NASA/TM—1998-206303 IEPC–97–144

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Prepared for the
25th International Electric Propulsion Conference
sponsored by the Electric Rocket Propulsion Society
Cleveland, Ohio, August 24–28, 1997

National Aeronautics and
Space Administration

Lewis Research Center

January 1998

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800 Elkridge Landing Road
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The Twin Electric Magnetospheric Probes Exploring on Spiral Trajectories mission concept was proposed as a Middle Explorer class mission. A pre-phase-A design was developed which utilizes the advantages of electric propulsion for Earth scientific spacecraft use. This paper presents propulsion system analyses performed for the proposal. The proposed mission required two spacecraft to explore near circular orbits 0.1 to 15 Earth radii in both high and low inclination orbits. Since the use of chemical propulsion would require launch vehicles outside the Middle Explorer class a reduction in launch mass was sought using ion, Hall, and arcjet electric propulsion system. Xenon ion technology proved to be the best propulsion option for the mission requirements requiring only two Pegasus XL launchers. The Hall thruster provided an alternative solution but required two larger, Taurus launch vehicles. Arcjet thrusters did not allow for significant launch vehicle reduction in the Middle Explorer class.

Introduction

The TEMPEST (Twin Electric Magnetospheric Probes Exploring on Spiral Trajectories) mission concept was proposed as a Middle Explorer (MIDEX) class mission. Figure 1 presents an early conceptual TEMPEST spacecraft. The pre-phase-A design utilizes the advantages of electric propulsion for Earth scientific spacecraft use. TEMPEST is derived from an earlier concept, TROPIX (Transfer Orbit Plasma Interaction eXperiment).[1]

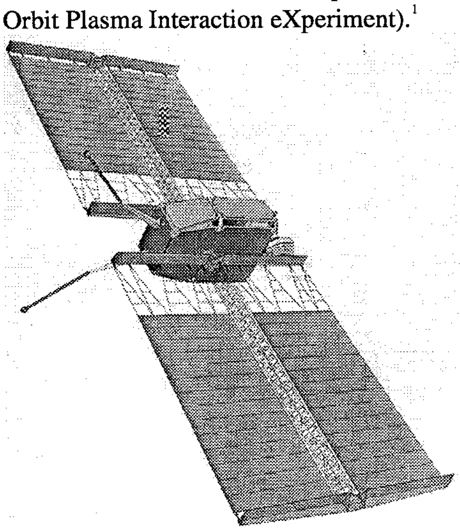

Figure 1. Conceptual TEMPEST Spacecraft

The following study draws requirements and conceptual information from the TEMPEST MIDEX Proposal. The propulsion system trades that form the bulk of this paper were made during the pre-phase-A process. 30-cm ion thrusters were preliminary selected for the TEMPEST science mission based on their performance.

Study Objectives and Approach

The objective of this paper is to demonstrate the advantage of using electric propulsion technology for MIDEX class Earth magnetospheric mapping mission. Mission performance comparisons between electric and chemical thrusters are made. In addition, specific requirements, impacts and benefits of using an ion propulsion system (IPS) on an Earth orbital spacecraft are identified.

Emphasis is placed on determining the performance effects of an electric propulsion system in terms of reduced launch mass. This study includes an assessment of two solar cell technology options and quantifies the radiation damage encountered during the transfer through the Van Allen Belts.

The following mission and science descriptions are excerpts from the TEMPEST MIDEX Proposal. They represent the final proposed mission concept chosen from the many different concepts studied during the science mission design process.

