orbit (apogee altitude nominally 19,323 nmi, perigee altitude nominally 160 nmi) is presented in SPAR-R.810, Volume I, Section 4.

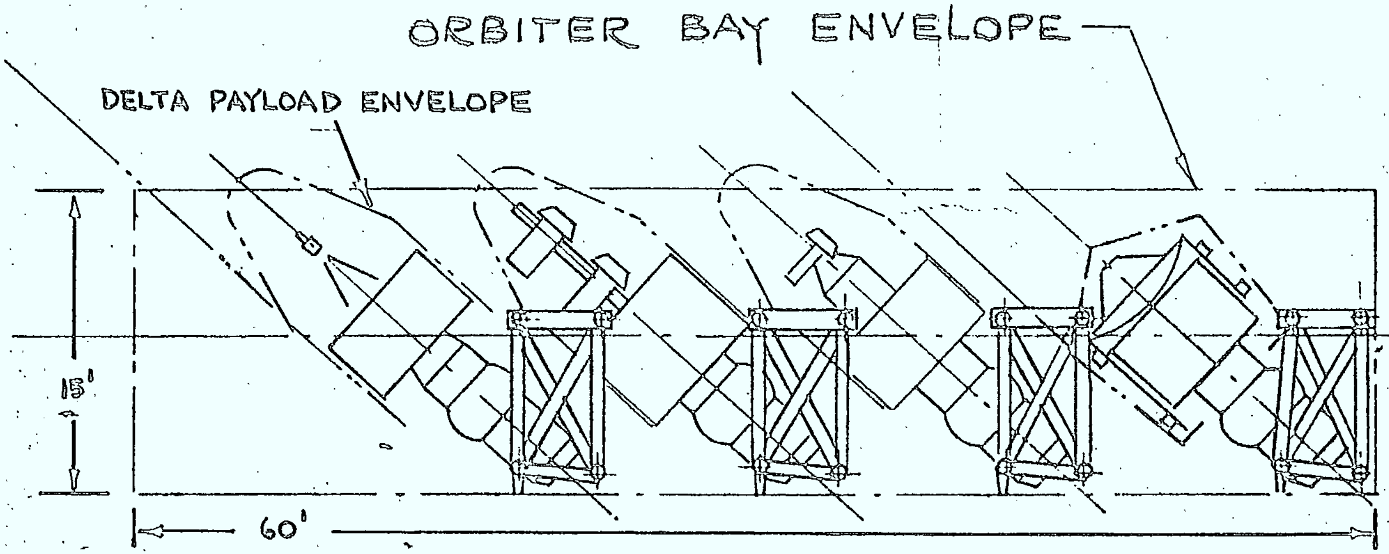
The PAM functionally performs the same task which is accomplished by the third stage of a conventional Delta Expendible Launch Vehicle (ELV) and the Orbiter functionally provides a guided platform in a parking orbit from which the PAM can be fired - similar to the first two stages of the Delta ELV.

Airborne Support Equipment (ASE), housed within the orbiter bay and reused from orbiter sortie to sortie, accomplishes the structural support in the bay to withstand ground handling and launch environments, spinup of PAM plus spacecraft and spring separation from the launch vehicle. This equipment is being designed to be as compatible as possible to present ELVs in the areas of S/C-to-launch-vehicle interfaces, including some environments, operations and envelopes. Important similarities and differences are pointed out in the above reference.

The cradle for the PAM plus spacecraft contains a mechanism which allows these spacecraft to be tilted in the bay prior to launch (see Figure 4-2) to minimize the Volume of the bay occupied. It is imperative at all times prior to separation that the payload does not protrude outside the closed bay door envelope (15 foot diameter).

In contrast to the present Delta ELV, where the total launch vehicle is sold by NASA to the customer, the PAM is being developed by MDAC as a commercial venture and will be sold directly to

SPACE TRANSPORTATION SYSTEM - MULTIPLE PAYLOAD INSTALLATION



- CRADLE POSITION PRELAUNCH ADJUSTABLE
- FOUR DELTA CLASS PAYLOADS IN 1 SORTIE

FIGURE 4-1

GPB MUSAT - INSTALLATION IN STS ORBITER BAY

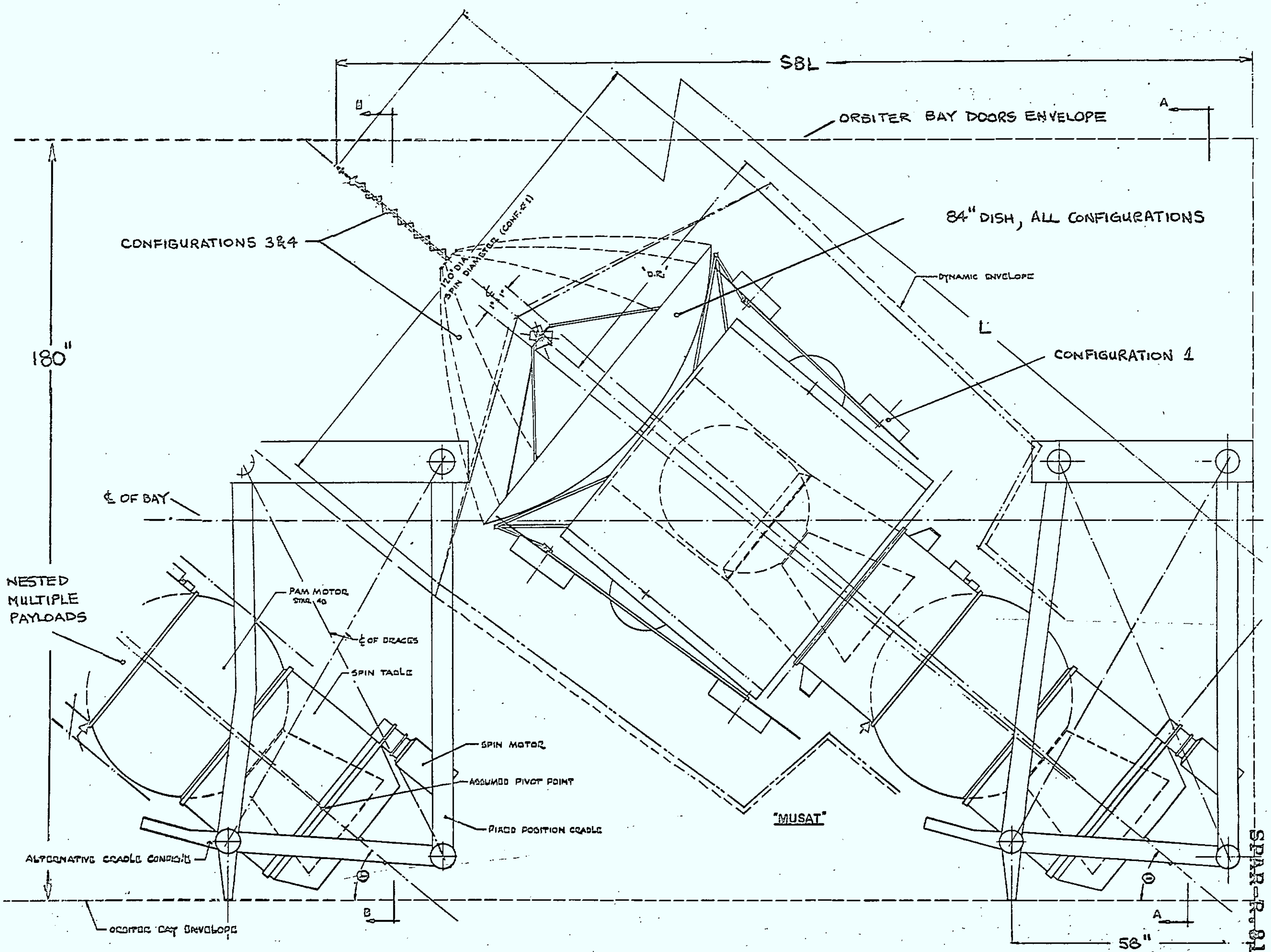


FIGURE 4-2

SPAR-R.813

5/GC.30

the user. MDAC will maintain control over the PAM during prelaunch checkout, S/C mating, and launch and will be responsible for in-flight performance. The expected cost of such a stage, with normal support services (loading, trajectory, balancing analysis, etc.) will be approximately $2M.

It is expected that this PAM concept, being called the Spinning Solid Upper Stage-Delta (SSUS-D), will allow for at least 4 (multiple) payloads to be carried on one orbiter sortie, providing these payloads fit within the standard Delta ELV 86 inch diameter shroud envelope. This is depicted in Figure 4-1. On the other hand, the spacecraft is not constrained by the Orbiter to fit within this envelope.

4.2 Installation in the STS Orbiter Bay

Spar drawing 31179L12, Sheets 1 and2, see Appendix D, shows the MUSAT installed with its PAM and supported by ASE in the orbiter bay. Also shown is another nested payload, also a GPB spacecraft. The pertinent portion of this drawing has been reproduced as Figure 4-2. The cradle design shown has been derived from very preliminary MDAC sketches (see 3J1 86911, SPAR-R.810, Volume I, Appendix M).

The spacecraft shown in this figure is a collage of all 4 of the MUSAT configurations. It has been assumed, after consultation with DOC, that the central support mast, UHF backfire and TT&C omni-antenna for configurations #3 and #4 are not and should not be made collapsable or retractable for launch.

The important parameters to be read from this figure are:

Θ ≡ the cant angle in the bay

L ≡ the total length of the spacecraft plus PAM from the assumed ASE pivot point

DR = dynamic radius of the payload at the station which would cause first interference with the orbiter, taking into account a potential ±1 degree rotational misalignment

SBL = total shuttle bay length required for the payload, PAM and ASE

5/GC.31

Figure 4-3 illustrates a view looking down the yaw, spin, axis of MUSAT to show the relative nominal spin radius of each of the 4 configurations. Configurations #4, and #2 with some small cut outs in the SHF dish periphery for UHF antennas support structure, would fit within the 86 inch Delta shroud diameter. Configurations #1 and #3, with east-west folded helices farms, require a greater spin radius.

Table 4-1 presents the important parameter values for the 4 configurations, with Θ maximized to minimize SBL and thus launch costs. Both configurations #1 and #2, without the long antenna central support mast, can be canted to approximately Θ = 50° and the resulting SBL is approximately 150 inches. Configurations #3 and #4 are restricted to Θ = 38 degrees and the SBL is an expensive 232 inches.

4.3 Estimated Shuttle Launch Cost

Figure 4-4 presents the NASA produced share-price formula for a shuttle flight. The load factor, in the case of the MUSAT payload with up to 3 companion spacecraft in the bay, will be determined by payload length, or SBL. The table with this figure utilizes the SBL previously determined to derive a C_f factor for each MUSAT configuration.

Strictly as an assumption and for the purposes of relative cost, a dedicated commercial launch cost, excluding PAM charges, of $17M was used and example launch costs were derived of $4.8M for configurations 1 and 2 and $7.3M for configurations 3 and 4. Since this assumed dedicated launch cost is likely low, the savings for configurations 1 or 2 over 3 or 4 would conservatively be $2.5M per flight.

MUSAT CONFIGURATIONS - STOWED, SHOWING SPIN RADIUS

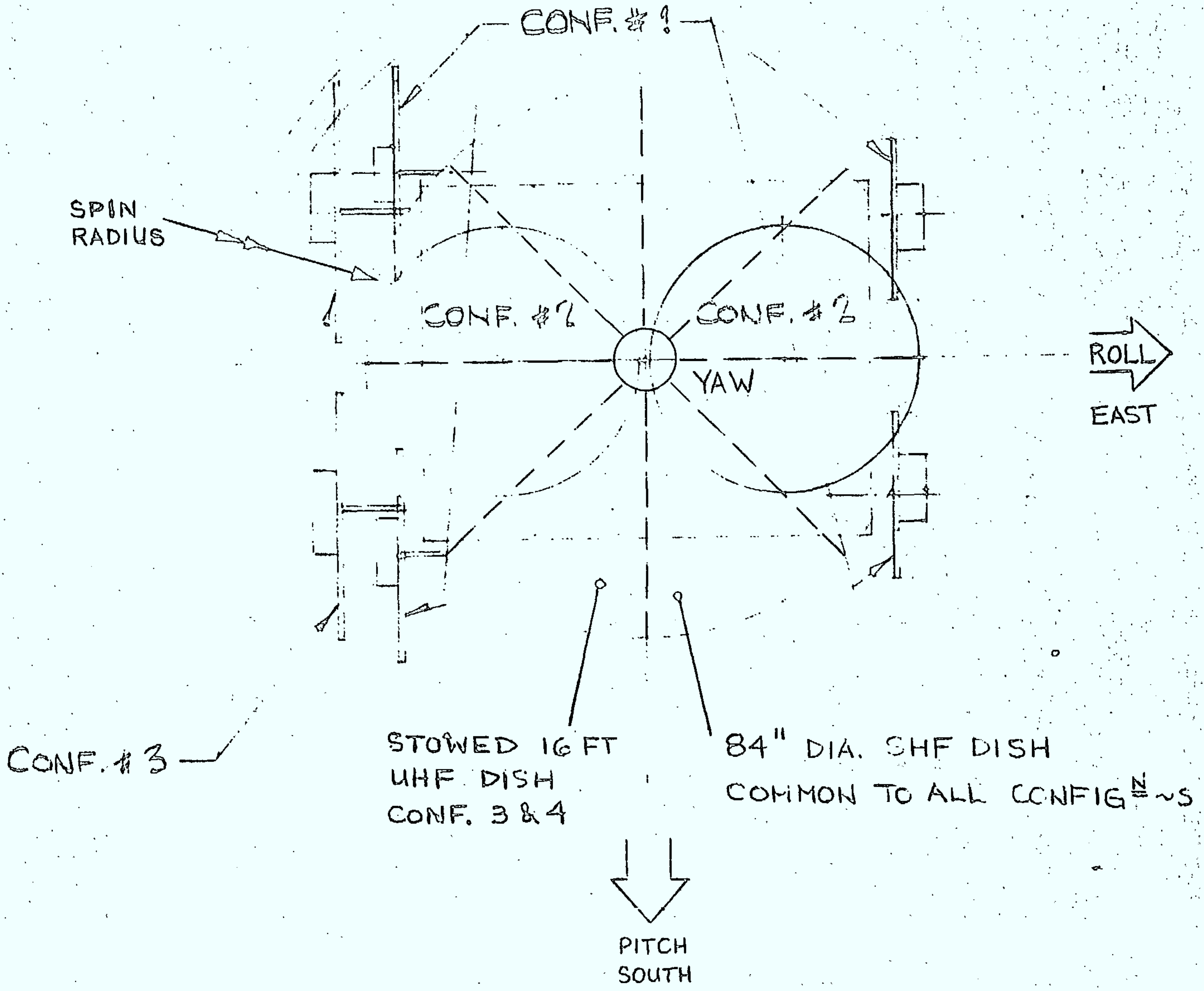


FIGURE 4-3

TABLE 4-1
GPB S/C OPTIONS - LAUNCH ENVELOPE PARAMETERS

S/C OPTION		S/C LENGTH	S/C + PAM	L	D.R. (MAX.)	θ (MAX.)	SBL
COM. SHF OPTION	A	135	222	215	47	46	184
—"— —"— —"—	B	80	167	160	47	54	129
—"— —"— —"—	C	73	160	153	47	61	109
MUSAT CONF.	1	98	185	178	63	50	149
—"— —"—	2	98	185	178	49	50	149
—"— —"—	3	169.5	256.5	249.5	69	38	232
—"— —"—	4	169.5	256.5	249.5	46	38	232

LEGEND:

DR = DYNAMIC SPIN RADIUS.
SBL = SHUTTLE BAY LENGTH.
θ = S/C CANT ANGLE IN BAY, ABOVE ORBITER ROLL (X-X) AXIS

GPB PAYLOAD OPTIONS - COST FACTOR COMPARISON

S/C LAUNCH COST - STS/PAM*

Configuration	Shuttle Bay Length (Including ASE)	C_f	Example Launch Cost ($M) *
Comm. Option A	184" (15.3 ft.)	0.34	5.78
Comm. Option B	129" (10.8 ft.)	0.24	4.08
Comm. Option C	109" (9.1 ft.)	0.20	3.40
MUSAT Config. 1	149" (12.4 ft.) 86" *	0.28	4.76 3. *
MUSAT Config. 2	149" (12.4 ft.) 96"	0.28	4.76
MUSAT Config. 3	232" (19.3 ft.)	0.43	7.31
MUSAT Config 4	232" (19.3 ft.)	0.43	7.31

Remarks:

(a) Assume all spacecraft installed at maximum cant angle
(b) Assume spacecraft weights are similar and C_f is length limited
(c) Comm. Option B & C, TT&C omni stowed for launch
(d) PAM length is 86"
* Based on assumed 17M Dollar dedicated commercial launch cost

* with vertical cradle

F-4 SHARED-PRICE FORMULA FOR A SHUTTLE FLIGHT

Shared price entitles user to pro rata share of standard services.

$$\text{PRICE} = C_f \times \text{DEDICATED PRICE}$$

$$C_f = f(\text{LOAD FACTOR})$$

$$\text{LOAD FACTOR} = \left\{ \begin{array}{c} \frac{\text{PAYLOAD WEIGHT}}{\text{SHUTTLE CAPABILITY}} \\ or \\ \frac{\text{PAYLOAD LENGTH}}{60} \end{array} \right\} \text{WHICHEVER THE GREATER.}$$

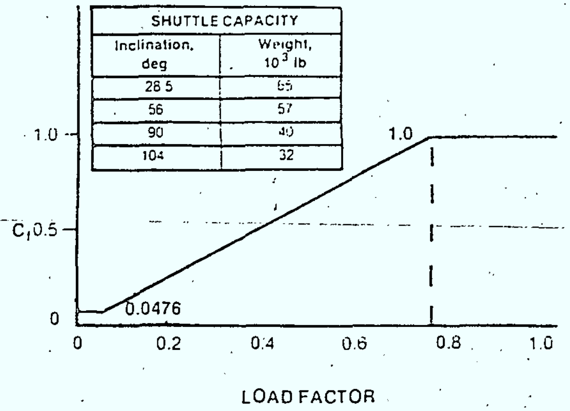


FIGURE 4-4

5.0 COMMUNICATIONS PAYLOAD INSTALLATION INTO THE GPB

Mounting of the two segments (transponder equipment and antennas) of the payload have been examined for each of the four dedicated MUSAT payloads. This section documents this investigation.

5.1 MUSAT Transponder Equipment Layout

5/GC.78

The Communications Research Centre, DOC, provided at the outset of the MUSAT study a table of transponder equipment box dimensions and footprint area and a layout drawing, CRC Drawing #U-10202E, entitled MUSAT UHF/SHF North Panel Equipment Layout, which is shown as Figure 5-1. This drawing packages the equipment required for configurations 1, 3 and 4, except for the SHF power regulators which were later added, on a single GPB radiation panel (north). Waveguide and coax routing has been taken into account. The only difference in the transponder equipment required for configuration #2 is that the UHF power amplifier is double the footprint area and double the heat dissipation at 320 watts rejected. Configuration #4 is unique in the requirement for a diplexer which would be mounted on the forward platform of the GPB next to the central support mast. It is important that the MUSAT payload can be physically accommodated on one of the large, high heat rejection, GPB equipment panels with payload mounted outside the north-south support ribs only.

This single panel mounting is applicable to the MUSAT mission where a piggyback payload is added on the south panel; this modularity would be beneficial for ease of integration and testing. A further discussion of this arrangement is presented in Section 8.

It was agreed that for the dedicated MUSAT payload (the subject of this section of the report) it would be allowable electrically and preferable mechanically to split the payload so that the high dissipation UHF equipment is mounted on the north panel (summer solstice solar radiation input lower

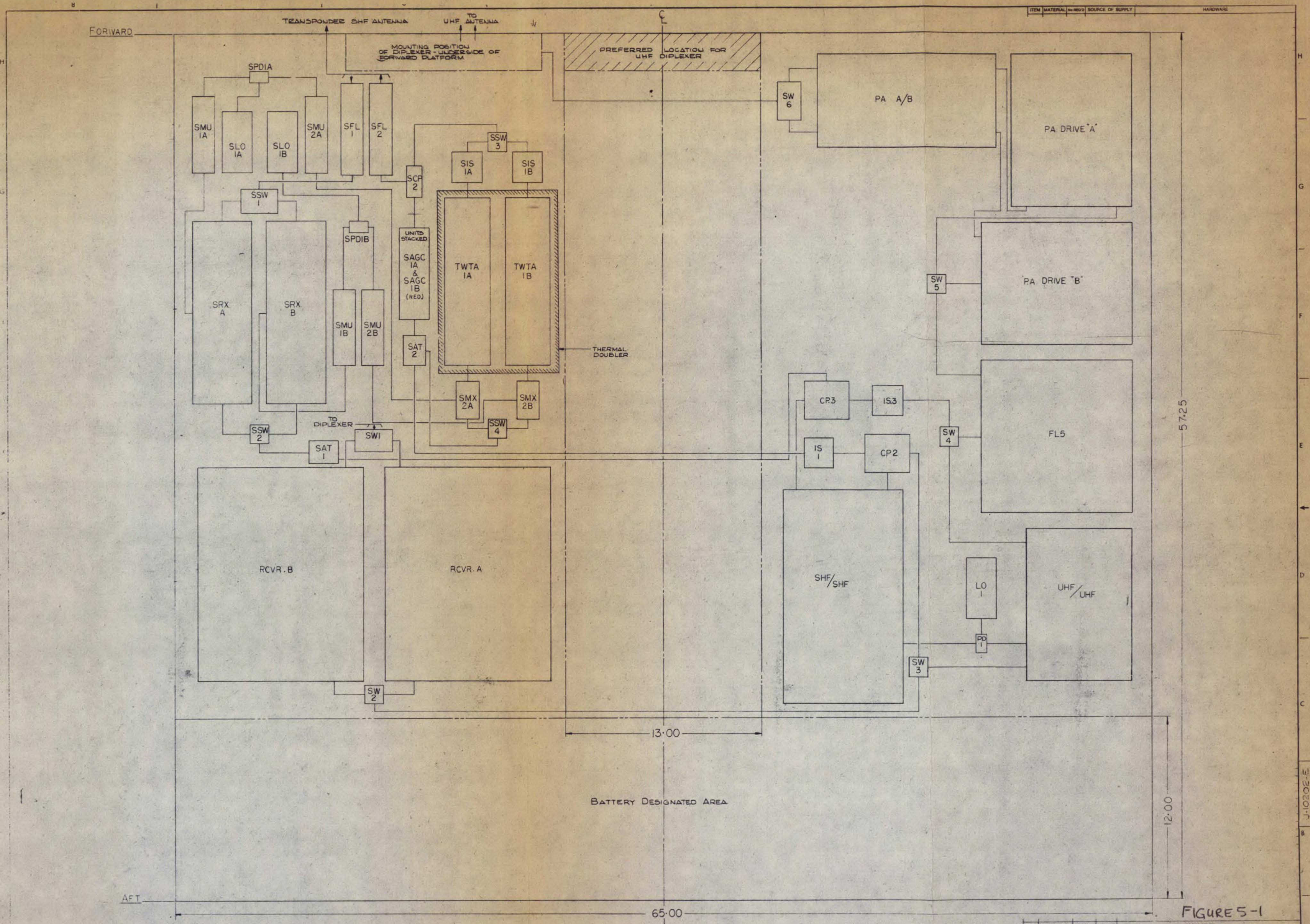


FIGURE 5-1

ITEM	DRAWING No.	MATERIAL	No REQ'D	DESCRIPTION

DEPARTMENT OF COMMUNICATIONS — MINISTÈRE DES COMMUNICATIONS
COMMUNICATIONS RESEARCH CENTRE
CENTRE DE RECHERCHES SUR LES COMMUNICATIONS
OTTAWA — CANADA

TOLERANCES UNLESS OTHERWISE NOTED
DECIMALS XXX ± .005
XX ± .010
X ± .015
ANGLES ± 1/2°
FRACTIONS
UNDER 6" ± 1/64
6" — 24" ± 1/32
OVER 24" ± 1/16
BREAK ALL INTERNAL & EXTERNAL CORNERS .010 — .020

No.	ZONE	DATE	REVISION	APP'D

MATERIAL
FINISH ✓
SCALE 1/2 -
No. REQ'D
DRAWN W. EDWARDS
DATE 30 Nov. 1976
CHECKED
DATE
W.O. No. 1568
PROJ. No. 65139
TITLE [illegible]SAT U.H.F-S.H.F NORTH PANEL EQUIPMENT LAYOUT.
APPROVED
DATE
ASS'Y No.
DWG. No. U-10202

than winter solstice) and the SHF equipment is mounted on the south panel. This achieves an acceptable mass balance and allows a larger panel area to be dedicated to heat rejection from the high dissipation UHF power amplifier.

5/GC.79

Figures 5-2 and 5-3 show the dedicated MUSAT north and south panel layouts. Note that Figure 5-2 shows, for configurations 1, 3 and 4, a physical and electrical subdivision of the UHF power amplifier into 16 discrete dissipating components, thereby allowing a cost efficient passive thermal design utilizing doublers without heat pipes. This concept, generated during the original study of configuration #1, was subsequently determined by CRC to be electrically unacceptable. Subsequent dedicated MUSAT panel mounted heat pipe layouts for configurations 1, 3 and 4, utilizing the same area as shown in this figure, have evolved and are presented in Section 6.5. Configuration #2, with double the heat dissipation, either requires a larger panel area for the heat pipe radiator than the batteries will allow (i.e. necessitating a re-distribution of housekeeping equipment) or requires an external heat pipe radiator which overhangs the edge of the north equipment panel. If dedicated configuration #2 were chosen to fly, a trade-off would need to be performed in this area.

5.2 MUSAT Payload Antenna Mounting and Deployment Mechanisms

This section of the report discusses the SHF and UHF antenna mounting details, basic configurations and deployment mechanisms associated with the four configurations identified by DOC whose requirements are given in Section 2 of this report.

In general, the treatment given must be considered preliminary at this time, since further work is required on the selected arrangement, specifically in the areas of:

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MUSAT DEDICATED SOUTH PANEL LAYOUT (SHF EQUIPMENT)

PAYLOAD CONFIGURATIONS # 1, 3 & 4

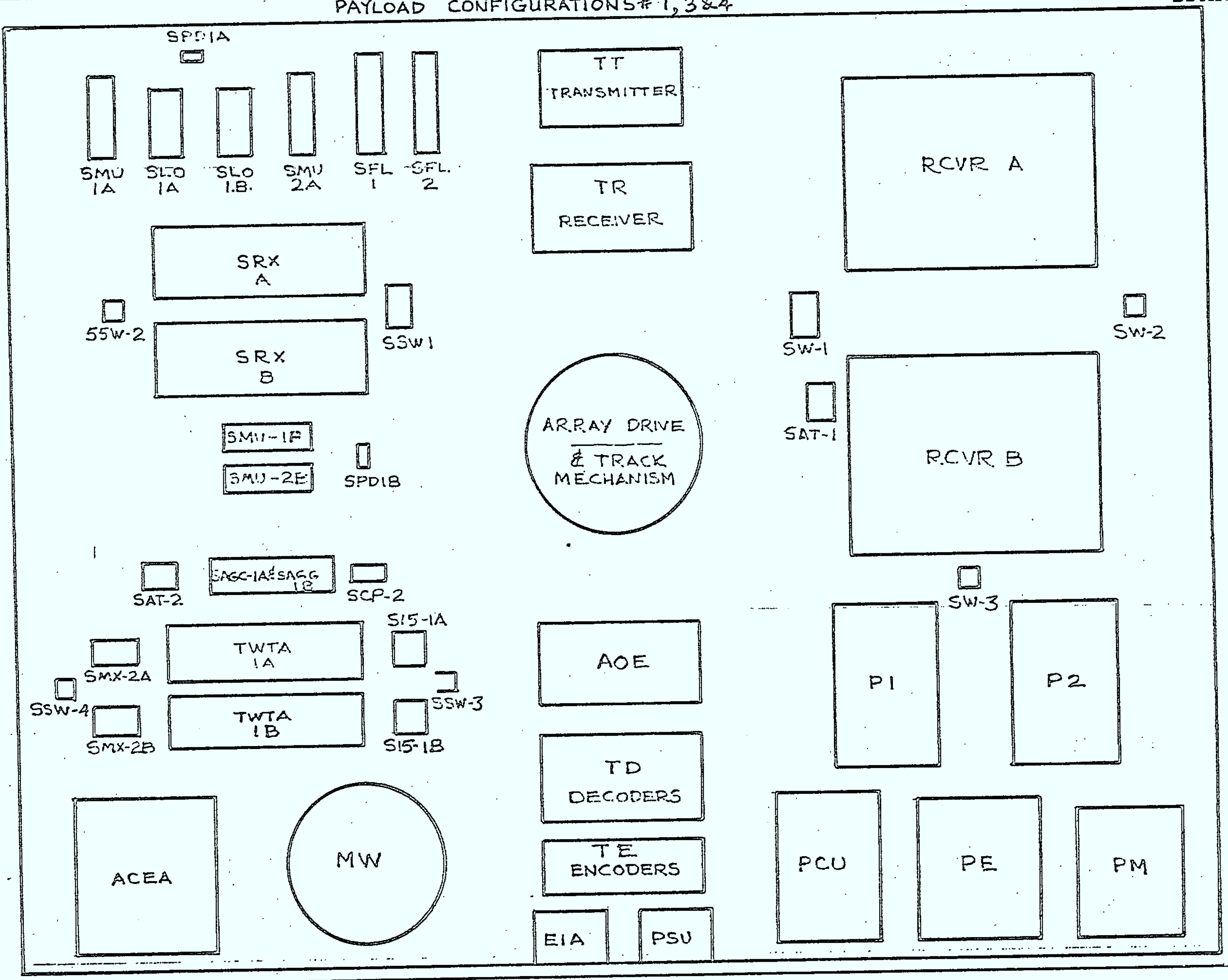
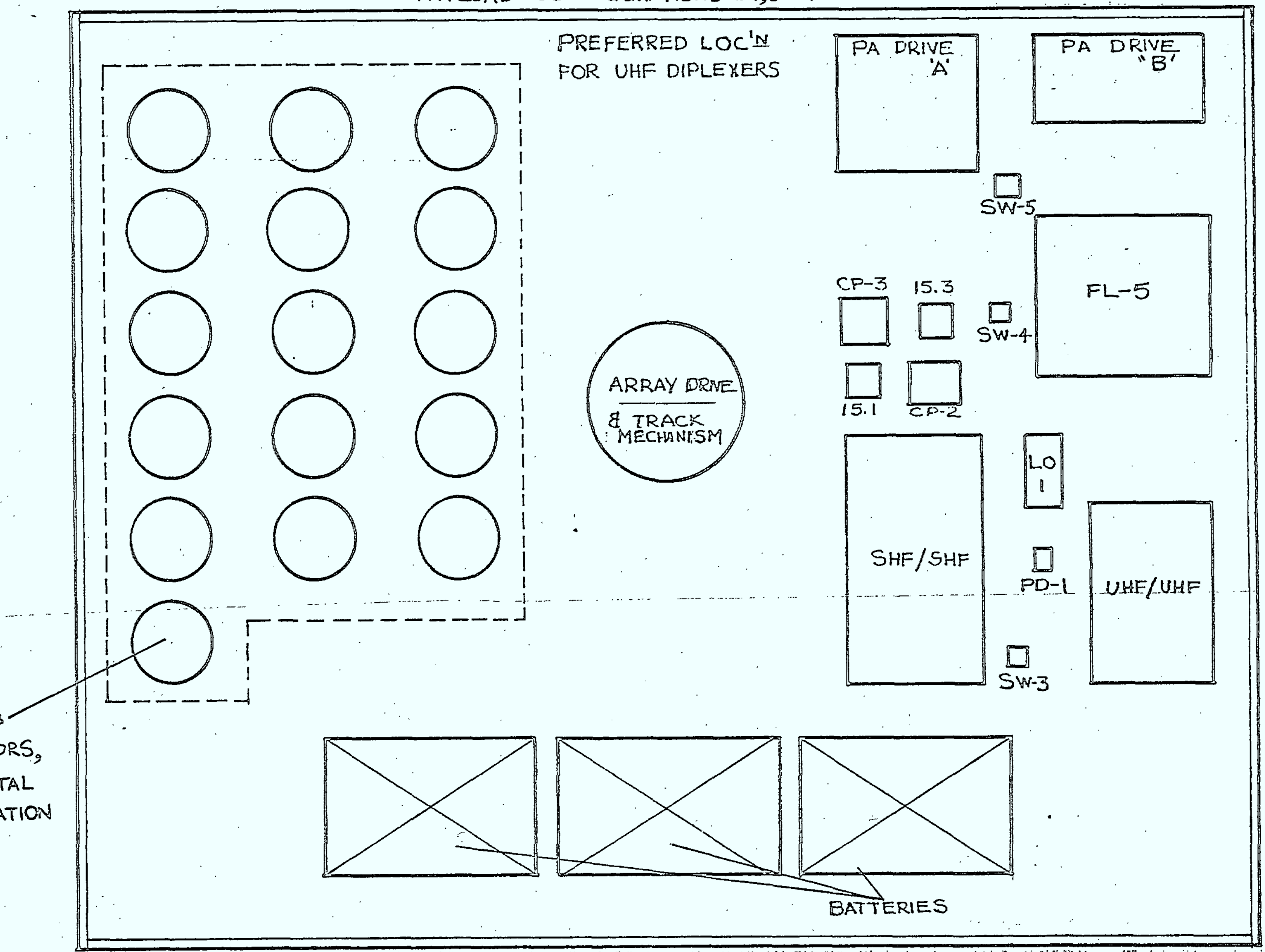


FIGURE 5-2

MUSAT DEDICATED NORTH PANEL LAYOUT (UHF EQUIP)
ACTIVE THERMAL CONTROL DESIGN

PAYLOAD CONFIGURATIONS #1,3 &4



UHF PA AB
16 TRANSISTORS,
160 WATT TOTAL
POWER DISSIPATION

AFT
(APOGEE MOTOR NOZZLE)

FIGURE 5-3

- Thermal distortion
- Pointing accuracy
- Natural frequency in the deployed condition
- Reliability trade-offs (re. optimum arrangement)
- Materials and mass properties

In this regard, configuration #3 which is the two deployed receive helix arrangement with the deployed TRW Fleet Satcon deployable transmit antenna has been examined in greater detail than the other deployed arrangements since it is considered to be more complex, and the additional analysis mentioned is presented in Appendices A & B. Details of antenna mounting for all configurations follow.

5
/
G
C
.
80

5.2.1 Configuration #1

(a) SHF Antenna

The SHF antenna is an 84 in. diameter, parabolic dish with 30 in. focal length and an F/D=0.357. The design of this antenna and its support would be the responsibility of the payload contractor. With support and interface analysis provided by the bus contractor, the target weight utilized during the study for this antenna is 15 lbs. - although, in conformity with the 0.5 lb/ft^2 specific weight for honeycomb using Kevlar, carbon fiber, and epoxy structures of comparable sizes - a figure of 20 lbs. is considered more realistic.

A suggested support for the reflector is illustrated in Figure 5-4. It is composed of 3 legs, each a 2 in. diameter, 0.020 in. wall-thickness, and 8 in. high fibreglass tube. These tubes are equally spaced 46.2" apart.

To accommodate thermal expansion, one leg is "fixed", while the other two are of the "floating" type. The floating arrangement can accommodate a 0.02 in. movement which is equivalent to 120°C temperature variation.

