NASA Technical Memorandum 108543

Tether-Based Investigation of the Ionosphere and Lower Thermosphere Concept Definition Study Report

L. Johnson and M. Herrmann, Editors
Marshall Space Flight Center • MSFC, Alabama

National Aeronautics and Space Administration
Marshall Space Flight Center • MSFC, Alabama 35812

September 1997

ACKNOWLEDGMENTS

Appreciation is expressed to the engineering team that provided the TIILT technical and programmatic analyses for the study. The team was led by MSFC engineers and included representatives from Johnson Space Center, Kennedy Space Center, Lockheed Martin Astronautics, Science & Technology Corporation, and Tethers Unlimited. Science data was obtained from Dr. Rod Heelis of the University of Texas in Dallas, and Dr. Brian Gilchrist of the University of Michigan. Specific engineering data were obtained from:

MSFC
Harold Blevins (Communications & Data Handling)
Holly Chandler (Mass Properties)
Greg Hajos (Configuration)
Kai Hwang (Environments)
Lou Maus (Electrical Power)
Steve Pavelitz (Environments)
Robert Shepard (Schedules)
Susan Spencer (Structures)
Carey Thompson (Cost)
Ken Welzyn (Tether Dynamics)

TETHERS UNLIMITED
Robert Forward (Alternative Tethers)
Robert Hoyt (Alternative Tethers)

LOCKHEED MARTIN
Howard Flanders (Tether Dynamics, Orbit Analysis)
Vern Lunsford (Tether Systems)
Lee Marshall (Tether & Deployer)

SCIENCE & TECHNOLOGY CORPORATION
Viren Dogra (Thermal, Attitude Control)
Leonard Melfi (Aerodynamic Analysis)
George Wood (STC Lead)

SMITHSONIAN ASTROPHYSICAL OBSERVATORY
Enrico Lorenzini (Orbital Dynamics, Tether Aerodynamics)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AO	Announcement of Opportunity
ATP	Authority to Proceed
CPU	Central Processing Unit
C&DH	Communications and Data Handling
bps	bits per second
DSMC	Direct Simulation Monte Carlo
K	Kelvin (temperature)
kbps	kilobits per second
kg	kilogram
kWh	kilowatts per hour
FOV	Field of view
IR	Infrared
mm	millimeter
N	Newton
PRCS	Primary Reaction Control System
S/C	Spacecraft
SE&I	Systems engineering and integration
SEDS	Small Expendable Deployer System
SDT	Science Definition Team
TDRSS	Tracking Data Relay Satellite System
TIILT	Tether-Based Investigation of the Ionosphere and Lower Thermosphere
TSS	Tethered Satellite System
UV	Ultraviolet
W	Watts

TECHNICAL MEMORANDUM

TETHER-BASED INVESTIGATION OF THE IONOSPHERE AND LOWER THERMOSPHERE CONCEPT DEFINITION STUDY REPORT

I. INTRODUCTION

Exploring the plasma and neutral atmosphere around the Earth in the low-altitude regions of the lower thermosphere and ionosphere is important in understanding the complexities of the mass and energy exchanges in those regions, and ultimately, for determining the evolution and degree of habitability of our environment. An upper atmosphere tether mission has been proposed that would collect much-needed data to further our knowledge of these regions. This mission is proposed as a shuttle experiment that would lower a tethered probe into certain regions of the Earth's atmosphere, collecting data over a 6-day period.

II. SCIENCE OBJECTIVES

Our planet is distinguished by the presence of an atmosphere and a magnetic field, both of which significantly affect the interaction of the planet with the interplanetary environment. Understanding this interaction, which is different from that of all the other planets, is a key piece of the puzzle that describes the evolution and degree of habitability of our environment. The near-Earth atmosphere serves to absorb most of the harmful photon radiation from the Sun, but the outer atmosphere provides the source for a conducting medium that, in conjunction with the Earth's magnetic field, provides a barrier for the electromagnetic and energetic particle radiation originating from the solar environment. Just as understanding the inner boundary interactions of the planet surface with the atmosphere is important, so too is our understanding of the interactions at the outer boundary. The outer boundary is extended in altitude, ranging from ~100 km at its lowest extent out to 10 Earth radii at the subsolar magnetopause. The processes within this extended boundary are many and varied and range from consideration of collisionless, fully ionized, magnetized plasmas at the outer limits to collision-dominated, partially ionized, nonmagnetized plasmas at the inner limit.

In the collision-dominated region near the inner limit, electric currents can flow perpendicular to the magnetic field and significant electromagnetic radiation is dissipated as heat and momentum in the neutral atmosphere. The source regions for these currents may be widely separated. One originates in the flowing solar wind and the interplanetary magnetic field, another in the thunderstorm distribution around the Earth, and still another in the moving neutral atmosphere at altitudes between 100 and 300 km. The interplay between these different generators and the current closure paths that they occupy is intimately related to the behavior of our outer space environment but it is, yet, poorly understood. This lower region of the boundary also represents the transition from a fully mixed neutral atmosphere to one that becomes diffusely separated. Energy is also deposited in this region by atmospheric waves with a wide spectrum of spatial scale sizes. The temperature of the region is controlled by the radiated emissions from carbon dioxide (CO_2) and nitrous oxygen (NO). All these factors are changing in time and changing the response of the atmosphere to the external forcings.

A global description of the dynamics of the region must be undertaken and can be accomplished with suitably instrumented constellations of satellites that provide in situ and remote measurements from altitudes of 400 km and above. However, to expose the major physical processes that are responsible for the observed global behavior, we must include in situ observations of the ion-neutral coupling processes that exist in the region itself over horizontal and vertical scale sizes of a few kilometers and larger. This cannot easily be achieved with conventional ground-based or space-based instrumentation because the probed region is not sufficiently extensive, either in space or time. The purpose of this report is to emphasize that the space shuttle and other manned space vehicles, which are an essential element of the nation's space program, can be used effectively to carry appropriately instrumented tethered vehicles into the region of interest.

This report describes a tethered satellite mission offering the opportunity to make measurements required to unravel many of the complexities involved in ion-neutral coupling in the region between 200 and 130 km. Though of limited duration, a shuttle-based tethered satellite mission provides the unique global access to a region of space required for significant understanding of the spatial scales of importance. The mission capitalizes on existing positive experiences from the tethered satellite program in a timely manner, and represents an application of the manned space flight program that can greatly contribute to our understanding of the Earth's environment.

III. MISSION REQUIREMENTS

To determine the feasibility, resources required, and implementation approaches for the space shuttle orbiter Tether-Based Investigation of the Ionosphere and Lower Thermosphere (TIILT), the Office of Space Science appointed a Science Definition Team (SDT) to define a strawman suite of 11 instruments that together would meet all of the mission objectives. A summary of the instrument complement and their accommodation requirements is shown in tables 1 and 2.

TABLE 1.—*Science instrument support requirements.*

Instrument Description	Sensor Dimensions (cm)	Electronics Dimensions (cm)	Sensor Mass (Kg)	E-Box Mass (Kg)	Instrument Power (W)	Telemetry Rate (bps)
Ion Drift Meter	12 dia 7 deep	21×12×16	0.9	2.3	3	2,000
Retarding Potential Analyzer	12 dia 7 deep	21×12×16	0.9	2.3	4	1,000
Ion Mass Spectrometer	18×12×11	18×12×16	1.8	2.0	6	500
Langmuir Probe	1 dia 15 long Boom Mount	15×15×10	0.35	3.0	4	5,600
Neutral Wind Meter	16 dia 19 deep	18×12×16	2.1	2.2	8	1,000
Neutral Mass Spectrometer	18×12×11	18×12×16	2.0	2.5	10	1,000
Energetic Particle Spectrometer	19×15×18	Included in Sensor	2.2	N/A	2	8,000
E-Field Double Probes	20 dia 6 deep	12×12×8	18.0 (3×6)	3.0	10	50k
IR Spectrometer*	10×10×21	18×18×13	7.0	2.0	13	128k
UV Photometer*	10×10×25	Included in Sensor	2.8	Included in Sensor	5	320
Three-Axis Magnetometer	8×8×21	18×18×13	1.0	2.5	2	1600
Total Payload			39.1	21.8	67	199k

*Optional instrument for endmass; may be orbiter-based.