TEMPEST Mission Requirements

The TEMPEST mission concept consists of two spacecraft launched into orthogonal low altitude orbits (high and low inclination) carrying a small complement of basic instruments to measure particles and fields. The spacecraft are required to trace out trajectories of near circular orbits from low Earth orbit (LEO) completely through the magnetosphere to 15 Earth radii in 2 years. Figure 2 shows a cutaway of the magnetosphere. The low inclination spacecraft is to fly through the heart of the equatorial magnetosphere where the ring current is formed, where the "killer" electrons are found, and where the crosstail current is disrupted at the onset of a substorm. These "killer" or high energy electrons are thought to be responsible for the demise of critical satellite equipment in geostationary orbit. The high inclination spacecraft will transfer upward through the acceleration region on auroral field lines, mapping the plasma populations from low to high altitudes, and determining where and how these particles are energized. Both missions provide complete coverage of magnetospheric regions heretofore inadequately explored, and provide unequivocal identification of access-, acceleration-, transport-, and loss-mechanisms for energetically charged particles in the magnetosphere. These measurements would lead directly to substantial improvements in the understanding of storms and substorms. The TEMPEST mission would test each of the three major theories of the initiation of substorms. It would determine how the ring current forms and how "killer" electrons are energized. TEMPEST would also enable quantified determination of the differences between the substorm and the geomagnetic storm.

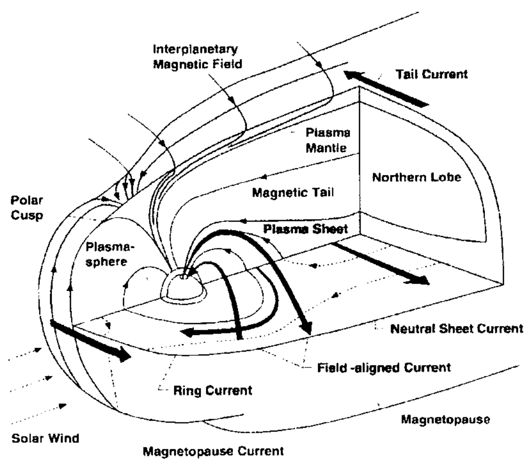

Figure 2 Cutaway of magnetosphere showing locations of its various plasma and electrical currents

To perform the TEMPEST mission the satellites need to be configured initially so that the low altitude, high latitude data can be compared with simultaneous data in the equatorial plane. During this phase the low altitude spacecraft measures waves and particle distributions where the loss cone can be well resolved, while the high altitude spacecraft measures the full equatorial distributions on the same field lines in the only region in which they can be measured. Later, the high inclination spacecraft joins the low inclination spacecraft at high altitudes. Together they transfer outward in orthogonal orbits through the "current disruption" region and the "near-Earth neutral point" region, with close encounters occurring twice per orbit. These orbits will carry each spacecraft through the magnetopause (in orthogonal planes) on the dayside of the orbit.

The payload required for this mission is quite simple. It consists of magnetic and electric field measurements, plasma observations with composition data, energetic particle data, plasma wave data and a spacecraft interactions package to probe the interactions of this new technology vehicle with the environment. The science payload mass is 30 kg for the high inclination spacecraft and 34 kg for the low inclination spacecraft.

Propulsion System Interaction with Science Collection

It is possible that the effects of the electric thrusters during operation may have an impact on in-situ plasma measurements. Initially, 5% of the daylight time will be devoted to making measurements without the thrusters firing. This "non-thrusting operation" will allow quantitative tests of the effects of the thrusters on in-situ particle and field measurements, crucial for future missions using such propulsion. It is noted that nearly half of the early orbits are in shadow, when the thrusters will not be operating because of power constraints; in those times the plasma measurements should be unaffected. Thus good science measurements will generally be obtained over at least half of the time, even in the first year when the thrust is maximized for the equatorial spacecraft. In the latter part of the

Table I Electric Propulsion System Parameters

Propulsion System	NSTAR	N_2H_4 Arcjet	Xe Hall	XIPS
Thruster Mass (with structure, gimbal, feed system)	17.5 kg	1.9 kg	9.4 kg	11.2 kg
PPU (with cable & thermal) Mass	19.1 kg	15.2 kg	18.6 kg	6.8 kg
Tankage Fraction	0.04	0.07	0.04	0.04
Maximum Thruster Power Level	2500 W	2390 W	1930 W	500 W
Thruster I_{sp} @ Max. Power	3462 sec	610 sec	1599 sec	2585 sec
I_{sp} curve fit multiplier	171.78	46.00	324.50	0.00
I_{sp} curve fit power	3.00	1.00	2.00	1.00
Overall Efficiency @ Max. Power	0.62	0.32	0.46	0.45
Efficiency curve fit multiplier	0.07	0.00	0.10	0.00
Efficiency curve fit power	2.00	1.00	2.00	1.00
Minimum Thruster Power Level	500 W	1000 W	700 W	500 W
Thruster Life Throughput	83 kg	156 kg	100 kg	20 kg

mission, non-thrusting science operations increase to over 50% in sunlight. A target mission duration of 2 years was sought because this operation time was called for in the MIDEX Program.