Each of the floating legs incorporates two "knife-edge" carbon-fibre flats mounted such that their

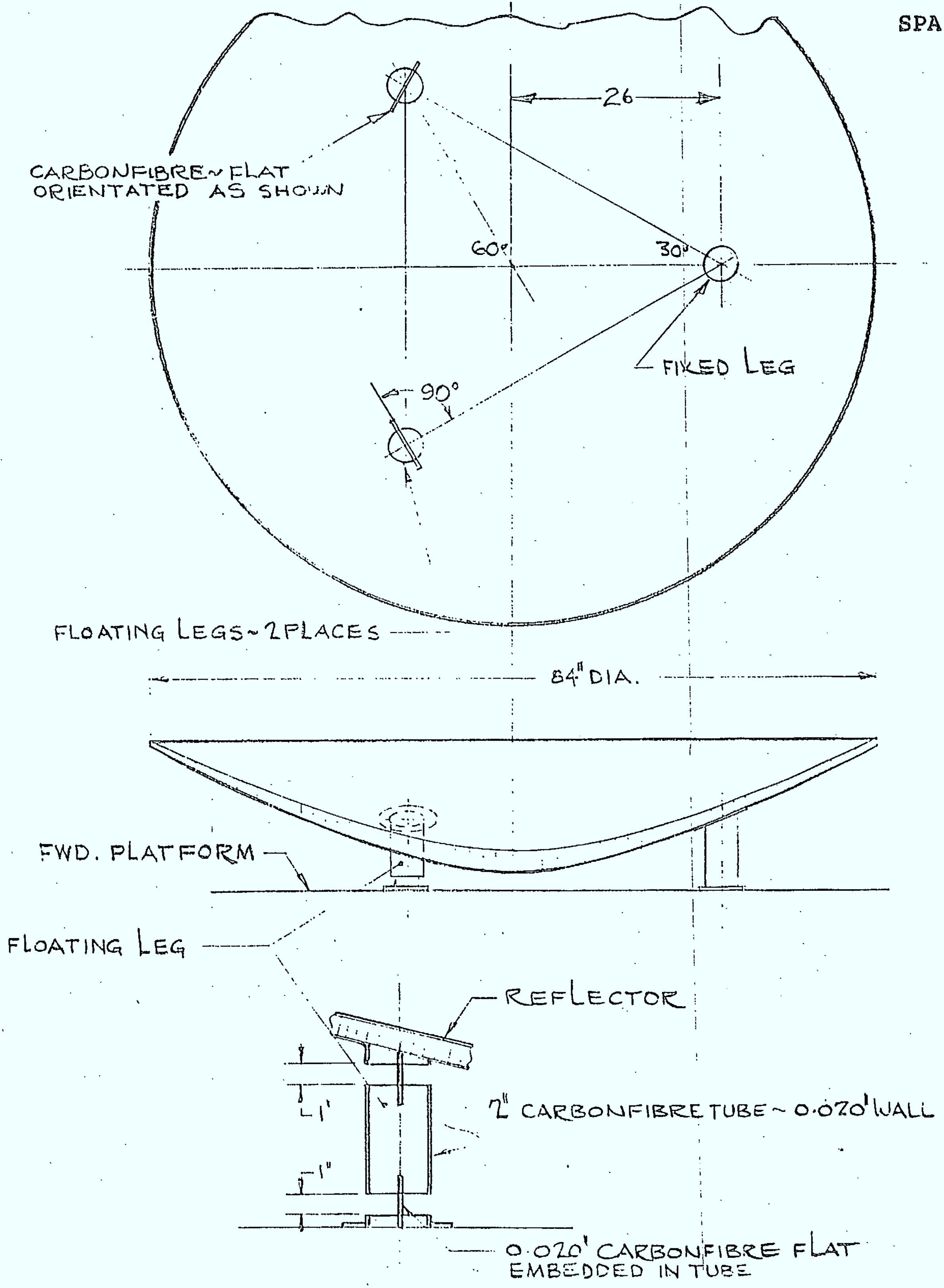


FIG. 5-4

SHF REFLECTOR SUPPORT - CONFIG. Nos 1 & 2 plane is perpendicular to the line connecting the floating legs to the fixed legs. By this means, bending of the carbon fibre legs can occur without distorting either the remaining supporting leg or the antenna itself.

The three-point support for the SHF dish has the advantage of providing a structure free of any assembly stresses. Also, by the very nature of this type of support, alignment of approximately 2 deg. can be accomplished without introducing any appreciable stress on the system, and is achieved by shimming of the support legs against the bus forward platform.

It is assumed that the SHF horns will be tripod supported in this configuration to avoid cutouts in the centre of the SHF dish.

(b) UHF Antennas

For this study, the UHF antennas comprise 8 helical Spar-Astro antennas; 4 on the West side transmit (Tx) and 4 on the East receive (Rx) side of the bus, as shown in Figure 2-1.

The helices are mounted on square support frames, (see Figure 5-5).

Between the supporting squares and the helices there are 8 circular ground plane plates - one for each helix - part of the UHF radiating system. These ground planes are placed concentrically with the respective helices and are of 32 in. diameter on the Tx side and 24 in. on the Rx side.

When the UHF system is in the stowed position, the support squares are tied down against the sides of East and West faces of the bus (see Figure 5-6) by a retention system which is not yet designed but

GPB SHOWING MUSAT CONFIGURATION #1 ANTENNAS
STOWED & RCS THRUSTER CLEARANCE (WESTFACE)

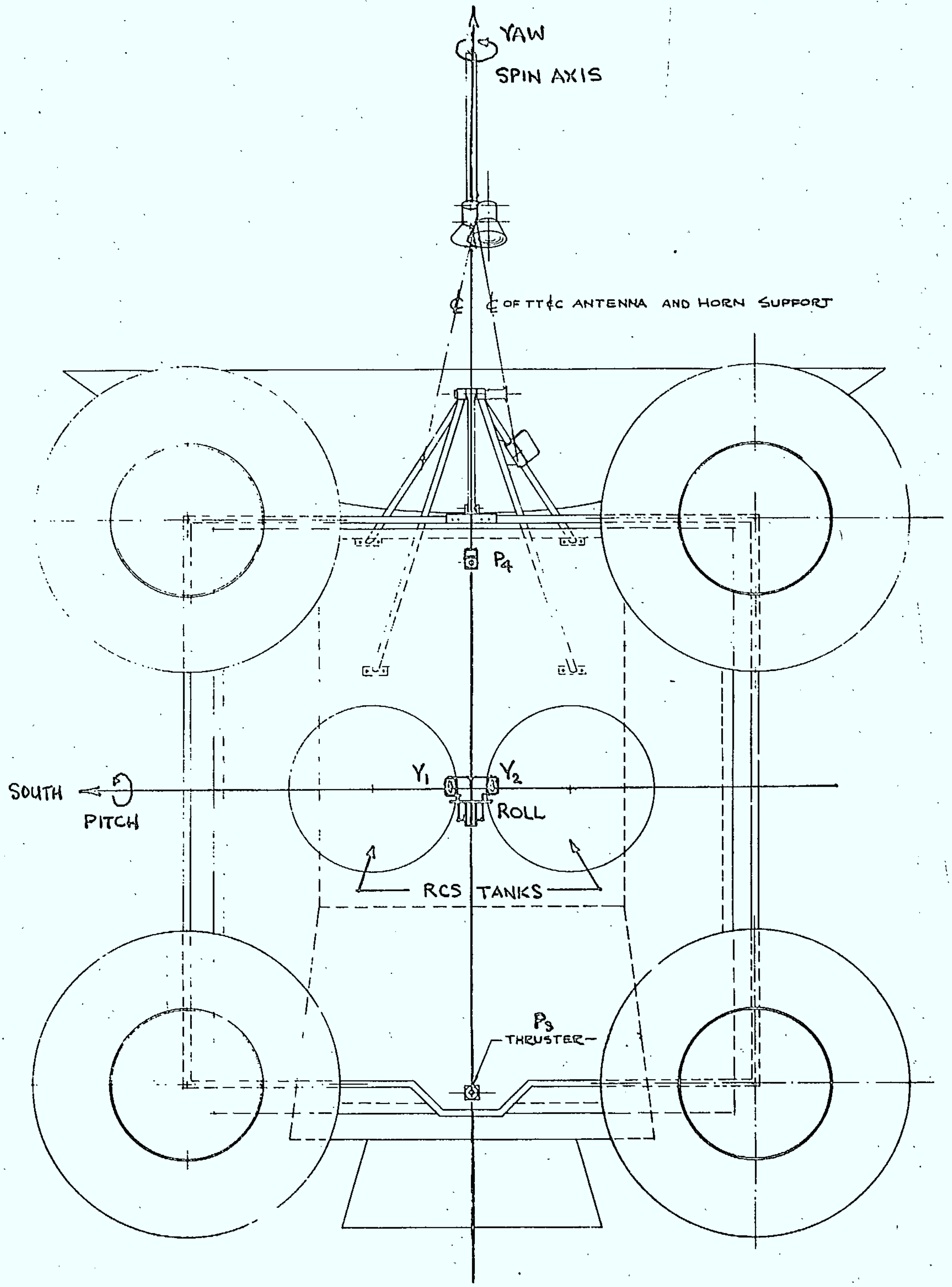


FIGURE 5-5

MUSAT, CONFIGURATION #1,
ANTENNA STRUCTURAL MOUNTING

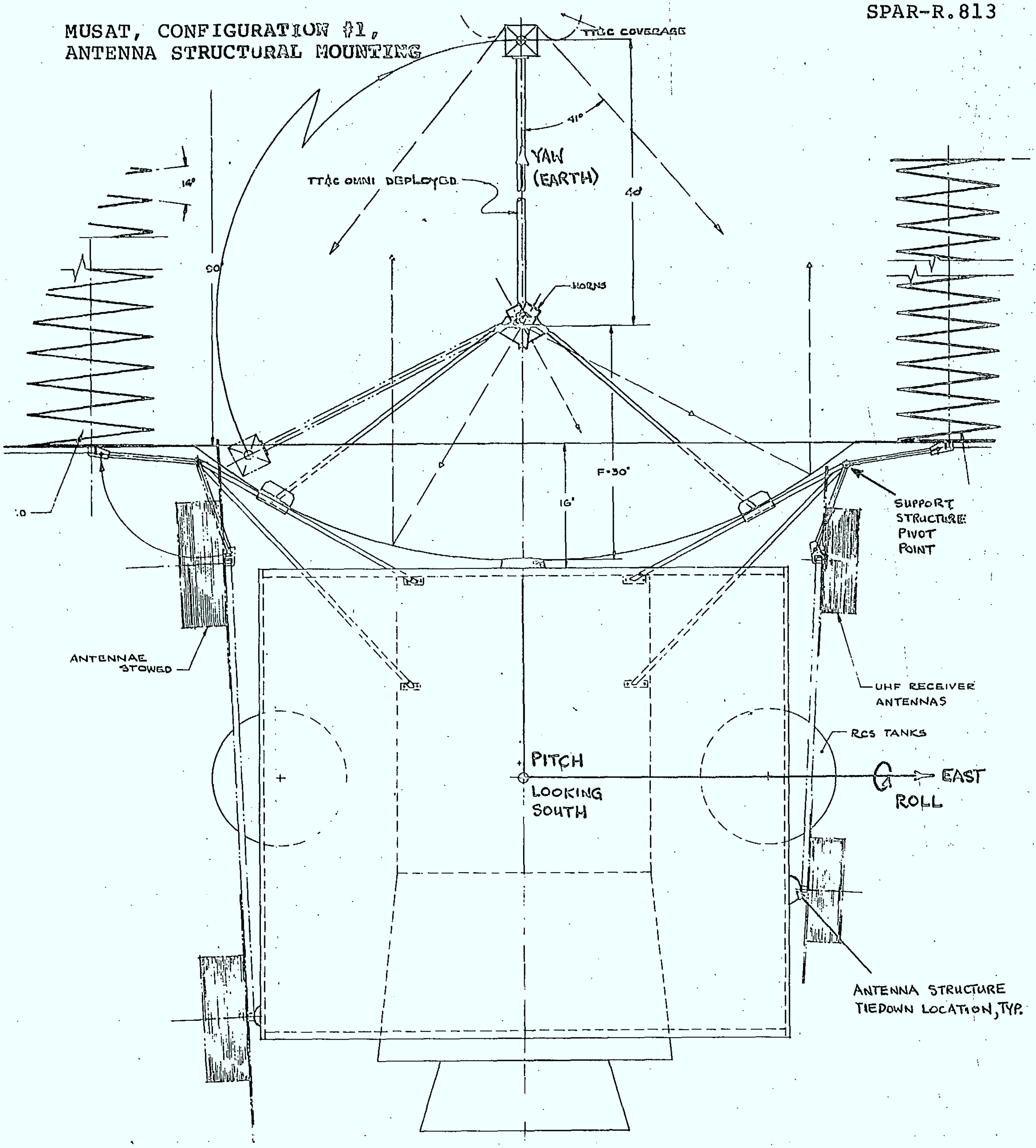


FIGURE 5-6

which must be able to meet a 35 Hz launch vehicle restraint.

The geometry, for the single stage deployment shown, results in an aft overhang of the Tx ground planes of 10 in. below the S/C separation plane. This is acceptable within the launch vehicle envelope constraints but would require further examination of effects of apogee motor plume, and stowed frequency.

5/GC.82

The deployment of the UHF system occurs in 2 stages. First, the support-frames are released and they deploy from the stowed position (parallel to the side of the bus).

During deployment, the articulating portion of the UHF antenna support structure pivots under torsional spring force about the forward-most point on the structural A-frame. This frame is rigidly attached to thrust tube rings. This mechanism rotates the assembly into the correct attitude when released from the stowed arrangement (see Figure 5-6).

The second stage of deployment involves the UHF helices, themselves. During deployment of the supports (first stage), the helical UHF antennas are still in their stowed state and not until the supports stop at their final horizontal position does the deployment of UHF antennas commence. Individual pyrotechnics, operating cable cutters, release each stowed helix allowing it to extend to its working length.

Owing to the stringent pointing and positioning accuracy requirements (see paragraph 2.1), the configuration and dimensional accuracy of the pivot assembly is critical.

5.2.2 Configuration #2

The second MUSAT arrangement is similar to that of configuration #1 in that the 7-8 GHz SHF dish will have the same antenna dimensions and mounting arrangements identified in Section 5.2.1(a). Consequently, only the UHF deployed helices details will be discussed here.

As previously discussed in Section 3.2, an alternate arrangement for this configuration is one where the ground plane of the antenna is 27" diameter enclosed in a cannister 9" high and placed as close as possible to the perimeter off the SHF dish. This arrangement does not need a structural deployment mechanism and consequently will not be discussed.

5/GC.83

Figure 5-7 shows the stowed and deployed UHF arrangement for configuration #2. In the stowed state, each helix - occupying a 4 in. high, by 17 in. diameter cylinder - is folded into the SHF dish thereby forming a stack on the East and West sides of the S/C. These assemblies are secured by fiberglass spacer tubes of 2 in. diameter and 0.020 in. wall, placed under each pair of stowed arrays. These spacers penetrate the SHF dish but are transparent to 7-8 GHz radiation. A thin cable goes through the inside of the tubes to preload the stacked array-pair against the GPB forward platform - an arrangement which provides rigid and stable configuration during launch, and spin phases of the mission.

When deployment commences, the retaining cable is cut by a pyrotechnic cutter and each stack opens up via spring loaded hinges. Note that the four helical antennas themselves, are still in their stowed state; only the support structures deploy to carry the helices outside the aperture circle of the SHF dish.

When this deployment is completed, the Fairchild helices pyro devices are activated one by one and the helices, by their own stowed energy, extend to their 78 in. working lengths.

In their fully deployed state, the coplanarity of ground planes (with respect to the aperture of the SHF dish) is assured by appropriate mechanical stops at the hinges; the bases of helices remain slightly pressed against these stops by the pivot springs. The short length of the support structure aids in attaining a rigid, aligned design.

5/GC.84

The helices are mounted onto four (one on each) 39 in. diameter, 0.02 in. thick aluminum (or magnesium) circular ground planes. These ground planes are supported by a backup structure consisting of a 16 in. diameter circular central support with a number of radial and targential ribs, as detailed stress and dynamic analysis may require. The weight of each of the circular ground planes is about 2.4 lbs. each (aluminum), or about 1.6 lbs. if they are magnesium. The baseline is aluminum. Each back structure weighs about 0.7 lb.

The 16 in. diameter size of the backup structure assures that the support of the ground plane occurs exactly under the helix attachment circle - thereby avoiding any lateral bending moment on the ground plane due to the inertial or gravitational weight of the helical antenna.

The four helices occupy - in their deployed state - a roughly symmetrical position with respect to the central SHF dish. Looking along the GPB yaw axis into the concave SHF antenna, the centres of the two Tx helices on the West side are 61 in. from the North-South and 34.5 in. from the East-West symmetry plane of the module. Similarly, for the Rx helices on the east side - they are 61 in. from the North-South and 22.5 inc. from the East-West axis (see Figure 5-7).

MUSAT CONFIGURATION #2 - UHF HELICES, STOWAGE & DEPLOYMENT

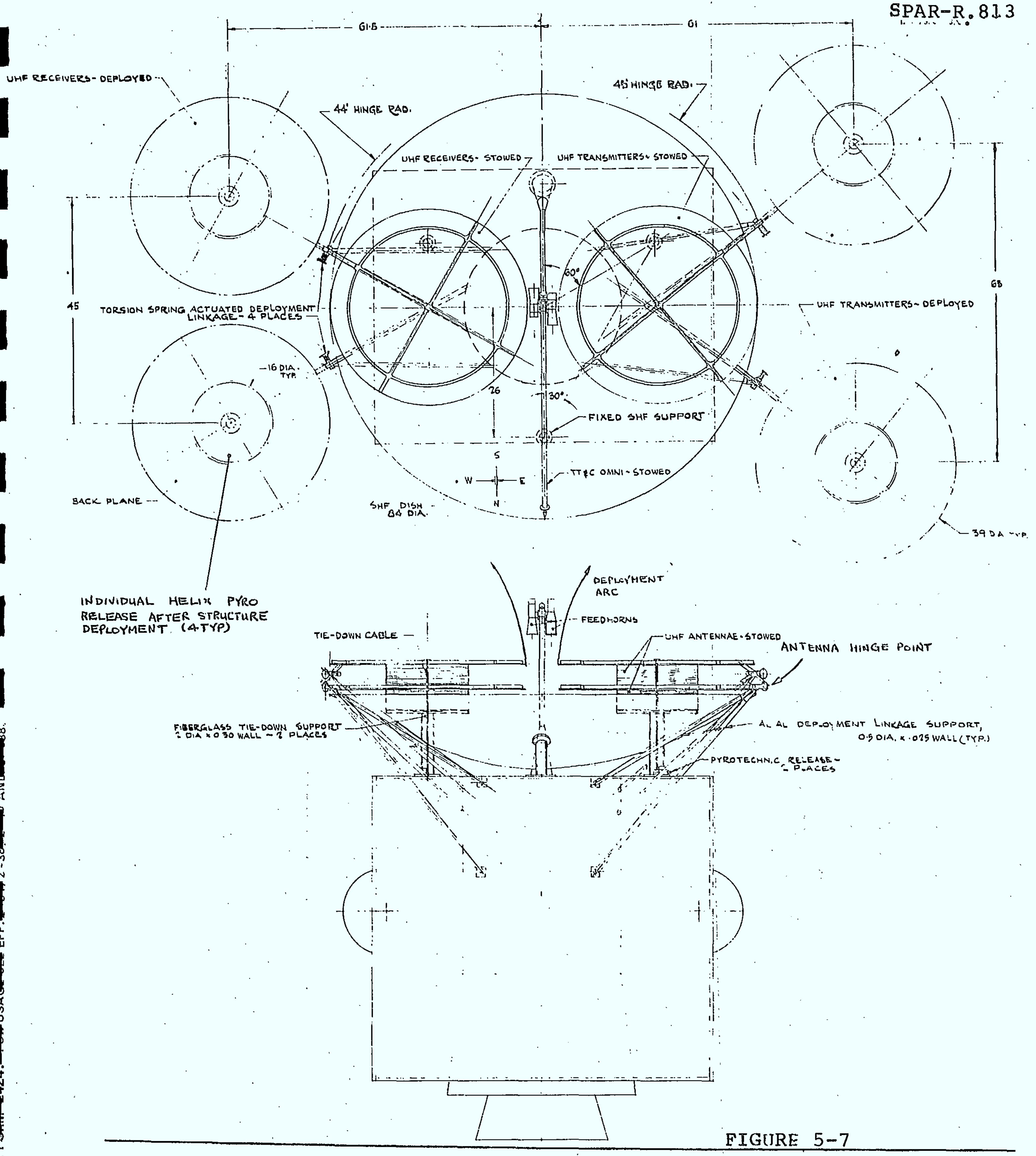


FIGURE 5-7

5.2.3 Configuration #3

(a) SHF and UHF Transmit Antenna

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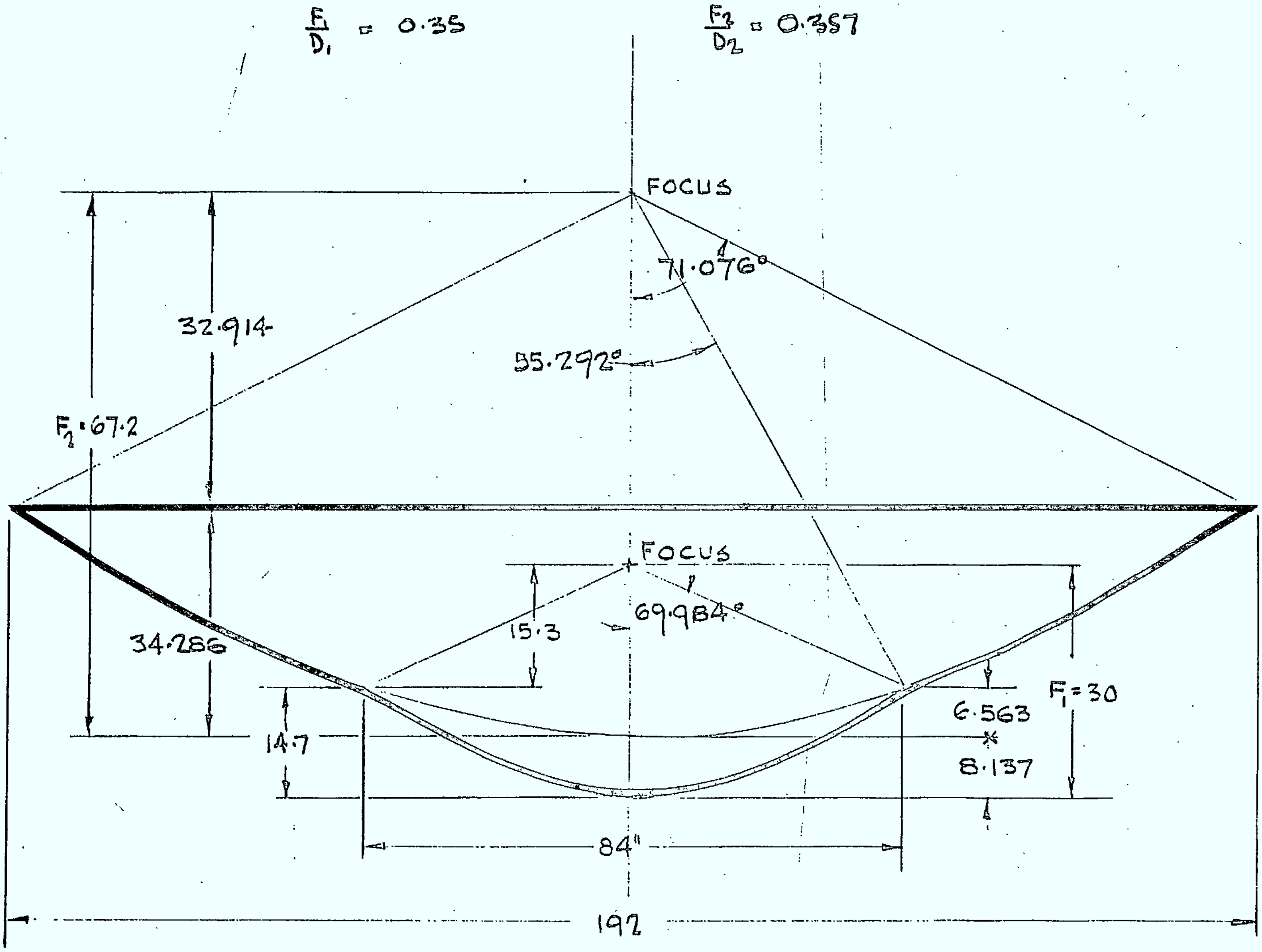
The system consists of a centrally located double paraboloidal reflector (see Figure 5-8) used for both SHF and UHF Transmit (Tx) communications. The SHF portion of the antenna is identical to that identified for configurations 1 & 2 while the UHF (Tx) portion is a 192 in. diameter paraboloid with 67.2 in. focal length; and F/D = 0.35. This arrangement is similar to that designed for and shortly to the flown on Fleet SatCom. Information given in this text is that obtained from discussions with DOC, and would need to be confirmed by TRW during a follow-on study.

The large dish is approximately 50%-75% optically transparent (light-rays perpendicular to the aperture plane). Stowed for launch, it is folded about the SHF (7 ft. dish) perimeter as shown in Figure 5-9).

The mount of the double reflector on the forward platform of the GPB is on a 26 in. diameter bolt circle.

When the UHF (Tx) antenna is folded, it assumes the shape approximating a 12-sided pyramidal frustum of height 46.5 in., base diameter 84 in. and top diameter 11 in. (see Figure 5-9 and Figure 5-10).

The feed for the SHF portion will run through the central support mast shown in Figure 5-10. Spar has been informed that this feed utilizes a double horn assembly situated on the focal plane, 30 in. away from the vertex. The feed of the UHF (Tx) (see Figures 5-9 and 5-10) is comprised of a 48 in. long, 3 in. diameter, helical "backfire" element the centre of which is at the focal plane of the UHF paraboloid - 67.2 in. from the vertex. It



CONFIGURATION No 3 & 4.

FIG. 5-8

DOUBLE-PARABOLOIDAL SHF-UHF
REFLECTOR

FIGURE 5-8

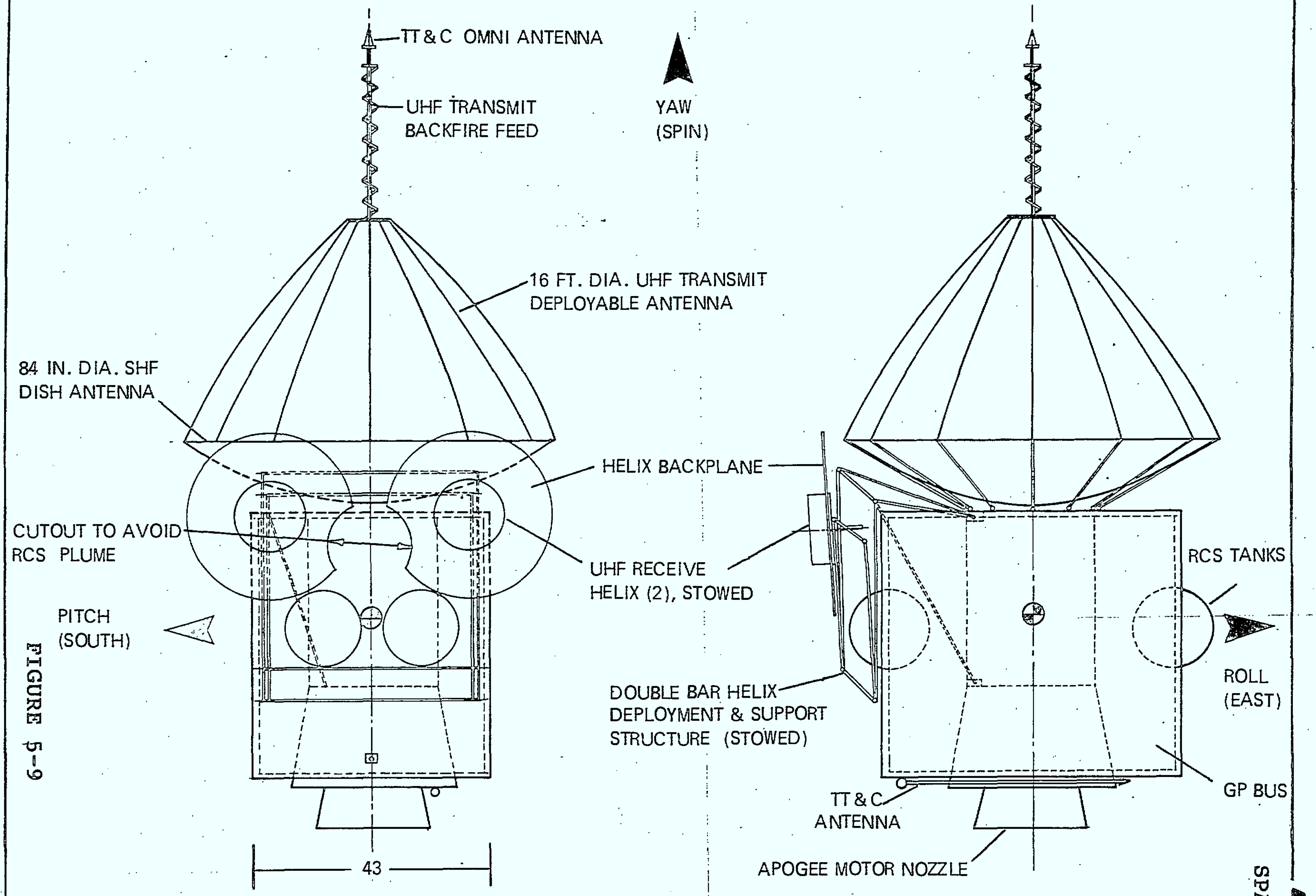
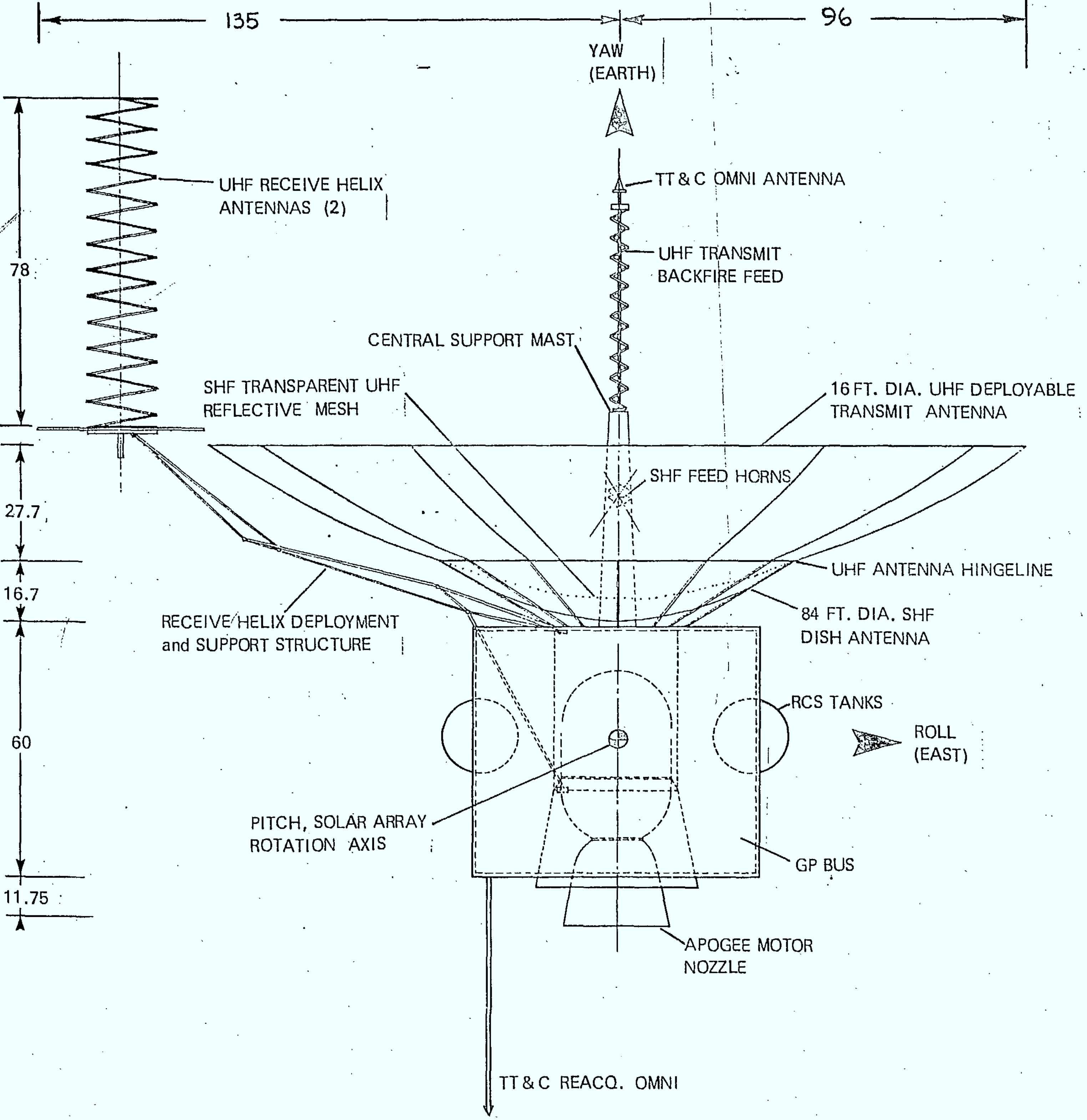


FIGURE 5-9

MUSAT — CONFIGURATION 3 — STOWED



MUSAT – CONFIGURATION 3 – DEPLOYED

FIGURE 5-10

is held by a fiberglass, hollow, 1/8 in. wall-thickness, central support structure with a shape of a conical frustum; its length is 57.6 in. and its base and top diameters are 8 in. and 5.9 in., respectively.

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On the top of the backfire feed an omni-directional TT&C antenna is situated; it is basically a 6 in. long 1/4 in. diameter rod with a conically shaped tip.

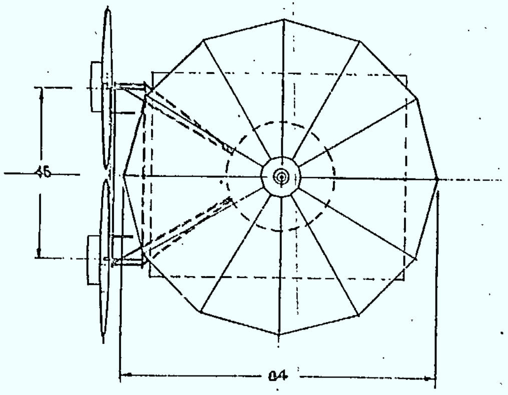
It is Spar's understanding that the uncontrolled deployment of the 16-foot diameter dish is initiated by a single, redundant pyrotechnic device, cutting a cable which has been holding the ribs in their folded state.

(b) UHF Receive (Rx) - Antennas

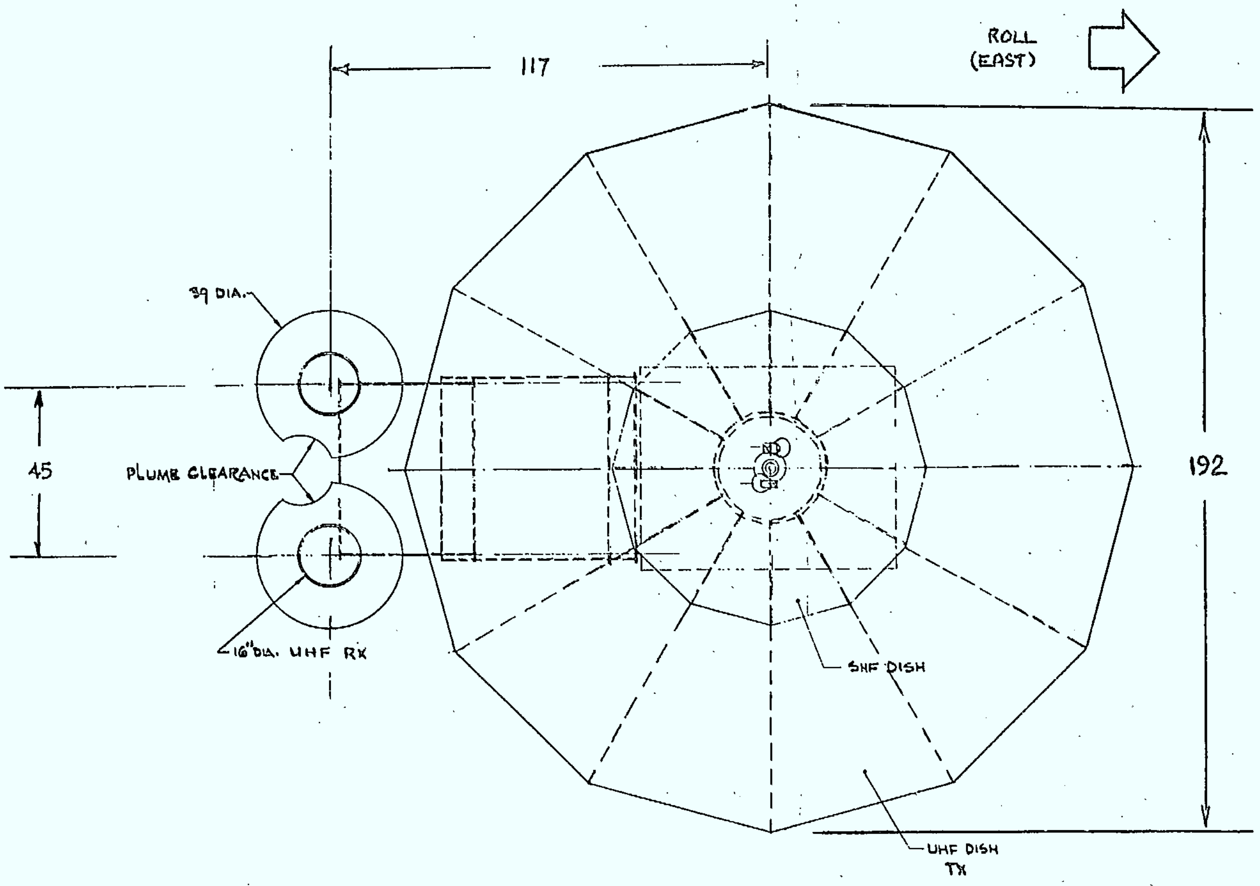
The UHF (Rx) portion comprises two helical antennas which are situated on the West of the S/C (see Figures 5-10 and 5-11). In order to clear the deployed perimeter of the UHF (Tx), 192 inch, paraboloidal dish, the UHF (Rx) helices - as deployed - have to be positioned at the end of a 82.2 inch long arm. This fact, together with the positioning and pointing accuracy requirements (see paragraph 2.1), makes the design of the support of these helices a difficult task, since these supports have to be stable, light, rigid and when deployed must not interfere with the 192 inch paraboloidal dish.

To arrive at a possible solution, Spar examined a straight cantilever type support and a triangular pin-jointed support. The former has the advantage of simplicity and low weight, however could suffer from low stiffness and reduce pointing and positioning accuracy. The latter exhibits - on the other hand - high stiffness and improved positioning and pointing accuracy properties, at the expense of higher weight, increased complexity, and possibly reduced reliability. For further examination of the relative strengths of these structures, see Appendix A.