TABLE 2.—*Science instrument mounting and viewing requirements.*

Instrument Description	Sensor Mounting Location	Field of View	Special Considerations	Attitude Knowledge
Ion Drift Meter	Cylinder Axis Along RAM	60° 1/2 Angle Cone	View Through Conducting Ground Plane	Control to 3° Postflight <0.1°
Retarding Potential Analyzer	Cylinder Axis Along RAM	60° 1/2 Angle Cone	View Through Conducting Ground Plane	Control to 3° Postflight <0.5°
Ion Mass Spectrometer	12×11 Face in RAM	20° 1/2 Angle Cone	View Through Conducting Ground Plane	Control to 3° Postflight <0.5°
Langmuir Probe	Short Boom Deployed Sideways	Unrestricted Envelope	None	N/A
Neutral Wind Meter	Cylinder Axis Along RAM	45° 1/2 Angle Cone	Baffles or Dome Project Beyond Ground Plane	Control to 3° Postflight <0.1°
Neutral Mass Spectrometer	12×11 Face in RAM	40° 1/2 Angle Cone	Unrestricted View Through Flat Front Plane	Control to 3° Postflight <0.5°
Energetic Particle Spectrometer	Side-Mounted	11° Fan With 360° in Vertical Plane		Control to 3° Postflight <0.5°
E-Field Double Probes	3 Plates Mutually Perpendicular Will Deploy Boom Pairs	Deployment to >3 m Will Clear All Obstacles	Retractable Deployer Available	Control to 3° Postflight <0.5°
IR Spectrometer	12×11 Face in RAM	40° 1/2 Angle Cone		
UV Photometer	10×10 Face is Upward Zenith	10° Full Angle Zenith	View of Tether Not a Concern	Control to 3° Postflight <0.5°
Three-Axis Magnetometer	Boom Mount in the Wake	N/A	N/A	Control to 3° Postflight <0.1°

Study Assumptions

The engineering feasibility study was conducted using the following guidelines and assumptions:

- Use as much existing hardware as possible and practical to meet mission objectives
- Require minimal use of orbiter resources
- Size endmass support subsystems to accommodate all scientific instruments, including those considered to be optional.

IV. MISSION CONCEPT

A. Mission Scenario

The baseline mission scenario calls for a 6-day mission with the instrumented endmass deployed from the orbiter for 2 days at each of the following altitudes: 170, 150, and 130 km. Two approaches for meeting mission objectives are presented.

Option 1: Deploy Only

The orbiter enters a 220-km circular orbit at a 57° inclination. On the first day, the tethered endmass will be deployed downward 50- to 170-km altitude and remain there for 2 days. On day 3, an additional 20 km will be deployed, lowering the endmass to an altitude of 150 km for 2 days. On day 5, the final 20 km of tether will be deployed, lowering the endmass to its final 130-km altitude where it will remain for 2 days. The orbiter altitude will be maintained by use of its Primary Reaction Control System (PRCS). On day 7, the tether will be cut, after which the endmass begins a reentry course that lasts less than 1,000 seconds from release to burnout. It is estimated that the fuel required for this scenario is 1996 kg (4,400 lb).

Option 2: Deploy/Retrieve

The orbiter enters a 280-km circular orbit at a 57° inclination. On the first day, the tethered endmass will be deployed downward 110- to 170-km altitude. As the orbit of the shuttle/tether system decays, tether is retrieved (~15 km) to maintain the endmass at a constant 170-km altitude. On day 3, the orbiter enters a 265-km-altitude orbit and an additional 20 km of tether is deployed, lowering the endmass to an altitude of 150 km. Again, more tether is retrieved (~25 km) to maintain the endmass at 150 km as the system altitude drops over the next 2 days. On day 5, the orbiter enters a 240-km orbit and deploys the final 20 km of tether, thus lowering the endmass to its final 130-km altitude where it will remain for 2 days. The orbiter altitude, controlled by means of the PRCS, will decay from 240 to 200 km during these 2 days. On day 7, the tether will be cut, after which the endmass begins a reentry course that lasts less than 1,000 seconds from release to burnout. It is estimated that the fuel required for this scenario is 364 kg (800 lb).

B. Endmass Configuration

The preliminary concept drawing of the TIILT endmass is seen in figure 1. Five of the science instruments are required to face the RAM (not an acronym but derived from the term"ramming") direction with two in the wake. A series of E-field double probes and Langmuir probes are placed at specific locations around the 1.6-m-diameter satellite shell. This concept shows an aerodynamic tail used to increase yaw stability.

A detailed drawing showing the internal location of the science instruments and major endmass subsystems is presented in figure 2.

Each science instrument has specific mounting location requirements and special considerations for viewing to maximize data collection. The instruments also have specific field-of-view requirements that are illustrated in figure 3.

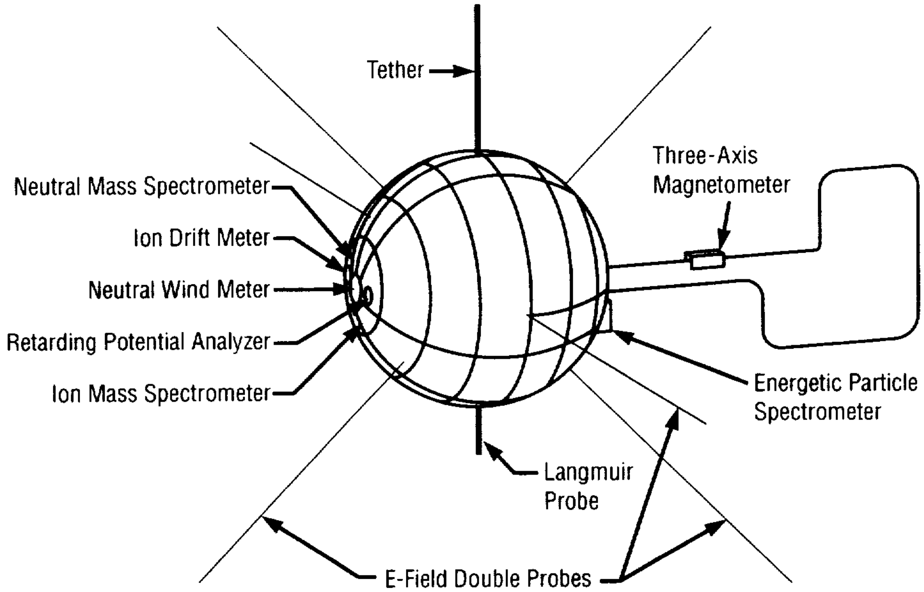

FIGURE 1.—TIILT endmass configuration showing instrument locations, tether orientation, and aerodynamic "tail" assembly.