Tools and Models

All of the TEMPEST mission scenarios were analyzed with the Electric Mission Optionizer (ELMO). ELMO provides an analytical way of determining an electric propulsion system's mission performance. By using the Edelbaum[3] ΔV and analytical integration, up to ten separate spiral mission (circular to circular orbit) phases with inclination change can be modeled. Coast times can be placed between the phases. The analysis allows for specific systems (mass, technologies, power level) to be simulated with the higher order mission effects of shading, oblateness (J2), atmospheric drag, solar array power degradation and built in coast times.

System and Mission Options

Figures of Merit

For the TEMPEST mission the ultimate objective is maximizing science return for a given (unit) cost. Simply put, science return is dependent on the quantity of instruments placed on the spacecraft (which influences and depends upon power, mass, volume, launch vehicle, etc.), the coverage area (viewing and/or orbit locations visited), and the spacecraft lifetime. The MIDEX funding level will limit all of these, mainly in terms of the launch vehicle, spacecraft, and mission operations. The following scenarios show the various optional approaches to these figures of merit. The variations are made by using different propulsion systems (including launch vehicles), power levels, and solar cell technologies.

Propulsion Options

Five candidate propulsion systems were considered for the TEMPEST analysis: chemical bipropellant, NSTAR 2.5 kW xenon ion thrusters, 2.4 kW N_2H_4 arcjet thrusters, 1.9 kW xenon Hall thrusters and the Hughes 0.5 kW Xenon Ion Propulsion System (XIPS). Each of these systems brings into play different specific impulses, power levels, lifetimes, and dry masses. A 310 second specific impulse, 450 N thrust bipropellant propulsion system, is assumed for the comparative chemical system. The chemical system tankage fraction is assumed to be 0.053. The characteristics of each electric propulsion system are shown in Table 1. Masses are broken out by thruster (includes structure, gimbal, and feed system), power processing unit (PPU) (includes cabling and thermal systems), and tanks (scaled with fuel mass).[4] Due to the possibility of array degradation, all of the electric propulsion systems except the XIPS were assumed to be throttleable. The I_{sp} and efficiency were modeled as a function of input power with the following relationships:

$$I_{sp} = I_{spmax} - M_{isp} \left(P_{max} - P^{E_{isp}} \right)$$

where I_{spmax} is the I_{sp} at the maximum power, M_{isp} is the curve fit I_{sp} multiplier, P_{max} is the maximum power per thruster (kW), P is the instantaneous power per thruster (kW) and E_{isp} is the curve fit Isp exponent.

$$\text{Efficiency} = \eta_{max} - M_\eta \left(P_{max} - P^{E_\eta} \right)$$

where η_{max} is the efficiency at the maximum power, M_η is the curve fit η multiplier and E_η is the curve fit η exponent.

The maximum and minimum power levels and curve fit exponents and multipliers can be found in Table I.

Table II Solar Array Parameters

Power System	GaAs APSA	Am-Si APSA
Power Ranges	varied 1.5 to 5.0 kW	varied 2.0 to 5.2 kW
Array Specific Mass (kg/kW) includes structure and mechanisms	14.25 kg/kW	16.3 kg/kW
Array Specific Area	188.0 W/m^2	80 W/m^2
Shield thickness included in Array specific mass	3 mils	3 mils
Extra array shield thickness (per side)	varied 0 to 60 mils	0 mils
Extra Array Shield Specific Mass (kg/kW) (per side)	0.3 kg/kW	-
PMAD Specific Mass (not incl. batteries or PPUs) Includes Power regulator, converter, distribution units and Harness	9.2 kg/kW	9.2 kg/kW