MUSAT CONFIGURATION #3 - LOOKING DOWN YAW AXIS



STOWED



DEPLOYED

FIGURE 5-11

In order to select a specific design, a major trade-off study should be undertaken to select the preferred deployment mechanism when and if this configuration is chosen for follow-on consideration. For this report, the triangular pin-jointed arrangement has been studied briefly; these results are summarized below and discussed more fully in Appendix B.

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In the design investigation of the triangular pin-jointed structural arrangement, several criteria apply. They are:

- in the deployed state the mechanism must assume a triangular - stable configuration.
- if the helices are deployed after the main dish, the deployment kinematics must provide a path of the payload (UHF compact helices) which clears the contour of the deployed 192 in diameter reflector,
- the deployment mechanism must be compactly stowed in to the West side of the GP Bus,
- the members of the deployment mechanism must clear the GP Bus, notably the RCS tanks, and they must be adaptable and mountable to the appropriate interface on the thrust tube.

A two stage, unequal 4 bar linkage mechanism has been examined as an example of a triangular pin-jointed UHF support structure. Details of its geometry and operation are presented in Appendix B. Figure 5-12 shows schematically the mechanism both stowed on the west face of the GPB and deployed.

In this stowed mode, the 39 inch ground planes, for the geometry presented, would intrude into the plume impingement field of the RCS P4 thruster. Consequently, crescent shaped cutouts have been provided in these ground planes to avoid this problem, as shown in the figure. An alternate approach would be to utilize the 27" diameter ground planes with 9" circumferential rim which might avoid the plume without need for cutouts.

MUSAT CONFIGURATION #3 - UHF HELICES, STOWAGE, CLEARANCE & DEPLOYMENT

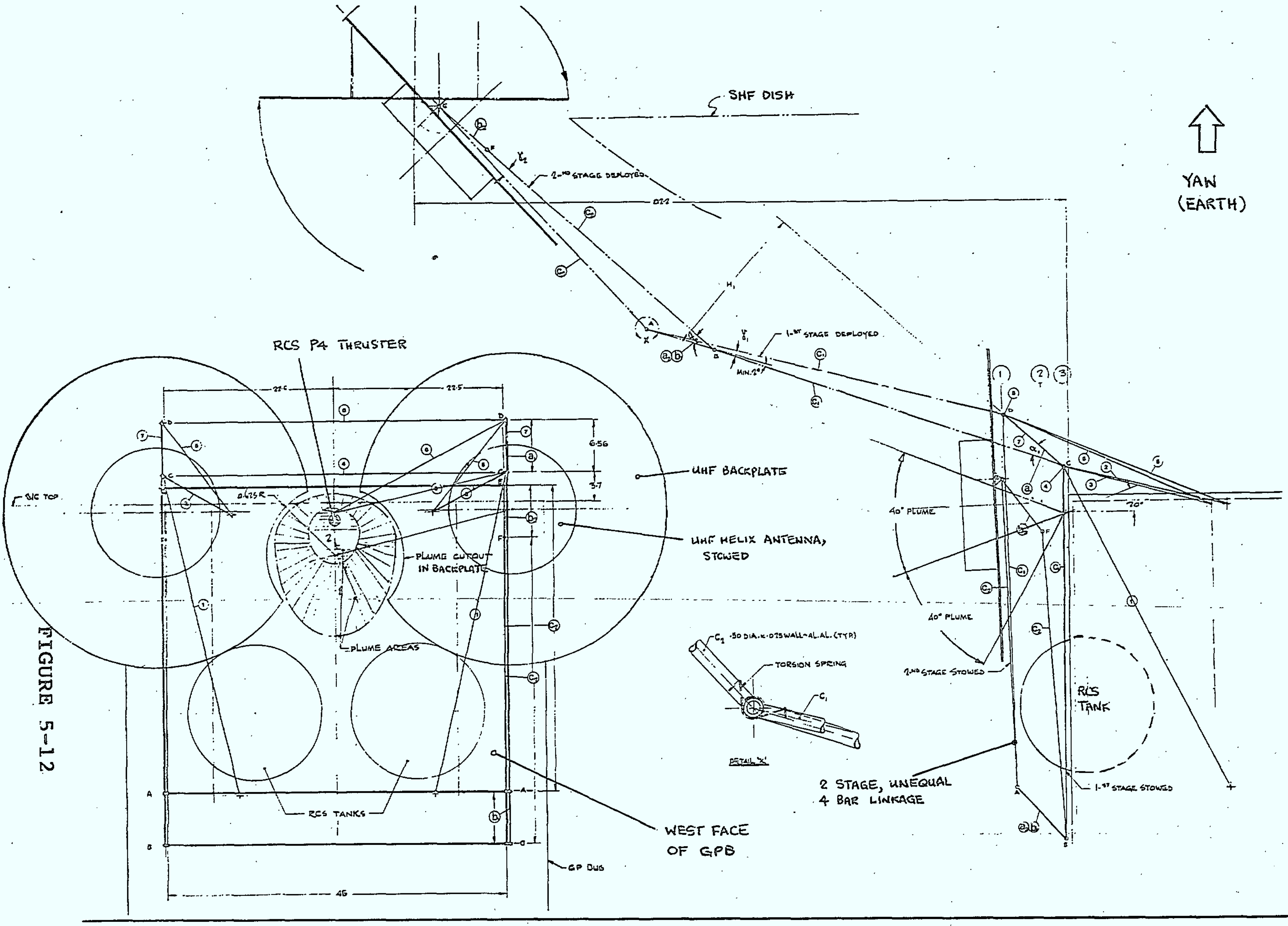

FIGURE 5-12

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The kinematics of the device together with the path of deployment of the payload is depicted in Figure 5-13. The second stage opens first, then the first stage unfolds. The path described by the payload is concave to clear the deployed 192 in. diameter paraboloidal antenna.

A single pair of torsional springs energizes the mechanism. They are located on the common shaft connecting the two stages. These springs act in such a way that they first open the second stage by exerting a slight moment on the member C_2 of the second stage; then, once this stage has opened up, they generate a slight force on the junction of 'b' and 'c'. This force then compels the first stage to open. The springs in questions are relatively weak; it takes several seconds for them to deploy the assembly.

The more important geometric details of the stowed and deployed stages are collected in Table 5-1 below.

	Stage		Remarks
	#1	#2	
a	10 in.	9 in.	base
b	9 in.	8.1 in.	top
c	46 in.	38.25 in.	arm's length
$\frac{b}{a}$	0.9	0.9	
$\frac{c}{a}$	4.6	4.25	
γ	5 deg.	5.3 deg.	apical angle as deployed
H	19.8 in.	16.7 in.	normal distance from apex to base as deployed

Table 5-1

Geometric Details of the 2-Stage UHF (Rx) Deployment Mechanism

MUSAT CONFIGURATION #3 - UHF HELICES, DEPLOYMENT KINEMATICS

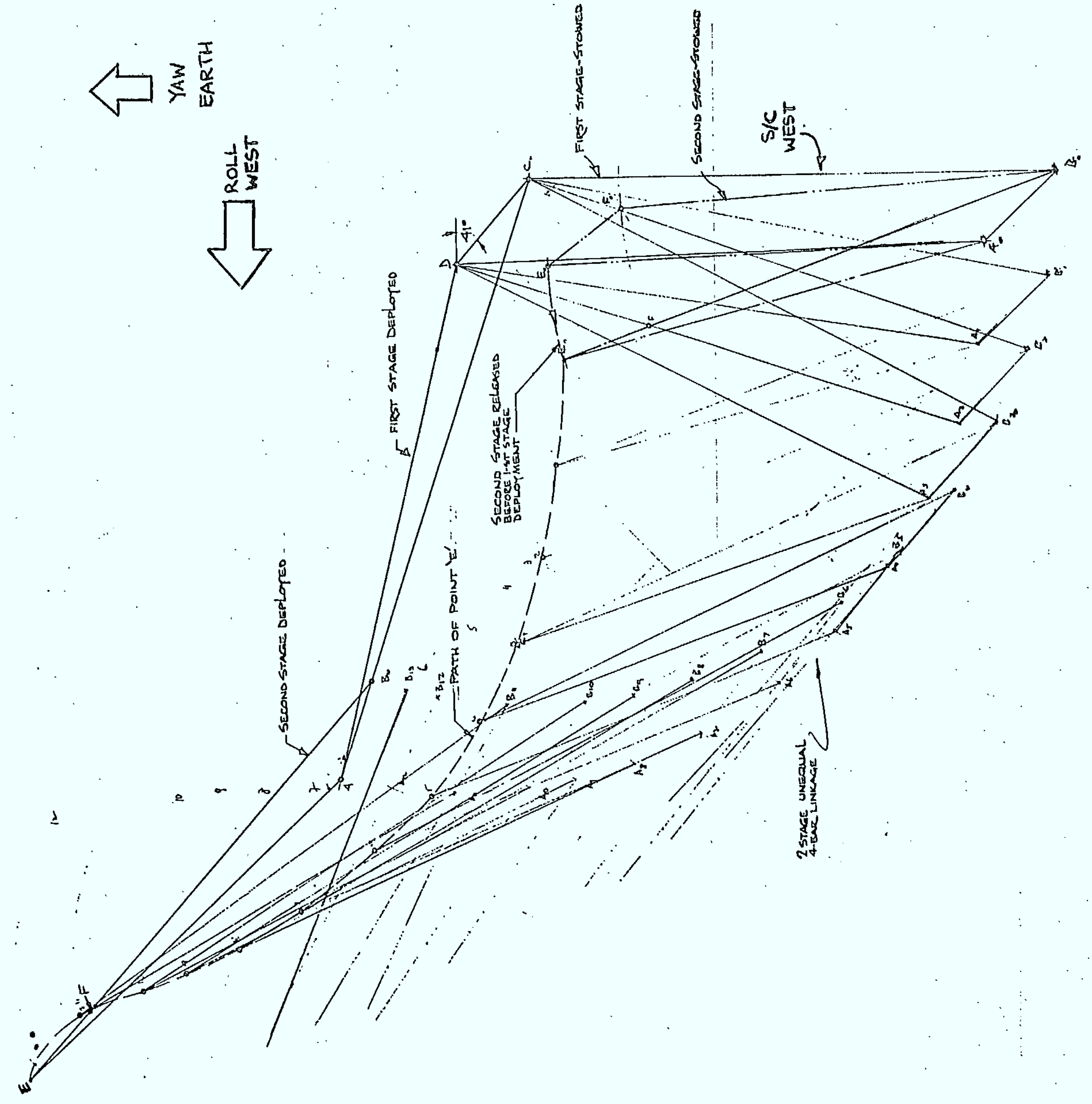

FIGURE 5-13

The UHF (Rx) helices are mounted onto the top of the second stage. When the deployment of both stages has been completed, the ground plane plates of these helices are rotated about 300 deg. by a smaller torsional spring. In the deployed state, both types of torsional springs (for the kinematism and for the ground plane plates) remain slightly tensed to insure stable positioning of UHF (Rx) helices.

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Mounting of this deployment mechanism has not been designed. It is envisaged however, that the four horizontal shafts, about which the members of mechanism rotate, would be held by tripod like outriggers anchored directly at the 'apogee-motor-ring' and the 'forward platform to thrust-tube-ring'. In this way, statically determined mounting is achieved - thereby freeing the assembly of excessive strains and stresses caused by minute assembly and/or fabrication inaccuracies.

Figures 5-9, 5-10 and 5-11 show the major envelope dimensions in the deployed and stowed states.

Dedicated MUSAT Configuration #4

The mechanical construction of Configuration #4 is identical to that of #3 - except that the helical UHF (Rx) antennas and their associated support structures are omitted.

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6.0 EFFECT OF THE DEDICATED MUSAT PAYLOADS ON THE GPB

6.1 General

The General Purpose Bus can accommodate all four of the potential dedicated MUSAT payload configurations with only minor modifications. This ease of interchangeability of payloads is a major feature of the Bus. The

- o relaxed pointing accuracy
- o lower payload mass
- o lower power requirement and
- o lower thermal dissipations

of each of these payloads, as compared with the commercial SHF payload for which the GPB was originally designed, result is significant margins being available with the GPB for the MUSAT application. The GPB will easily meet the Bus pointing accuracies required.

Thermal control does require heat pipes, which have been dictated by the power dissipation density of the UHF power amplifier (P.A.). However, with the dedicated MUSAT complement as the baseline, the UHF and SHF transponder equipment can be mounted onto separate north and south panels and sufficient radiating area then exists on the north panel to support a panel mounted radiator for the UHF P.A. heat pipe, thereby avoiding the need for an external fin heat pipe radiator design. This is described in more detail in Section 6.5.

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6.2 Structural Changes

All four of the MUSAT antenna configurations would be mounted directly to the GPB thrust tube and, in the case of the SHF antenna, to the forward platform near the thrust tube. Additionally, each of these configurations could be assembled as a unit from the forward end of the spacecraft with strut supports attached to the thrust tube generally at the forward and the apogee motor rings. Although some consideration has been given to the location of these struts to ensure clearance from internal spacecraft components, more work is needed in this area once the payload configuration has been chosen. It may be necessary to provide an intermediate strengthening ring.

Tie down provisions for the antennas are not expected to cause significant structural design changes. However, the use of the 16-foot diameter, Fleet SatCom, 34 lbs., deployable antenna with centre of mass extended forward, expecially during Shuttle launch environments, could cause bending moments which would require strengthening of the thrust tube, itself. This possibility has not been thoroughly examined due to the undefined state of Orbiter/PAM S/C launch environment.

Most importantly, compact configuration #2 would require only a single tripod mount of the SHF antenna and should therefore not cause structural changes to the GPB.

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6.3 Solar Array Subsystem Changes

The solar array design chosen as the baseline for the MUSAT GPB examination is the Spectrolab cell, rigid frame-flexible substrate array described in detail in Section 3.4 of SPAR-R.810, Volume I. Vendor response data discussed in Section 5.4 of that document has not been incorporated into, but would not have a major impact on, the MUSAT trade-off.

The major design features of this 3 frame per wing array is:

- EOL, 7 years power output = 1092 watts
- spinning phase average power of 150 watts available
- total subsystem weight including Solar Array Drive is 125 lbs. (ultra-light weight)
- design with live cells has survived Delta qualification level sine vibration

This design is shown in Figure 6-1.

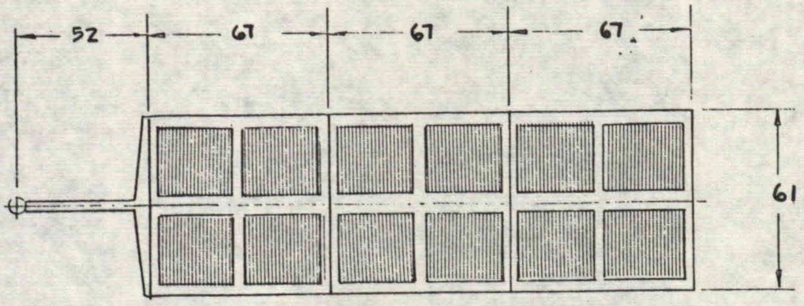
6.3.1 Sunlight Power Requirements

Table 6-1 presents the sunlight maximum power requirements for the MUSAT dedicated payload and GPB housekeeping functions, for all MUSAT configurations. The housekeeping values reflect the requirements of the standard GPB and the only change from the commercial SHF GPB values is the addition of 5 watts to the TT&C power budget during all mission phases for the security box which is required for this miliary application.

6.3.2 Solar Array Shadowing by the Communications Antennas

The communications antennas for MUSAT generally cast significant shadows on the solar arrays

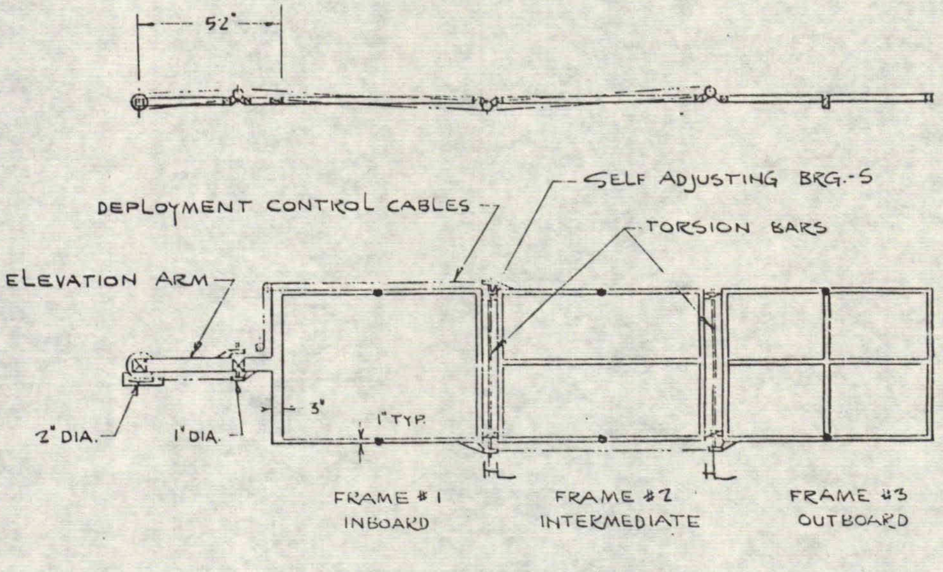
FIGURE 6.1



POWER:

BoL STOWED 243 WATTS
EoL DEPLOYED 548 WATTS
BASE LINE A
WT: 51 LB. PER WING
$f_{MIN.}$: ·26 Hz

DEPLOYABLE SOLAR ARRAY CONFIGURATION



DEPLOYABLE SOLAR ARRAY
MECHANICAL SYSTEM

TABLE 6-1

MUSAT DEDICATED POWER REQUIREMENTS

o PAYLOAD

SUNLIGHT OPERATIONS

UHF COMMUNICATIONS = 269 WATTS
SHF COMMUNICATIONS = 44 WATTS
TOTAL = 313 WATTS

ECLIPSE OPERATIONS

UHF COMMUNICATIONS = 169 WATTS
SHF COMMUNICATIONS = 44 WATTS
TOTAL = 213 WATTS

o HOUSEKEEPING

	TRANSFER	SUNLIGHT	ECLIPSE
TT&C	25W*	25W	25W
POWER CONDITIONING (Hkg)	10	20	10
BATTERY CHARGE	-	83	-
HARNESS	5	5	5
DSA	-	10	10
ACS	4	25	25
RCS	6	10	10
THERMAL	10	65	20
TOTAL	60 WATTS	243 WATTS	105 WATTS

* INCLUDES 5 WATTS FOR SECURITY BOX

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during solstice conditions. Examination of this worst case condition for all configurations, conservatively assuming slant angle opacity of the helices and the 16-foot diameter dish, reveals that;

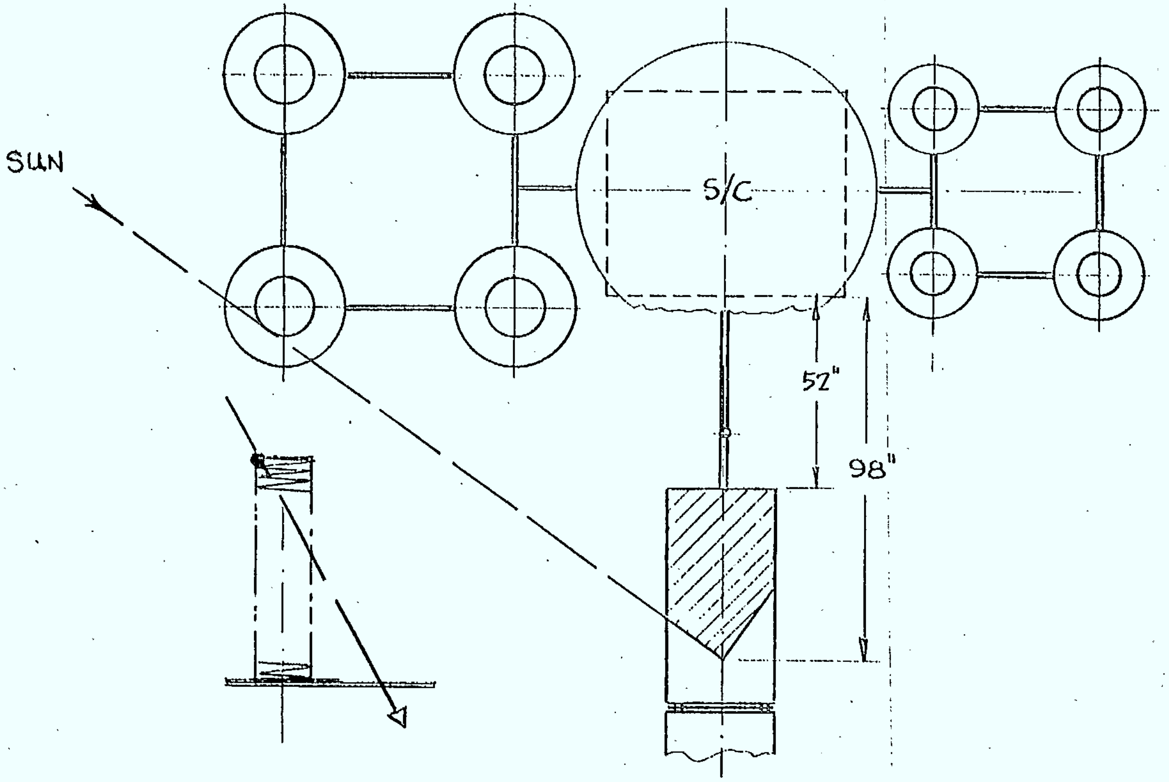
- with configuration #1 the outboard helix shadows 98 inches maximum from the S/C north or south panel (i.e. 46 inches of length of the array inboard frame, see Figure 6-2)
- with configuration #4, the 16-foot diameter dish shadows approximately 100" maximum from the S/C north or south panel (i.e. 48 inches of length of the array inboard frame, see Figure 6-3)
- configuration #3, with additional helices as well as the 16-foot dish, will cause more significant shadowing of the array.
- with configuration #2 there is no significant shadowing of the arrays since the helices are shorter than configuration #1 and further inboard (east- west)

A computer program has been written at Spar which calculates array shadowing for any antenna configuration modelled as a function of sun declination, time of day, array geometry and rotation, etc.

6.3.3 Solar Array Sizing

Figure 6-4 shows the total S/C power requirements in sunlight including a 5% end of life (EOL) margin for all dedicated MUSAT configurations. In no case does the requirement utilize the standard GPB capabilities defined above (at least 247 watts low, EOL 7 years).

There are several ways in which the standard array could be "off-loaded" to provide a minimum weight bus adequate for the requirements. The method chosen for this study is removal of all surplus



MAX. POTENTIAL S/A SHADOWING.

MUSAT CONFIGURATION #1

FIGURE 6-2

SOLAR ARRAY SHADOWING DUE TO 16 FOOT DIAMETER COMMUNICATIONS ANTENNA MUSAT CONFIGURATIONS #3 & 4

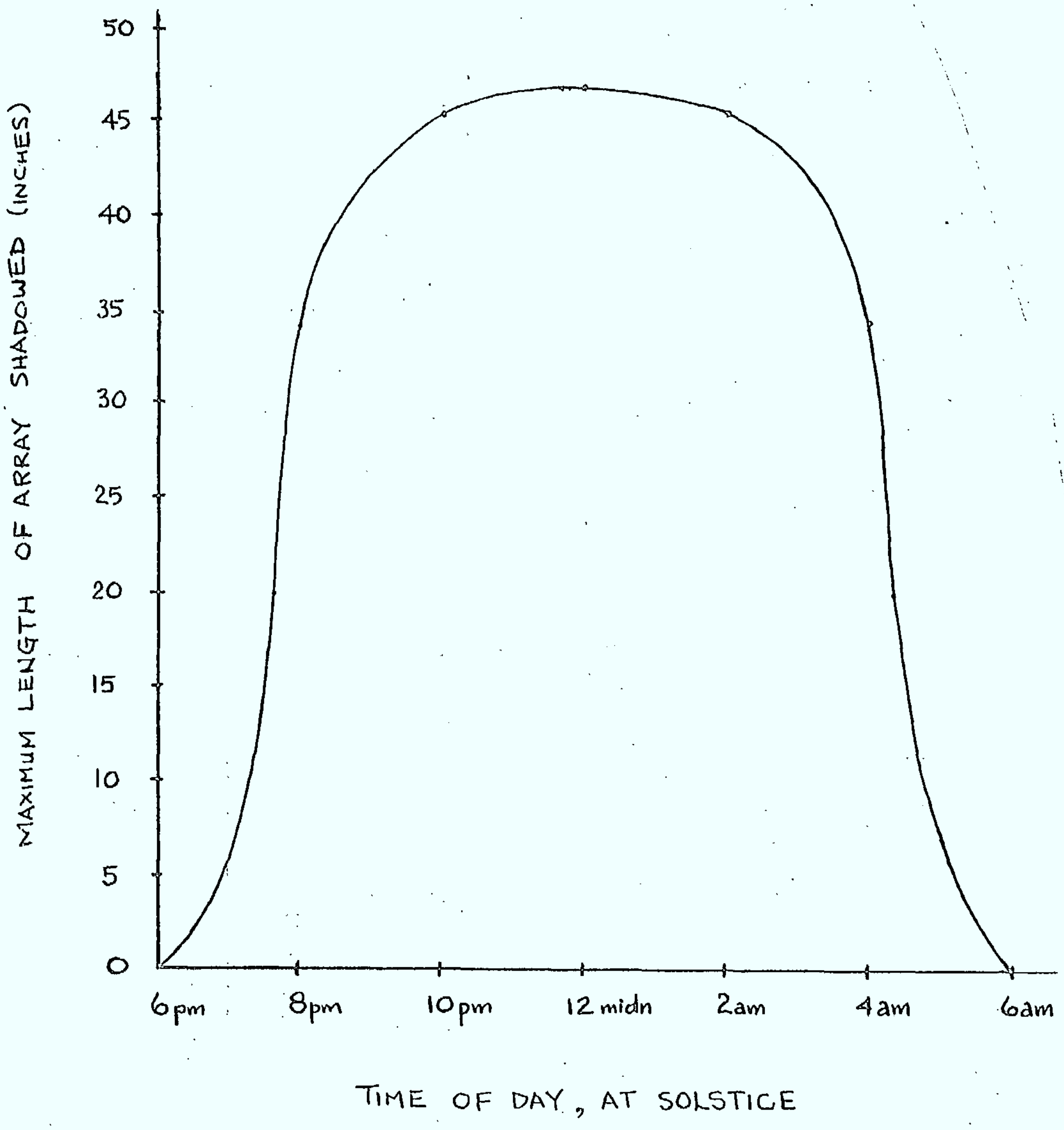
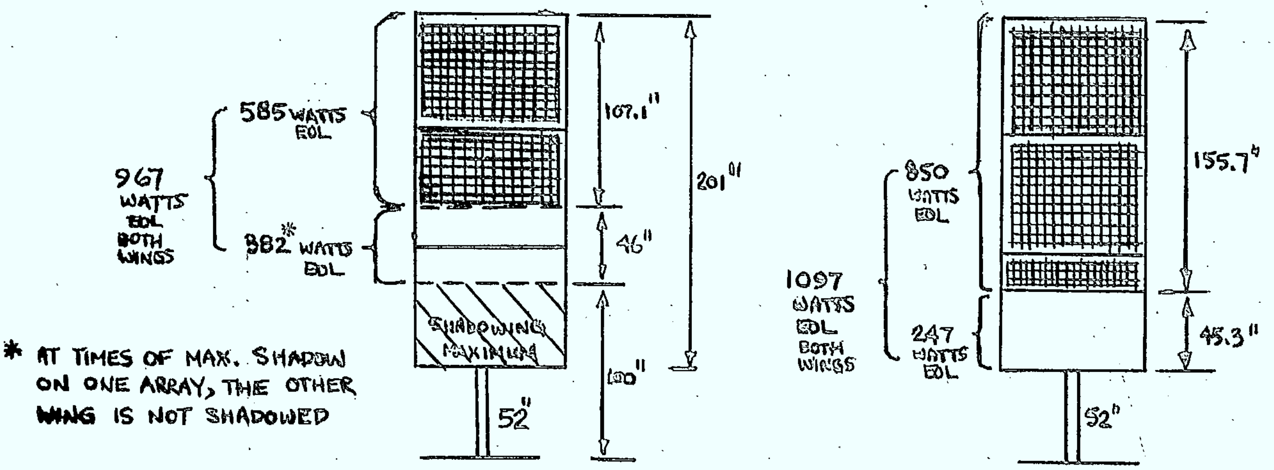


FIGURE 6-3

DEDICATED MUSAT POWER REQUIREMENTS - SUNLIGHT

	CONFIGURATIONS 1, 3 & 4	CONFIGURATION 2
EOL PAYLOAD POWER	313 WATTS	563 WATTS
EOL HOUSEKEEPING POWER	243	243
SUBTOTAL	556	806
CONTINGENCY (5%)	29	44
TOTAL	585 WATTS	850 WATTS
ARRAY LENGTH (@ 2.73 W/IN.)	107.1" PER WING	155.7" PER WING
ELECT. WEIGHT (@ .1380 LB/IN.)	29.6 LBS. BOTH WINGS	43.0 LBS. BOTH WINGS

3 PANEL, SPECTROLAB CELL BASELINE



* AT TIMES OF MAX. SHADOW ON ONE ARRAY, THE OTHER WING IS NOT SHADOWED

ADDITIONAL SOLAR ARRAY POWER AVAILABLE WITH STANDARD GPB SOLAR ARRAY	382 WATTS EOL	247 WATTS EOL

FIGURE 6-4

electrical cell strings but retention of the flexible substrate on all inboard areas not required for the power demand. For the Spectrolab, January 1977 array baseline, the array characteristics could be converted to:

- o 2.73 watts/in. of length, EOL 7 years
- o 0.138 lbs./in. of length for the electrical assembly

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As shown in Figure 6-4, the array length required for configurations 1, 3 and 4 is approximately 49 inches shorter per wing than for configuration #2 and the electrical weight for the former is approximately 13.4 lbs. lighter than for the latter (total array). These values are reflected in the mass properties presented in Section 6.10.

It is interesting to note that because of the differences in shadowing characteristics, the additional capability at solstice with the standard bus is 247 watts, EOL 7 years, above the requirement for configuration #2, but only 382 watts, EOL 7 years, above the requirements for the other configurations even though their power consumption values are 265 watts apart.

With configurations 1, 3 and 4, if MUSAT were to fly with the standard GPB array without cell removal, the additional capability of 382 watts would be a worst case minimum occurring only at EOL and during maximum shadowing. For some missions it would clearly be preferable to leave the full complement of cells on the array even though, at certain times, a portion of them would be shadowed.

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6.4 Power Control Subsystem Changes

It is not anticipated that the power control subsystem, as presented in Section 3.9 of SPAR-R.810, Volume I, would be altered for the dedicated MUSAT mission other than to potentially offload batteries to achieve a minimum Bus weight.

Table 6-2 shows that the standard GPB battery capacity is 1900 watt hours at a total weight, including case and harness, of approximately 140 lbs. Certain augmented MUSAT missions may choose to fly the standard batteries, as discussed in Section 8.

As shown in Table 6-3, this would provide 568 watt hours of additional capability in excess of the dedicated MUSAT eclipse requirement for configurations #1, 3 and 4 and 388 watt hours additional for configuration #2.

Alternatively, if the minimum bus weight is required, and assuming that the appropriate amp. hr. battery cells for the application could be procured with the same power to weight ratio as the standard batteries, the requirement would be for only approximately 56 lbs. of batteries for configurations #1, 3 and 4 and approximately 83 lbs. for configuration #2.

STANDARD GPB BATTERIES

CONFIGURATION SELECTED

THREE G.E. COMSAT TYPE CELL BASED BATTERIES*. EACH BATTERY WILL HAVE 22 CELLS.

TOTAL CAPACITY = 1900 WATT HRS. (ASSUMING AVERAGE 1.2V/CELL)
ESTIMATED TOTAL MASS = 140 LBS. (ALLOWING 15% FOR HARNESS AND CASE)
ESTIMATED SIZE = 7.7" x 12.2" x 5.2" /BATTERY

* PREFERRED SUPPLIER IS GENERAL ELECTRIC

POTENTIAL FUTURE ENHANCEMENT WHEN ELECTROCHEMICAL IMPREGNATION PROCESS GOES INTO PRODUCTION

THESE CELLS NOT THIN WALLED

TABLE 6-2

TABLE 6-3

MUSAT POWER REQUIREMENTS - ECLIPSE

	CONFIGURATIONS 1, 3 & 4	CONFIGURATION 2
PAYLOAD POWER	213 WATTS	363 WATTS
HOUSEKEEPING POWER	105	105
SUBTOTAL	318 WATTS	468 WATTS
ECLIPSE REQUIREMENTS	382 WATT HRS.	562 WATT HRS.
BATTERY REQUIREMENT (@ 13.6 WH/LB.)	56.2 LBS.*	82.6 LBS.*
ADDITIONAL WH. CAPABILITY WITH STANDARD GPB BATTERIES (@ 950 WATT HRS., 50% DOD)	568 WATT HRS.	388 WATT HRS.

* ASSUMPTION MADE THAT APPROPRIATE AMP. HR. BATTERY CELLS CAN BE PROCURED.

6.5 Thermal Control Subsystem Changes

The GPB MUSAT thermal subsystem requirements (see Table 6-4) and design are essentially identical to that of the GPB SHF configuration, except for the thermal control provision for the respective payloads. As the requirements and design for the spacecraft housekeeping components have been documented in the GPB SHF report, this section will only address the requirements and the design established for the MUSAT payload and identify any differences that may exist in the configuration of housekeeping subsystems as a result of this payload.

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6.5.1 Thermal Subsystem Design Drivers and Assumptions

The following requirements for the MUSAT payload (UHF & SHF systems) have been transmitted to Spar over the course of the present GPB study.

- o Payload component dimensions: as per CRC Dwg. #U-10202 E "MUSAT UHF/SHF North Panel Equipment Layout, Single Panel, (see Section 8). Figures 6-5 and 6-6 show a passive thermal control split panel design layout.
    - UHF power amplifier 31" x 14" total, (configuration 2), and half this footprint area for configurations #1, 3 and 4.
- o Payload component power dissipations - see Table 6-5

The only component having any significant impact on the thermal design is the UHF power amplifier having a maximum dissipation of:

- 320 watts split amongst 4 operating output transistors for configuration #2
- 160 watts split between 2 operating output transistors for configurations #1, 3 and 4.

TABLE 6-4

GPB MUSAT THERMAL DESIGN REQUIREMENTS

- o Provide acceptable thermal environment for a multipurpose UHF transponder payload having the following power input/output features:

<u>Payload Configuration #2</u>

Power Required:	563 watts sunlight. 363 watts eclipse.
Transmit Power, UHF:	160 watts.
Power Dissipation, Power Amplifier:	320 watts.

<u>Payload Configuration #1, 3 and 4</u>

Power Required:	313 watts sunlight. 213 watts eclipse.
Transmit Power, UHF:	80 watts.
Power Dissipation, Power Amplifier:	160 watts.

- o Maintain spacecraft batteries within an on-station temperature range of 0 to 10 C with occasional excursions to 15 C permitted.

- o Provide an acceptable thermal environment for all spacecraft components during all mission phases, including seven years of on-station operation, using passive thermal design techniques if possible.

- o Launch Vehicle: STS/SSUS.