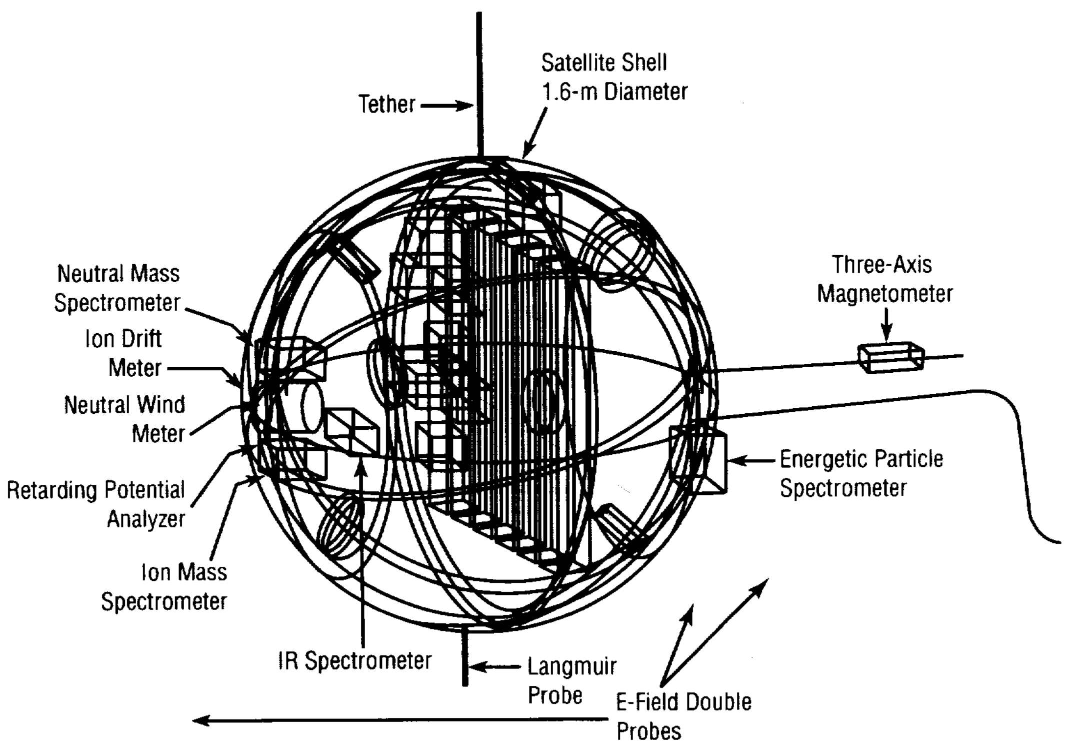

FIGURE 2.—Detailed TIILT endmass configuration showing internal instrument and subsystem locations.

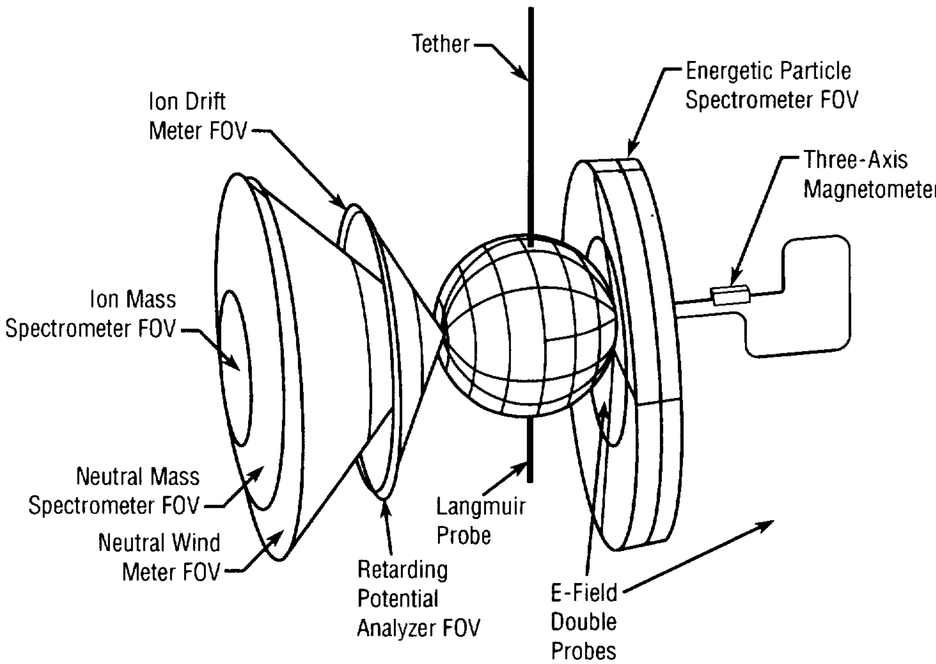

FIGURE 3.—Instrument fields of view from the endmass.

C. Aerodynamic Analysis of Endmass

A detailed direct simulation Monte Carlo analysis calculated the drag for a spherical-shaped endmass (1.6 m in diameter) to range from 0.92 N at 130-km altitude to 0.11 N at 170-km altitude (fig. 4). It is important to note that the aerodynamic flow regime at the altitudes of interest is considered to be transition flow. This introduces significant unknowns into the overall aerodynamic assessment in that the atmospheric density in this region varies dramatically as a function of the diurnal and solar cycles. For altitudes greater than 160 km, free molecular flow models can be accurately used. Continuum flow models are considered accurate for altitudes below 100 km. However, the bulk of TIILT mission science will occur in the transition region between 100 and 160 km. For this reason, the "tail" assembly is added to the endmass to aid in RAM pointing at the lowest mission altitudes (~130 km). Note: Knudsen numbers are defined to be a dimensionless parameter that relates the mean free path in a flow to the characteristic length of a body immersed in the flow.

D. Endmass Attitude Control System

Two of the major design constraints on the attitude control system are (1) avoidance of large torques that will disturb the endmass force and acceleration measurements, and (2) the inability to use magnetic torquers because they cause disturbances in the magnetic field flux measurements. The science instrument requirements state that the endmass should be pointed within $\pm 3^{\circ}$ of RAM with a $\pm 0.1^{\circ}$ postflight knowledge requirement. An attitude control system combining the use of reaction wheels and strategically placed cold gas thrusters is the current proposed baseline. A top-level trade was performed

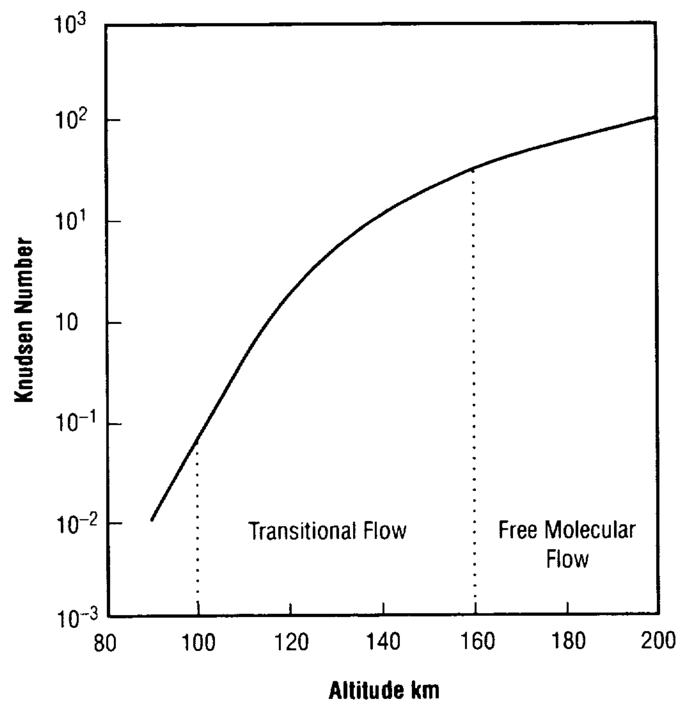

FIGURE 4.—Aerodynamic drag analysis of a spherical 1.6-m-diameter endmass.

to determine the most applicable approaches for attitude control. A summary of the systems traded can be seen in table 3. The location of thrusters will be determined using Direct Simulation Monte Carlo (DSMC) analysis to avoid instrument and endmass contamination. The control system is estimated to weigh 15 kg.

TABLE 3.—*Endmass attitude control system options.*

Benchmark	Cold Gas Thrusters	Reaction Wheels	Magnetic Torquers	Gravity Gradient Only
Controllable Axes	3	3	1	2
Control of Yaw	Yes	Yes	Yes	No
Control System Mass (Approximate)	20 kg	15 kg	10 kg	0 kg
Volume Required	Large	Large	Moderate	None
Accuracy (Best Possible)	±0.5°	±0.1°	±5°	±5°
Power Required	30 W	45 W	5 W	0

E. Communications and Data Handling System

The science instrument data requirement is to transmit data at a rate of 250 kbps (including the optional infrared and ultraviolet instruments) continuously over the 6-day mission. The proposed communications system will include a dedicated radio frequency system on the endmass which will transmit the data by S-band or ultrahigh frequency to a similar system on the deployer. The data stream will then be hard-wired from the payload bay to the orbiter Ku-Band signal processor. The science data will be recorded on the orbiter or downlinked via the Tracking Data Relay Satellite System (TDRSS) to a designated ground station. The proposed Communications and Data Handling (C&DH) system for the endmass consists of a Central Processing Unit (CPU), a receiver, transmitter, and two omnidirectional antennas with a total weight of 5.5 kg, requiring 33.3 W of power. A block diagram of the C&DH system is shown in figure 5.