Power: Solar Cell Options

Two solar cell technology options were explored. GaAs[5] was chosen over state of the art Si cells due to its greater resistance (approximately 1/3) to high energy protons. The other option chosen was a new technology, amorphous silicon (a-Si), which may be a cheap and self annealing alternative to today's cells. Current tests have shown that a-Si cells when exposed to the proper temperature can repair degradation damage by a self annealing process.[6] The critical characteristics of each of the considered power systems are shown in Table II. The assumed power management and distribution (PMAD) is the same for both solar cell technologies. Note that the a-Si cells have a lower specific area and thus would require larger arrays for the same power when compared to GaAs celled arrays. Both options used the new flexible APSA (advanced photovoltaic solar array) technology.

During the analysis, solar array power level was varied to that allowable (in terms of mass) by the launch vehicle. The higher power levels provided quicker trip times and/or longer coast times. Each array type had a different degradation rate and thus affected the total trip times.

Mission Options

Orbit

To map the magnetosphere, high and low inclination orbits were used for the mission orbits. Thus variations in launch site latitudes and mission orbital parameters were made. The variation of launch site latitude rather than an existing launch facility was due to the air launch capability of the Pegasus and the assumed portability of the Taurus launchers. See TEMPEST Mission Requirements Section for the desired orbit and science gathering relationships. Separately launched spacecraft, one in a high and the other in a low inclination, is considered the baseline mission scenario. Other mission scenarios were explored including planar orbits and both spacecraft launched on a single launch vehicle. Planar orbits were examined to explore the benefits of removing the plane change from the electric propulsion trajectory. The launch of two spacecraft on one launch vehicle was explored in the single launch/dual spacecraft option.

Launch Vehicle

The MIDEX mission opportunity specified one 'free' Med-Lite launcher. Only MIDEX (or the small explorer SMEX) class launch vehicles were considered for the mission (see Figure 3). These include the Taurus and Delta-Lite launch vehicles with various upper stages and solid rocket strap-on options. See Table III for the MIDEX launchers[7] and their estimated performance to various orbits. Two

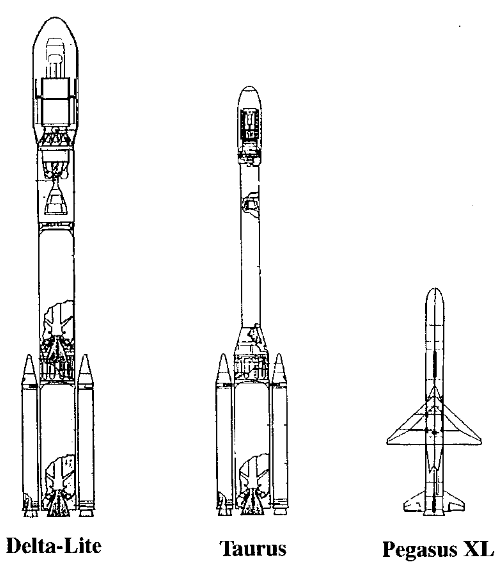

Figure 3 MIDEX and SMEX Launch Vehicles

Table III Estimated Launcher Performance

Launcher	400kmx90°	400kmx70°	400kmx28.5°	400kmx0°
Pegasus XL	310 kg	354 kg	410 kg	430 kg *
Taurus	900 kg	1000 kg	1200 kg	
Taurus with Orion 38	1100 kg	1250 kg	1500 kg	
Taurus with SSRMs	1200 kg	1300 kg	1600 kg	
Taurus with Star 37	1300 kg	1400 kg	1650 kg	
Delta-Lite	1450 kg	1600 kg	1800 kg	
Taurus with Orion 38 and SSRMs	1500 kg	1700 kg	1850 kg	
Taurus with Star 37 and SSRMs	1700 kg	1800 kg	2050 kg	
Delta-Lite and SSRMs	1950 kg	2100 kg	2500 kg	
* non-standard service				

Pegasus XL launch vehicles[8] were assumed to be 'equivalent' in cost to a MIDEX vehicle and thus allowed two spacecraft launches. As will be shown, the desire for a high and low inclination spacecraft requires electric propulsion.