FIGURE 6-5

MUSAT DEDICATED SOUTH PANEL LAYOUT (SHF EQUIPMENT)

PAYLOAD CONFIGURATIONS# 1,3&4

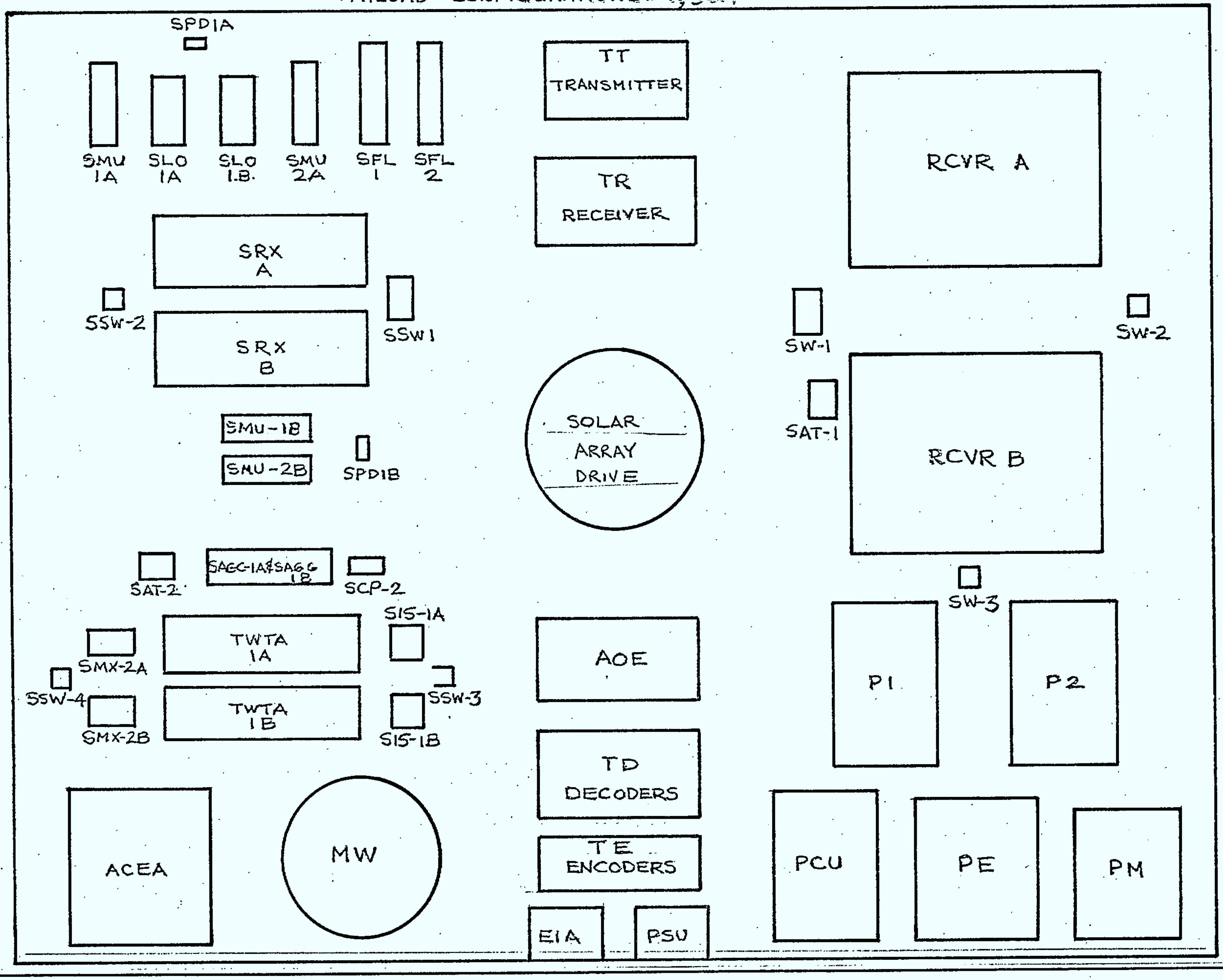

FIGURE 6-6
MUSAT DEDICATED NORTH PANEL LAYOUT (UHF EQUIP)
ACTIVE THERMAL CONTROL DESIGN

PAYLOAD CONFIGURATIONS # 1,3 & 4

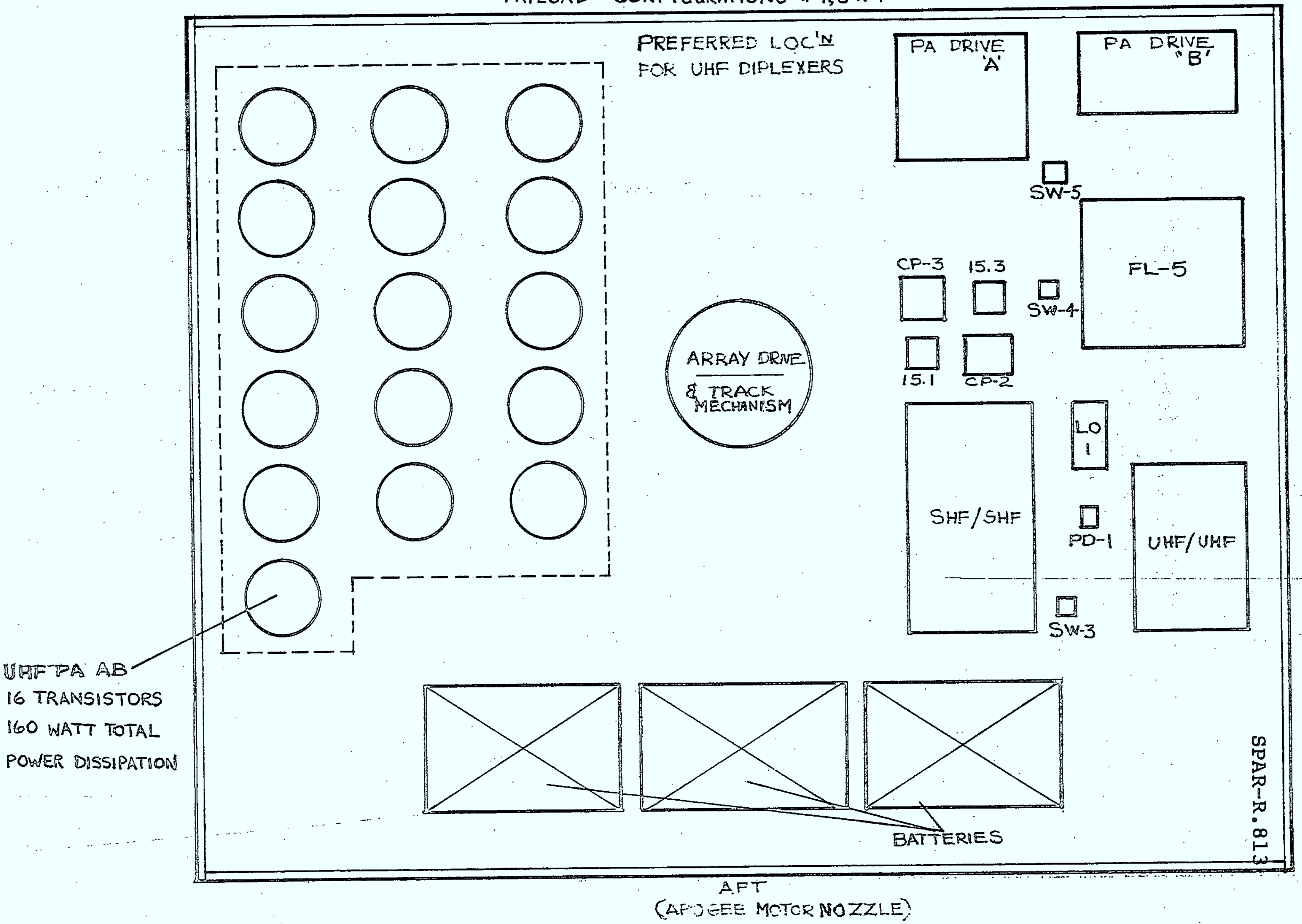

TABLE 6-5

GPB MUSAT PAYLOAD POWER REQUIREMENTS/DISSIPATIONS

COMPONENT/SUBASSEMBLY		POWER CONSUMPTION (WATTS)	POWER DISSIPATION (WATTS)
POWER AMPLIFIER (PA)	- CONFIGURATION #2	500	320
	- CONFIGURATION #1,3,4.	250	160
PA DRIVER		9	9*
UHF/UHF AM-3		3.5	3.5*
SHF/SHF AM-4		.54	.54*
SRXA		6.0	6.0*
SHF REGULATOR		7.0	7.0*
SHF TWT		20.0	20.0*
SAT 2.		.9	.9*
AGC 1		1.5	1.5*
SLO1		1.4	1.4*
SMU 112		7.2	7.2*
RX -A		4.4	4.4*
LO -1		1.4	1.4*
TOTAL	- CONFIGURATION #2	563 watts	383 watts
	CONFIGURATION #1,3,4.	313 watts	223 watts

* Assumed

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In the graphic presentation of Figures 6-7 and 6-8, the UHF power amplifier blocks shown are per transistor even though they would be mounted in one box. This is done because heat transport must be considered separately for each major dissipating element.

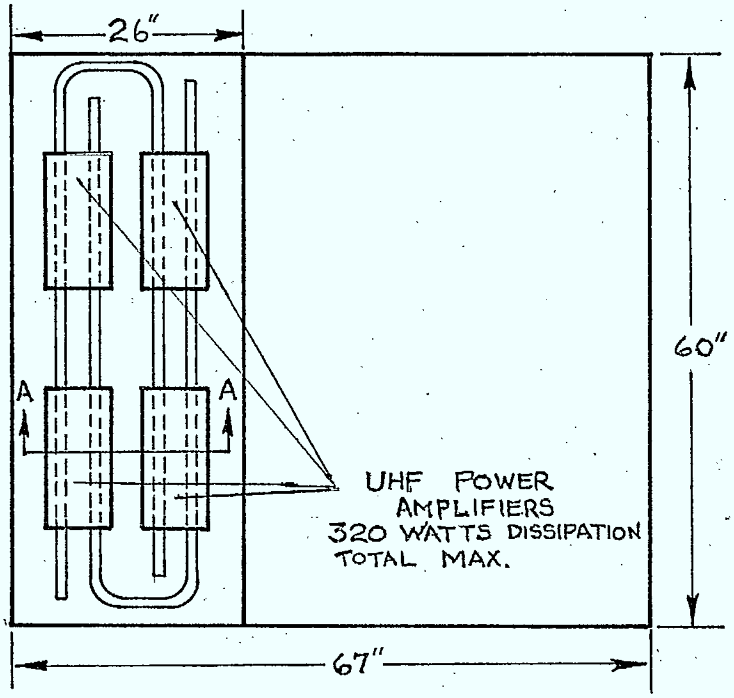
- Payload component temperature limits
  - UHF power amplifier +60°C to -30°C
  - other payload components as per Hermes (CTS) design requirements (assumed +50°C to -20°C)

6.5.2 Thermal Subsystem Design Configuration

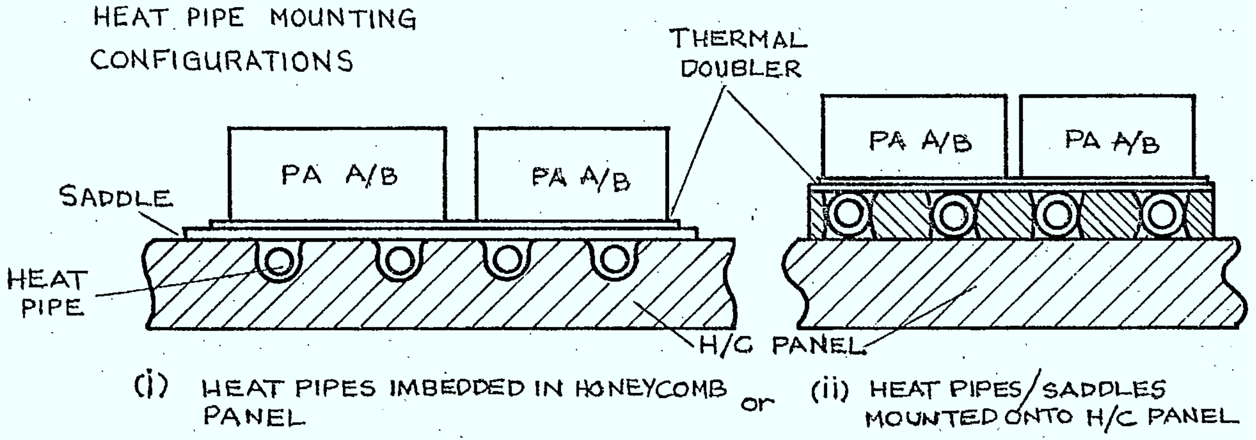
- The thermal subsystem design has focused on the thermal control required by the UHF power amplifier as this is the only component of thermal significance.

- Work reported at the interim presentation in January 1977 at CRC, addressed the 160 watt dissipation, UHF power amplifier (configurations #1, 3 and 4) split into 16 identical dissipating components. This arrangement (see Figure 6-6) permitted the use of a thermal doubler to reject the dissipated power, as no highly concentrated heat sources existed. Subsequent direction was received from DOC to use a heat pipe design for all of the configurations, since the electrical complexity associated with splitting the amplifier into many dissipating elements is now considered unacceptable. Additionally, as identified in Section 6.5.1, the current maximum UHF power amplifier configuration dissipates a maximum of 320 watts (configuration #2) in 4 closely located sources. This configuration demands a heat pipe assembly to reject the energy.

FIGURE 6-7
PANEL RADIATING HEAT PIPE LAYOUT
DEDICATED MUSAT
CONFIGURATION #2



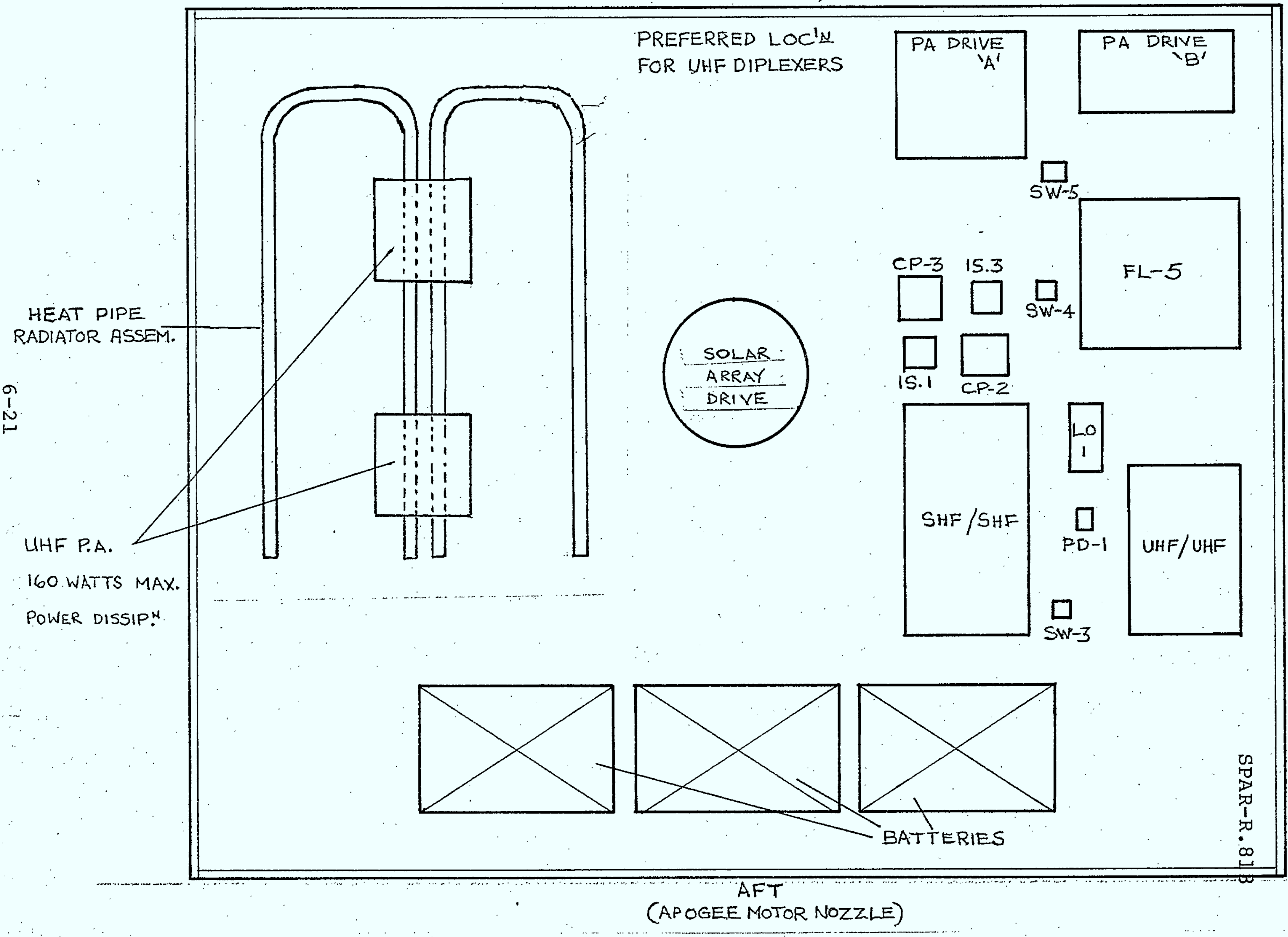
NORTH PANEL



SECTION A-A

FIGURE 6-8
MUSAT DEDICATED NORTH PANEL LAYOUT (UHF EQUIP)
ACTIVE THERMAL CONTROL DESIGN

PAYLOAD CONFIGURATIONS 1,3 &4



- Considerable heat pipe analysis/design activity for MUSAT has been conducted by CRC (V. Werhle) and by Thermowatt Inc. of Kitchener, the latter concentrating on the heat pipe design required to accommodate a 160 watt dissipation power amplifier. Reports on the above work have been reviewed by Spar who are in general agreement with their conclusions. However, the safety factor of 2 employed on heat pipe radiation area under the conditions where 1 pipe has failed is considered excessive.

- For a dedicated MUSAT configuration, sufficient areas (assumed to be isothermal within 5C°) exists on the North or South panels to reject 320 watts at a temperature of 60°C at the source. The isothermallizing of the area by non controllable (ie. no variable conductance feature) heat pipes would require the pipes to be either incorporated into the honeycomb panel or mounted onto the panel (in both cases attached by a saddle to the internal facesheet of the panel). The former arrangement permits relatively easy installation of the power amplifier onto the panel whilst the latter permits much easier installation of the heat pipe onto the panel. Area required on the South Panel is 24" x 60" (slightly less required on the North Panel). The heat pipe configuration is shown in Figure 6-7 for payload configuration #2 and in Figure 6-8 for payload configurations #1, 3 and 4.

  Heat pipe fin (doubler) thickness over the above radiating area is .048" for configuration #2 (320 watts dissipation).

In summary, with the dedicated payload, a heat pipe with panel mounted radiator, not requiring the radiator to overhang the edge of north or south panel, is sufficient, although with configuration #2, due to area required, some rearrangement of housekeeping components would be required.

6.5.3 Thermal Subsystem Weight & Heater Power Requirements

Thermal subsystem weight breakdown for the GPB dedicated MUSAT configurations are as for the SHF payload configuration (SPAR-R.810, Volume I, Section 3.6) with the exception of the thermal doublers (and/or heat pipes) required.

- o For payload configuration #2:

the heat pipe system weight (including fin and saddle) is	13.2 lbs
20 watt TWT doubler	1.5 lbs
Total	14.7 lbs

plus battery doublers

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This is consistent with the thermal doubler weight estimate for the commercial SHF configuration of 17 lbs. and a total subsystem weight of 33 lbs.

- o For payload configuration #1, 3 and 4, the heat pipe system weight would be $\leq$10 lbs.

Heater power required when the UHF power amplifiers are non-operational would be approximately 150 watts maximum (configuration #2). This high power requirement, which arises from the fact that the pipes would not be variable conductance pipes, will not impact array power requirement as it would only be required when the power amp. is non operational.

If a tighter excursion of temperature were to be recommended during operational periods for the amplifier, a variable conductance heat pipe could be provided which would also help to reduce the non-operational power requirement. However, with this type of pipe, there would be a weight and reliability penalty and additional complexities during ground testing.

6.6 Attitude Control Subsystem

The MUSAT pointing requirements are similar to but less stringent than the commercial SHF requirements and the standard GPB ACS (SPAR-R.810, Volume I, Section 3.7) is adequate. The major areas of difference occur as a result of the large flexible antennas and a potential unfavourable moment in inertia ratio during the mission spin phases.

The large antennas, when configured, would require additional investigation of:

(a) perturbation torques, particularly due to solar array shadowing

(b) appendage structural frequencies less than 1 Hz, particularly about the pitch axis

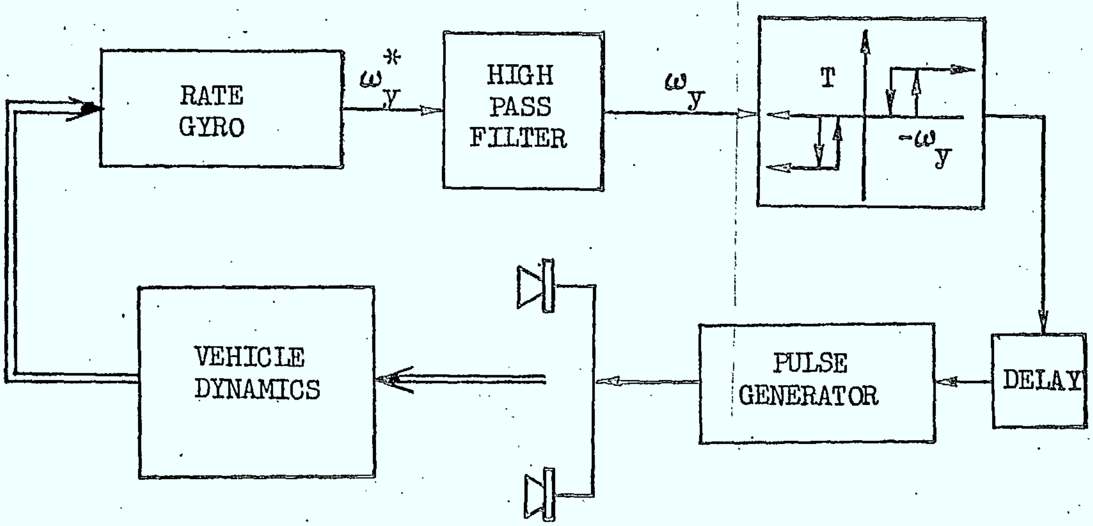
(c) a method for obtaining adequate earth and sun sensor fields of view

(d) free deployment dynamics

(e) centre of mass shifts due to antenna deployment

During the spin phases of the mission, should an unfavourable moment of inertia exist, active nutation damping may be considered, with rate gyros, accelerometers or even sun sensors used to determine nutation rates and fire appropriate thrusters (Figure 6-9).

TYPICAL ACTIVE NUTATION CONTROL



- o YAW AXIS (SPIN) MINIMUM MOMENT OF INERTIA
- o RATE GYRO SENSITIVE TO PITCH RATE
- o PITCH THRUSTERS FOR NUTATION CONTROL

FIGURE 6-9

6.7 Reaction Control Subsystem Changes

The Reaction Control Subsystem as presented in Section 3.8, SPAR-R.810, Volume I for the commercial SHF payload would not require modification for the dedicated MUSAT spacecraft. A vectorial schematic of the RCS 16 thruster configuration is shown in Figure 6-10 (depicted with MUSAT antennas, configuration #1). Because of the yaw axis 180 degree rotation between the commercial SHF and the MUSAT applications, there would be a sign reversal within the ACS, requiring a wiring change, but the RCS hardware would be unaffected.

6.7.1 RCS Thruster Plume Impingement on Communications Antennas

During the initial MUSAT activity, configuration #1, a plume impingement analysis was performed for the east and west thrusters during steady state stationkeeping to determine the approximate spacecraft external perturbation torque and thrust degradation to be expected due to plume impingement on the UHF antenna farms. The ground plane plates and the helices were considered; the latter being conservatively approximated by opaque flat plates.

The results of this examination are presented in Table 6-6. With the ground planes forward of the forward panel by 15" (ie. coplanar with the SHF dish aperture plane) the unwanted pitch torque expected at maximum engine thrust (BOL) is approximately 0.03 ft. lbf. This is a significant contributory value when compared to the maximum allowable torque of 0.1 ft. lbf. imposed by the ACS requirements, but is secondary to the 0.084 ft. lbf. potentially caused by firing 2 opposing pitch thrusters (east, or west) with nominal 33" moment arms but thrust mismatch of ±2.5%, misalignment of ±0.35° and S/C C of M excursion of 1 inch in the yaw direction. A significant portion of this plume impingement takes place in the inboard side of the outboard

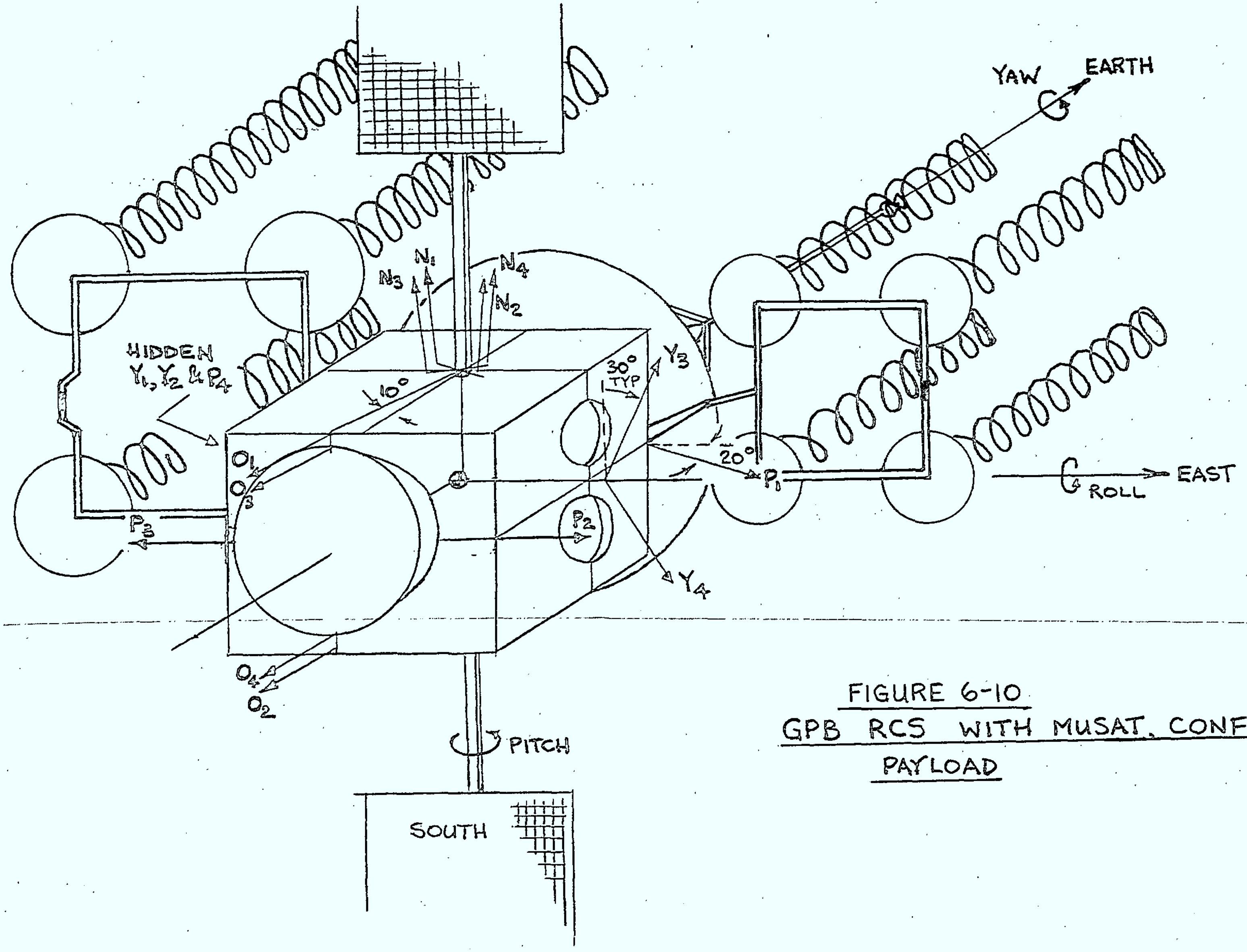


FIGURE 6-10

GPB RCS WITH MUSAT, CONFIG. 1

PAYLOAD

SUMMARY OF PLUME IMPINGEMENT ANALYSIS
FOR BASELINE RCS DESIGN

ACCOMPLISHED

- NORTH STATIONKEEPING
  2, .1 LBF THRUSTERS FIRING

2, .1 LBF THRUSTERS FIRING	F_N (% of SS)	F_{TA} (% OF SS)	YAW TORQUE (FT LBF)
• ON SOLAR ARRAY	0.3%	1.5%	.012
• ON ELEVATION ARM	1.3%	1.4%	.010

- EAST-WEST STATIONKEEPING
  2, .25 LBF THRUSTERS FIRING

2, .25 LBF THRUSTERS FIRING	F_N (% OF SS)	F_{TA} (% OF SS)	PITCH TORQUE (FT. LBF.)
• COMMERCIAL OPTION A	NIL	NIL	NIL
• COMM. OPTION C			
◦ X = 10"	3.1%	1.3%	.041
X = 15"	1.2%	.4%	.018
• UHF-MUSAT BASELINE	0.9%	2.3%	.030

TO BE PERFORMED DURING S/C PROGRAM (NO PROBLEMS EXPECTED)

- OFFSET THRUSTERS – ELEVATION ARMS–STOWED
- YAW THRUSTERS – COMMUNICATIONS ANTENNAE

TABLE 6-6

helices. It should be noted that a 2.3% thrust degradation can also be expected which will result in a slight ($\lesssim$ 1/4 lb.) increase in fuel expenditure.

Configuration 2, 3 and 4 have not been analyzed for plume impingement. However, it would be possible to say that:

- configuration #1 would likely be the worst case followed by #3, then #4 and finally
- configuration #2, with only inboard helices, should not have any significant plume impingement due to pitch engine firing

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6.7.2 Dedicated MUSAT RCS Fuel and Pressurant Budget

As shown in Section 6.10, with batteries mounted aft on the north panel, the S/C C of M shift due to antenna and array deployment could be as high as 1.8 inches along the yaw axis with configuration #1. The value is much lower for configurations #4 and #2. With this large shift comes an unwanted pitch torque effect during in-plane station-acquisition, if it occurs prior to attitude acquisition as suggested for the commercial SHF GPB mission. In this case, since the spacecraft would still be spinning at approximately 60 rpm during this manoeuvre, precession would occur, requiring fuel expenditure (up to 2.5 lbs.) to correct the attitude deviation. However, with the use of the IR non-spinning earth sensor assembly it could be possible, depending upon TT&C coverage, to perform attitude acquisition and appendage deployment prior to in-plane station-acquisition. This would remove the thruster pointing problem as would choice of configuration #2.

Assuming that the above problem can be solved without additional fuel allotment, the expected N_2H_4 fuel expenditure for the configuration #1 dedicated MUSAT flown on the standard GP Bus would be approximately 201 lbs. for the 7 year mission

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(while utilizing superheated electrothermal thrusters for north stationkeeping at a mission effective Isp. of 300 lbf. sec/lbm).

It should be noted that within the scope of this study a fuel weight allocation for active nutation control, if required, has not been determined. This tends to present a non-conservative estimate of fuel expenditure for configurations #3 and 4 which would undoubtedly require ANC because of unfavourable $I_{spin}/I_{transverse}$ during spinning phases.

RCS fuel for the off-loaded (batteries and solar array electrical) min. Bus dedicated MUSAT payload would be approximately 177 lbs. for 7 years with configuration #1.

The pressurant weight is higher in the dedicated MUSAT (7 years) than for the commercial SHF GPB because lower fuel mass in the tanks for the former with the same initial pressure requires more pressurant.

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6.8 Telemetry, Tracking and Command Subsystem Changes

Although unspecified, it is understood from DOC that for the purposes of this study the TT&C frequency allocations should be assumed to be the same for MUSAT as they are for the commercial SHF application of the GPB.

The standard GPB TT&C equipment is therefore directly applicable to the MUSAT mission. The antenna complement is the same for all MUSAT configurations and differs from the standard GPB only in the addition of a cone to the deployable, aft facing omni. This is included to provide 4 steradian coverage in the event that a reacquisition manoeuvre is required. In the case of configurations #1 and #2, the forward facing normal mode omni (cone plus dual bicone) would be stowed to minimize Shuttle Bay length required during launch and deployed after separation from the Orbiter. This antenna would be mounted on the end of the central support mast with configurations #3 and 4.

Figure 6-11 shows a schematic of the antenna configuration connected to the representative CTS electronics complement. Figures 6-12 and 6-13 illustrate the antenna locations and coverage.

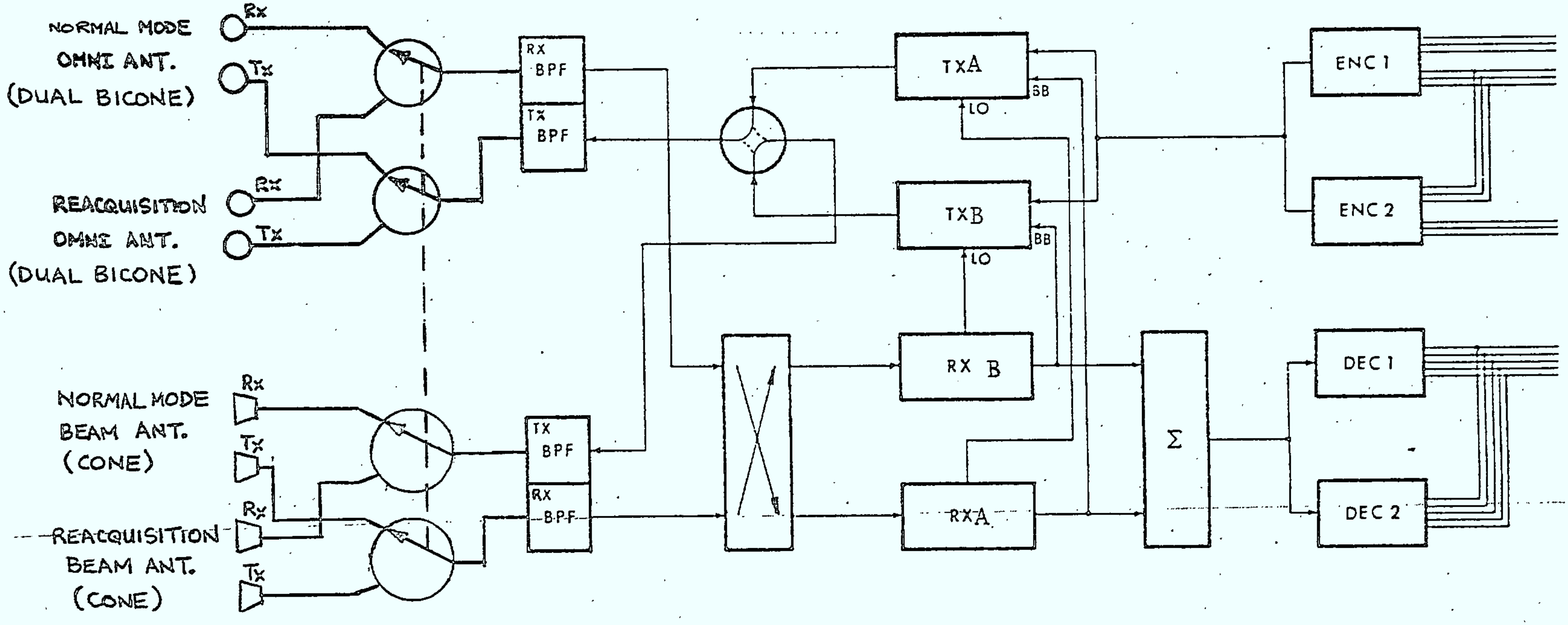
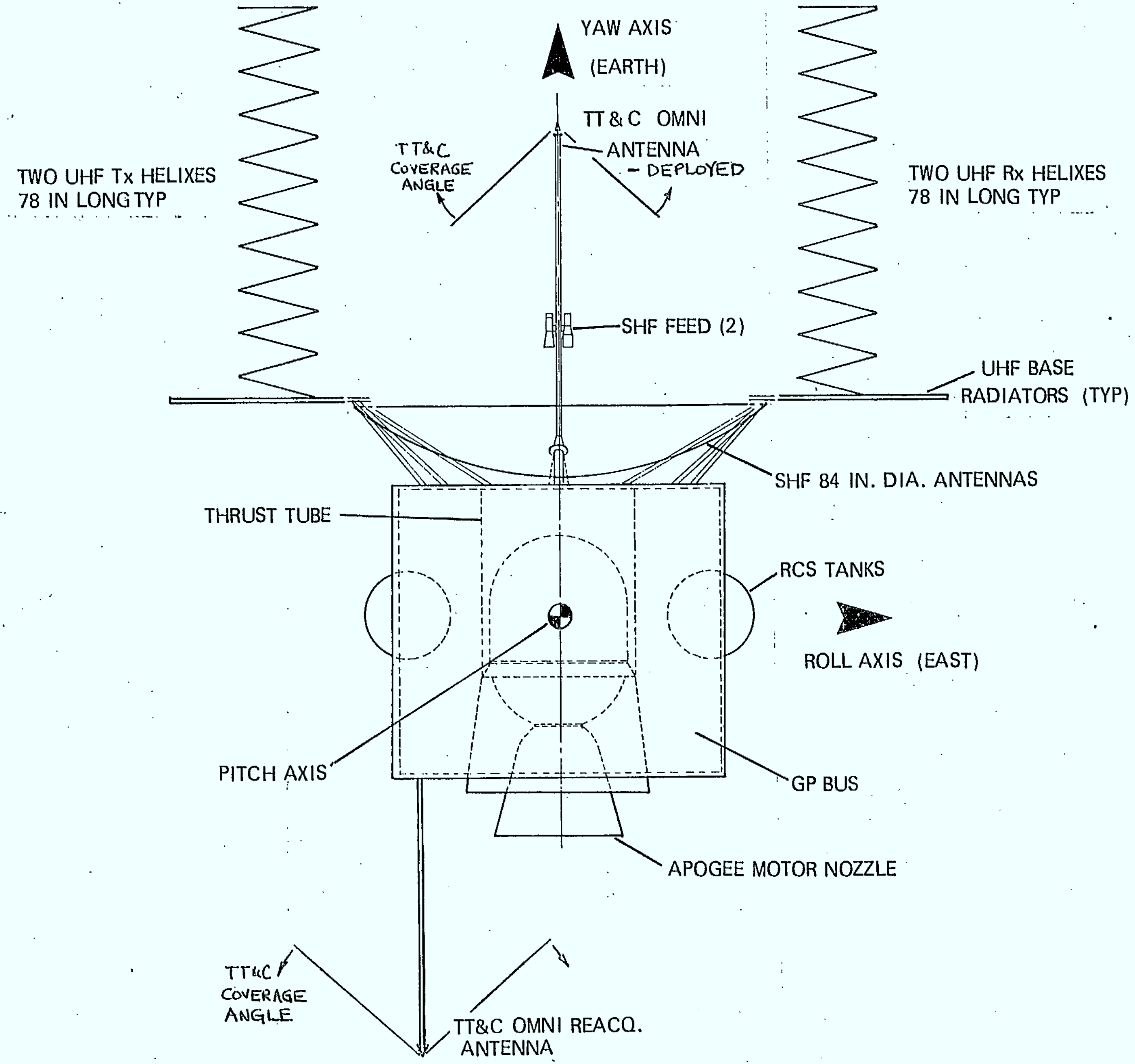


FIGURE 6-11

MUSAT TT&C SUBSYSTEM CONFIGURATION - PRELIMINARY

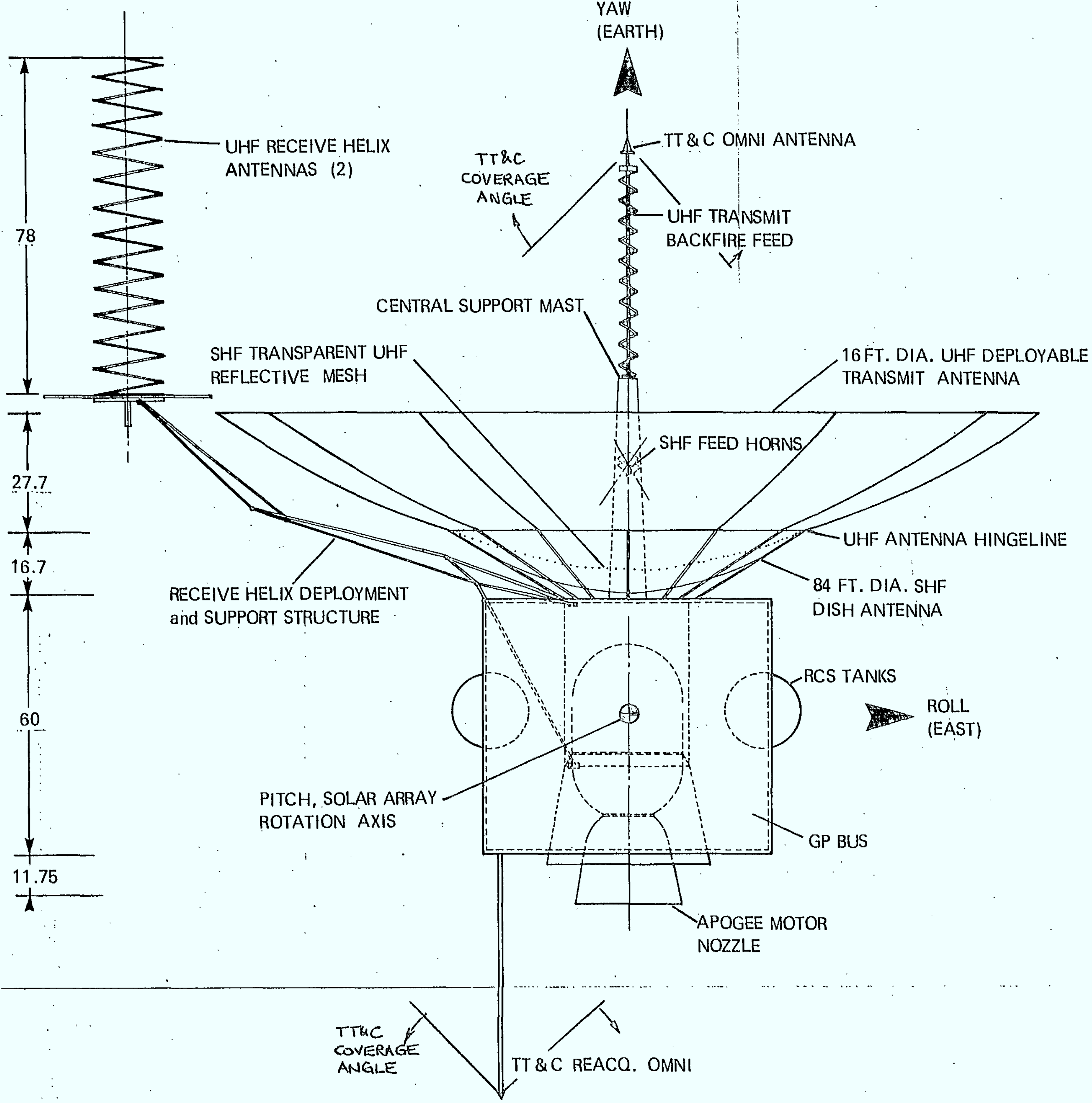


MUSAT – CONFIGURATION #2 – DEPLOYED

(TYP. OF CONFIG #1 & #2)

FIGURE 6-12

MUSAT TT&C COVERAGE



MUSAT – CONFIGURATION 3 – DEPLOYED

(TYP. OF CONFIG #3 &4) FIGURE 6-13

6.9 Apogee Motor Subsystem Changes

The elongated, STAR 30, EP 65-75, solid propellant apogee kick motor, which, for the standard GPB, as described in SPAR-R.810, Volume I, Section 3.3, has been sized for 1179 lbs. of propellants plus expended inerts, could be offloaded to provide the correct delta velocity for any dedicated MUSAT launch.