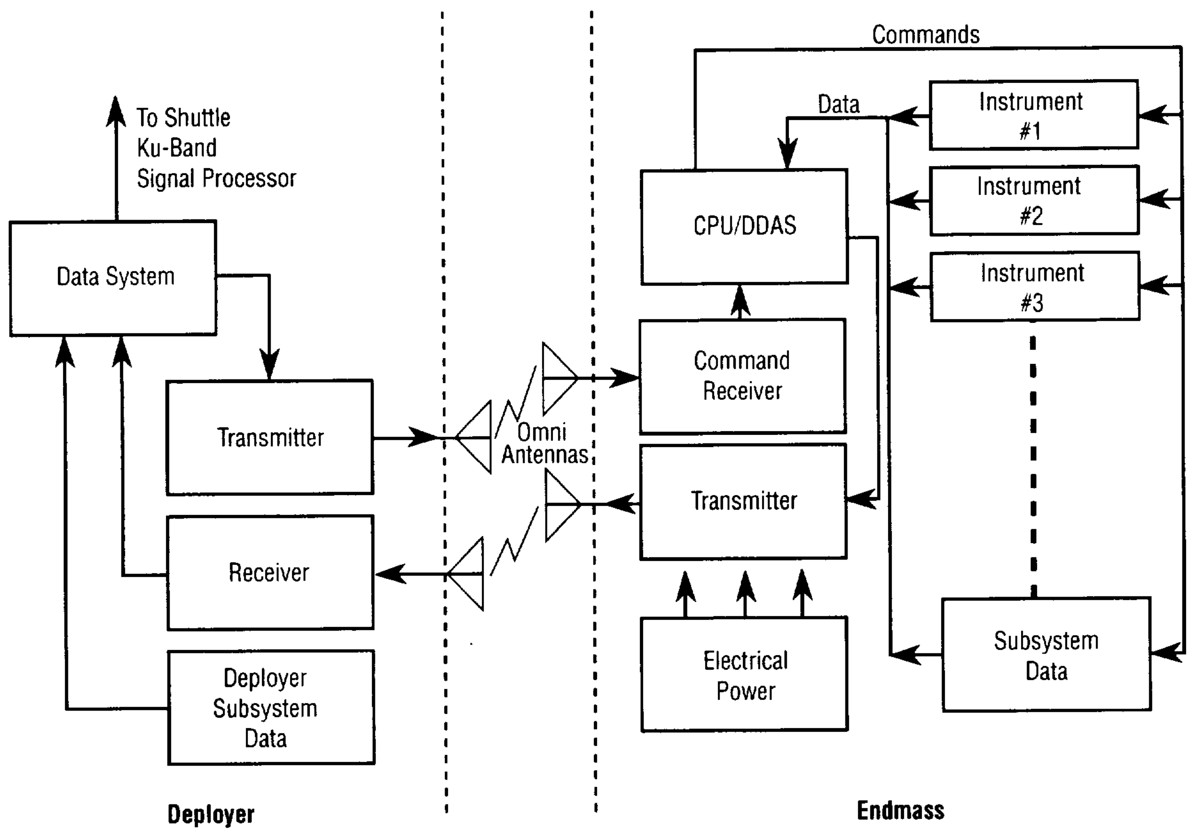

FIGURE 5.—C&DH system block diagram.

F. Endmass Electrical Power System

The mission lifetime of 6 days requires seven lithium-thionyl chloride ($Li/SOCL_2$) type batteries weighing 105 kg. The additional cables, harnesses, and distribution weights bring the electrical power system to an estimated 155 kg. The total desired power loads are estimated at 176.6 W which includes a 25-percent contingency. This total includes the science instruments (including the two endmass optional instruments) and electronics, and the endmass major subsystem equipment. A summary of the electrical power system mass versus potential mission duration is seen in figure 6.

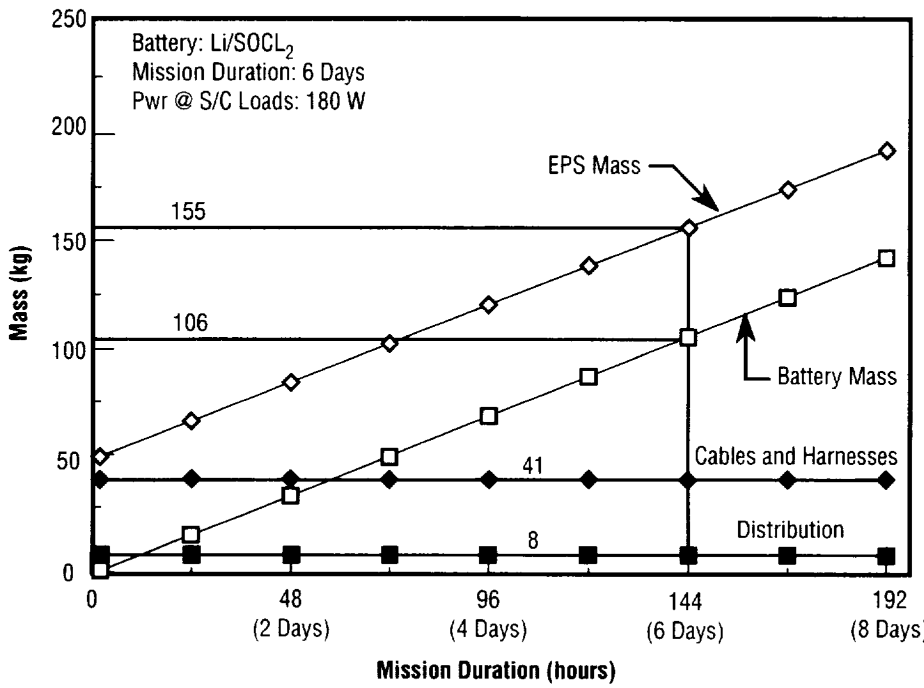

FIGURE 6.—Electrical power system mass is driven by the battery power required to support a 6-day mission.

The user loads on the electrical power system are detailed in table 4. The total system load is estimated to be around 177 W. The energy required at 90 percent degree-of-degradation for a 6-day mission is 25.43 kWh.

TABLE 4.—*Electrical power system loads.*

	Watts
Electrical Power Requirements	
Communications and Data Handling	33.3
Attitude Control Subsystem	29.6
Thermal Control Subsystem	4.0
Electrical Power Subsystem	7.5
Subtotal	74.4
Total Electric Power Loads	
Instrument Suite (Desired)	67.0
Spacecraft Subsystems	74.4
Contingency (25%)	35.2
Total	176.6

G. Endmass Thermal Environment

A flowfield temperature analysis was performed at an altitude of 130 km (fig. 7). The temperature variations occur in shock layers ranging from 800 to 12,000 K. The flowfield is in a thermal nonequillibrium state and its chemical composition can be obtained from the DSMC calculations. Terms used in the figure to describe the endmass thermal characteristics are defined as follows:

T = overall temperature—the mean of translational and internal temperatures where $T_{infinity}$ = ambient temperature and T_W = surface temperature

K = degrees Kelvin

$V_{infinity}$ = orbital velocity at 8 km/sec

x,m horizontal axis is the axial distance (m) from the stagnation point measured along the axes of symmetry

y,m vertical axis is the radial distance (m) from the axes of symmetry.