Mission Scenarios

Overview

The final selected mission scenario proposed for the MIDEX mission involved two spacecraft, each launched by a Pegasus XL launch vehicle and propelled by an NSTAR thruster. This mission scenario was found to be the best choice to fulfill the science objectives in view of the available propulsion and power technologies as well as other orbit and launch configurations. What follows is a description of the selected scenario as well as some information on other unselected mission scenarios using various combinations of launch vehicle, propulsion and power technologies, and orbit scenario.

Proposed TEMPEST Mission using Chemical Propulsion

Figure 4 shows a mass comparison for the proposed TEMPEST low inclination mission performed by two spacecraft: the proposed vehicle using ion electric propulsion and one using chemical propulsion. In order to map the magnetosphere with near circular orbits, 200 Hohmann transfers are assumed for the chemically propelled spacecraft. The same spacecraft bus as the ion propulsion vehicle is assumed with the same scientific payload. The ion propulsion system is replaced with a 310 second specific impulse, 450 N thrust bipropellant propulsion system, and the 2 kW power system is replaced by a 350 W power system. The chemical spacecraft dry contingency is set to 15%. The result is devastating for a MIDEX class mission. The total launch mass is almost eight times larger for the chemical TEMPEST versus the ion TEMPEST. The huge increase in fuel mass and tankage far outweighs the reduced propulsion and power system masses combined. Not even the largest Med-Lite class launch vehicle (proposed Delta 7320) is capable of launching the chemical TEMPEST.

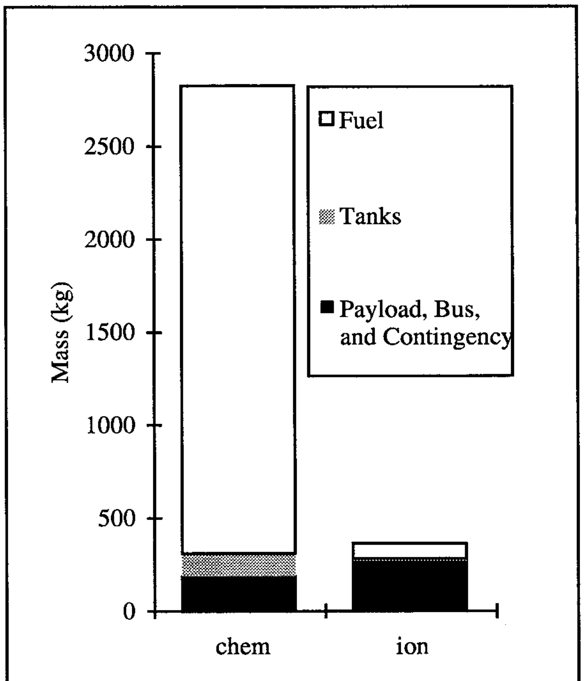

Figure 4 Mass Breakdown of Chemical and Ion TEMPEST Spacecraft

Proposed TEMPEST Scenario: Dual Launch, High and Low Inclination Orbit Scenario

Over one hundred mission scenarios were run. Low inclination missions are designated as 'LO' followed by a number designation. 'HI' denotes the high inclination missions. The selected missions for the TEMPEST proposal are shown by scenarios LO-10 and HI-48. Comparing these mission scenarios with those using other electric propulsion technologies shows the relative benefits and penalties associated with each of these technologies.

Table IV presents the mission summaries side by side. Note that for the HI and LO mission's destinations both coast percentages, and payload masses are the same. Thus each propulsion technology has different thrust times and launch masses to complete the same science mission. Both arcjet cases show the effect of a low I_{sp}; the required launch masses are similar to the chemical. The reason that the LO arcjet case requires roughly a thousand kilograms more launch mass is due to the slightly higher LO mission ΔV of 6800 m/s versus the HI mission ΔV of 6270 m/s. The other propulsion systems also require a larger LO launch mass for the same reason. However, the Hall and XIPS specific impulses are much higher and can easily perform the increased 530 m/s mission requirement with relatively little additional fuel. Thus the higher specific impulse of a technology such as the NSTAR system allows for the greatest mission flexibility, requiring only slight amounts of additional fuel for extended missions. The XIPS thruster technology, while basically a lower power, earlier version of the NSTAR thruster, does not perform as well due to a relatively shorter life, heavier component weights, and a lower efficiency. This is understandable since the XIPS thruster was primarily designed to sufficiently perform north-south stationkeeping duties for two-ton class geostationary satellites