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If MUSAT configuration 4, 7 year mission, were to be launched with the minimum GPB (56 lbs. batteries and 76 lbs. solar array) as described in Section 6.10, - this is not likely to be a viable launch configuration - a minimum AKM propellants plus expended inerts weight of 843 lbs. would be required. This represents a 28.5% offload where the AKM Specification SPAR-SG.356, Issue B requires only 25% offload capability. However, Thiokol have indicated that this increased offload could easily be accommodated with an associated increase in igniter charge weight of ≮ 0.5 lbs. and increased insulation of ≮ 2 lb. The high Isp. level could be maintained by (re) optimization of throat area.

Mass properties of this motor have been utilized in the MUSAT/GPB mass properties evaluation.

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6.10 Mass Properties

The mass properties of the dedicated MUSAT payload layout, as shown in Section 5.1 with the payload mounted forward to minimize waveguide length and complexity, have been examined. This section shows the weight breakdown and margin for each of the 4 configurations for both the standard and the minimum GPB as defined in Section 1 , as well as the moments of inertia and centre of mass shifts which occur as a result of apogee motor firing and appendage deployment.

6.10.1 Weights

Table 6-7 shows the weight breakdown of the dedicated MUSAT spacecraft utilizing the standard GPB. As previously discussed, the Spar-Astro deployable helical UHF antennas were specified with unequal geometries east and west for configuration #1 whereas Fairchild helices were specified for configurations 2 and 3. This change was made by DOC in the course of design iteration and would presumably be applicable to configuration #1 if it were to be studied further during follow-on activity.

The UHF helical antennas for both configurations 1 and 3 have significant east-west mass imbalance when deployed. Configuration #1 has opposing east and west deploying appendages. Consequently a balance weight can be and has been added to the outboard frame of the support structure of the lighter east side to prevent an unacceptable 1 inch spacecraft centre of mass shift upon deployment. The weight required, as shown in Table 6-7, is 11.6 lbs. Configuration #3 has only a west deploying UHF appendage and a balance weight cannot easily be added to counteract the deployment centre of mass shift.

The single weight change to the GP standard bus, as compared to the commercial SHF application, is the addition of a 10 lbs. security box to the TT&C subsystem. Table 6-8 shows the breakdown of the

DEDICATED (SPLIT PANEL) MUSAT STANDARD BUS, WEIGHT BREAKDOWN

ITEM	CONFIGURATION WEIGHT (LBS.)			
	1	2	3	4
Musat Transponder System	105.4	127.4	105.4	105.4
Duplexer	-	-	-	6.0
SHF Antenna - Dish	15.0	15.0	-	-
- Feed & Horns	5.0	5.0	5.0	5.0
UHF Antennas - Helices East	24.0	6.0	-	-
- Helices West	14.8	6.0	6.0	-
- Ground Planes	included	9.6	4.8	-
- Support Struct.	10.0	8.7	9.4	-
- Backfire Feed	-	-	5.0	5.0
Deployable 16' Antenna (SHF & UHF)	-	-	34.0	34.0
Antenna Balance Weight	11.6	-	-	-
Payload Subtotal	185.8	177.7	169.6	155.4
TT&C Security Box	10.0	10.0	10.0	10.0
Batteries	139.7	139.7	139.7	139.7
Solar Array	102.1	102.1	102.1	102.1
Common Dry Weight	468.6	468.6	468.6	468.6
Dry Weight Subtotal	906.2	898.1	890.0	875.8
Contingency (5% Dry Wt.)	47.7	47.3	46.8	46.1
TOTAL DRY WEIGHT	953.9	945.4	936.8	921.9
N_2H_4	200.9	199.2	197.3	194.2
Pressurant	4.2	4.2	4.2	4.2
Apogee Prop/Expended Inerts	990.2	981.5	972.4	957.0
Adaptor	139.0	139.0	139.0	139.0
Lift-Out Weight	2288.2	2269.3	2249.7	2216.3
Launch Vehicle Capability	2450.0	2450.0	2450.0	2450.0
Unutilized Capability	161.8	180.7	200.3	233.7

TABLE 6-7

TABLE 6-8
DEDICATED, SPLIT PANEL, MUSAT WEIGHT BREAKDOWN HARDWARE COMMON TO ALL CONFIGURATIONS

ITEM	WEIGHT (LBS.)
TT&C ELECTRONICS	24.4
TT&C ANTENNAS	
- 2 OMNIS	2.4
- 2 SUPPORT RODS	1.0
ACS	72.0
RCS HARDWARE	46.5
SOLAR ARRAY DRIVE	22.8
POWER CONDITIONING	40.0
HARNESS	30.0
THERMAL CONTROL*	33.0
STRUCTURE	130.5
AKM - BURNED OUT	59.0
BALANCE (GPB)	7.0
TOTAL	468.6

* CONSERVATIVE FOR DEDICATED MUSAT, DESIGN CONTINGENCY MAINTAINED

dry weight components common to both the standard and the minimum bus with 33 lbs. for the thermal control subsystem retained with contingency.

As can be seen from Table 6-7, even with an allowance of 5% contingency to the spacecraft dry weight, the GPB dedicated MUSAT has a further lift out growth capability of approximately 162 lbs. for configuration #1 and up to approximately 234 lbs. for configuration #4 when launched on the STS/PAM vehicle (2450 lbs. capability with adaptor).

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When consideration is being given to an additional payload to the MUSAT mission (for example an ANIK A follow-on as discussed in Section 8) it is important to determine the weight of the MUSAT with power producing components offloaded (tailored) and expendibles adjusted. This information for the dedicated MUSAT with the minimum bus, as presented in Table 6-9, shows that a lift out margin of at least 345 lbs. exists with the higher power configuration #2 and up to 487 lbs. exists for configuration #4.

6.10.2 Moments of Inertia

Table 6-10 presents a summary of MUSAT dedicated moments of inertia ratios = $I_{spin}/I_{traverse}$ = I_{zz}/I_{xx} and I_{zz}/I_{yy} for the standard GPB with batteries mounted aft. Calculations were made for each configuration before and after apogee motor firing and after antenna and solar array deployment. Only configuration #1 has an acceptable spinning moment of inertia ratio to preclude the need for active nutation damping. For the other configurations, I_{yy}, about the spacecraft pitch axis, has relatively too high a value especially for configurations #3 and #4 with the 34 lbs. deployable 16-foot antenna cantilevered very far forward.

DEDICATED (SPLIT PANEL) MUSAT MINIMUM BUS, WEIGHT BREAKDOWN

ITEM	CONFIGURATION WEIGHT (LBS.)			
	1	2	3	4
Musat Transponder System	105.4	127.4	105.4	105.4
Duplexer	-	-	-	6.0
SHF Antenna - Dish	15.0	15.0	-	-
- Feed & Horns	5.0	5.0	5.0	5.0
UHF Antennas - Helices East	24.0	6.0	-	-
- Helices West	14.8	6.0	6.0	-
- Ground Planes	included	9.6	4.8	-
- Support Struct.	10.0	8.7	9.4	-
- Backfire Feed	-	-	5.0	5.0
Deployable 16' Antenna (SHF & UHF)	-	-	34.0	34.0
Antenna Balance Weight	11.6	-	-	-
Payload Subtotal	185.8	177.7	169.6	155.4
TT&C Security Box	10.0	10.0	10.0	10.0
Batteries	56.2	82.6	56.2	56.2
Solar Array	76.2	89.6	76.2	76.2
Common Dry Weight	468.6	468.6	468.6	468.6
Dry Weight Subtotal	796.8	828.5	780.6	766.4
Contingency (5% Dry Wt.)	41.9	43.6	41.1	40.3
TOTAL DRY WEIGHT	838.7	872.1	821.7	806.7
N_2H_4	176.7	183.7	173.1	169.9
Pressurant	4.6	4.5	4.7	4.8
Apogee Prop/Expended Inerts	870.8	905.4	853.2	842.8
Adaptor	139.0	139.0	139.0	139.0
Lift-Out Weight	2023.8	2104.7	1991.7	1963.2
Launch Vehicle Capability	2450.0	2450.0	2450.0	2450.0
Unutilized Capability	426.2	345.3	458.3	486.8

TABLE 6-9

MUSAT DEDICATED/STANDARD GPB MASS PROPERTIES

		Before AKM	After AKM	After Deploy
Configuration 1	I_{zz}/I_{xx}	1.171	1.229	1.102
	I_{zz}/I_{yy}	1.025	1.059	3.566
	C of M	34.18	32.06	X=-.09, Y=0, Z=33.8 7
2	I_{zz}/I_{xx}	1.107	1.153	1.033
	I_{zz}/I_{yy}	.975	.998	4.214
	C of M	34.51	32.67	X=-.06, Y=-.01, Z=33.35
3	I_{zz}/I_{xx}	1.007	1.033	1.030
	I_{zz}/I_{yy}	.975	.938	3.657
	C of M	34.75	33.10	X=-1.0, Y=0.0, Z=34.22
4	I_{zz}/I_{xx}	.995	1.021	1.027
	I_{zz}/I_{yy}	.923	.937	4.709
	C of M	34.61	32.82	X=0, Y=0, Z= 32.89

TABLE 6-10

The large displacement of the highly dense batteries away from the antennas creates a dumbell effect thereby resulting in high I_{yy}. Subsequent examination has shown that if the batteries were to be mounted forward on the north panels, with a similar relocation of housekeeping components on the south panel, and the payload were to be moved aft, which would increase waveguide complexity, this dumbell effect can be significantly reduced to a point where both configurations #1 and #2 have acceptable ($\geqslant$ 1.05) spinning moment of inertia ratios. This would still not be the case, however for configurations #3 and #4.

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6.10.3 Centre of Mass

Table 6-10 also shows for the dedicated MUSAT, standard GPB the spacecraft centre of mass at various mission stages. The spacecraft would be balanced for the spin phase and antenna deployment in all but one case would result in less than 0.1 inches lateral shift in the centre of mass. In the case of configuration #3, as previously noted, deployment causes a significant shift of up to 1 inch along the x or roll axis of the spacecraft. If configuration #3 were to be chosen for further study, it would be necessary to investigate this problem fully with regard to its impact on the Attitude Control Subsystem design.

Table 6-10 shows the expected location of the centre of mass along the Z or yaw axis during various mission phases; reference zero is the spacecraft separation plane. A comparison with similar figures shown for the commercial SHF/GPB spacecraft in SPAR-R.810, Volume I, reveals that the centre of mass is consistently 4 inches lower with MUSAT. This is also primarily due to battery location. In any event, the values shown are acceptable to the PAM from a launch environment-induced bending moment point of view and their changes are acceptable to the GPB.

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7.0 IMPLEMENTATION PLAN AND COST

7.1 Implementation Plan/Schedule

This section discusses a suggested implementation plan for the UHF payload flying on a GP Bus. Assumptions made are that the Bus has not been developed and qualified at program start and the UHF Payload (Antenna and Transponder Equipment) have been partially developed to a stage where breadboard work has been completed and the preferred configuration chosen.

Based on the above assumptions, the attached program schedule is presented showing that the UHF antenna and payload path is critical since it is the major unqualified subsystem. All other subsystems would have been previously flown or qualified on other programs. We have used the basic Bus implementation plan identified for the commercial SHF payload reported in SPAR-R.810, Volume III for the Bus, recognizing that its plan does not signficantly change even though it will be affected by the interfaces with the payload.

After examining major items of the spacecraft, we have found that the bus does not significantly change from that prescribed for the SHF; however, as mentioned, the payload is critical to achieving the schedule suggested. Additional development testing will be required plus further complex integration and testing is envisioned for the qualification and flight spacecraft. Also, all interface data would have to be frozen at the C.D.R. stages of the Bus and Payload schedule. Typical additional tests envisioned at the spacecraft level include:

- Release/deployment tests of the UHF antenna system
- Antenna alignment measurements
- Stringent and complex antenna performance measurements

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At the subsystem level, the additional testing to that mentioned in SPAR-R.810 will be static and have been partially developed to a stage where deployment testing of the Antenna system, followed by vibration tests on the Development Test Model Spacecraft and thermal testing of each radiating equipment panel with its heat pipe and related payload.

These additional tests, it is suggested, will add approximately 6 months to each major program phase and, as a result of the above, the following program milestones are identified in the schedules bar charts attached, Figures 7-1, 7-2 and 7-3:

- PDR is at month 3 ARO
- CDR is at month 8 ARO
- Initial FDR is month 20 ARO followed by a further FDR at month 30 ARO after the spacecraft qualification tests have been completed.
- Flight 1 Bus delivery at month 27 ARO.
- Flight 1 Payload delivery at month 27 ARO.
- Flight 1 Integration & Test at month 35 ARO.
- Flight 1 Launch at month 36 ARO.

IMPLEMENTATION PLAN SCHEDULE GENERAL PURPOSE BUS - DEDICATED MUSAT PAYLOAD

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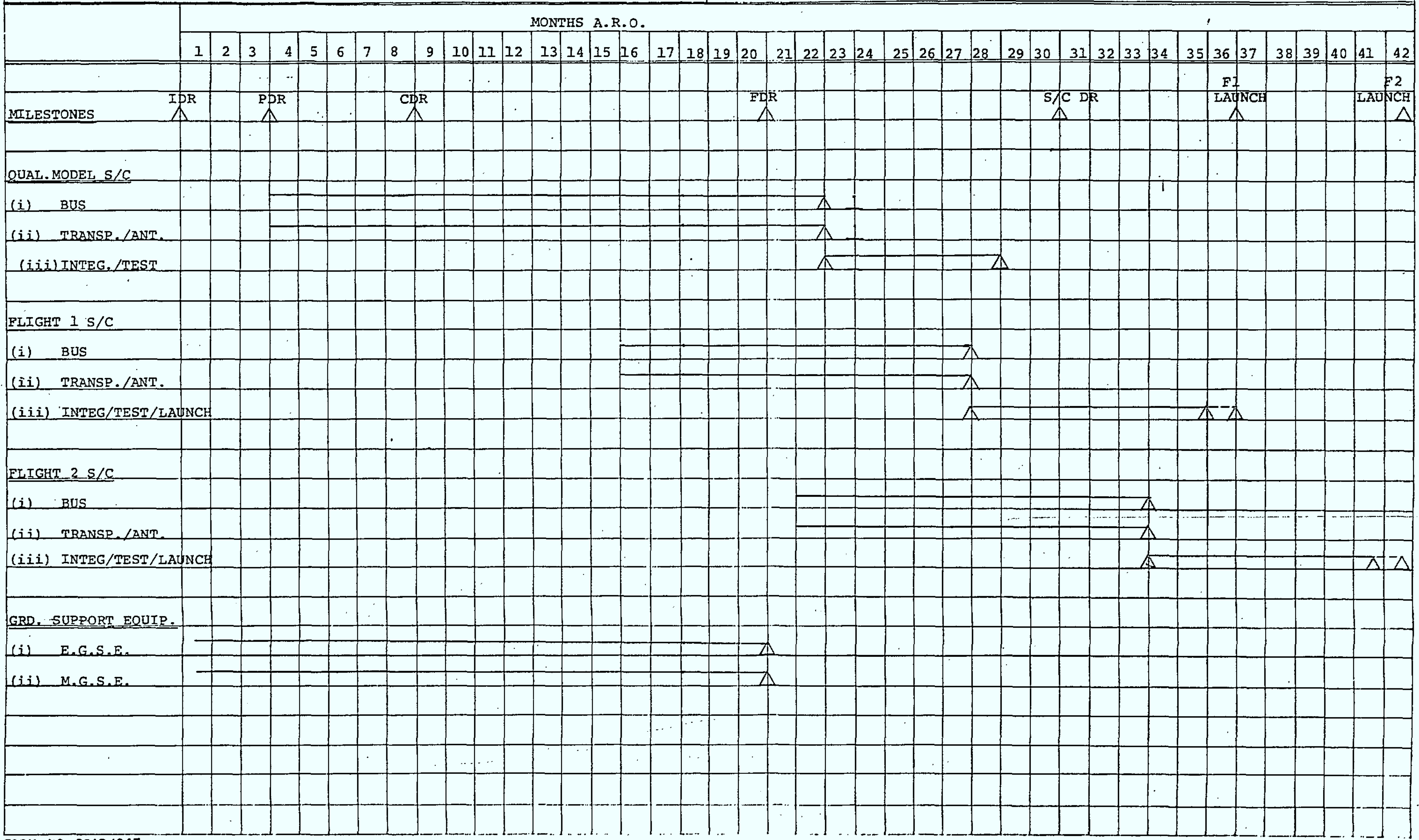

FORM NO. SPAR 1047

Figure 7-1

G.P. BUS SATELLITE PROGRAM SCHEDULE - DEDICATED MUSAT PAYLOAD

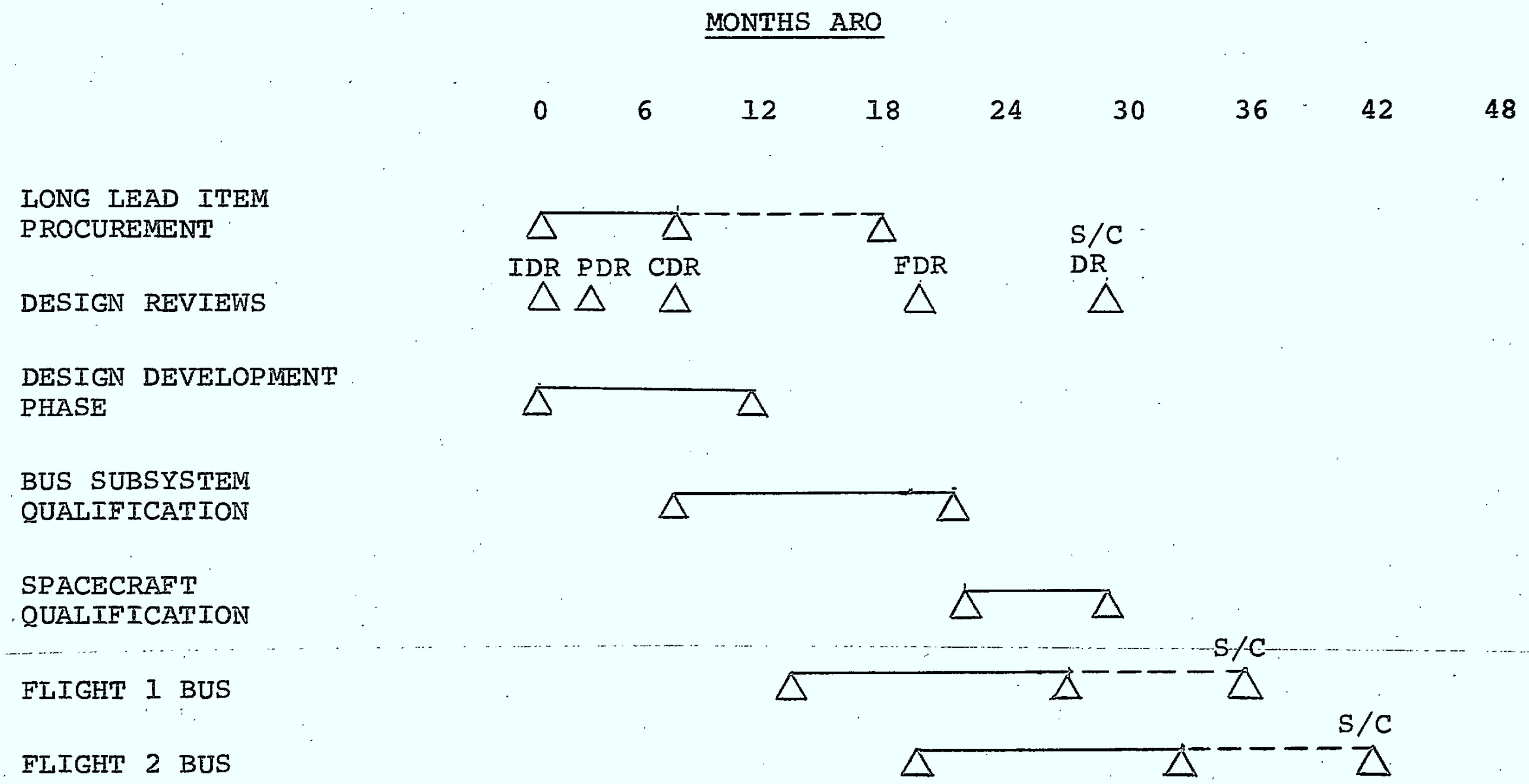

Figure 7-2

ENGINEERING PLAN SCHEDULE

GENERAL PURPOSE BUS – DEDICATED MUSAT PAYLOAD

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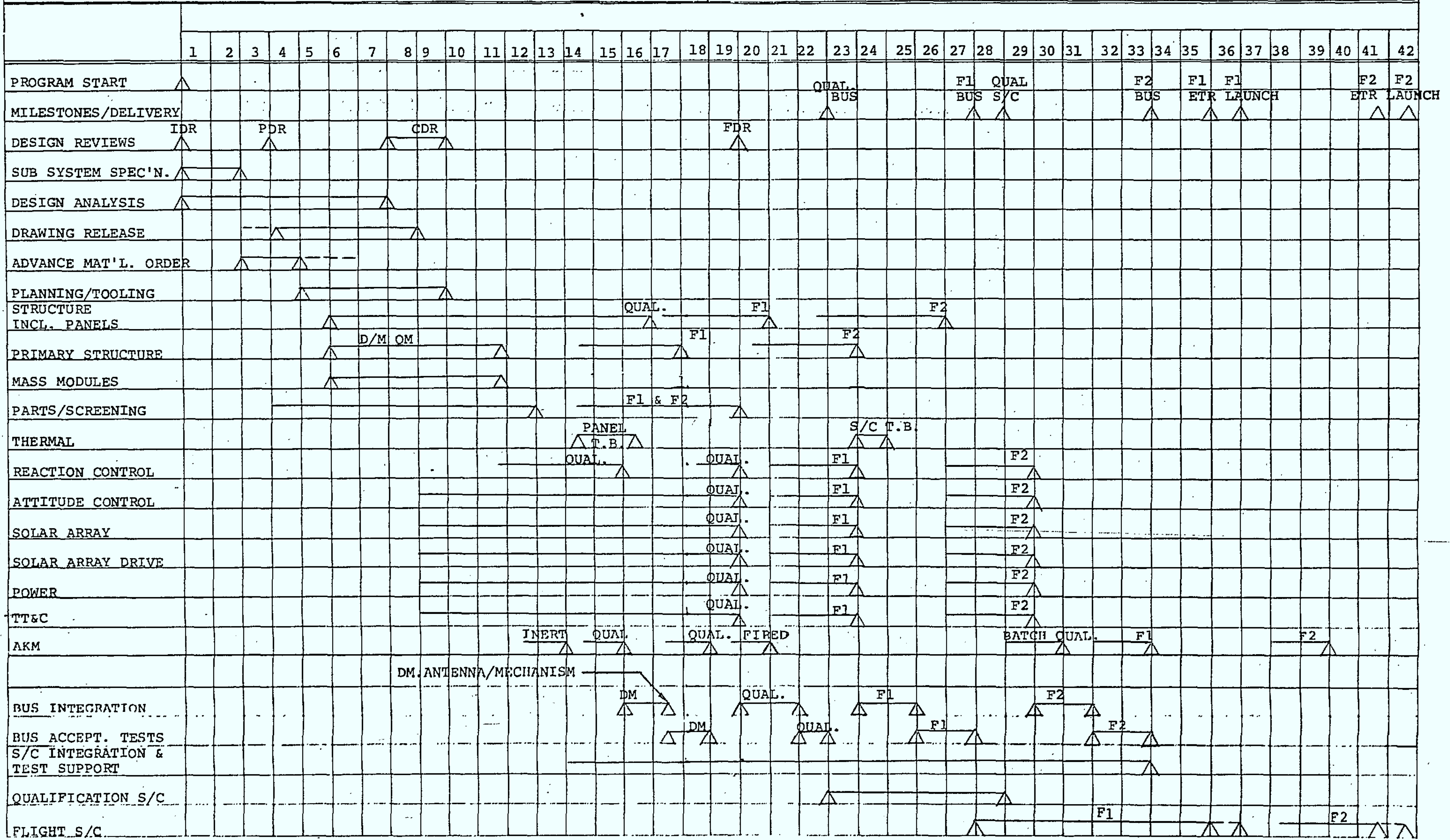


FORM NO. SPAR 1047

Figure 7-3

7.2 Management Plan

The management plan basically will not change from that identified in SPAR-R.810, Volume III. It is recognized that additional interfacing will be required between the Bus and the Payload supplier, and an additional Project Manager with Support Personnel will be assigned to the program if the stowed/deployed mechanism and antenna is defined as part of the mechanical Bus.

As such, there will be an increase in the overall manpower for such a program at the Bus level.

Costs

5/GC.51

The basic cost for the Bus will differ from that given for the commercial SHF carrying Option presented in SPAR-R.810 in that the following items are included and added:

(a) Additional interface activity
(b) Structural changes to incorporate the antenna mechanism design
(c) Additional thermal vacuum testing
(d) Additional antenna/Bus deployment tests

This cost is included within a separate letter.

8.0 MUSAT LONG LIFE AND HYBRID PAYLOAD CONFIGURATIONS

8.1 General

The previous sections of this report have dealt with the dedicated MUSAT payload (split onto north and south panel), 7 year mission, only. It has been shown for this payload that:

- o none of the configurations fully utilize the standard GPB power or weight capabilities (see Section 6.10)
- o the heat pipe which is mandatory for transporting heat from the UHF power amplifier can be panel mounted without need for external heat pipe radiators which would overhang the edges of the north panel. (see Section 6.5)

5/GC.52

It would be possible to launch these payload complements with the STS/PAM system, by employing a non-efficient plane change to the transfer orbit with the PAM STAR 48 perigee kick motor. However, there are several potential concepts of augmenting the payload which could result in a more productive mission. These include:

- o the addition of a piggyback payload such as L-Band or 4/6 GHz communications channels or
- o fuel addition to increase the life of the dedicated payload

This section presents a discussion of such potential payloads.

The evaluation presented is based on the January 1977 design of the GPB and would be subject to updating for the modificatons presented in SPAR-R.810, Volume I, Section 5.

8.2 MUSAT Dedicated (Split Panel) - Standard GPB, For 10 Year Life

The highest weight dedicated MUSAT payload, 7 year life, utilizing the standard GPB as described in SPAR-R.810, Volume I, Section 3, is configuration #1 at 2288.2 lbs. lift-out weight (see Section 6.10). This payload complement under-utilizes the STS/PAM launch capabilities by 162 lbs. and requires the expenditure of approximately 201 lbs. of hydrazine fuel.

5/GC.53

The RCS GPB fuel tanks, 16.8 inches I.D., have been examined to determine the maximum fuel load permissible from a blowdown expulsion - engine performance point of view. The standard GPB with the commercial SHF option C payload would have a tankage blowdown ratio of approximately 3:1.

Based upon a preliminary assessment of:

o tank qualification maximum operating pressure and
o engine performance - inlet pressure range, including N-S S/K thrusters

and assuming that

o tank temperature excursions can be minimized
o tanks can structurally support the additional fuel load during launch environments
o surface tension devices can feed additional propellant

it appears that a maximum blowdown ratio of approximately 4.25:1 could be provided (350 psia - 82 psia). In this case, the maximum propellant load could be approximately 275 lbs. (ie. a surplus of approximately 74 lbs. over the configuration #1 requirement).

5/GC.54

The additional fuel required for each year of operation beyond the required 7 year mission, including N-S stationkeeping, would be approximately 23 lbs. Consequently, to extend the dedicated MUSAT/standard GPB life by 3 years to 10 years would require an additional 69 lbs. of hydrazine. This is, from preliminary examination, within the capabilities of the present hydrazine tanks and within the launch vehicle capabilities. Note that the delta launch capability of 162 lbs. results in a delta on orbit fuel capability of approximately 85 lbs.

Use of the standard GPB provides at least 247 watts, see Section 6.3, surplus power from the array at the EOL, 7 years. It is considered that this would be adequate to allow for further solar cell degradation during the 8th, 9th and 10th years of operation. Similarly, surplus battery capability (~ 1140 watt hours) would exist. Considering the historical track record of batteries in space for long missions, this additional capability would be cost efficient insurance for a ten year mission.

This ten year mission with the dedicated MUSAT payload, therefore, would efficiently use up the weight capability of the GP Bus if the standard power and solar array subsystems were provided.

8.3 MUSAT Plus Other Payloads

Figure 8-1 shows the approximate production schedules for existing and planned Canadian synchronous orbit communication satellites. Of particular interest is the juxtaposition of required launch dates for the MUSAT and the replacement ANIK A (6/4 GHz) spacecraft.

Figure 8-2 depicts a communications system which includes both MUSAT and a government mobile L-band system which could provide service to ships and aircraft in the Canadian Arctic, a region not properly serviced by either the proposed Atlantic or Pacific Aerosat or Marisat.

Other potential piggyback payloads could include scientific or spacecraft technology advancement experiments (eg. an ion engine experiment would utilize the additional power capability).

The MUSAT plus ANIK A follow-on hybrid payload applicability to the GPB is examined next.

8.3.1 GPB Subsystem Enhancement Factors

In considering MUSAT plus additional payloads, the minimum GP Bus required to meet the MUSAT requirements which:

- o minimizes solar array electrical weight
- o minimizes battery weight
- o correspondingly offloads RCS & AKM fuel

should be used as the foundation on which to build. The highest weight minimum bus, as presented in Section 6.10, is configuration #2 with a lift-out weight of 2104.7 lb. This payload under-utilizes the STS/PAM launch capabilties by approximately 345 lbs.