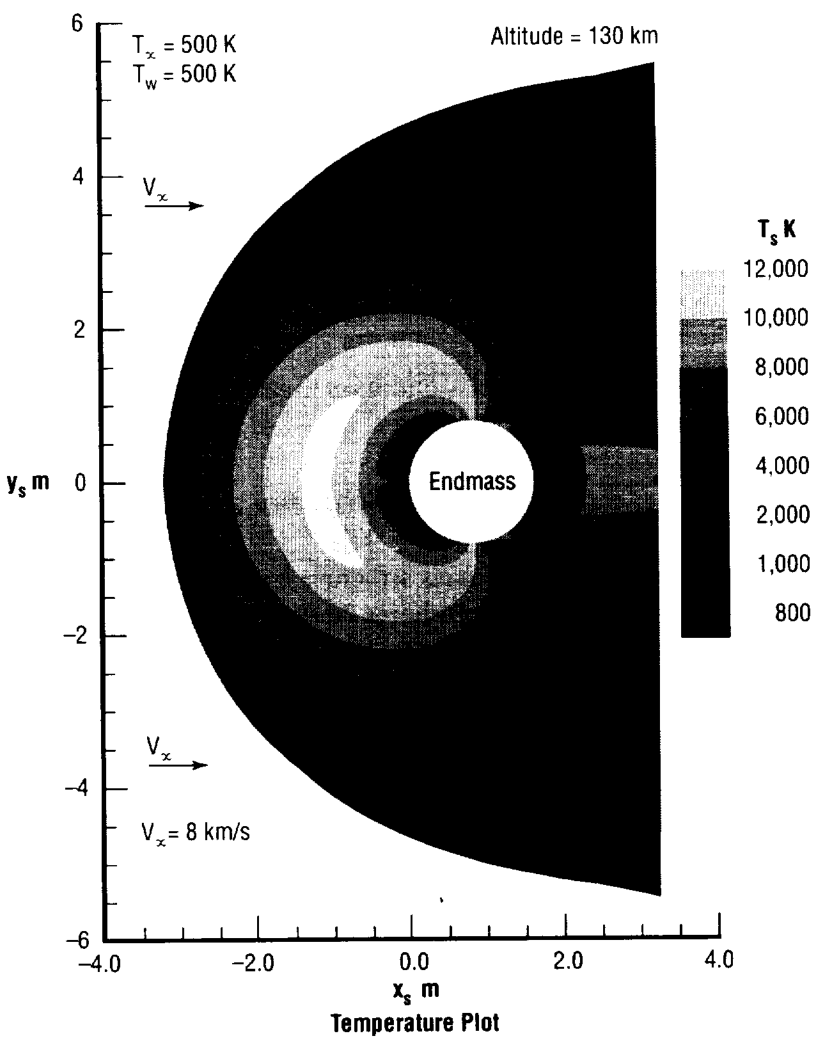

FIGURE 7.—Endmass flowfield temperature analysis.

The maximum aeroheating on the endmass surface shows the stagnation point heat flux for different altitudes (see fig. 8). The surface heat flux can be obtained from the DSMC calculations. Assessment of thermal heating effects on the tether and deployed booms is pending. A combination of thermal blankets and heaters comprise the current endmass thermal control system. The estimated weight of the system is 7 kg, requiring 4 W of power.

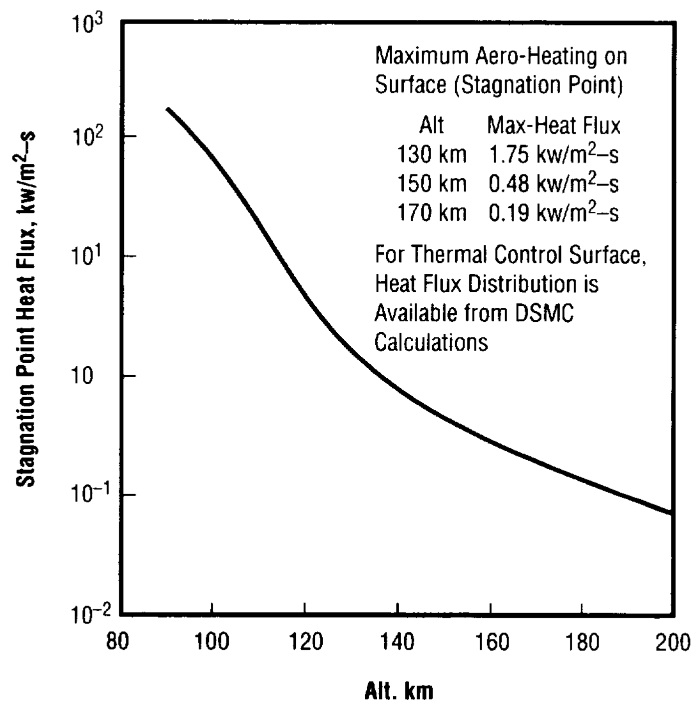

FIGURE 8.—TIILT endmass thermal input.

H. Endmass Structure

The recommended material for the endmass structure is Aluminum 2219. The endmass structure is composed of an equatorial ring with two hemispheres of four flanged quadrants each. A mounting panel attached to the ring will be provided for mounting internal equipment. Local stiffening of the shell will be required for the mounting of deployables and some instruments, and attachment of the aerodynamic tail. A smooth surface is desired for aerodynamics requiring the use of flush closeouts. The estimated weight of the endmass structure is 81.9 kg.

I. Baseline Tether Concept

The baseline tether concept, shown in figure 9, is a 1.65-mm-diameter Kevlar strength member surrounded by a Nomex jacket, with a total diameter of 2.16 mm. A tether with a 2.16-mm diameter and a length of 110 km would be subjected to a sizable drag when lowered into the lower thermosphere. The present estimates of aerodynamic drag on the tether itself, for a flight in the year 2001, are 17.5, 6.5, and 3.1 N for lower tip altitudes of 130, 150, and 170 km, respectively.

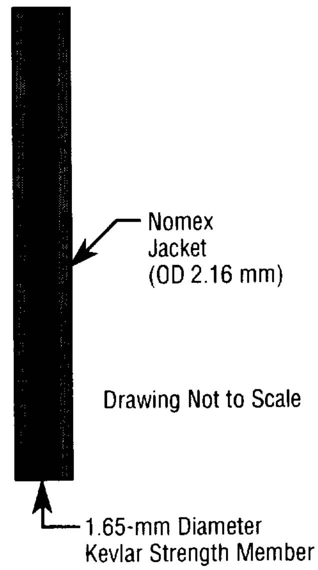

FIGURE 9.—The baseline tether concept.

Tether length will be 110 km maximum, have a break strength of 2,892 N, and weigh 4.03 kg per km. The TIILT tether is nonconductive and, therefore, not susceptible to the same factors that caused the tether break on TSS-1R. The probability of tether survival in the micrometeoroid and debris environment of low-Earth orbit over a 6-day mission, assuming a critical particle size of 0.3 times the tether diameter, is approximately 0.93. The probability of survival is highly sensitive to critical particle size. A graph showing survival probability sensitivity with respect to impactor particle size is shown in figure 10.