Of the three alternate propulsion technologies, the Hall thruster seems to be the best alternative to the NSTAR thruster. Although it can perform the mission more quickly or with increased coast times, the launch mass is still too great for the Pegasus XL launch vehicle. Thus, the Hall option would require two Taurus launch vehicles which would increase launch costs.

Planar Mission

Making the plane change for the LO selected mission to the desired 0° inclination required significant ÆV. (It was desirable to place the HI spacecraft into a ~70°, low altitude orbit for the beginning of the mission to take data on the auroral field lines.) In an attempt to eliminate this plane change requirement, mission options were analyzed that launched directly into a 0° orbit. This assumed launching the low inclination spacecraft from the equator (an option only available with the Pegasus XL). The low inclination planar missions are designated 'LP'. Table V shows some examples of planar missions.

Table IV TEMPEST Scenarios using Electric Propulsion

Mission ID Number	LO-10	LO-11	LO-12	LO-13	HI-48	HI-49	HI-50	HI-51
Thruster Type	**nstar**	**xips**	**hall**	**arcjet**	**nstar**	**xips**	**hall**	**arcjet**
Starting Inclination	30°	30°	30°	30°	70°	70°	70°	70°
Final Inclination	0°	0°	0°	0°	90°	90°	90°	90°
Max. Distance from Earth Center (Re)	15	15	15	15	15	15	15	15
Mission Time (days)	**703***	**1155***	**516***	**1127***	**701**	**1108**	**508**	**804**
up to 2 or 4 Re % Coast	4%	4%	4%	4%	21%	21%	21%	21%
up to 10 Re % Coast	89%	89%	89%	89%	89%	89%	89%	89%
up to Final Orbit % Coast	73%	73%	73%	73%	73%	73%	73%	73%
Payload Mass (kg)	**30**	**30**	**30**	**30**	**34**	**34**	**34**	**34**
Solar Cell Type	a-Si	a-Si	a-Si	a-Si	a-Si	a-Si	a-Si	a-Si
Total Power (kW)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Initial Mass (kg)	**354**	**511**	**492**	**3117**	**354**	**483**	**478**	**2126**
ELV Type	**PXL**	**T**	**T**	**!**	**PXL**	**T**	**T**	**DL/S**
# Engines (# on)	1	7(3)	2(1)	15(1)	6(3)	6(3)	2(1)	1
# of PPU	1	3	1	1	3	3	1	1
Shielding Front&Back (mils)	0	0	0	0	0	0	0	0
Fluence (1e^15 MeV e-/cm2)	146	255	129	309	15	7	13	9

* Does not include 120 day loiter period waiting for HI spacecraft to catch up
PXL: Pegasus XL, T: Taurus, DL/S: Delta-Lite with SSRMs, ! above Med-Lite Class

Table V Planar mission scenarios

Mission ID NUMBER	LP-49	LP-37	LP-38	LP-39
Thruster Type	**nstar**	**arcjet**	**hall**	**xips**
Starting Inclination	0°	0°	0°	0°
Final Inclination	0°	0°	0°	0°
Max. Distance from Earth Center (Re)	15	15	15	15
Mission Time (days)	**625***	**680***	**510***	**520***
up to 2 or 4 Re % Coast	4%	0%	0%	0%
up to 10 Re % Coast	89%	10%	10%	10%
up to Final Orbit % Coast	73%	25%	25%	25%
Payload Mass (kg)	**40**	**50**	**50**	**25**
Solar Cell Type	a-Si	GaAs	GaAs	a-Si
Total Power (kW)	2.0	3.7	4.0	2.7
Initial Mass (kg)	**354**	**3437**	**1116**	**630**
ELV Type	**PXL**	**!**	**T**	**T**
# Engines (# on)	1	14 (2)	4 (2)	6(5)
# of PPU	1	2	2	5
Shielding Front&Back (mils)	0	12	12	0
Fluence (1e^15 MeV e-/cm2)	202	55	39	250