CANADIAN SATELLITE PROGRAMS

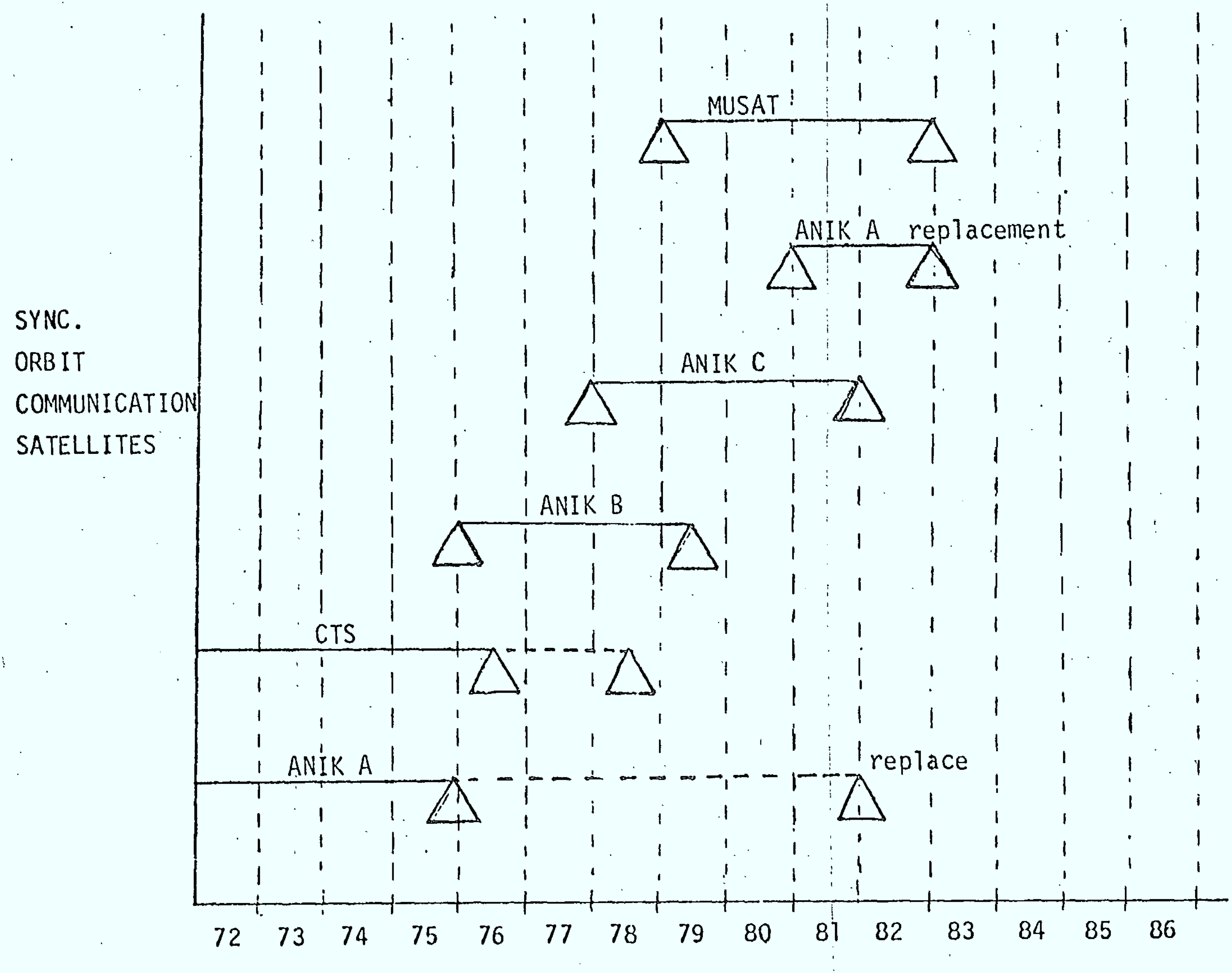


FIGURE 8-1

L-BAND PLUS UHF COMMUNICATIONS SYSTEM CONCEPT

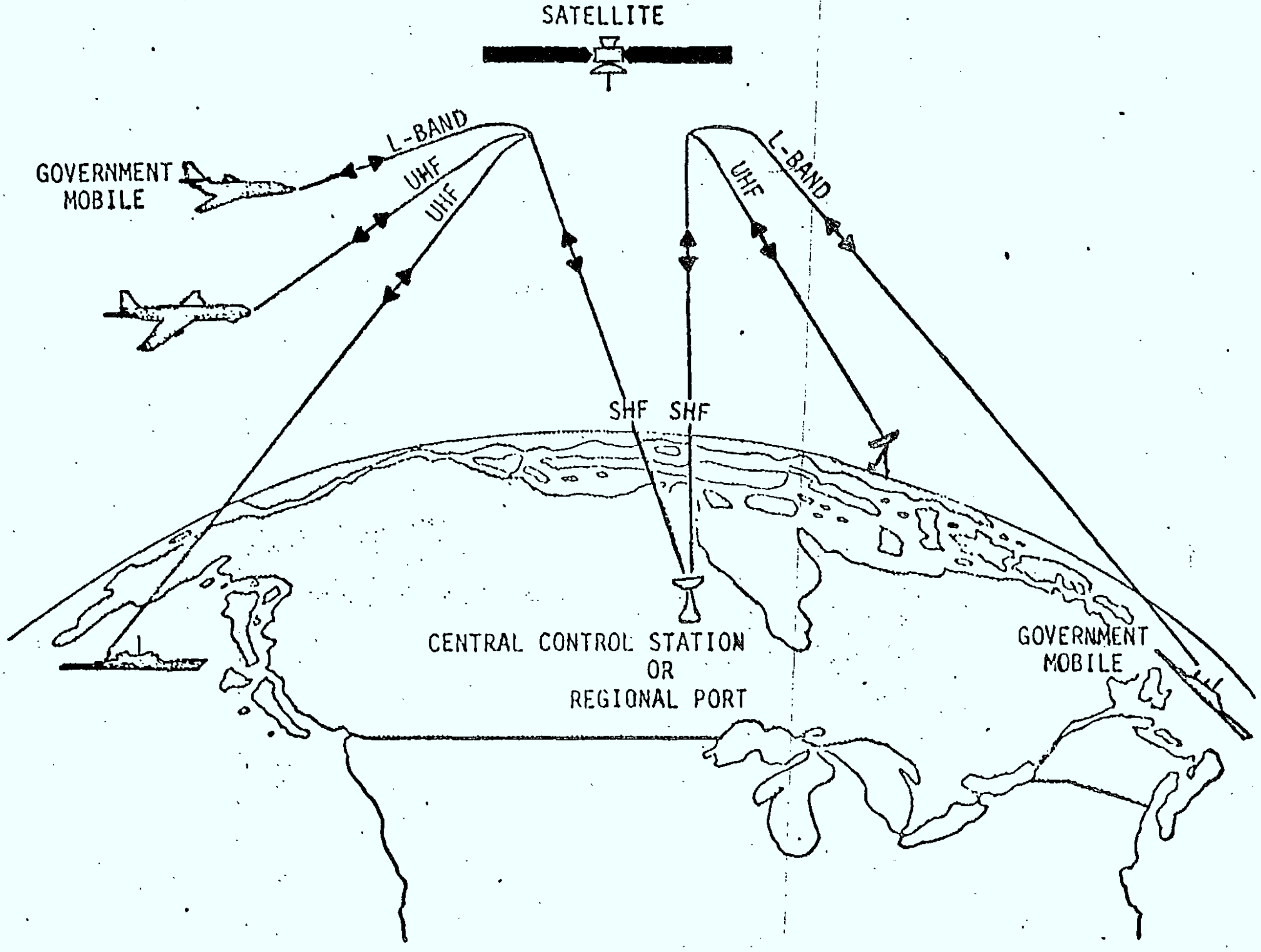


FIGURE 8-2

The following GPB subsystem weight factors are approximately valid over the range of onloading allowable:

-	solar array electrical	19.8 watts/lb.
-	batteries (including harness)	13.6 watt hrs/lb.
-	RCS fuel	0.21 lbs. N_2H_4 per lb. hardware added
-	AKM fuel	0.86 lbs. per lb. hardware plus N_2H_4 added

5/GC.56

These factors are now applied to the MUSAT plus ANIK A follow-on hybrid payload.

8.3.2 MUSAT Plus ANIK A Follow-on

For the purpose of this evaluation, the ANIK A follow-on payload is assumed to be 12 channels of 5 watt RF output 6/4 GHz communications with the following requirements:

payload transponders:	88 lbs.
payload antennas:	13 lbs.
power:	200 watts, sunlight & eclipse including 5% margin.

The total weight increase due to this payload would then approximately be:

payload		101 lbs.
solar array electrical		10 lbs.
battery allocation		35 lbs.
	hardware subtotal	146 lbs.
N_2H_4 fuel		31 lbs.
	subtotal	177 lbs.
AKM fuel		152 lbs.
	Total Weight Increase	329 lbs.

The GPB capability to meet the hybrid complement is presented in Table 8-1. There is good matching in all areas of weight, solar array power and battery capability with sufficient BUS weight margin included. This hybrid is thus considered a viable and efficient GPB payload from weight and power points of view.

There are several additional considerations:

- payload layout and associated thermal constraints
- mass properties
- antenna placement
- frequency allocations
- spacecraft operational control

which are addressed below.

With a hybrid MUSAT payload, it would likely be necessary to consolidate the MUSAT transponder equipment onto a single north or south panel and utilize the other radiating panel for the piggyback load. The MUSAT layout presented in CRC Drawing U-10202E, see Section 5, would therefore be representative and the other panel would have sufficient mounting and radiating area for the ANIK A payload.

This single panel MUSAT configuration would necessitate changes to the UHF power amplifier heat pipe radiator assembly. A preliminary examination of the heat pipe requirements in this case with MUSAT configuration #2, ie. 320 watts dissipated by the UHF P.A., is presented in Appendix C. As can be seen from the appendix, several heat pipe configurations are possible, each having its own weight and other GPB impact.

EG. ANIK A FOLLOW-ON (12 CHANNELS, 5W RF OUT, 4-6 GHz)

SPACECRAFT CAPABILITY VS REQUIREMENT

	WEIGHT (LBS.)	SOLAR ARRAY (WATTS)	BATTERY (W.HRS.)
MAXIMUM MUSAT REQ'T (CONFIGURATION 2)	2104.7 *	850	562
ANIK A FOLLOW-ON REQ'T	~ 329	200	240
TOTALS	~ 2434	1050	802
CAPABILITY	2450	1097	950 (50% DOD)

o THIS HYBRID SPACECRAFT APPEARS TAILORED TO GPB CAPABILITY. PANEL AREA FOR ANIK A MOUNTING AVAILABLE.

* ASSUMES HEAT PIPE RADIATOR ON PANEL EXTERNAL FACE-SHEET.

TABLE 8-1

In summary:

Concept	Weight	GPB Impact
#1 with 2, 7" width radiators	25.4	offset thruster aft bracket extension required
#2 with 1, 15" width radiator	18.8	communications antennas moved 8" forward
#3 with radiator on panel external facesheet	12.3	panel structural design

5/GC.58

The only solution which is compatible with the thermal control weight budget of 33 lbs. is #3. This configuration has been assumed in utilizing the 2104.7 lbs. MUSAT requirement in Table 8-1.

The mass properties of this hybrid spacecraft are discussed in Section 8.4. Antenna location for the 6/4 GHz transmission has not been examined in this study.

The acceptability, internationally, of a spacecraft operating at 300-400 MHz, 4-6 GHz and 7-8 GHz at a single geosynchronous longitude is a question which would require investigation. The precedent has been set, with ANIK B, for close cooperation between the Canadian commercial and government communications communities in production and operation of a multi-frequency hybrid payload spacecraft.

8.4 Mass Properties

5/GC.59

Moments of inertia and centre of mass estimates were obtained for both the dedicated, standard GPB MUSAT spacecraft loaded with fuel for the 10 year mission and then loaded with a small delta hardware weight up to the launch vehicle capacity and also for the minimum GPB MUSAT plus hybrid payload loaded up to the launch vehicle capacity for the 7 year mission. In both cases, the battery aft configuration was utilized. The results, shown in Tables 8-2 and 8-3, indicated that the moment of inertia (M of I) ratios do not improve significantly with these additions to the spacecraft. The main driver of the M of I ratio is still the location of the batteries and other high density housekeeping equipment forward or aft on the north and south panels.

[redacted]-FOR[redacted]23. [redacted]SAGE[redacted]PP.2[redacted]-38.[redacted]AND[redacted]. [redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted]

MUSAT/GPB MASS PROPERTIES

BEFORE AKM BURN

		Dedicated Standard GPB	Dedicated, Standard, Loaded for 10 Year Life, Up to LV Capacity	Minimum Bus Plus Hybrid Payload, 7 Yrs. Up to LV Capacity
Configuration 1	I_{zz}/I_{xx}	1.171	1.243	1.185
	I_{zz}/I_{yy}	1.025	1.035	1.037
	C of M	34.18	34.36	34.28
2	I_{zz}/I_{xx}	1.107	1.181	
	I_{zz}/I_{yy}	.975	.993	
	C of M	34.51	34.67	
3	I_{zz}/I_{xx}	1.007	1.079	
	I_{zz}/I_{yy}	.925	.944	
	C of M	34.75	34.87	
4	I_{zz}/I_{xx}	.995	1.068	
	I_{zz}/I_{yy}	.923	.949	
	C of M	34.61	34.74	

TABLE 8-2

MUSAT/GPB MASS PROPERTIES AFTER AKM BURN

		Dedicated Standard GPB	Dedicated, Standard, Loaded for 10 Year Life, Up to LV Capacity	Minimum Bus Plus Hybrid Payload, 7 Yrs. Up to LV Capacity
Configuration 1	I_{zz}/I_{xx}	1.229	1.313	1.244
	I_{zz}/I_{yy}	1.056	1.065	1.068
	C of M	32.06	32.44	32.33
2	I_{zz}/I_{xx}	1.153	1.239	
	I_{zz}/I_{yy}	.998	1.017	
	C of M	32.67	32.99	
3	I_{zz}/I_{xx}	1.033	1.116	
	I_{zz}/I_{yy}	.938	.959	
	C of M	33.10	33.38	
4	I_{zz}/I_{xx}	1.021	1.105	
	I_{zz}/I_{yy}	.937	.966	
	C of M	32.82	33.13	

TABLE 8-3

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The MUSAT feasibility study has shown that the General Purpose BUS, as designed for the commercial SHF payload and the STS/PAM launch vehicle, can accommodate all four dedicated MUSAT configurations, although not efficiently utilizing the BUS capabilities.

MUSAT configuration #2 is preferred from the point of view of low cost and minimal development risks for the BUS and for the launch vehicle and its operations.

Several potential augmented MUSAT programs can be found which will maximize mission productivity, including longer life (up to 10 years) or addition of an ANIK A follow-on payload.

9.2 Recommendations

Spar feels that the MUSAT Program is at a crossroads, and recommends that either:

> the dedicated MUSAT concept be adopted with or without extended 10 year lifetime

or

> the hybrid MUSAT concept, with the most favourable MUSAT configuration plus a 12 channel ANIK A follow-on or other additional payload, using dedicated radiating and mounting panels for each payload, be chosen.

Subsequently, antennas configuration and their stowage and deployment mechanisms should be studied in detail and then breadboard hardware should be produced and development tested.

The antenna study should include all potential effects on the GP Bus. These would include:

- examination of ACS interactions with antenna $f_n < 1.0$ Hz,
- free-free deployment dynamic effects
- earth and sun sensor blockage,
- solar torque effects due both to antennas directly and to their shadowing of the solar arrays,
- S/C moments of inertia and centre of mass shifts,
- potential heat pipe/antenna interference (depending upon configurations chosen),
- potential array shadowing profile due to antennas,

5/GC.64

- antenna pyrotechnic circuits and their safety requirements for the STS/PAM application,
- detailed positioning of TT&C antennas to provide required coverage around antennas.

During this evolution of the General Purpose BUS, the most up-to-date bought-out subassembly vendor data and launch vehicle interface data should be incorporated. For example, an amendment, to the MDC G6626 document discussed in SPAR-R.810, Volume I, Section 5, just received prior to printing of this document, appears to show a PAM vertical cradle design which would allow configuration #2 of MUSAT (and only configuration #2, which could be made Delta 3910 envelope compatible), to be mounted vertically in the orbiter bay, thereby reducing the shuttle bay length required to 86 inches.

APPENDIX A

QUANTITATIVE COMPARISON OF CANTILEVER AND PIN-JOINTED STRUCTURES FOR STATIC DYNAMIC AND DIMENSIONAL CHARACTERISTICS

APPENDIX A

QUANTITATIVE COMPARISON OF CANTILEVER AND PIN-JOINTED STRUCTURES FOR STATIC DYNAMIC AND DIMENSIONAL CHARACTERISTICS

5/GC.66

A.1 General

This appendix shows the relative merit of a 3 dimensional pin-jointed structure over a cantilever for supporting and accurately positioning the UHF receive helical antennas for MUSAT configuration #3.

A.2 Discussion

Given a cantilever beam and a pin-jointed structure of identical spans, both laterally loaded with a force P as illustrated in Figure A-1

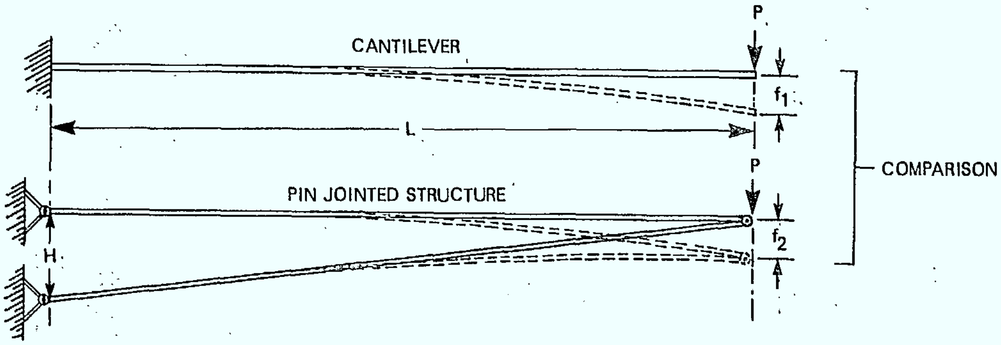


FIGURE A-1

STATIC & DYNAMIC STIFFNESS

The deflection of the cantilever beam will then be

$$f_1 = \frac{PL^3}{3JE} \qquad (1)$$

5/GC.67

which is the standard formula. (J = square moment or cross-section, E = Young's modulus). The deflection of the pin-jointed structure can be determined by several means - one of the easiest is by Castigliano's theorem.

By omitting the details of derivation the deflection will be

$$f_2 = k\,\frac{PL}{AE} \qquad (2)$$

where A = area of cross-section
E = Young's modulus
L = span
P = load

and

$$k = \frac{L^3 + (L^2 + H^2)^{3/2}}{L \cdot H^2} \qquad (3)$$

a dimensionless constant.

The ratio of deflections by (1) and (2) is then:

$$\rho = \frac{f_1}{f_2} = \frac{AL^2}{3Jk} \qquad (4)$$

Considering now a thin-walled (wall thickness = v) tubular structure of diameter D

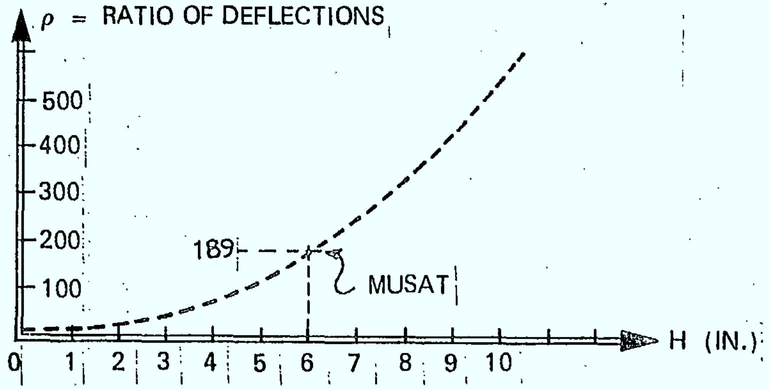
$$\frac{A}{J} \cong \frac{8}{D^2} \quad (v \ll D) \qquad (5)$$

Hence by (4) and (5)

$$\rho = \frac{8L^2}{3D^2k} \qquad (6)$$

This relation does not contain the wall thickness (as long as it is small in comparison with the diameter) and ρ is strongly dependent upon the ratio D/L.

Selecting now a reasonable value for D (= 0.5 in.) and the appropriate length L = 46 in., the dependance of ρ upon H can be established, Figure A-2 below plots ρ against H for a given tip force P, MUSAT relevant L = 46 in. and, D = 0.5 in.



D = 0.5 IN.
H ≅ 6 IN.
L ≅ 46 IN.
— MUSAT

$$\rho \equiv \frac{f_1}{f_2} = \frac{8L^2}{3D^2 K}$$

$$K \equiv \frac{L^3 + (L^2 + H^2)^{3/2}}{L^3 H^2}$$

$$K = 0.056 \text{ IN.}^{-2}$$

FIGURE A-2

Comparison Between Static Deflections of Cantilever and Pin-Jointed Structures

For example if H = 6 in. (a likely value) then K = 119.06 and by (6) the ratio of deflections ρ = 189 meaning that a cantilever under identical load conditions deforms 189 times more then a pin-jointed structure of identical span.

A pin-jointed structure is however heavier than the cantilever. If it is assumed that the weight is proportional to the total length of all structural members, then the weight increase can be expressed by the Factor of Weight Penalty (P_W) as follows:

$$P_W = \frac{G_{pin}}{G_{cant}} = 1 + \frac{H + \sqrt{L^2 + H^2}}{L} \qquad (7)$$

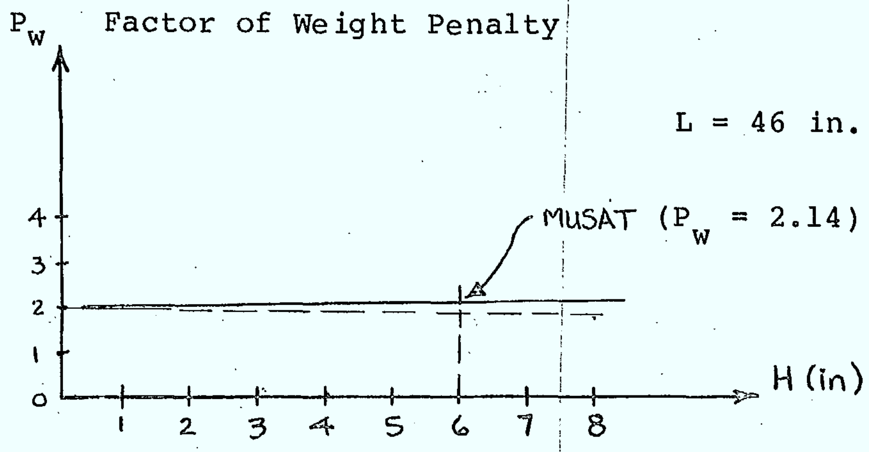


FIGURE A-3

Factor of Weight Penalty for Using Pin-Jointed Structure for Cantilever

In Figure A-3 we can see that in the case of the MUSAT configuration #3 structure, (H = 6 in.), the weight penalty is 114 percent, i.e. if we employ a pin-jointed structure then its weight will be 2.14 times that of a cantilever of identical span.

We can now see that by using a pin-jointed structure instead of a cantilever the Statistic Utilization of Material (SUM) improves by a factor of:

$$\text{SUM} = \frac{\rho}{P_W} = \frac{189}{2.14} = 88.3$$

that is, for relevant MUSAT's values of given length L (= 46 in.) and H (= 6 in.), the utilization of material per pound improved 88.3 fold.

5/GC.70

Considering now the dynamic characteristics of the system, it is noted first that the weight carried by the beam is about 5-8 times the weight of the vibrating part of the structure. Therefore the use of a simplified equation in both cases is justified. The relevant relationship is

$$\nu \; \frac{3.13}{\sqrt{f}} \; \text{Hz} \qquad (8)$$

where f is the deflection under the given weight. Accordingly, since

$$\nu_1 = \frac{3.13}{\sqrt{f_1}} \qquad (9)$$

and

$$\nu_2 = \frac{3.13}{\sqrt{f_2}} \qquad (10)$$

the Ratio of Frequency (RF) will be:

$$RF = \frac{\nu_2}{\nu_1} = \sqrt{\frac{f_1}{f_2}} = \sqrt{\rho} \qquad (11)$$

which by (4) and (6) can be expressed as

$$RF = \frac{L}{D} \cdot \frac{1.63}{\sqrt{K}} \qquad (12)$$

where k is defined by (3), L = length, D = diameter of structural tubular member, the wall thickness of which is small in comparison with the diameter.

In our particular case (MUSAT)

$L = 46$ in.
$D = 0.5$ in.
$k = 119.06$ (dimensionless)

therefore:

$$(RF) = 13.74 \qquad (13)$$

which means that the lowest natural frequency of the pin-jointed structure is about 13.74 times higher than that of the cantilever beam of identical span.

5/GC.71

The expression (12) is not exact because it approximated the ratio (A/J) by $8/D^2$. The error committed can be expressed as a ratio of the approximate value to the exact one and is

$$e = 1 - 2\left(\frac{v}{d}\right) + 2\left(\frac{v}{d}\right)^2 \qquad (14)$$

in the MUSAT's case, $v = 0.02$ in., $d = 0.5$ in. $(v/d) = 0.04$, hence the error $e = 0.923$ representing 7.7 percent.

For different H values, the Ratio of Frequencies (RF) is shown in Figure A-4 below. It is seen that with good approximation the improvement in frequency varies linearly with H.

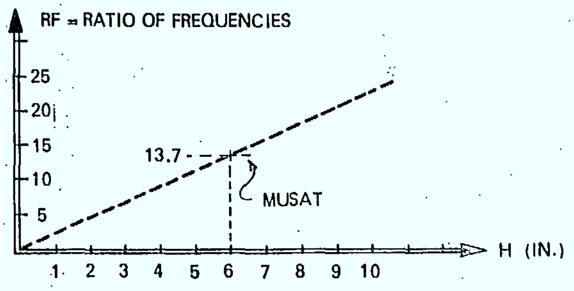


FIGURE A-4

Ratio of Frequencies for Cantilever and Pin-Jointed Truss

There is a weight penalty to pay for this frequency increase; the Dynamic Utilization of Material (DUM) is therefore:

$$(\mathrm{DUM}) = \frac{(\mathrm{RF})}{P_W} = \frac{1.63\,L^2}{D\sqrt{K}\left\{L+H+\sqrt{L^2+H^2}\right\}} \quad (15)$$

where (RF) is given by (12) and P_W is given by (7). In MUSAT's case (L = 46 in., H = 6 in.)

$$(\mathrm{DUM}) = \frac{13.74}{2.138} = 6.43 \quad (16)$$

Meaning that for every 1 lb. of weight - for MUSAT's geometry - a pin-jointed structure offers 6.43 times higher natural frequency then does a simple cantilever.

To compare lateral and vertical position and angular pointing accuracy of the pin-jointed structure with the cantilever, we first consider a cantilever. Imagine a cantilever beam L = 46 in. long, pivoted about a pin 0.375 in. (3/8) diameter. Suppose there is a mechanical stop at the pin restricting the angular motion of the torsion spring-driven arm. Let us also assume that the inaccuracy of the length of the arm can be kept within 0.005 in. Finally let us consider that the mechanical stop operates within 0.002 in. error.

By this simple model the error in lateral, longitudinal and angular positions will be:

vertical error:

$$\Delta y = \frac{46}{(0.375/2)} \cdot 0.002 = 0.491 \text{ inches.}$$

longitudinal error:

$$\Delta x = 0.005 \quad \text{(by assumption)}$$

angular error (pointing accuracy):

$$\Delta\beta = \tan^{-1}\frac{0.002}{(0.375/2)} = 0.61 \text{ degrees}$$

It is to be noted that the vertical and angular positions are extremely sensitive to the minute inaccuracies (and flexibilities) of the mechanical stop. This is because of the very large magnification factor = 245 (46/0.188) between the pivot radius and arm's length.

For the pin-jointed structure, the inaccuracies in positions are caused exclusively by the errors of lengths of the two longitudinal members. To assess the magnitude in question, let us again assume that the error in lengths in both arms can be kept within ΔL_1, = ΔL_2 = ΔL = 0.005 in. - which is a conservative figure. Then considering a triangularly pin-jointed structure of base H, the vertical (y), longitudinal (x) and angular (β) positions of the payload can be expressed by (derivation is elementary and omitted)

$$x = \frac{1}{2H}\sqrt{4H^2L_1^2 - (H^2+L_1^2-L_2^2)} \equiv g_2(H, L_1, L_2) \qquad (17)$$

$$y = \frac{1}{2H}(H^2+L_1^2-L_2^2) \equiv g_1(H, L_1, L_2) \qquad (18)$$

$$\beta = \cos^{-1}\frac{H^2+L_1^2-L_2^2}{2HL_1} \equiv g_3(H, L_1, L_2) \qquad (19)$$

where x and y are expressed in an appropriate coordinate system - the selection of which for our purpose is irrelevant since we are interested only the change of values. The angle β is a reference angle characterising the angular position of the payload.

The vertical, longitudinal and angular positional changes of the payload upon the length changes, ΔL_1 and ΔL_2 can now be obtained by:

5/GC.73

longitudinal error:

$$\Delta x = \frac{\partial g_2}{\partial L_1} \Delta L_1 + \frac{\partial g_2}{\partial L_2} \Delta L_2 \qquad (20)$$

vertical error:

$$\Delta y = \frac{\partial g_1}{\partial L_1} \Delta L_1 + \frac{\partial g_1}{\partial L_2} \Delta L_2 \qquad (21)$$

angular error:

$$\Delta \beta = \frac{\partial g_3}{\partial L_1} \Delta L_1 + \frac{\partial g_3}{\partial L_2} \Delta L_2 \qquad (22)$$

Calculating the partial derivatives and other data the following values can be obtained.

$$\left.\begin{array}{l} H = 6 \text{ in.} \\ L_1 = 46 \text{ in.} \end{array}\right\} \text{given}$$

$L_2 = 46.39$ in. calculated

$$\left.\begin{array}{l} \Delta L_1 = 0.005 \text{ in.} \\ \Delta L_2 = 0.005 \text{ in.} \end{array}\right\} \text{assumed}$$

$$\left.\begin{array}{l} \frac{\partial g_1}{\partial L_1} = 7.667 \\ \frac{\partial g_1}{\partial L_2} = 7.732 \\ \frac{\partial g_2}{\partial L_1} = 1 \end{array}\right\} \text{calculated}$$

$$\left.\begin{array}{l} \frac{\partial g_2}{\partial L_2} = 0 \\ \frac{\partial g_3}{\partial L_1} = 0.166 \\ \frac{\partial g_3}{\partial L_2} = 0.168 \end{array}\right\} \text{calculated}$$

5/G0G05.75

These values will yield:

By (20)

Δx = 0.005 in. longitudinal position error.

By (21)

Δy = 0.077 in. vertical position error.

By (22)

$\Delta\beta$ = 0.095 deg. angular pointing accuracy error

Table A-1 below collects these results.

	Errors		
	Positionkeeping		Pointing Accuracy
	longitudinal x	vertical y	angular
Cantilever Structure	0.005 in.	0.491 in.	0.61 deg.
Pin-jointed Structure	0.005"	0.077"	0.095 deg.

Table A-1

Positioning and Pointing Accuracy Errors

To sum up the above overall results, we established that - for the MUSAT geometry and given carried weight - a pin-jointed truss structure offers, against a cantilever structure:

- a 189 fold static stiffness improvement,
- a 13.7 fold dynamic stiffness improvement,

- a 2.14 fold weight increase,
- 6.4 fold increase of vertical station accuracy,
- a 6.4 fold increase of angular positioning accuracy,
- no change in longitudinal station accuracy.

5/GC.76

In comparison with a cantilever, a pin-jointed structure utilizes the structural material

- 88.3 times more efficiently for static deflection,
- 6.4 times more efficiently for dynamic resonance,
- 3 times more efficiently for vertical stationkeeping accuracy,
- 3 times more efficiently for angular positioning accuracy,
- 2.14 times less efficiently for longitudinal positioning accuracy.

APPENDIX B

A SIMPLIFIED KINEMATIC ANALYSIS OF THE UNEQUAL FOUR-BAR LINKAGE

APPENDIX B

A SIMPLIFIED KINEMATIC ANALYSIS OF THE UNEQUAL FOUR-BAR LINKAGE

5/GY.42

B.1 General

The unequal four bar linkage has been examined as a potential structural pin-jointed support mechanism for the UHF helices for MUSAT configuration #3. It is recognized that this represents only one of many potential concepts. This appendix describes the ability of this mechanism to meet the kinematic requirements of the mission.

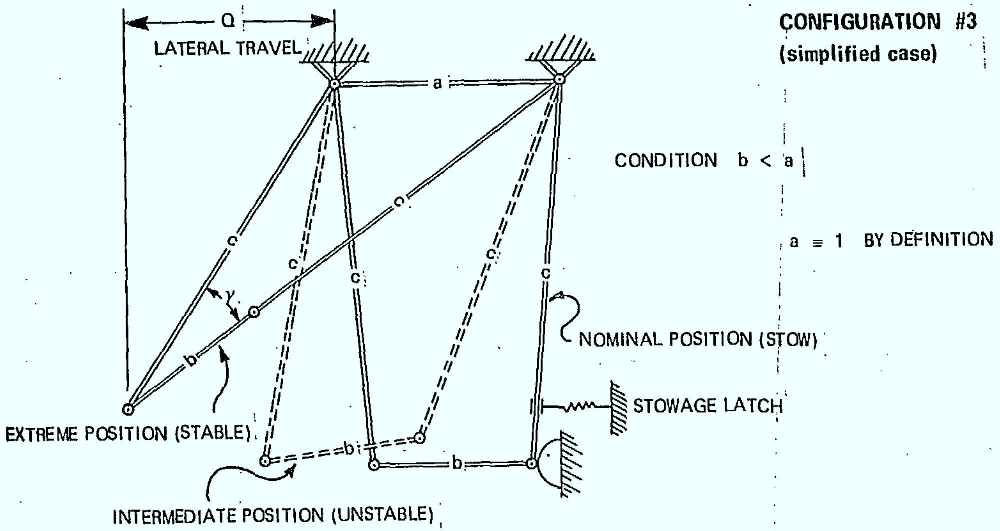
B.2 Discussion

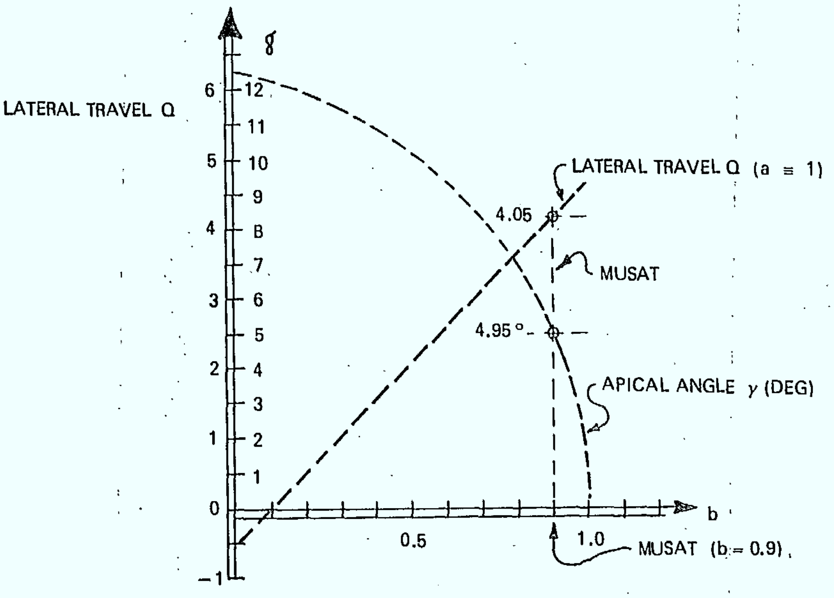
Let us start with a one stage 'unequal' four bar linkage as illustrated in the top part of Figure B-1. It is assumed that the 'base' - marked by 'a'-of this mechanism is attached to the GP Bus primary structure and the 2 members "c" adjacent to "a" are of equal lengths. The member opposite to "a" labelled "b" is of shorter length than "a". Therefore "a" and "b" are not of the same lengths, hence the adjective "unequal".

In this simplified analysis we further assume that when the mechanism is in the stowed position it assumes a symmetrical configuration with respect to "a" as illustrated. The stowage latch (symbolically) on the figure consists of a spring which pulls the assembly against a mechanical stop by slightly stressing member 'c'.

The mechanism actually deploys by rotating the two members 'c' about their respective pivots at base 'a'. Member 'b' swings out to the left, as shown in Figure B.1, 'b' and member 'c' form a straight line. At this instant the four-bar linkage becomes a triangular pin-jointed 'structure'.

FIGURE B-1 UNEQUAL FOUR - BAR LINKAGE





KINEMATIC PROPERTIES

The rigidity and stiffness of this structure are very sensitively influenced by the apical angle γ; it is desirable to have large γ and at the same time large linear excursion Q.

The numerical value of ratio a/b is of critical importance. For if a/b = 1 then we have a parallelogram device in which the 'c' members can rotate 360° and member 'b' remains parallel to 'a' and itself; if a/b > 1 then we have a trapezoidal device in which 'c' can still rotate 360° but 'b' rotates as well. For these two configurations (i.e. a/b = 1,) therefore all positions are unconstrained. However, if a/b < 1 the rotation is limited - as shown in the upper part of Figure B-1.

5/GY.43

The maximum excursion of the "tip" of the assembly is attained when members 'b' and 'c' form a straight line thereby generating a triangular configuration; in this position the assembly is theoretically stable. In practice, however the apical angle, γ should not be small because at very small γ values the assembly would act as a large torsional spring - albeit a strong one - thereby reducing the overall rigidity of the structure.

For the given geometry if, by definition a = 1, then

$$\gamma = \cos^{-1}\left(\frac{b^2-1}{2c(c+b)}+1\right) \qquad (1)$$

It is seen in this solution that if b = 1 then $\gamma = 0°$; we have a parallelogram (since b=a) and the system is unconstrained; if b > 1 then the argument in the bracket is larger than 1, hence γ has no real value - corresponding to the fact that the position of member 'b' is undetermined. A unique solution is only provided if b < 1 in which case $0° < |\gamma| < 90°$.

5/GY.44

For the reason mentioned above, it is impractical to go below $\gamma = 5°$, for this value $b = 0.9$ as the lower portion of Figure B-1 illustrates.

The lateral excursion Q is also a function of b and c: in case of $a \equiv 1$

$$Q = \frac{1}{2}\left(b^2 + 2bc - 1\right) \qquad (2)$$

which shows that Q increases with b; the maximum obtained at $b = 1$ and $Q_{max} = c$.

It is desirable to have large Q (excursion) and large γ (stability) - but unfortunately these are contrary requirements. As the plot in Figure B-1 shows as γ increases, Q decreases; one must aim at an acceptable compromise. In case of MUSAT we selected $b = 0.9$ [i.e. $b/a = 0.9$]; $c = 4.6$ [i.e. $c/a = 4.6$] a combination which gives us sufficiently large γ for stability ($\cong 5°$) and an excursion, Q, of 4.05 ($a \equiv 1$) which is equivalent to 40.5 in. for the MUSAT case where $a = 10$ in.

However, the attained $Q = 40.5$ in. excursion is not sufficient to reach the approximately 80 in. span required by configuration #3 (see Figure 8-2). Therefore, a second stage is coupled to the first one such that the base "a" of the second stage is identical in length to the "b" member of the first stage, i.e. $a_2 = b_1$. Furthermore, the nominal positions of these stages are not symmetrical to bases a_1 and a_2; their stowed positions are attained if the first stage is slightly pulled back (negative bias) and the second stage is slightly pulled forward (positive bias) with respect to their nominal positions.

The deployment kinematics of the second stage moving first and then the first stage, results in a path of the helices which clears the deployed UHF 16-foot parabolic antenna.

APPENDIX C

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THERMAL DESIGN FOR A SINGLE PANEL MUSAT CONFIGURATION

5/GY.46

APPENDIX C

THERMAL DESIGN FOR A SINGLE PANEL MUSAT CONFIGURATION

In the case of the thermally most severe GPB MUSAT payload configuration #2 (320 watts dissipation), having auxilliary payload to take better advantage of the launch vehicle and spacecraft capability, three different heat pipe layouts have been investigated. Variable conductance heat pipes (VCHPS) consisting of heat pipes connecting equipment mounting plates to space radiation(s) are employed. The heat pipes are attached to the mounting plates by thermal doublers and a common saddle and to the radiator by individual saddles (as per the Hermes design).