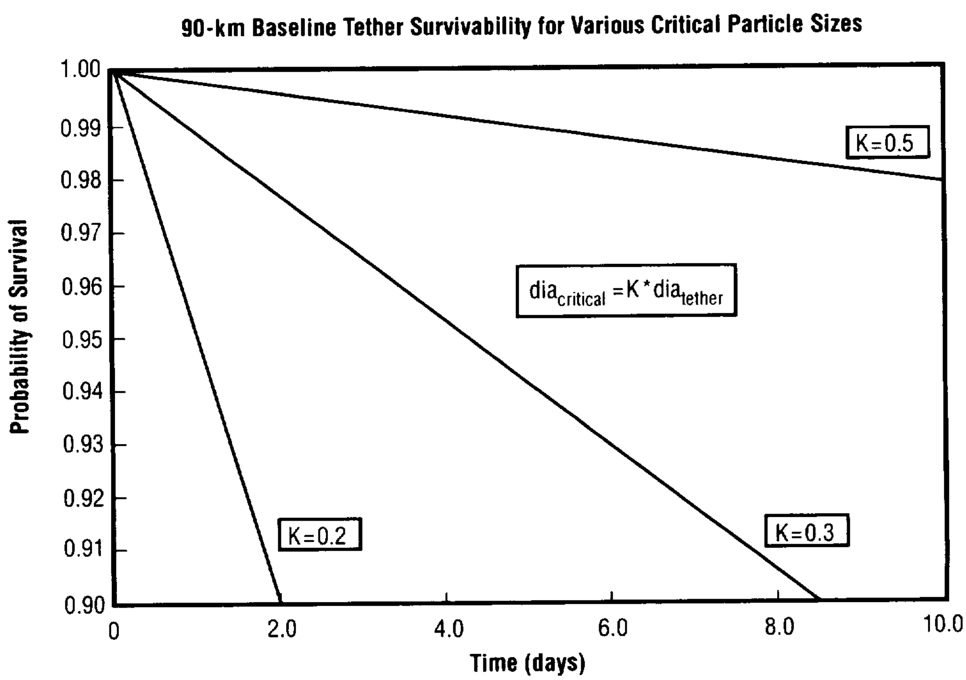

FIGURE 10.—Comparison of critical particle sizes and the probability of tether survival versus time.

For the baseline tether diameter of 2.16 mm and a critical particle size of 0.3 of the tether diameter, figure 11 provides insight into the survival probability as a function of tether length. High probability (>0.99 percent) of survival is not possible for missions lasting more than 1.5 days for tether lengths of 50 to 100 km unless a highly survivable tether is used, described in the following section.

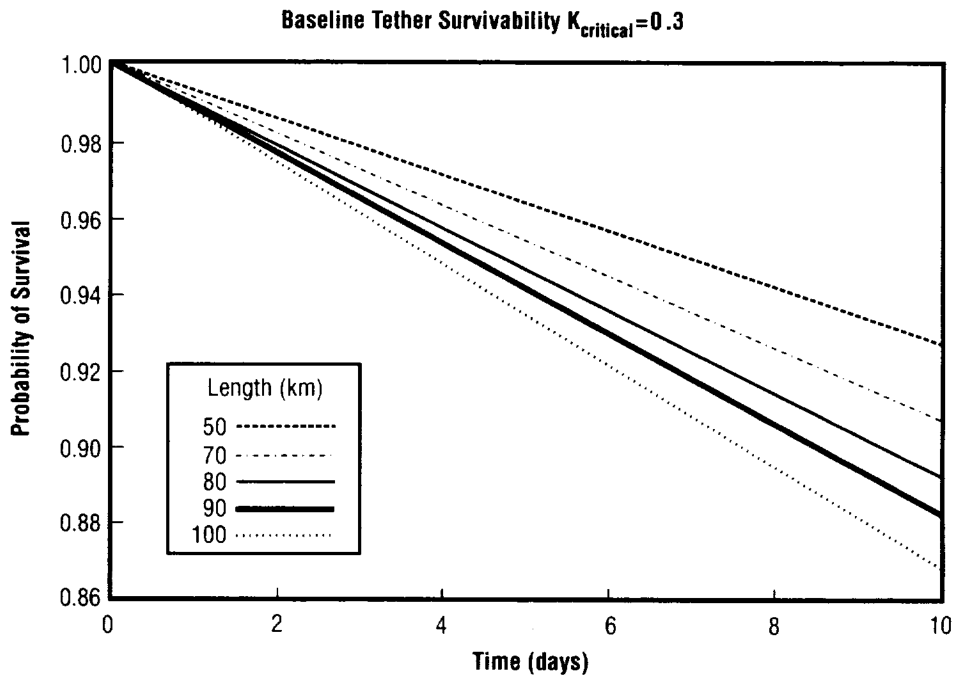

FIGURE 11.—Tether survival probability as a function of final deployed length (critical particle size is 30 percent of the tether diameter).

J. Alternate Tether Concepts

Alternate highly survivable tether designs are being considered for the mission. When considering comparative lifetimes, a single line tether (baseline) is compared to a minimal Hoytape type of tether shown in figure 12. A Hoytape tether is made from much smaller individual tether strands widely separated from each other to increase the overall tether's likelihood of surviving a given impact. During such an impact, presumably, one strand would break but several would remain to pick up the load.

The survival probability using a particle size of 0.3 of the tether diameter jumps from 91 percent for a single line tether to 99.99 percent for the Hoytape. The minimal Hoytape with four 0.54-mm-diameter lines has the same drag area as the single 2.16-mm-diameter line and a total mass of 275 kg instead of ~500 kg. Other Hoytape designs using smaller diameter members will decrease the drag and tether mass even further, while maintaining survivability near 100 percent.

K. Atmospheric Drag and Tether Dynamics

The atmospheric drag on the tether and endmass will induce libration oscillations of the tether system. This is due to the fact that the atmospheric density is not constant, thus affecting the in-plane libration of the tether. Figure 13 shows the in-plane and out-of-plane libration angles over time. The endmass pitch and roll motions are predominately controlled by the tether tension but the endmass yaw axis motion must be controlled by a combination of an aerodynamic tail and an on-board attitude control system.

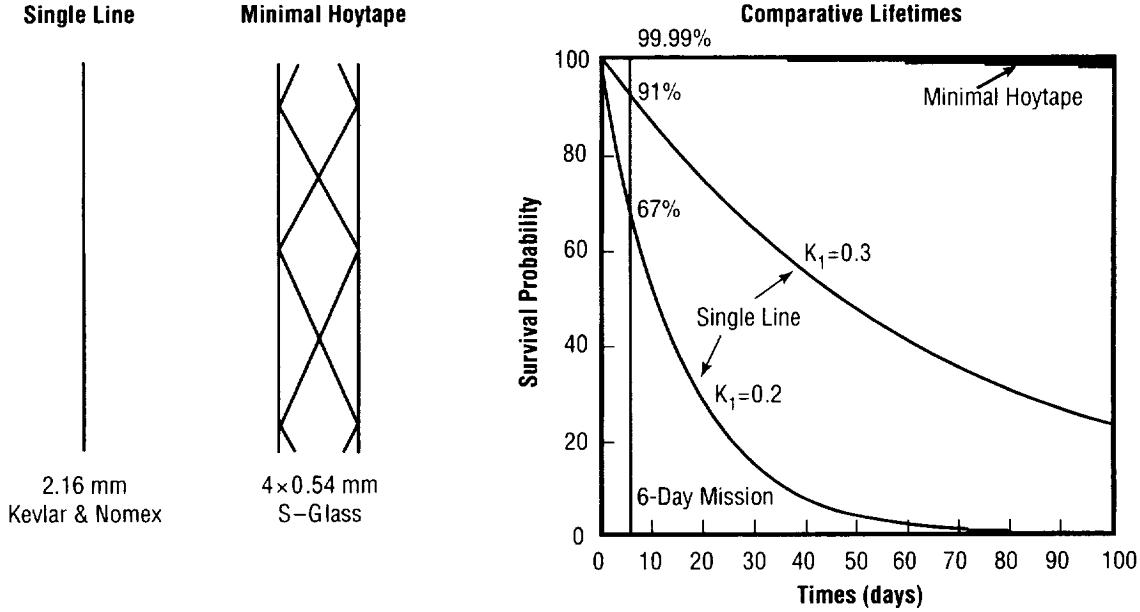

FIGURE 12.—Lifetime comparison of the baseline single-strand tether and the Hoytape tether.