* Does not include 120 day loiter period waiting for HI spacecraft to catch up
PXL: Pegasus XL, T: Taurus, DL/S: Delta-Lite with SSRMs, ! above Med-Lite Class

Comparison of LP-49 and LO-10 (the final selected low inclination mission) shows that removal of the plane change reduces mission time (~78 days shorter) and adds 10 kg of payload. Preference of the LO-10 over the LP-49 case trajectory was mainly based on cheaper launch costs from the eastern US coast as opposed to non-standard launch costs from Kourou. The NSTAR thrusters high performance enabled the use of this cheaper launch scenario. Even with the reduced mission ΔV when launching from an equatorial site the other propulsion technologies still require the Taurus or larger launch vehicles, which currently are not operational from Kourou.

Single Launch, Two Spacecraft Mission

Yet another option explored was the launch of two spacecraft on one Med-Lite launcher to some intermediate inclination. Each spacecraft would then plane change to its final inclination. Eight of these mission options are shown in Table VI. Based on the results of the dual launch scenario only the NSTAR thruster was considered. The dual launch of HI-52 and LO-14 require more

Table VI Single Launch, Two Spacecraft Scenarios

Mission ID NUMBER	HI-52	HI-53	HI-54	HI-55	LO-14	LO-15	LO-16	LO-17
Thruster Type	**nstar**	**nstar**	**nstar**	**nstar**	**nstar**	**nstar**	**nstar**	**nstar**
Starting Inclination	45°	45°	45°	45°^	45°	45°	45°	65°
Final Inclination	90°	90°	90°	90°	0°	0°	0°	0°
Max. Distance from Earth Center (Re)	15	15	15	15	15	15	15	15
Mission Time (days)	**732**	**1641**	**1496**	**1238**	**733**	**1721**	**1549**	**976**
up to 2 or 4 Re % Coast	3%	3%	3%	3%	0%	0%	0%	0%
up to 10 Re % Coast	89%	89%	89%	89%	89%	89%	89%	89%
up to Final Orbit % Coast	73%	73%	73%	73%	73%	73%	73%	73%
Payload Mass (kg)	30	30	30	30	30	30	30	30
Solar Cell Type	a-Si	GaAs	GaAs	a-Si	a-Si	GaAs	GaAs	a-Si
Total Power (kW)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Initial Mass (kg)	**371**	**423**	**444**	**459**	**372**	**427**	**446**	**439**
ELV Type	**Td**	**Td**	**Td**	**Td**	**Td**	**Td**	**Td**	**Td**
# Engines (# on)	1	2(1)	2(1)	2(1)	1	2(1)	2(1)	2(1)
# of PPU	1	1	1	1	1	1	1	1
Shielding Front&Back (mils)	0	3	15	0	0	3	15	0
Fluence (1e^15 MeV e-/cm2)	120	83	33	42	160	113	44	170

Td:dual launch on Taurus, ^plane changed 45° to 65° at LEO fuel but are similar to the final proposal missions HI-48 and LO-10. Less coast time is provided by the dual launch scenario but the mission is completed in the prescribed two year limit. Unfortunately, a science requirement exists to explore the region around 65°-70° inclination in low Earth orbit. This region contains the auroral kilometric radiation. The HI-52 mission reaches 70° at 6 Re which is too high to take auroral data. The HI-55 scenario changes the plane from 45° to 65° at a LEO altitude to take this data. This significantly increases the mission ΔV and thus requires an extra thruster (due to life limits) and over the three year mission time. Another alternative is to launch both spacecraft into 65° and plane change the LO spacecraft to 11° by 4 Re then to 0° by 8 Re (LO-17). Science requirements drive the 4 Re 11° requirement. This inclination and altitude combination was deemed close enough to the equatorial magnetospheric phenomena by the science team. Again the mission ΔV is significantly increased, making necessary an additional thruster and over a two and a half year trip time. Note that although the mission time is increasing up to a year longer for the more challenging missions the launch mass is not; again showing the advantage of the high I_{sp} electric thrusters.

It is important to point out that the HI-52 and LO-14 missions are enabled not only by the NSTAR thruster but also by the amorphous silicon arrays assumed ability to anneal out radiation damage. Missions HI-53 and LO-15 use the same assumptions as HI-52 and LO-14, respectively, except for the use of gallium arsenide arrays with 3 mils shielding. The lack of radiation resistance of the GaAs arrays results in the constant lowering of power during the mission -- down to 45% of the initial power level. This loss of power requires the throttling of the operational thruster which must run at lower specific impulses and lower efficiencies. The lowered I_{sp} requires more fuel which, in turn, requires a spare thruster since 83 kg is the NSTAR thruster's life measured as propellant throughput. The mission times increase to over four and a half years -- over twice that allotted for a MIDEX mission. In the HI-54 and LO-16 scenarios the arrays were shielded with an additional 12 mils of cover glass to reduce the degradation. The result is higher launch masses and slightly shorter trip times (around four years). An extra thruster is still required due to thruster throughput limits.

Conclusions

The TEMPEST proposed science mission is enabled by electric propulsion technology, allowing two low mass spacecraft to explore the magnetosphere within the perceived limits of the MIDEX program. It was shown that the NSTAR technology is the best propulsion option for such a mission with only the Hall thruster providing a somewhat less beneficial alternative. Each of the NSTAR operational parameters provides a benefit to the mission when compared to other propulsion technologies: the high 3400 sec Isp at 1800 W reduces fuel requirements, the long life allows for a single thruster per spacecraft, and the benign impacts made by the thruster system on the spacecraft design and handling should reduce costs.

Acknowledgments

Research for this paper was done at the NASA Lewis Research Center and the University of California, Los Angeles. We recognize Mark Hickman, Leonard Dudzinski, and the whole TEMPEST team for their work on the TEMPEST proposal which provided the basis for this study.

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Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1998	Technical Memorandum

4. TITLE AND SUBTITLE

Electric Propulsion Options for a Magnetospheric Mapping Mission

5. FUNDING NUMBERS

WU–632–1B–1B–00

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

E–11000

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—1998-206303
IEPC–97–144

11. SUPPLEMENTARY NOTES

Prepared for the 25th International Electric Propulsion Conference sponsored by the Electric Rocket Propulsion Society, Cleveland, Ohio, August 24–28, 1997. Steven Oleson, NYMA, Inc., 2001 Aerospace Parkway, Brook Park, Ohio 44142 (work funded by NASA Contract NAS3–27186); Chris Russell, University of California, Institute of Geophysics and Planetary Physics, Los Angeles, California 90095; Kurt Hack and John Riehl, NASA Lewis Research Center. Responsible person, Steven Oleson, organization code 5430, (216) 977–7426.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories: 20 and 15 Distribution: Nonstandard

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Twin Electric Magnetospheric Probes Exploring on Spiral Trajectories mission concept was proposed as a Middle Explorer class mission. A pre-phase-A design was developed which utilizes the advantages of electric propulsion for Earth scientific spacecraft use. This paper presents propulsion system analyses performed for the proposal. The proposed mission required two spacecraft to explore near circular orbits 0.1 to 15 Earth radii in both high and low inclination orbits. Since the use of chemical propulsion would require launch vehicles outside the Middle Explorer class a reduction in launch mass was sought using ion, Hall, and arcjet electric propulsion system. Xenon ion technology proved to be the best propulsion option for the mission requirements requiring only two Pegasus XL launchers. The Hall thruster provided an alternative solution but required two larger, Taurus launch vehicles. Arcjet thrusters did not allow for significant launch vehicle reduction in the Middle Explorer class.

14. SUBJECT TERMS

Electric propulsion; Hall thruster; Arcjets; Ion thrusters; Orbit raising; Magnetospheric

15. NUMBER OF PAGES

14

16. PRICE CODE

A03

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