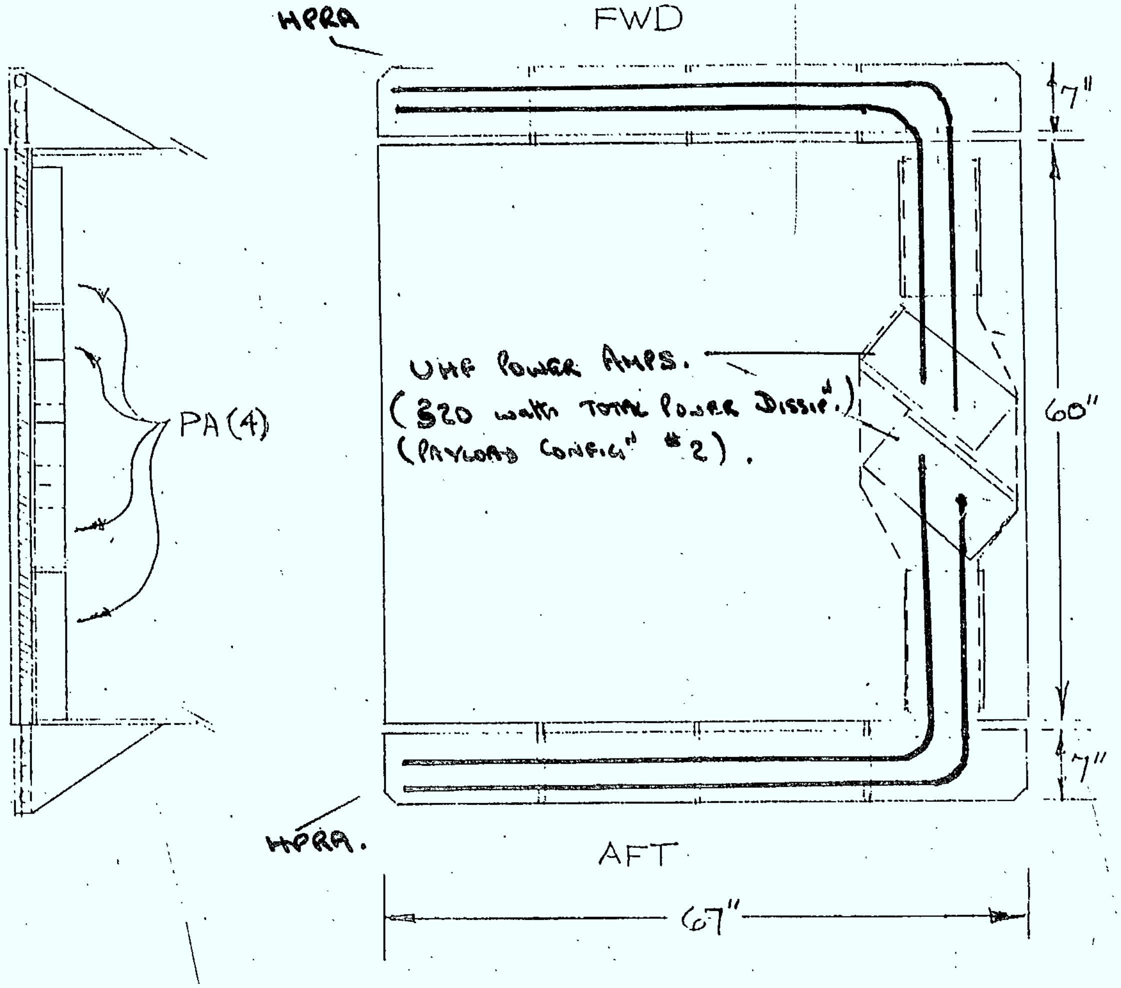
Layout #1 (see Figure C-1)

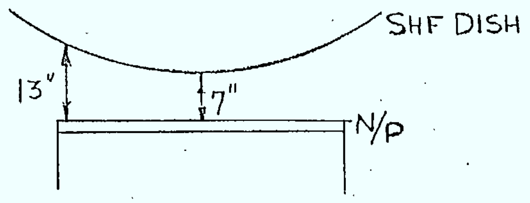
To dissipate a maximum of 320 watts with a maximum saddle temperature not greater than 60°C, two stainless steel methanol heat pipes (having heat transport capability of 150 watts each over the lengths involved i.e. approximately same as in Hermes design) are required with the system mounted to the S/C south panel with radiators in the plane of the south panel. Location on the south panel was chosen so as to minimize the heating effect of the power amplifiers, on the batteries which have to be mounted on the north panel. Each of the two radiators, radiating from one face only (away from S/C), will probably be about 7" x 67", dictated by the clearance of approximately 7" between the SHF dish and N/S panels. Such a configuration for the heat pipe radiator can be tolerated if moment of inertia considerations prevent forward relocation of the SHF/UHF antennas.

Layout #2 (see Figure C-2)

This assumes that the SHF dish can be located further away from Forward Platform to allow for a bigger, single radiator (again radiating from one

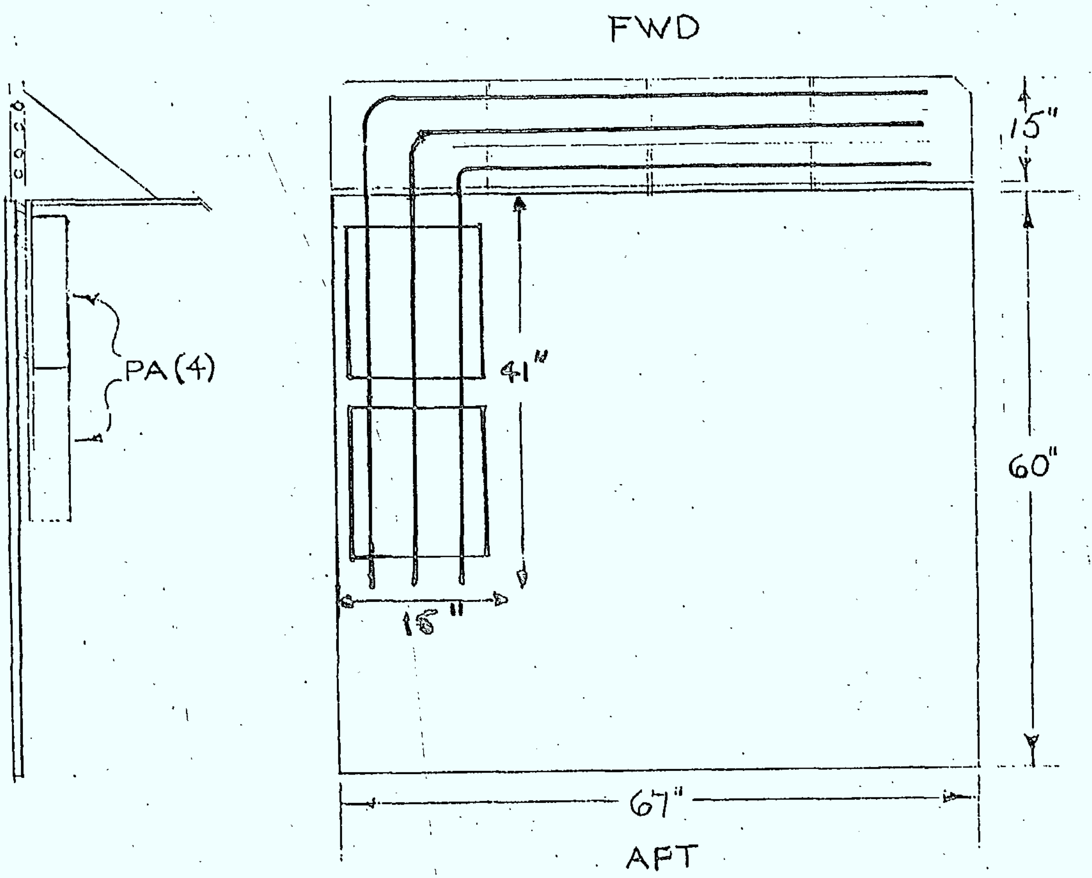
(Payload Configuration #2)





SINGLE PANEL MUSAT CONFIGURATION
POWER AMP & HPRA LAYOUT ON N. PANEL

(Payload Configuration #2)



face only) so that the heat removal capability of the VCHPS can be improved considerably (ie. more weight efficient). This layout also requires much less panel area.

The use of 3 heat pipes (having performance capability as per Hermes design) would be required. These would provide some small margin even with one pipe failed. Again location on North or South panel would depend on battery electrical and thermal requirements, with the minimum weight design for the heat pipe radiator assembly being associated with a north panel location (minimum solar heat input).

5/GY.47

Layout #3

UHF power amplifier and heat pipe system configuration is as presented in Section 6.5 of the report, Figure 6-7. The two heat pipes are located on the external face sheet of the honeycomb panel with cutouts required in the core and internal face sheet of the panel to permit mounting of the UHF power amplifiers directly onto the heat pipe radiator assembly. Total area occupied by the heat pipe radiator is approximately 26 x 60 ins.^{2}. Components mounted in the vicinity of the HPRA would have to have very low power dissipation and have an upper temperature limit of 55°C.

Unlike layouts 1 and 2, for layout #3 variable conductance heat pipes would not be required. Radiator fin thickness required is .022 ins. aluminum.

Presented in Table C-1 are the weight estimates for the above 3 heat pipe configurations and a comparison made with the weight for a dedicated MUSAT configuration.

MUSAT TRANSPONDER & HPRA , CONFIGURATION Vs WEIGHT TRADE OFFS.

TRANSPONDER / HPRA CONFIGURATION	UHF POWER AMPs	HPRA WEIGHT
	P/L CONFIG. #1,3,4.	P/L CONFIG. #2
o DEDICATED MUSAT (PANEL HEAT PIPE)	≤10 lbs.	13.2 lbs.*
o SINGLE PANEL MUSAT		
7 ins. WIDTH RADIATORS	12.7 lbs.	25.4 lbs.
15 ins. WIDTH RADIATORS	/	18.8 lbs.
RADIATOR ON PANEL EXT. FACE-SHEET	/	12.3 lbs.

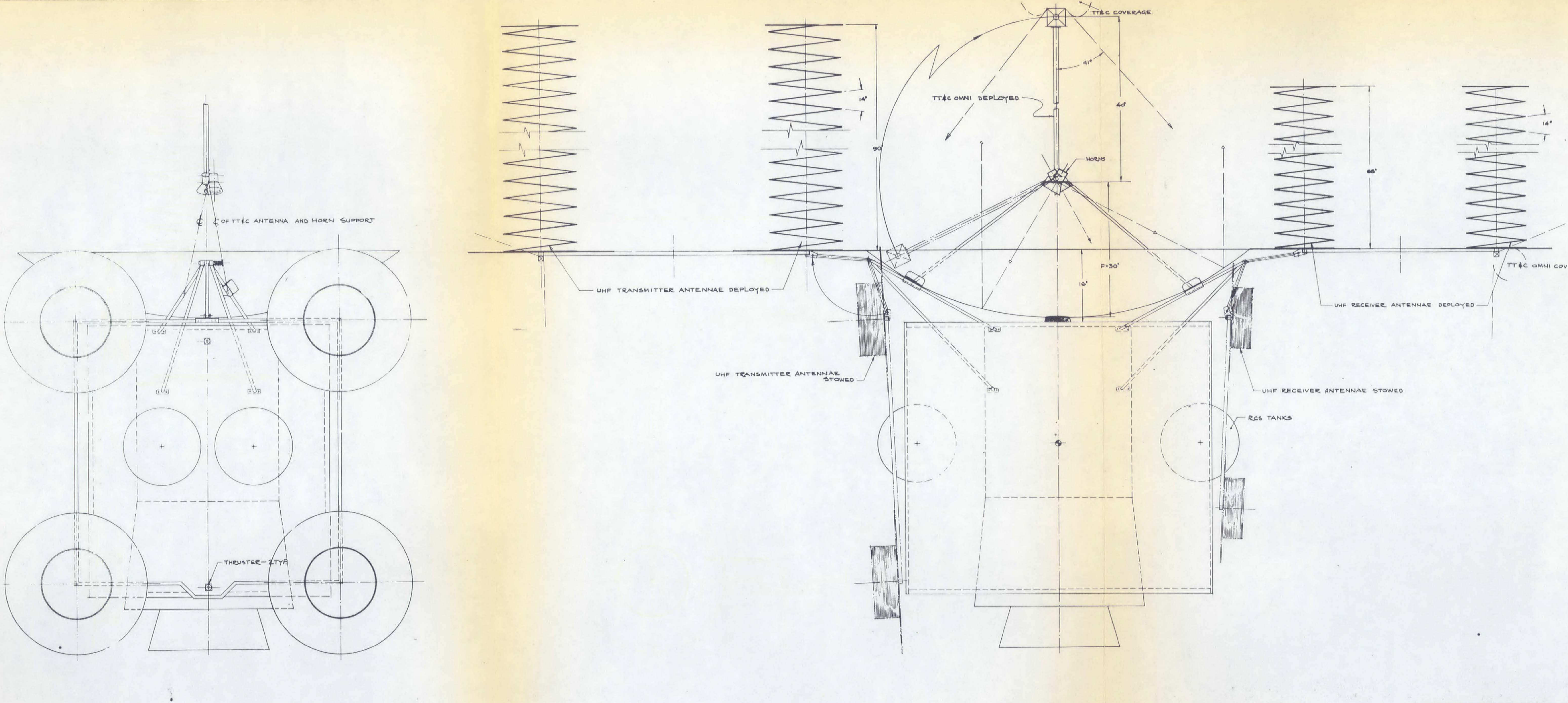
*WITH 1.5 LBS. SHF TRANSPONDER DOUBLER, PLUS BATTERY DOUBLER, THIS VALUE CONSISTENT WITH 17.1 LBS. CARRIED IN WEIGHT BUDGET

TABLE C-1

5/GY.48

APPENDIX D

GENERAL PURPOSE BUS STUDY MUSAT DRAWINGS



QUANTITY REQ PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL SPEC	HEAT TREAT	FINISH

LIST OF MATERIAL

REQUIREMENTS—UNLESS OTHERWISE SPECIFIED

GENERAL	LIMITS
1. DIMS ARE IN INCHES 2. TOLERANCE SYMBOLS IN ACCORDANCE WITH USAS Y14.5-1966 3. HOLES IN ACCORDANCE WITH AND10387 4. MACHINE FINISH [illegible] 5. INTERNAL RADII .015 6. CHAMFER EXTERNAL CORNERS [illegible] 7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC	1. LINEAR DIMS .X = ± .020 .XX = ± .010 .XXX = ± .005 2. ANGLES ± ½° 3. CONCENTRICITY .005 T.I.R. DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG. NO.

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APPROVED		
STRESS		

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DRAWING TITLE
MUSAT
STOWAGE & DEPLOYMENT
CONFIGURATION

CODE IDENT. NO.		DRAWING NO.	RELEASE	REV.
36480		31179L11		

SCALE 1/16 = 1"	WGT. CALC.	ACTUAL	SHEET 1 OF 1

REPORT ALL DRAWING ERRORS TO ENGINEERING

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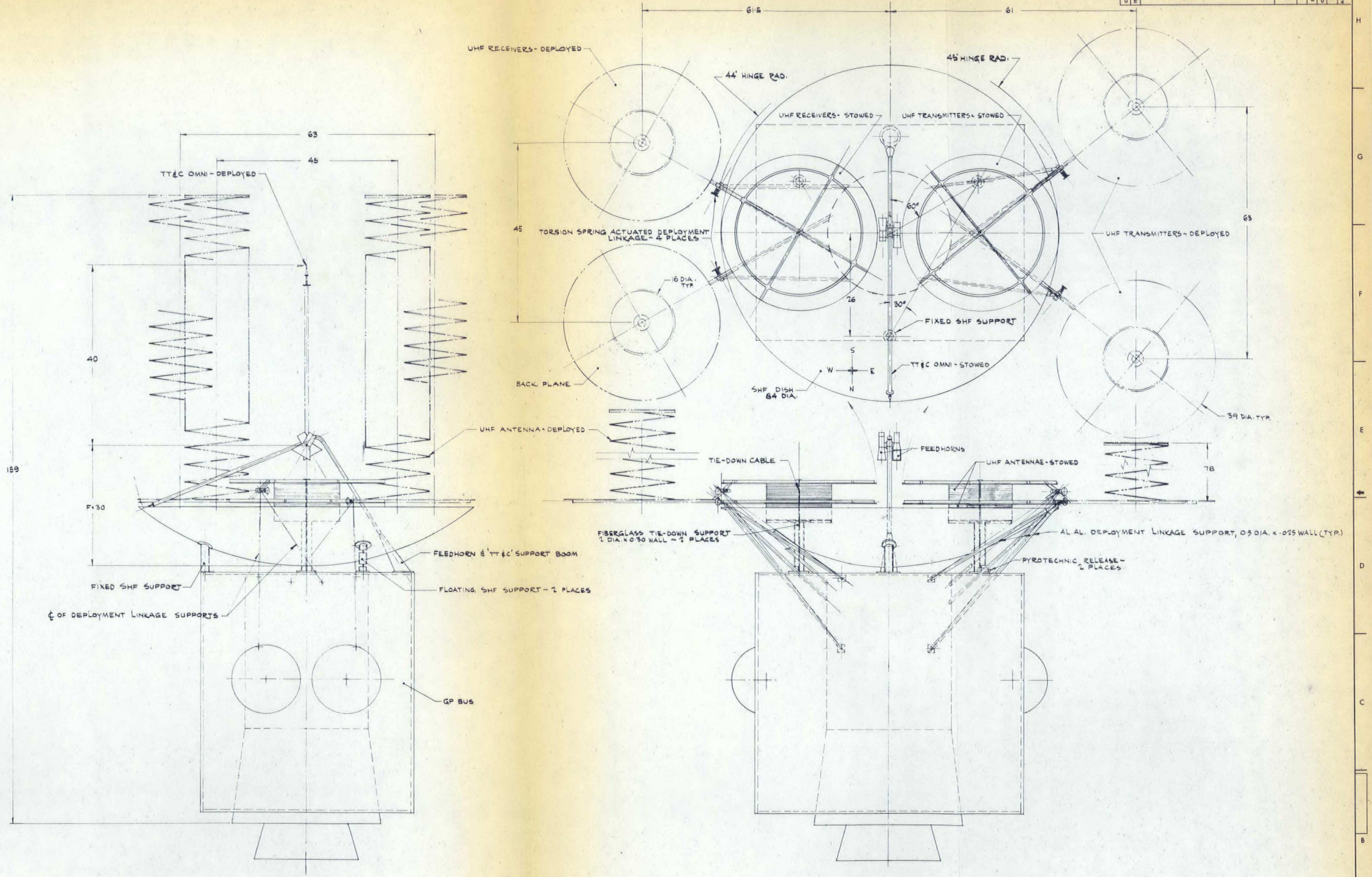
CHANGE	ITEM NO.	DESCRIPTION	MOD. NO.	DATE	DRAWN	CHECKED	STRESS	APPROVED



VIEW FROM EAST

QUANTITY REQ PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL SPEC	HEAT TREAT	FINISH

LIST OF MATERIAL

REQUIREMENTS — UNLESS OTHERWISE SPECIFIED

GENERAL
1. DIMS ARE IN INCHES
2. TOLERANCE SYMBOLS IN ACCORDANCE WITH MIL-STD-8
3. HOLES IN ACCORDANCE WITH AND10387
4. MACHINE FINISH 63 RMS
5. INTERNAL RADII .015
6. CHAMFER EXTERNAL CORNERS .03x45°
7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC

LIMITS
1. LINEAR DIMS
.0 = ± .030
.00 = ± .015
.000 = ± .005
2. ANGLES ± ½°
3. CONCENTRICITY .005 T.I.R.

DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG NO.

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MUSAT

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DRAWING NO. 31179E13
ISSUE
REV.
SCALE 1:8
WGT CALC
ACTUAL
SHEET 1 OF 1

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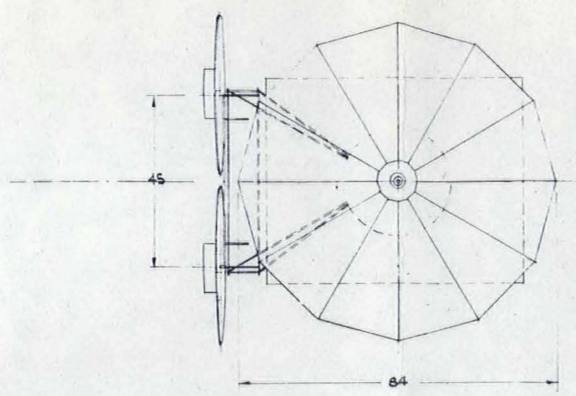

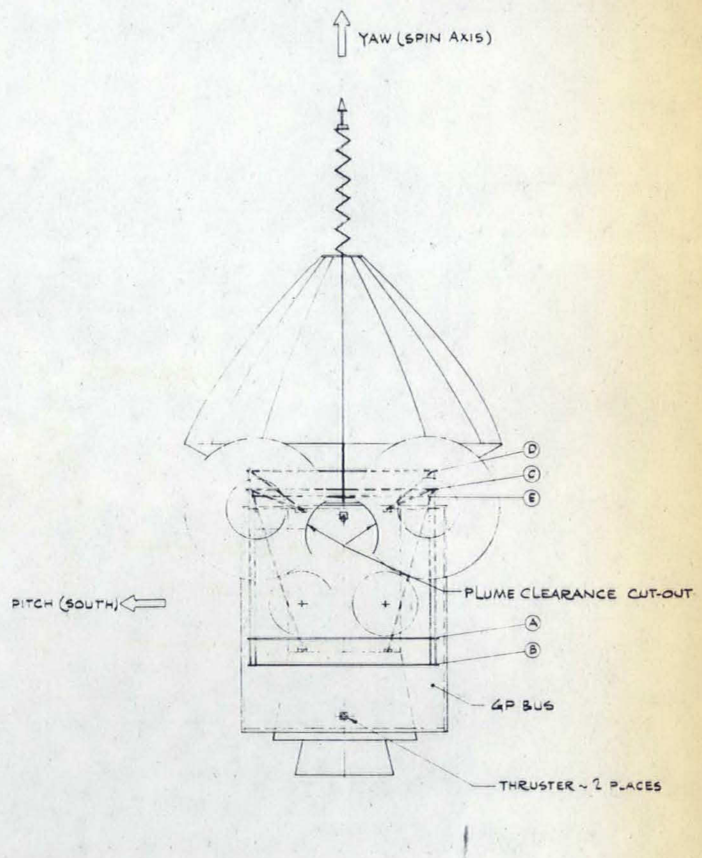

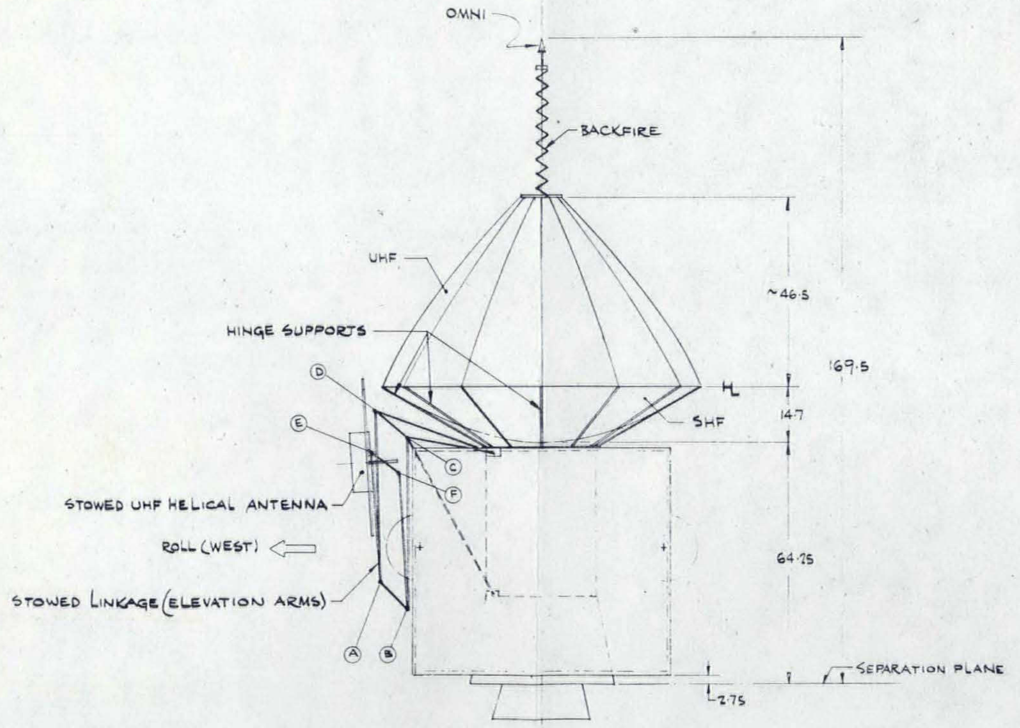

QUANTITY REQ PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL SPEC	HEAT TREAT	FINISH

LIST OF MATERIAL

REQUIREMENTS – UNLESS OTHERWISE SPECIFIED

GENERAL
1. DIMS ARE IN INCHES
2. TOLERANCE SYMBOLS IN ACCORDANCE WITH MIL-STD-8B
3. HOLES IN ACCORDANCE WITH AND10387
4. MACHINE FINISH 63 RMS
5. INTERNAL RADII .015
6. CHAMFER EXTERNAL CORNERS .03x45°
7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC

LIMITS
1. LINEAR DIMS
.0 = ± .030
.00 = ± .010
.000 = ± .005
2. ANGLES ± ½°
3. CONCENTRICITY .002 T.I.R.

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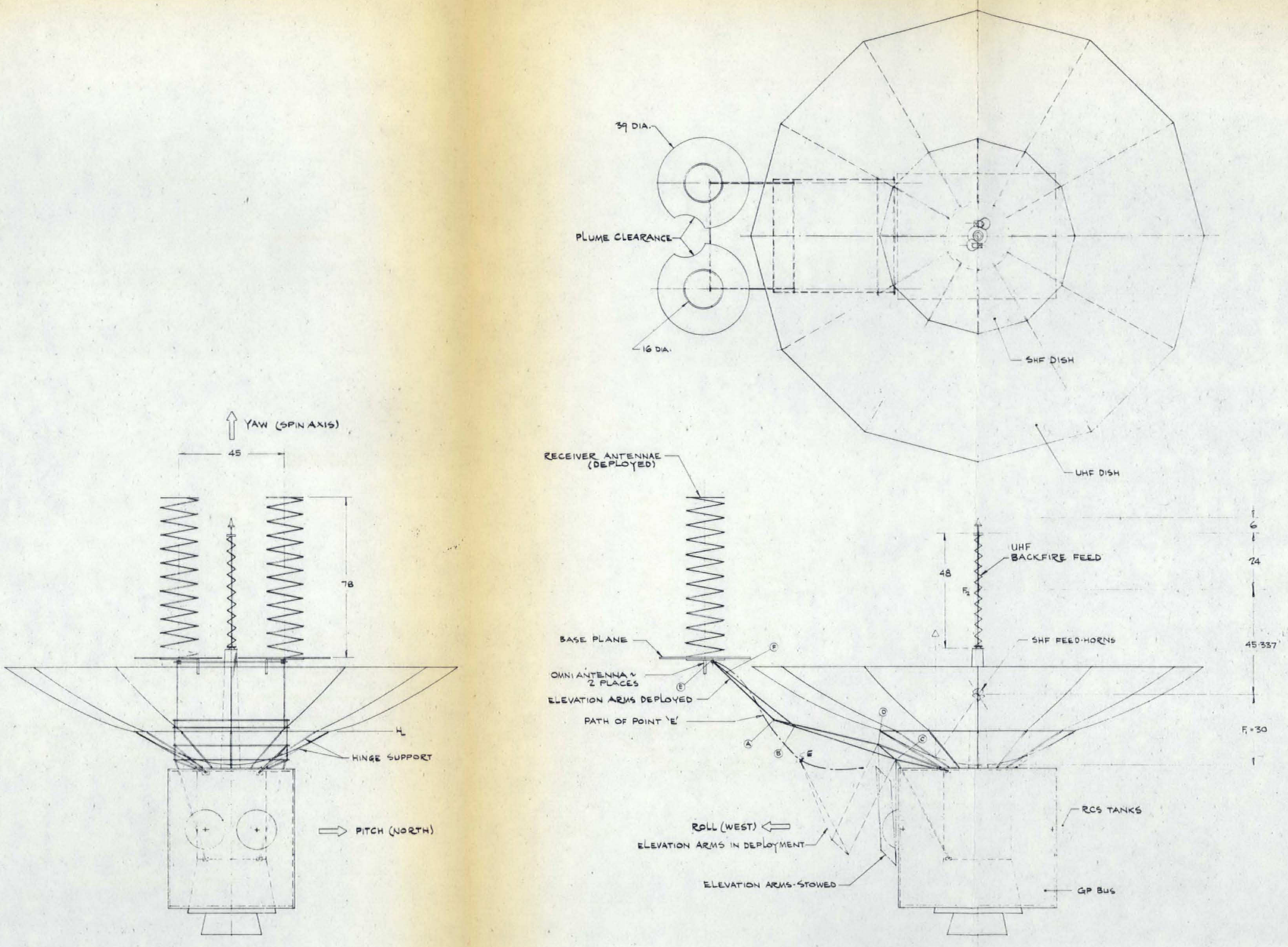
CONFIGURATION Nº 3 – STOWED
— MUSAT —

CODE IDENT NO.		DRAWING NO.	RELEASE	REV.
36480	E	31179E17		
SCALE 1:16	WGT CALC	ACTUAL	SHEET 1 OF 1	

REPORT ALL DRAWING ERRORS TO ENGINEERING

CHANGE ITEM NO.	DESCRIPTION	MOD. NO.	DATE	DRAWN	CHECKED	STRESS	APPROVAL
REVISIONS							



QUANTITY REQ PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL SPEC	HEAT TREAT	FINISH

LIST OF MATERIAL

REQUIREMENTS — UNLESS OTHERWISE SPECIFIED

GENERAL
1. DIMS ARE IN INCHES
2. TOLERANCE SYMBOLS IN ACCORDANCE WITH MIL-STD-8B
3. HOLES IN ACCORDANCE WITH AND10387
4. MACHINE FINISH 63 RMS
5. INTERNAL RADII .015
6. CHAMFER EXTERNAL CORNERS .03x45°
7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC

LIMITS
1. LINEAR DIMS
.0 = ± .030
.00 = ± .010
.000 = ± .005
2. ANGLES ± ½°
3. CONCENTRICITY .002 T.I.R.

DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG NO.

NEXT ASS'Y | USED ON | NO. REQ. PER UNIT
PART NO.

MOD NO.		
DRAWN	Allie	FEB. 27. 77
CHECKED		
APPROVED		
STRESS		

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CONFIGURATION Nº 3 ~
DEPLOYED
— MUSAT —

CODE IDENT NO.		DRAWING NO.	ISSUE	REV.
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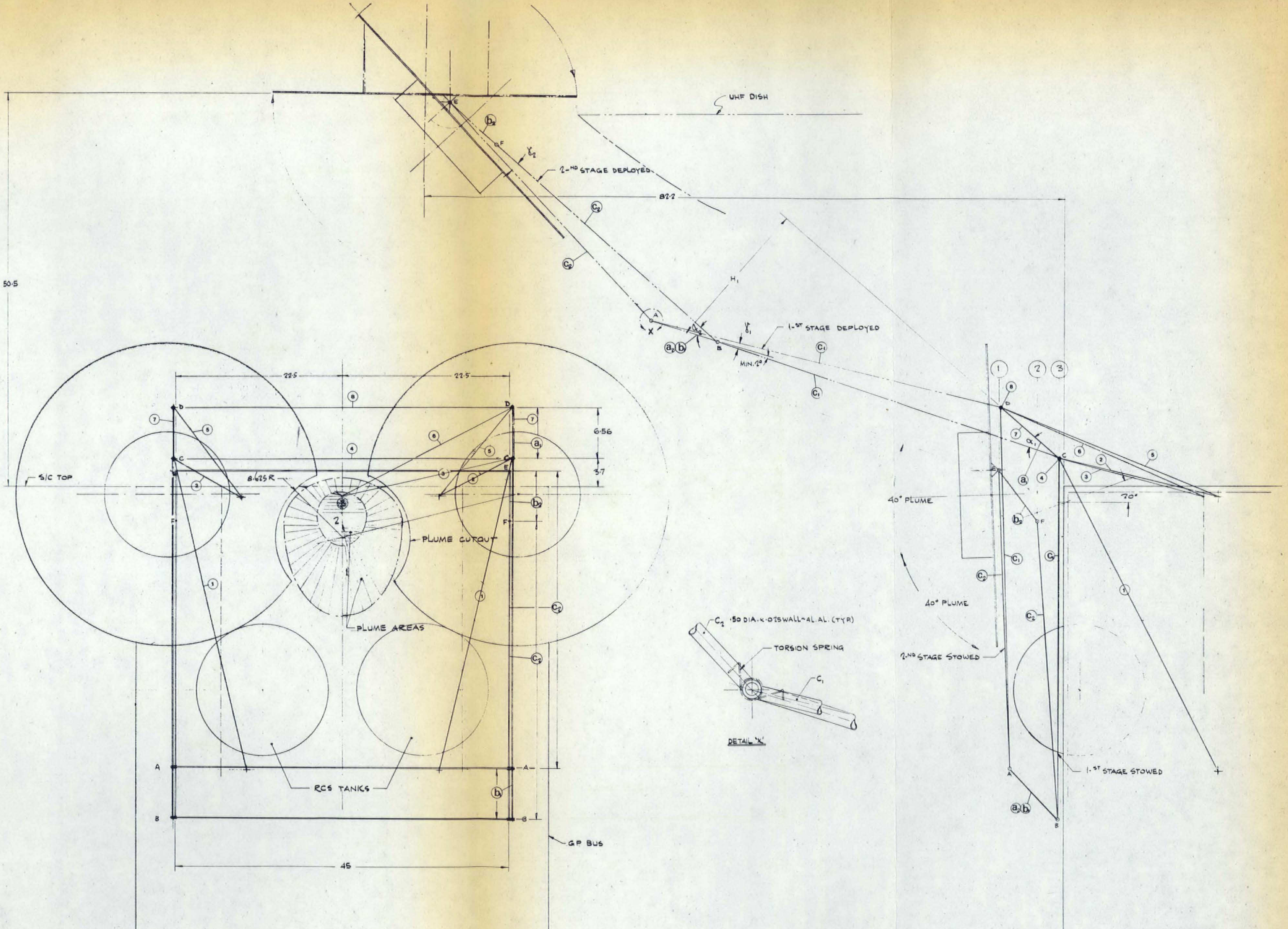
SCALE 1:16	WGT CALC	ACTUAL	SHEET 1 OF 1	



SYM	1-ST STAGE	2-ND STAGE
a	10	9
b	9	8.1
c	46	38.25
$\frac{b}{a}$	0.9	0.9
$\frac{c}{a}$	4.6	4.25
α	23.45°	23.3°
γ	5°	5.3°
H	19.84	16.74

CONFIG. #3.

REQUIREMENTS—UNLESS OTHERWISE SPECIFIED

GENERAL
1 DIMS ARE IN INCHES
2 TOLERANCE SYMBOLS IN ACCORDANCE WITH USAS Y14.5 1966
3 HOLES IN ACCORDANCE WITH AND10387
4 MACHINE FINISH 63 RHS
5 INTERNAL RADII .015
6 CHAMFER EXTERNAL CORNERS .02x45°
7 DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC

LIMITS
1 LINEAR DIMS
.X ± .020
.XX ± .010
.XXX ± .005
2 ANGLES ± ½°
3 CONCENTRICITY .002 T.I.R.

DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG NO

MOD NO		
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CHECKED		
APPROVED		
STRESS		

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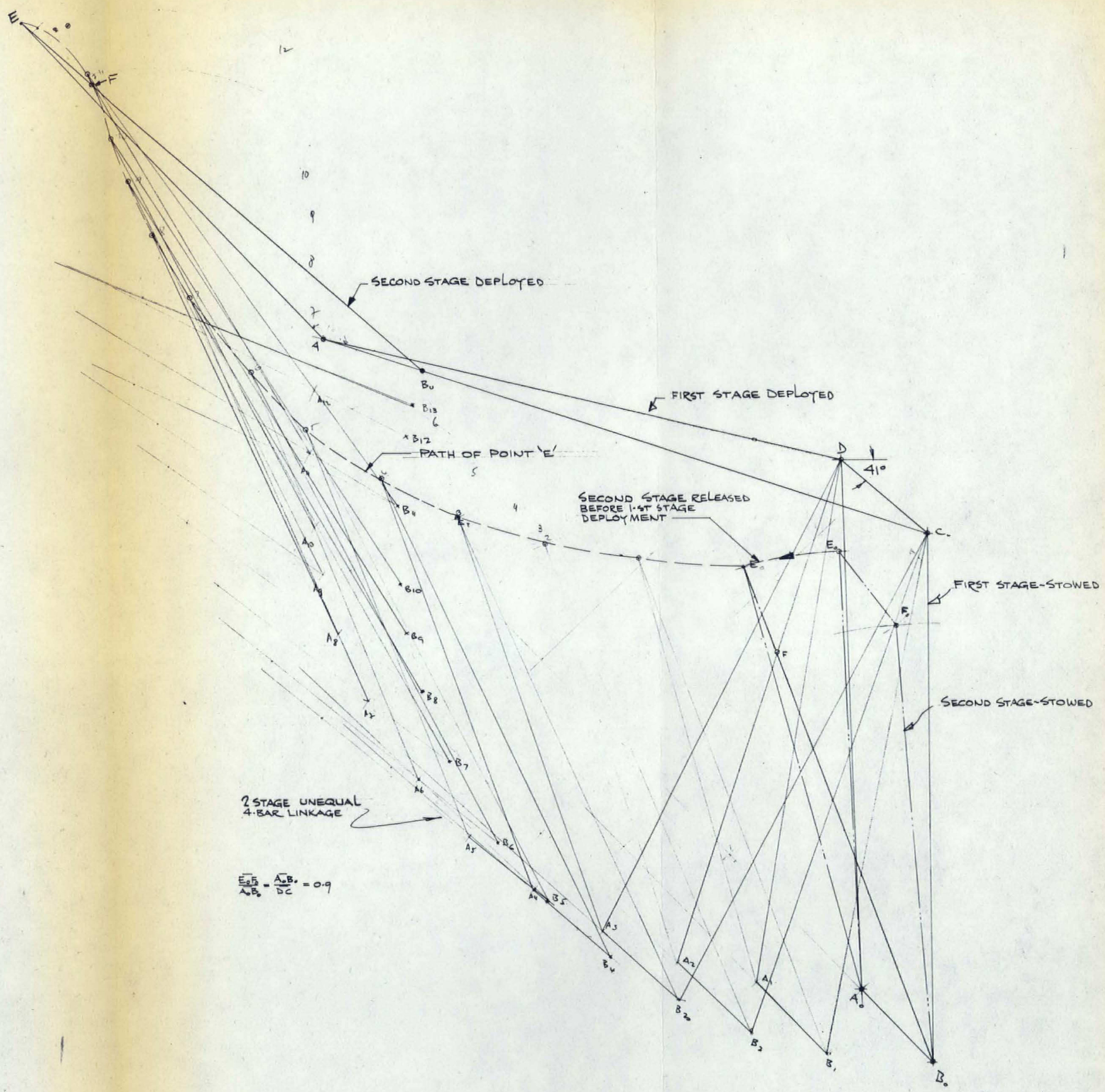
— MUSAT —

CODE IDENT NO		DRAWING NO	RELEASE	REV
36480	L	31179L14		

SCALE	WGT. CALC.	ACTUAL	SHEET
1:4			1 OF 1



$$\frac{\overline{E_0F_0}}{\overline{A_0B_0}} = \frac{\overline{A_0B_0}}{DC} = 0.9$$

CONFIG. #3.

REQUIREMENTS—UNLESS OTHERWISE SPECIFIED				
GENERAL	LIMITS	MOD NO		
1. DIMS ARE IN INCHES	1. LINEAR DIMS .0 = ± .020 .00 = ± .010 .000 = ± .005	DRAWN	Zatuy	MAR. 1/77
2. TOLERANCE SYMBOLS IN ACCORDANCE WITH USAS Y14.5-1966	2. ANGLES = ½°	CHECKED		
3. HOLES IN ACCORDANCE WITH AND10387	3. CONCENTRICITY .002 T.I.R.	APPROVED		
4. MACHINE FINISH 63 RMS		STRESS		
5. INTERNAL RADII .015				
6. CHAMFER EXTERNAL CORNERS .02x45°	DO NOT SCALE DWG			
7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC				
APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG. NO.				

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KINEMATICS OF
DEPLOYMENT MECHANISM.
—MUSAT—

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36480		31179L15		
SCALE 1:4	WGT. CALC.	ACTUAL	SHEET 1 OF 1	

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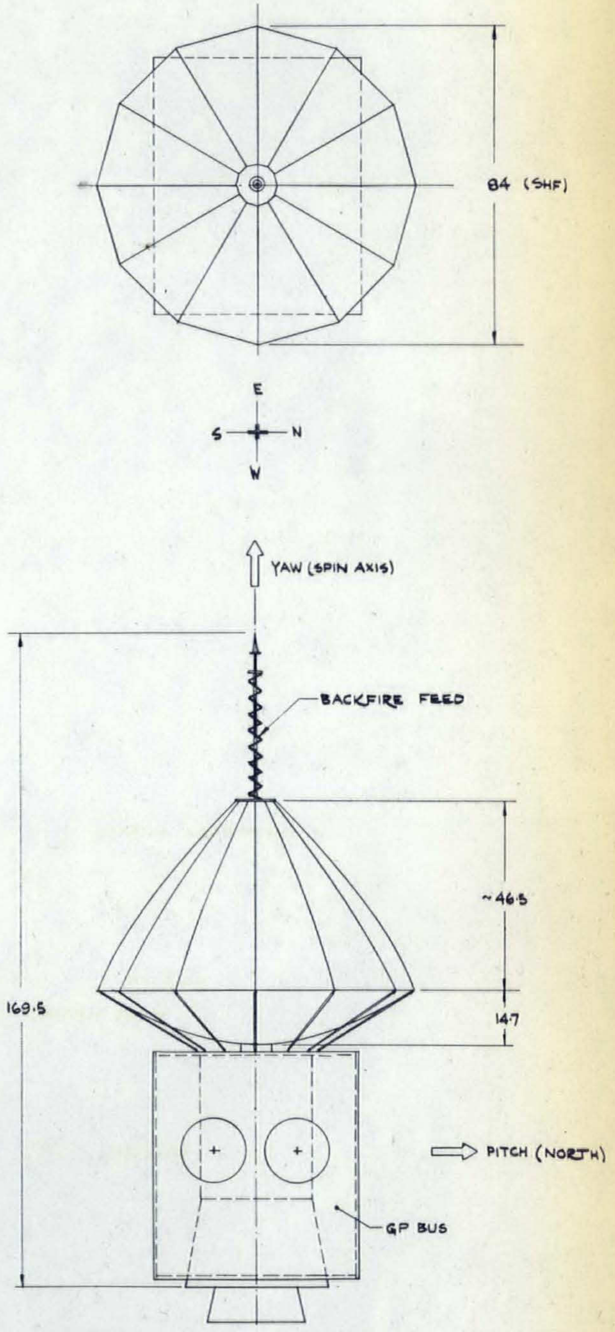
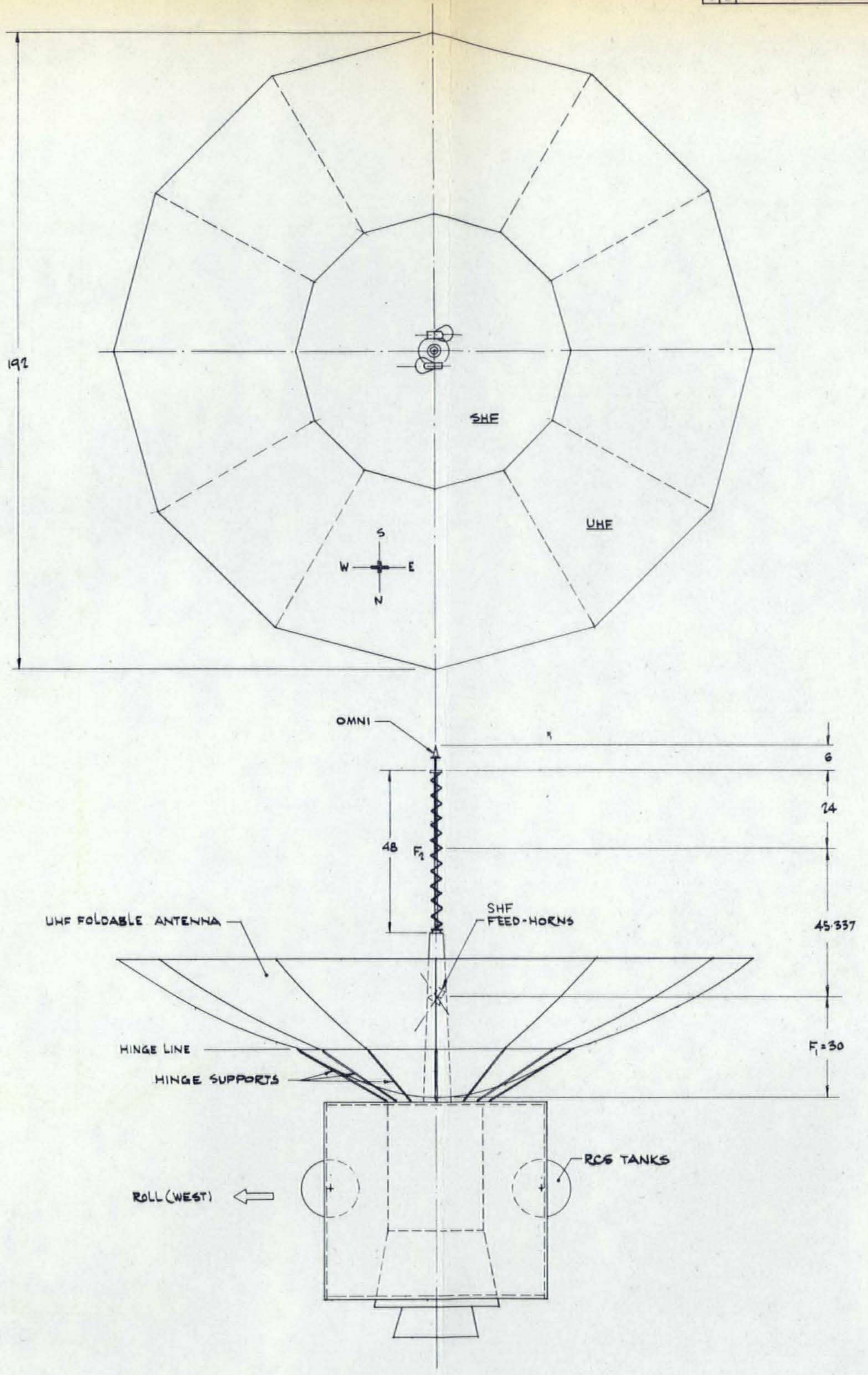


UHF ANTENNA STOWED



UHF ANTENNA DEPLOYED

QUANTITY REQ PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MAT'L SPEC	HEAT TREAT	FINISH

LIST OF MATERIAL

REQUIREMENTS — UNLESS OTHERWISE SPECIFIED

GENERAL	LIMITS
1. DIMS ARE IN INCHES	1. LINEAR DIMS .X = ±.030 .XX = ±.010 .XXX = ±.005
2. TOLERANCE SYMBOLS IN ACCORDANCE WITH MIL-STD-8B	2. ANGLES ±½°
3. HOLES IN ACCORDANCE WITH AND10387	3. CONCENTRICITY .002 T.I.R.
4. MACHINE FINISH 63 RMS	
5. INTERNAL RADII .015	
6. CHAMFER EXTERNAL CORNERS .XXx45°	
7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC	DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG NO.

NEXT ASS'Y	USED ON	NO. REQ. PER UNIT	
PART NO.			

MOD NO.		
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APPROVED		
STRESS		

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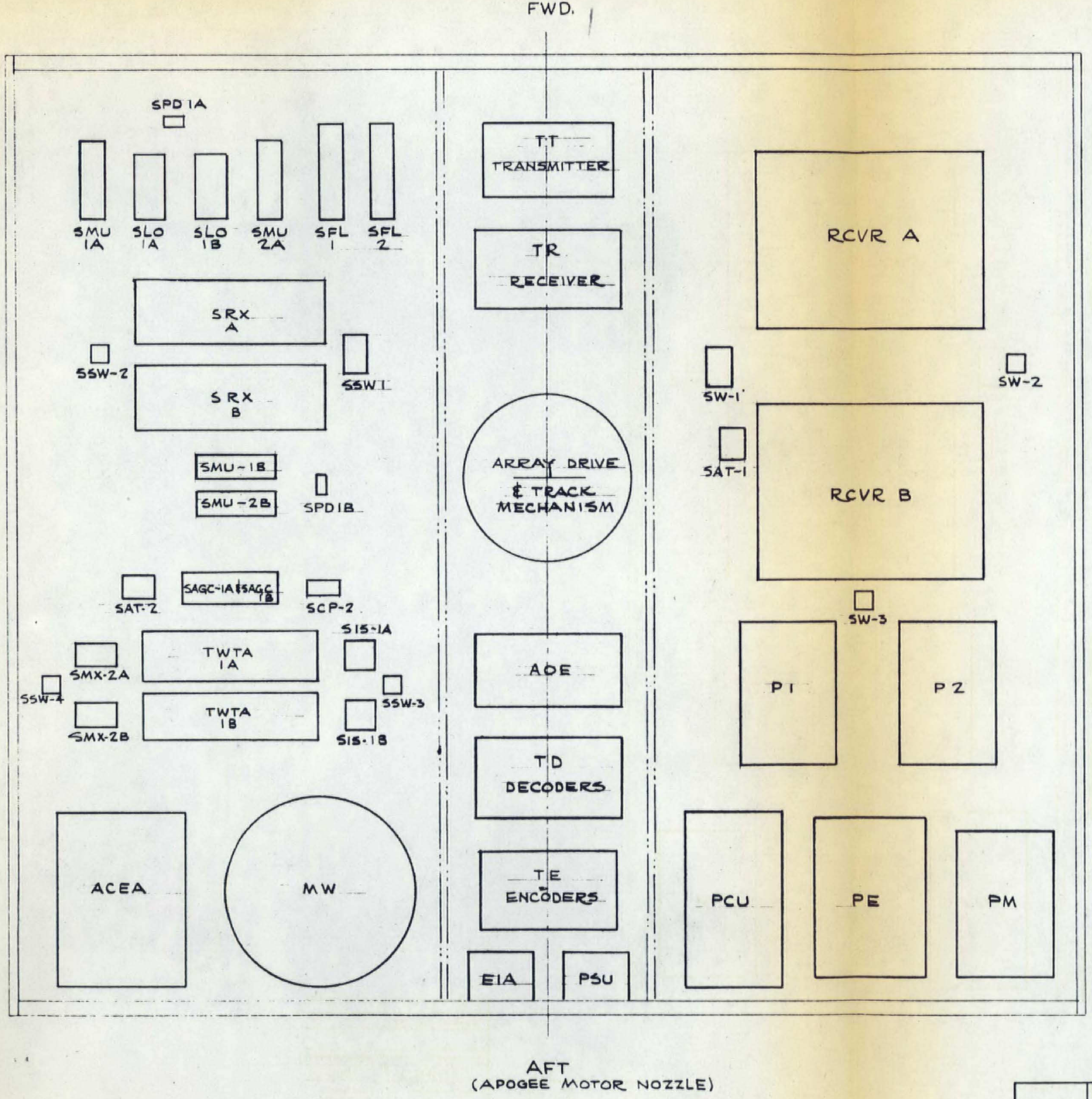
DRAWING TITLE
CONFIGURATION No 4.
—MUSAT—

CODE IDENT NO.		DRAWING NO.		REV.
36480	E	31179E18		
SCALE 1:16	WGT CALC	ACTUAL	SHEET 1 OF 1	

REPORT ALL DRAWING ERRORS TO ENGINEERING

REVISIONS

CHANGE	ITEM NO.	DESCRIPTION	MOD. NO.	DATE	DRAWN	CHECKED	STRESS	APPROVD.



QUANTITY REQ. PER				ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL. SPEC.	HEAT TREAT	FINISH

LIST OF MATERIAL

NEXT ASSY	USED ON	NO. REQ. PER UNIT
PART NO.		

REQUIREMENTS—UNLESS OTHERWISE SPECIFIED

GENERAL	LIMITS
1. DIMS ARE IN INCHES 2. TOLERANCE SYMBOLS IN ACCORDANCE WITH USAS Y14.5-1966 3. HOLES IN ACCORDANCE WITH AND10387 4. MACHINE FINISH 63 RMS 5. INTERNAL RADII .015 6. CHAMFER EXTERNAL CORNERS .02 x 45° 7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC	1. LINEAR DIMS .0 = ± .020 .00 = ± .010 .000 = ± .005 2. ANGLES ± ½° 3. CONCENTRICITY .002 T.I.R.

DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG. NO.

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STRESS		

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DRAWING TITLE

GPB~MUSAT
SOUTH PANEL
EQUIPMENT LAYOUT

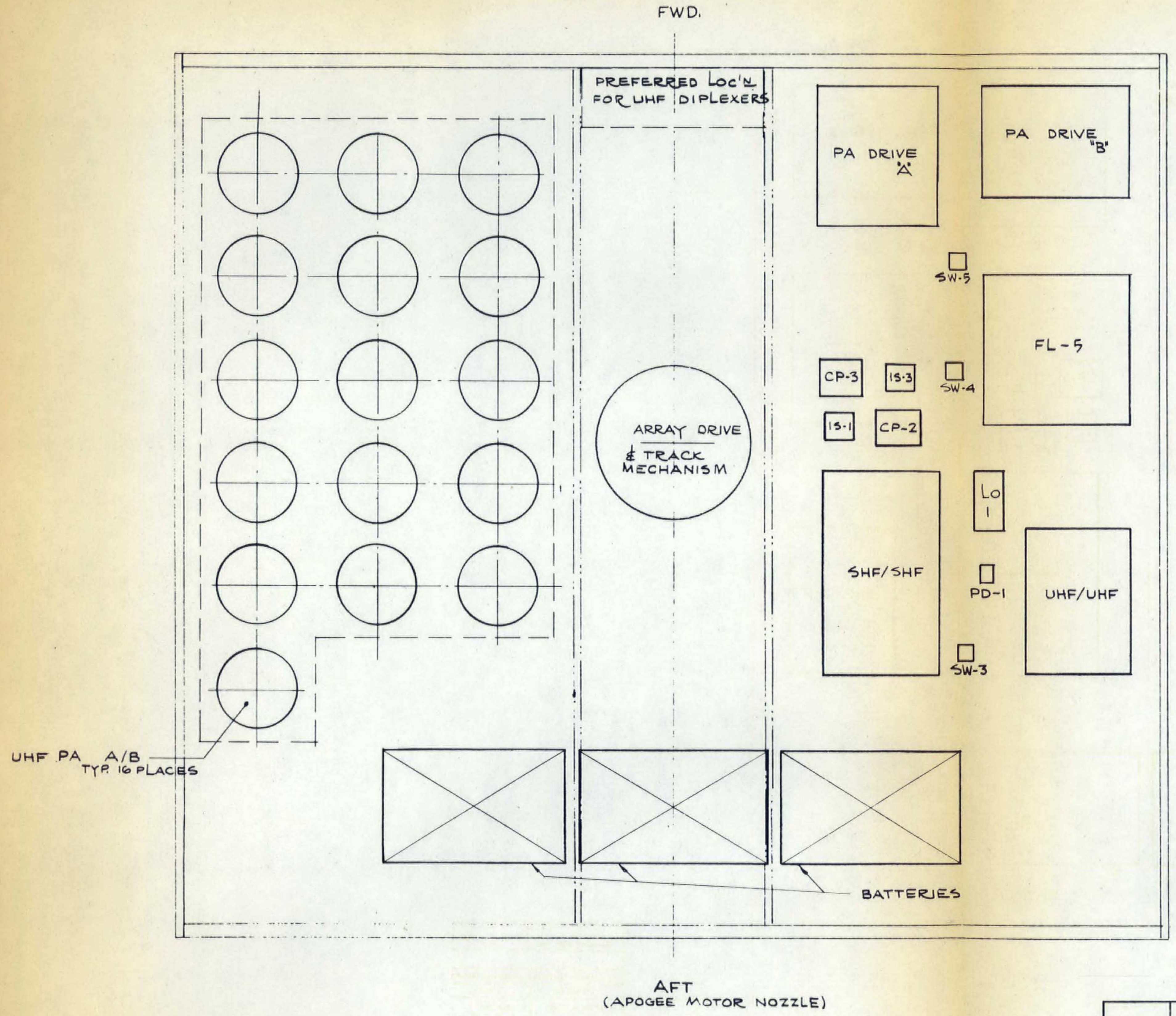
CODE IDENT NO.		DRAWING NO.	RELEASE	REV.
36480	D	31179D8		

SCALE 1:4 | WGT CALC | ACTUAL | SHEET 1 OF 1

REPORT ALL DRAWING ERRORS TO ENGINEERING

REVISIONS

CHANGE	ITEM NO	DESCRIPTION	MOD. NO.	DATE	DRAWN	CHECKED	STRESS	APPROVD



QUANTITY REQ. PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL. SPEC.	HEAT TREAT	FINISH

LIST OF MATERIAL

NEXT ASSY	USED ON	NO. REQ. PER UNIT
PART NO.		

REQUIREMENTS—UNLESS OTHERWISE SPECIFIED

GENERAL	LIMITS
1. DIMS ARE IN INCHES 2. TOLERANCE SYMBOLS IN ACCORDANCE WITH USAS Y14.5-1966 3. HOLES IN ACCORDANCE WITH AND10387 4. MACHINE FINISH 63 RMS 5. INTERNAL RADII .015 6. CHAMFER EXTERNAL CORNERS .02 x 45° 7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC	1. LINEAR DIMS .0 = ± .020 .00 = ± .010 .000 = ± .005 2. ANGLES ± ½° 3. CONCENTRICITY .002 T.I.R.

DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG. NO.

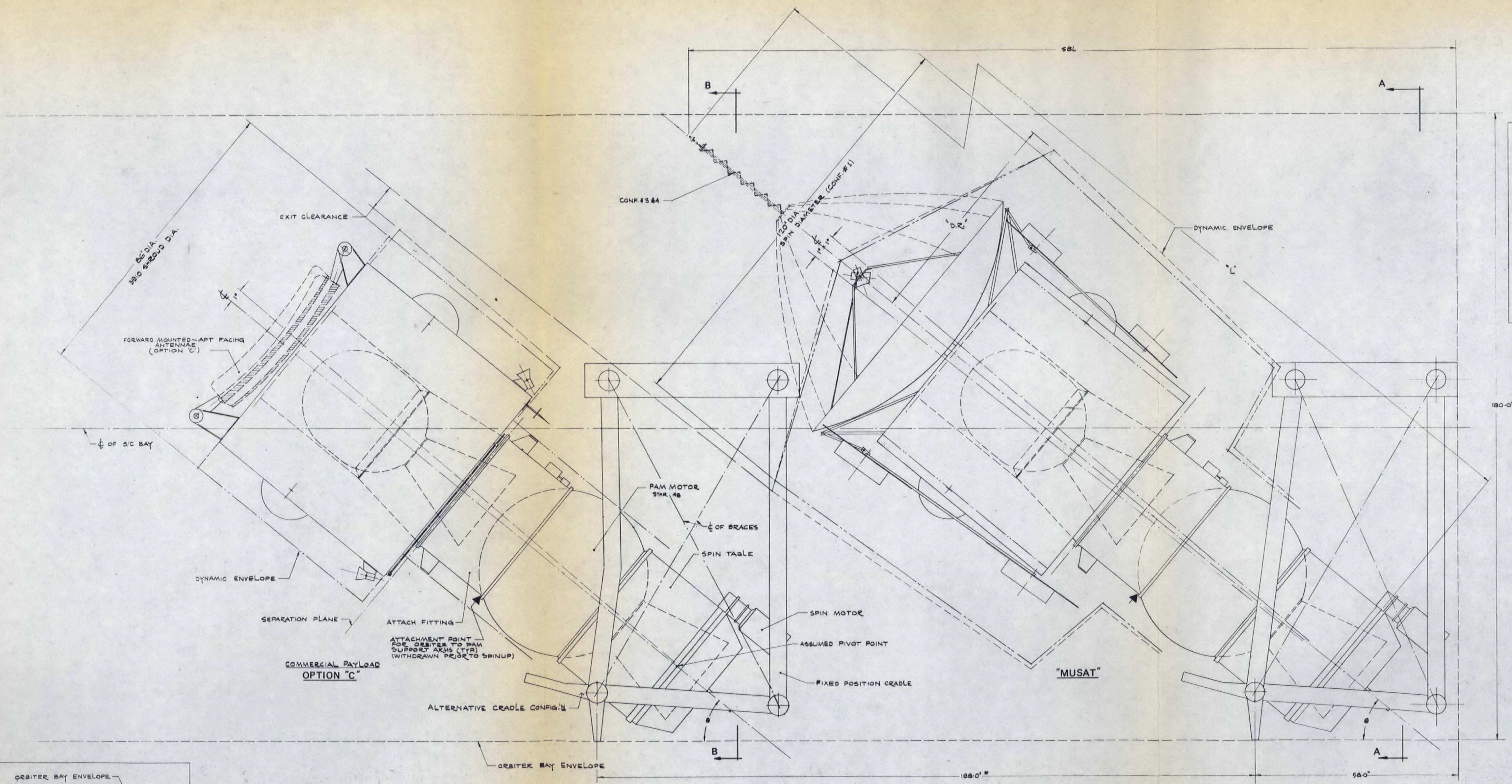
MOD NO.		
DRAWN		JAN.4/77
CHECKED		
APPROVED		
STRESS		

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

DRAWING TITLE
GPB MUSAT
NORTH PANEL
EQUIPMENT LAYOUT

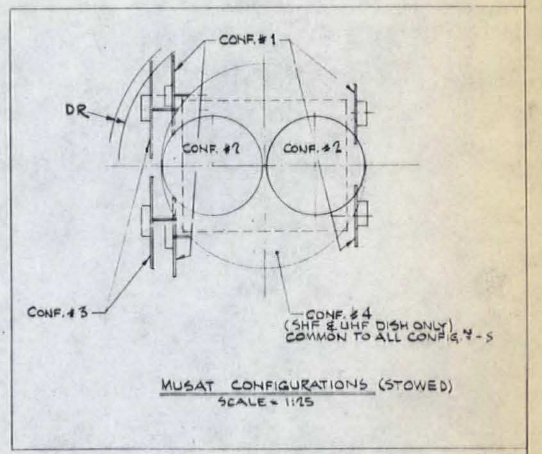
CODE IDENT NO. 36480
D
DRAWING NO. 3117909
RELEASE
REV.

SCALE 1:4
WGT CALC
ACTUAL
SHEET 1 OF 1



COMMERCIAL PAYLOAD
OPTION "C"

"MUSAT"

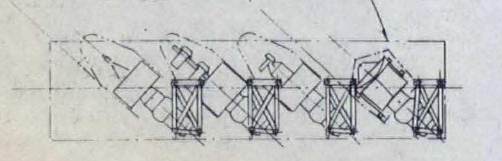


MUSAT CONFIGURATIONS (STOWED)
SCALE = 1:25

S/C OPTION		S/C LENGTH	S/C + PAM	L	D.R. (MAX.)	θ (MAX.)	SBL
COM. SHF OPTION	A	135	222	215	47	46	184
—"— —"— —"—	B	80	167	160	47	54	129
—"— —"— —"—	C	73	160	153	47	61	109
MUSAT CONF.	1	98	185	178	63	50	149
—"— —"—	2	98	185	178	49	50	149
—"— —"—	3	169.5	256.5	249.5	69	38	232
—"— —"—	4	169.5	256.5	249.5	46	38	232

LEGEND:
DR = DYNAMIC SPIN RADIUS.
SBL = SHUTTLE BAY LENGTH.

* FOR MUSAT CONFIGURATION No. 1 & COMMERCIAL OPTION 'C' COMBINATION (DEPENDING ON L, $\theta_{MAX.}$ AND DR ~ SEE TABLE)



MULTIPLE INSTALLATION

QUANTITY REQ PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL SPEC	HEAT TREAT	FINISH

LIST OF MATERIAL

REQUIREMENTS—UNLESS OTHERWISE SPECIFIED

GENERAL	LIMITS
1. DIMS ARE IN INCHES 2. TOLERANCE SYMBOLS IN ACCORDANCE WITH USAS Y14.5-1966 3. HOLES IN ACCORDANCE WITH AND10387 4. MACHINE FINISH 63 RMS 5. INTERNAL RADII .015 6. CHAMFER EXTERNAL CORNERS .03x45° 7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC	1. LINEAR DIMS .0 = ± .020 .00 = ± .010 .000 = ± .005 2. ANGLES ± ½° 3. CONCENTRICITY .005 T.I.R. DO NOT SCALE DWG

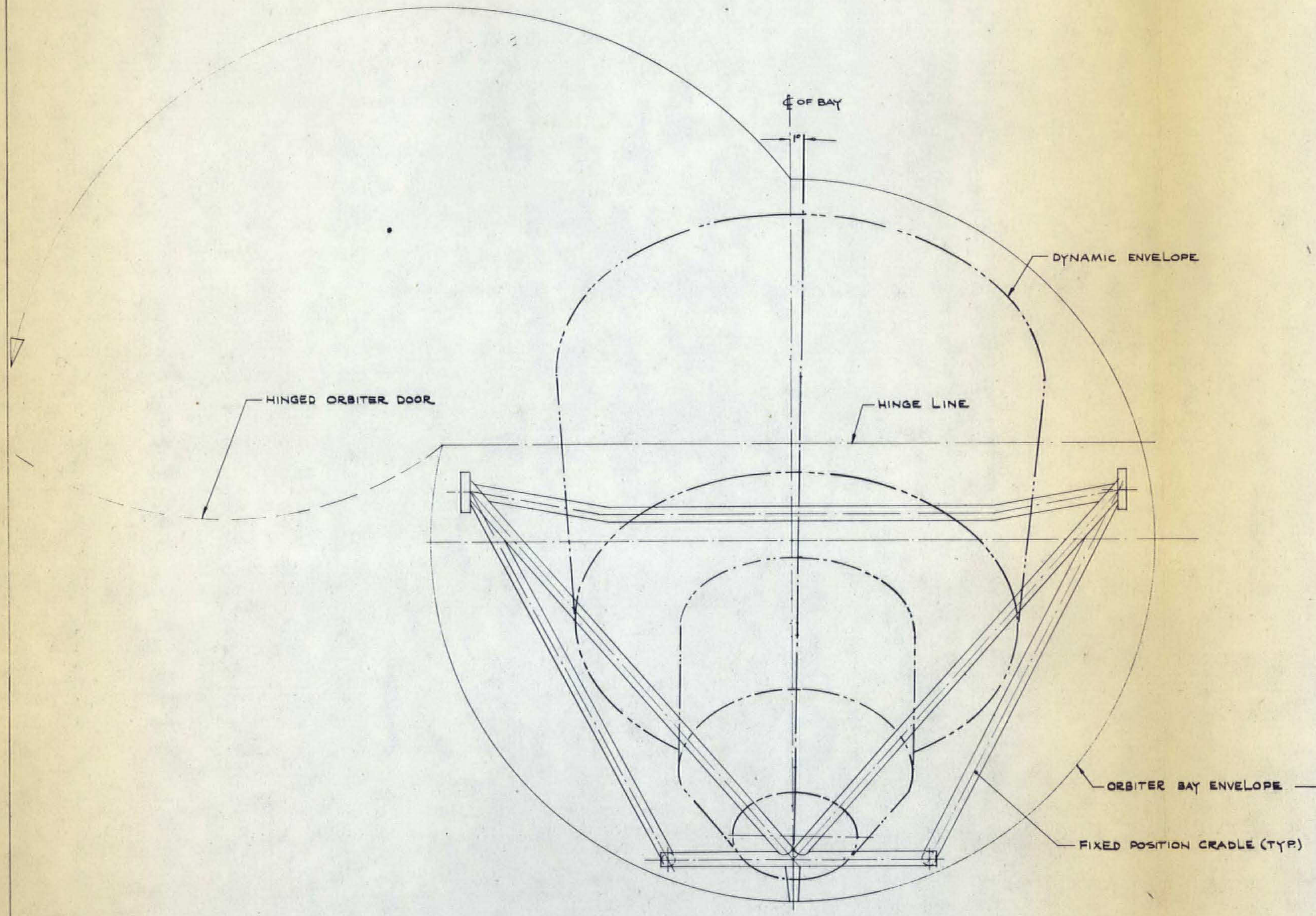
APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG. NO.

MOD NO		
DRAWN	Artley	JAN. 11/77
CHECKED		
APPROVED		
STRESS		

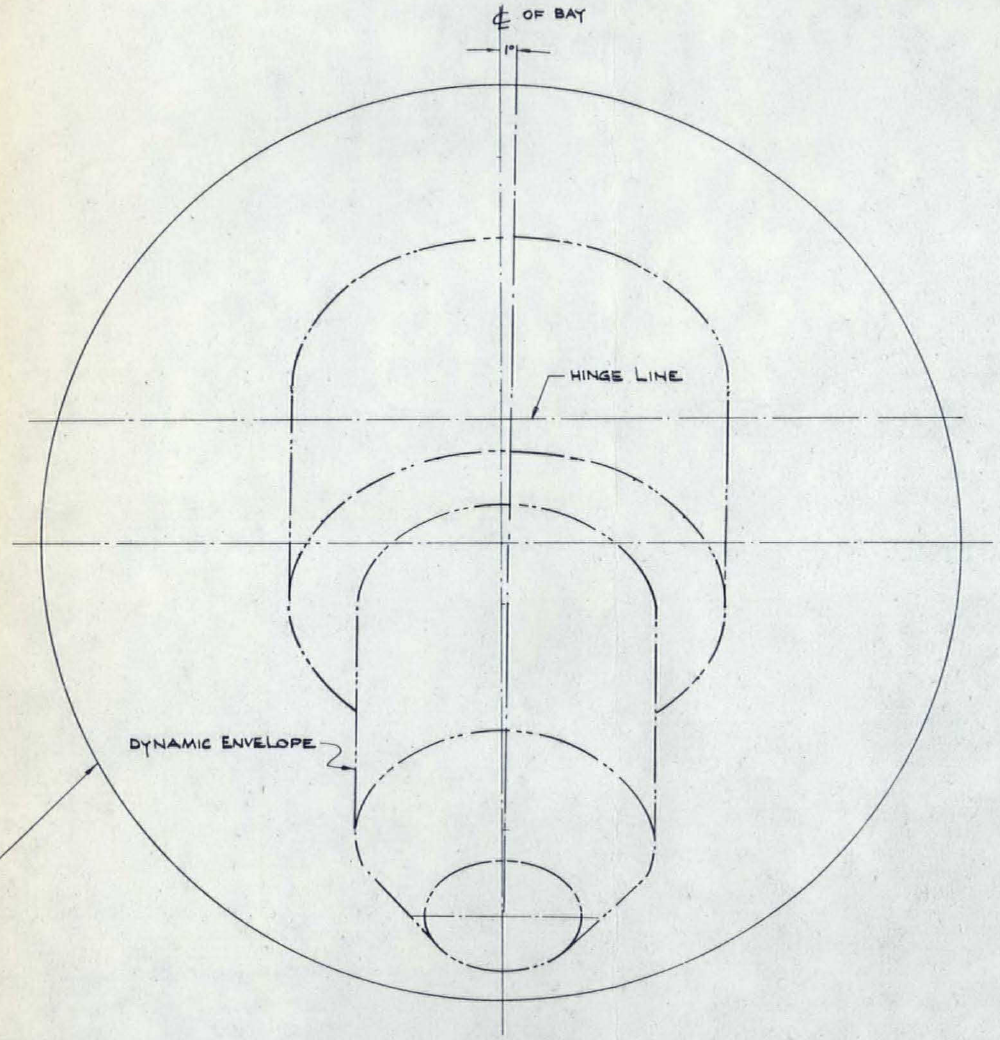
SPAR AEROSPACE PRODUCTS LTD.
825 CALEDONIA RD., TORONTO, ONTARIO M6B 3X8, CANADA

DRAWING TITLE
MUSAT & COMMERCIAL,
OPTION 'C'
SHUTTLE LAUNCH

CODE IDENT. NO.		DRAWING NO.	RELEASE	REV.
36480		31179 L12		
SCALE 1:8	WGT. CALC.	ACTUAL	SHEET 1 OF 2	



SECTION A–A
(SHOWING MUSAT–CONFIG. Nº1)



SECTION B–B
(SHOWING COMMERCIAL)

QUANTITY REQ PER	ITEM	PART NO.	CODE	DESCRIPTION	MATERIAL	MATL SPEC	HEAT TREAT	FINISH

LIST OF MATERIAL

REQUIREMENTS—UNLESS OTHERWISE SPECIFIED

GENERAL	LIMITS
1. DIMS ARE IN INCHES 2. TOLERANCE SYMBOLS IN ACCORDANCE WITH USAS Y14.5-1966 3. HOLES IN ACCORDANCE WITH AND10387 4. MACHINE FINISH 63 RMS 5. INTERNAL RADII .015 6. CHAMFER EXTERNAL CORNERS .02x45° 7. DIMENSIONS LOCATING TRUE POSITIONS ARE BASIC	1. LINEAR DIMS .0 = ± .020 .00 = ± .010 .000 = ± .005 2. ANGLES = ± ½° 3. CONCENTRICITY .002 T.I.R. DO NOT SCALE DWG

APPLICABLE PROCESS SPECIFICATIONS AND INSPECTION REQUIREMENTS SHALL BE IN ACCORDANCE WITH DWG. NO.

MOD NO		
DRAWN	Dauer	JAN.11/77
CHECKED		
APPROVED		
STRESS		

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

DRAWING TITLE
MUSAT & COMMERCIAL,
OPTION 'C'
SHUTTLE LAUNCH

CODE IDENT. NO.		DRAWING NO.	RELEASE	REV.
36480		31179L12		
SCALE 1:12	WGT. CALC.	ACTUAL	SHEET 2 OF 2	

FEASIBILITY STUDY OF A GENERAL
PURPOSE BUS FOR THE POTENTIAL MUSAT..