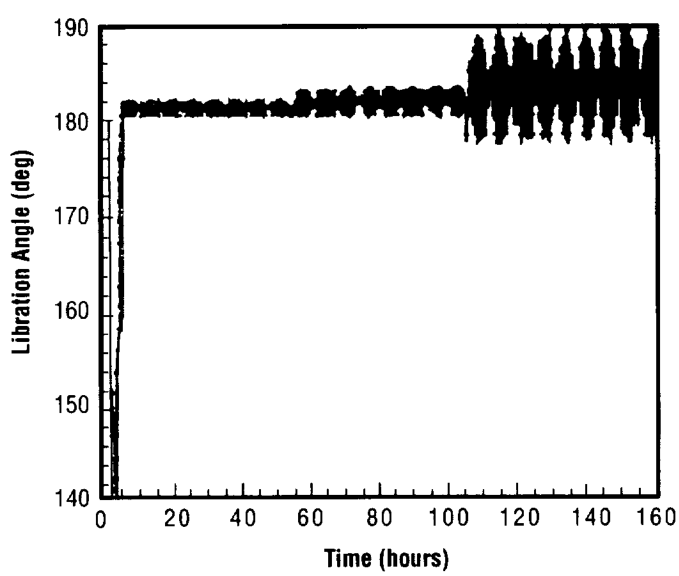

FIGURE 13.—Coupled with the frequent PRCS thruster firings on the orbiter, the nonuniform atmospheric density will make the libration of the endmass become rather large at the lowest altitudes.

A drawing summarizing libration control issues is shown in figure 14. The atmospheric drag on the tether and endmass will induce libration oscillations. This is due in part to the atmospheric density not being constant. The current analysis shows the endmass pitch attitude excursions are maintained within 10° of RAM passively. Based on the current analysis, a libration and/or satellite pitch attitude control scenario may be required to hold the endmass attitude to within the science requirement of 3° of RAM.

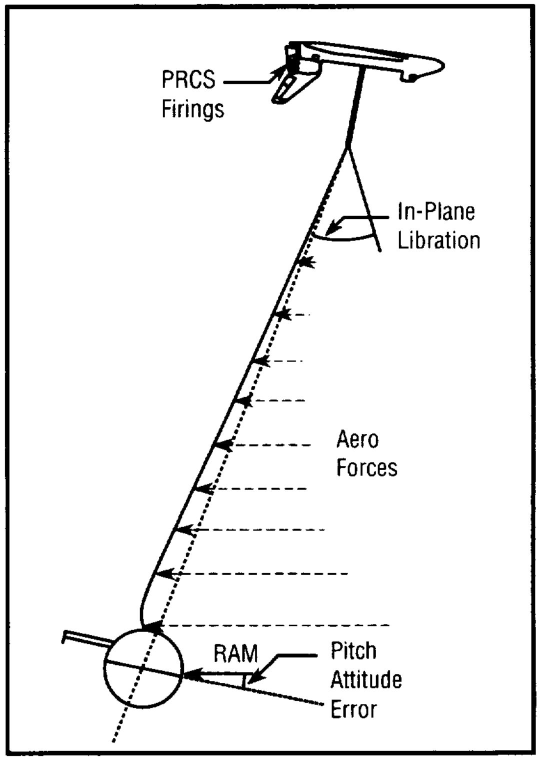

FIGURE 14.—Summary of libration control issues.

L. Deployer Options

There are two types of deployers considered for the TIILT mission—a modified Tethered Satellite System (TSS) deployer (fig. 15) and a modified Small Expendable Deployer System (SEDS) (fig. 16). The TSS deployer has flown twice on the orbiter but must be modified for the TIILT mission. The SEDS deployer is smaller, would require extensive modification, and is not orbiter-qualified. Deployment with SEDS is stable and controllable as demonstrated in the SEDS II mission (March 1994) where the tether was stabilized very close to the local vertical. However, SEDS, in its present configuration, can neither retrieve the tether nor damp out the residual in-plane libration during on-station operations. The current baseline deployer of the TIILT system is a modified TSS-type deployer. Tether deployment using the TSS is stable and has been demonstrated successfully in the TSS-1R mission. The TSS deployment control strategy is proven and suitable for the expected endmass altitudes required in the TIILT mission. The proposed TIILT system will be mounted on a Spacelab pallet in a designated location in the orbiter payload bay.

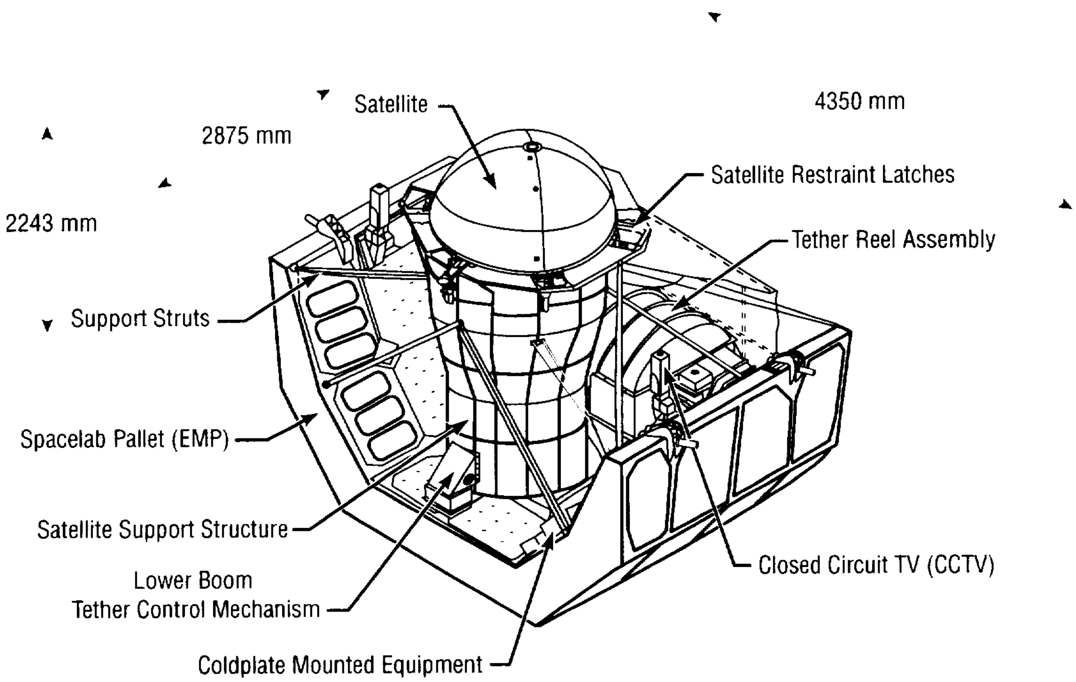

FIGURE 15.—TSS deployer on a Spacelab pallet.

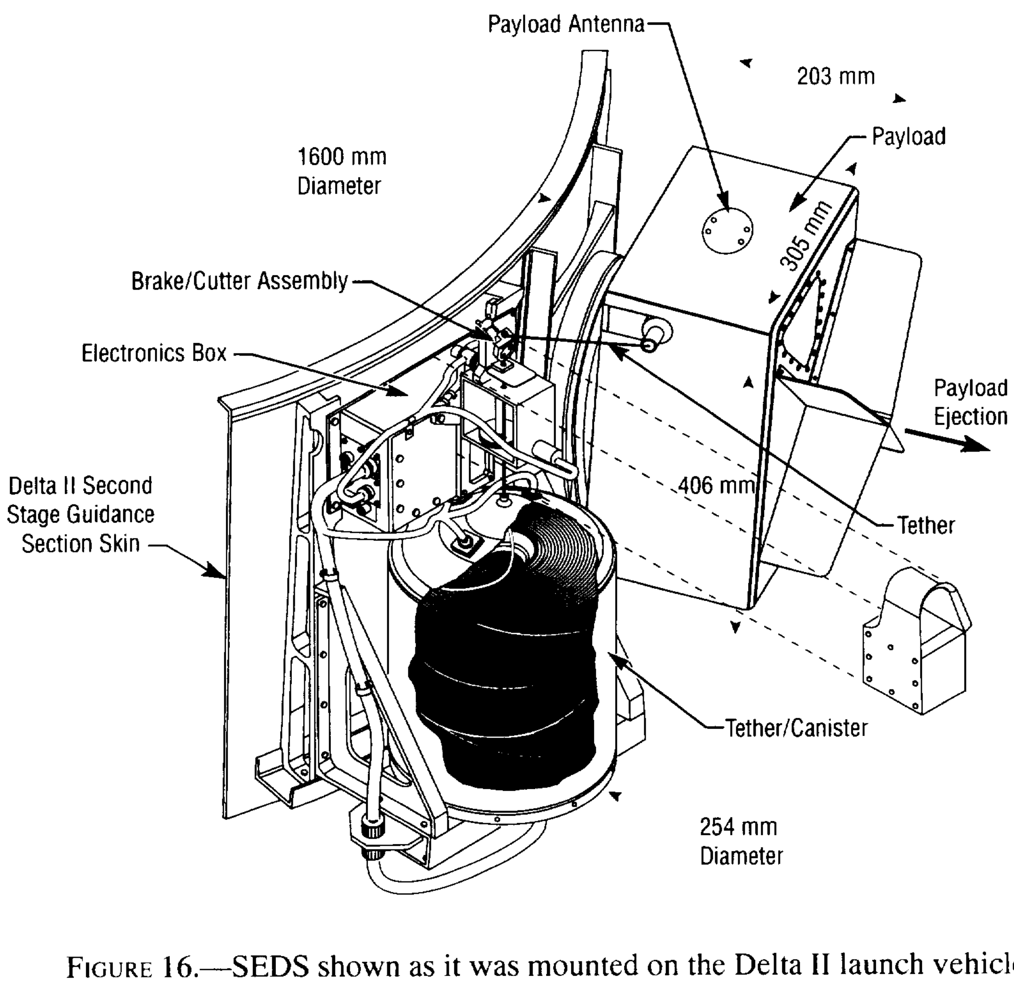

FIGURE 16.—SEDS shown as it was mounted on the Delta II launch vehicle.

M. Weight Statement

The total estimated weight (without contingency) of the endmass is 325.3 kg. The TSS deployer reel, electronics, support structure, and Spacelab pallet add an additional 2940 kg and the tether adds 500 kg. With a 30-percent contingency, the total weight of the TIILT system is 4895 kg. Table 5 details the TIILT weight statement.

TABLE 5.—*TIILT weight statement.*

	kg
Endmass	
Science	60.9
Structures	81.9
Electrical Power System	155.0
C&DH System	5.5
Thermal Control	7.0
Attitude Control System	15.0
Deployer	
Reel, Electronics, Support Structure, SL Pallet	2940.0
Tether (120 km)	500.0
Contingency (30%)	1129.6
Total	4894.9

N. Development Schedule

Following a standard procurement and development approach, the TIILT program schedule is shown in figure 17. From Authority To Proceed (ATP), the development of the TIILT is planned to take 4 years. A 6-month phase A study for engineering design would begin immediately followed by a 9-month phase B definition. Parallel to the beginning of phase A, an Announcement of Opportunity (AO) would be released for the science instruments. The selection of the instruments would occur at the beginning of phase B and the science instrument design, development, fabrication, and testing would begin. Development of the endmass and tether would begin parallel to the instrument development, with the deployer development starting within the next quarter. All hardware would be delivered and integrated into the orbiter in the beginning of the fourth year with a projected launch in the third quarter of the year.

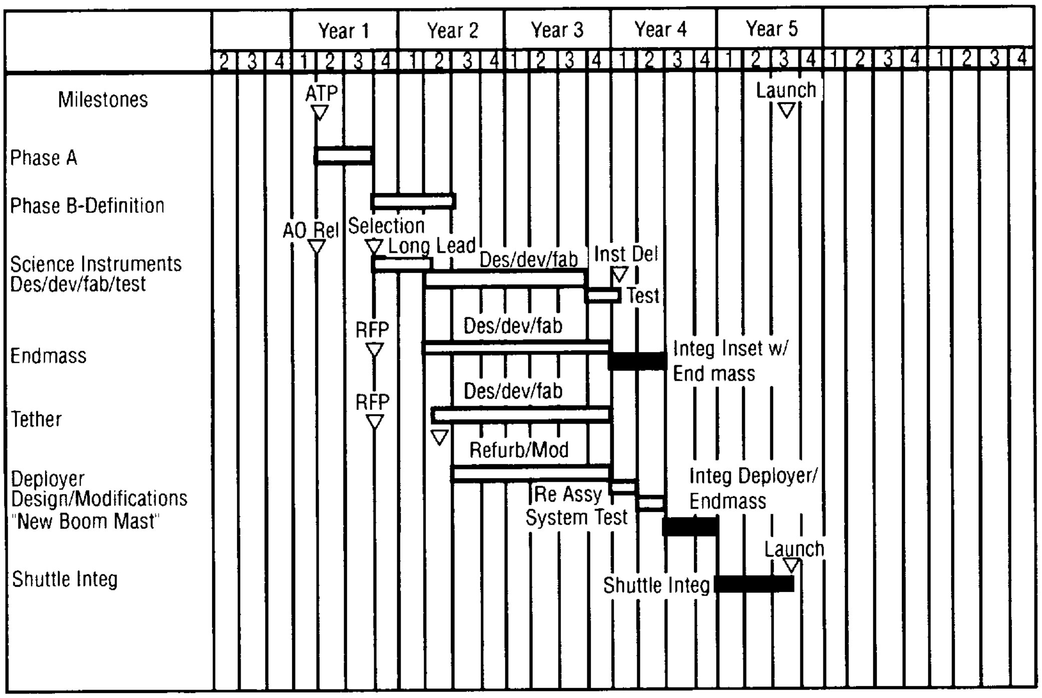

FIGURE 17.—TIILT development schedule.

Should the mission become considered time-critical, it may be possible to shorten the schedule significantly by combining and accelerating the studies of phases A and B, utilizing existing "tether" contractors in lieu of a new procurement, and working with other governments to provide end-item hardware supporting the mission.

O. Cost Estimate

Estimated mission costs (table 6) are based on NASA standard models for the endmass, scientific instruments, and orbiter-related costs. Data for refurbishment and modification to the tether and deployer are from Lockheed Martin Astronautics. A 30-percent contingency is applied. "Wraps" include project management, systems engineering and integration (SE&I), physical integration, assembly, checkout, ground support equipment, and system testing. The estimates assume an 80-percent contracted effort.

TABLE 6.—*Estimated TIILT costs ($M).*

Item	DDT&E ($M)	Flight Unit ($M)
Endmass	3.5	2.7
Deployer & Tether	6.8	4.0
Instruments	2.7	4.1
Hardware Total	13.0	10.8
"Wraps"	7.0	6.5
Subtotal Costs	20.0	17.3
Cont. & Fee	5.5	4.7
Total Costs	25.5	22.0
Total		47.5

V. CONCLUSIONS

The proposed TIILT mission appears to be technically feasible for a reasonable cost. Further study should resolve any major issues resulting from this preliminary concept study.

APPROVAL

TETHER-BASED INVESTIGATION OF THE IONOSPHERE AND LOWER THERMOSPHERE CONCEPT DEFINITION STUDY REPORT

Edited by Les Johnson and Melody Herrmann

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

A. ROTH
DIRECTOR, PROGRAM DEVELOPMENT DIRECTORATE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1997	Technical Memorandum

4. TITLE AND SUBTITLE
Tether-Based Investigation of the Ionosphere and Lower Thermosphere Concept Definition Study Report

5. FUNDING NUMBERS
116–10–02

6. AUTHORS
L. Johnson and M. Herrmann, Editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM–108543

11. SUPPLEMENTARY NOTES
Prepared by Program Development Directorate

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified–Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Understanding the plasma and atmosphere around the Earth in the lower altitude regions of the mesosphere, lower thermosphere, and ionosphere is important in the global electric system. An upper atmosphere tether has been proposed to NASA that would collect much-needed data to further our knowledge of the regions. The mission is proposed as a shuttle experiment that would lower a tethered probe into certain regions of Earth's atmosphere, collecting data over a 6-day period. This report is a summary of the results of a concept definition study to design engineering system that will achieve the scientific objectives of this mission.

14. SUBJECT TERMS
multipoint measurements, tether, ionosphere, spectrometer, magnetometer

15. NUMBER OF PAGES
28

16. PRICE CODE
NTIS

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified