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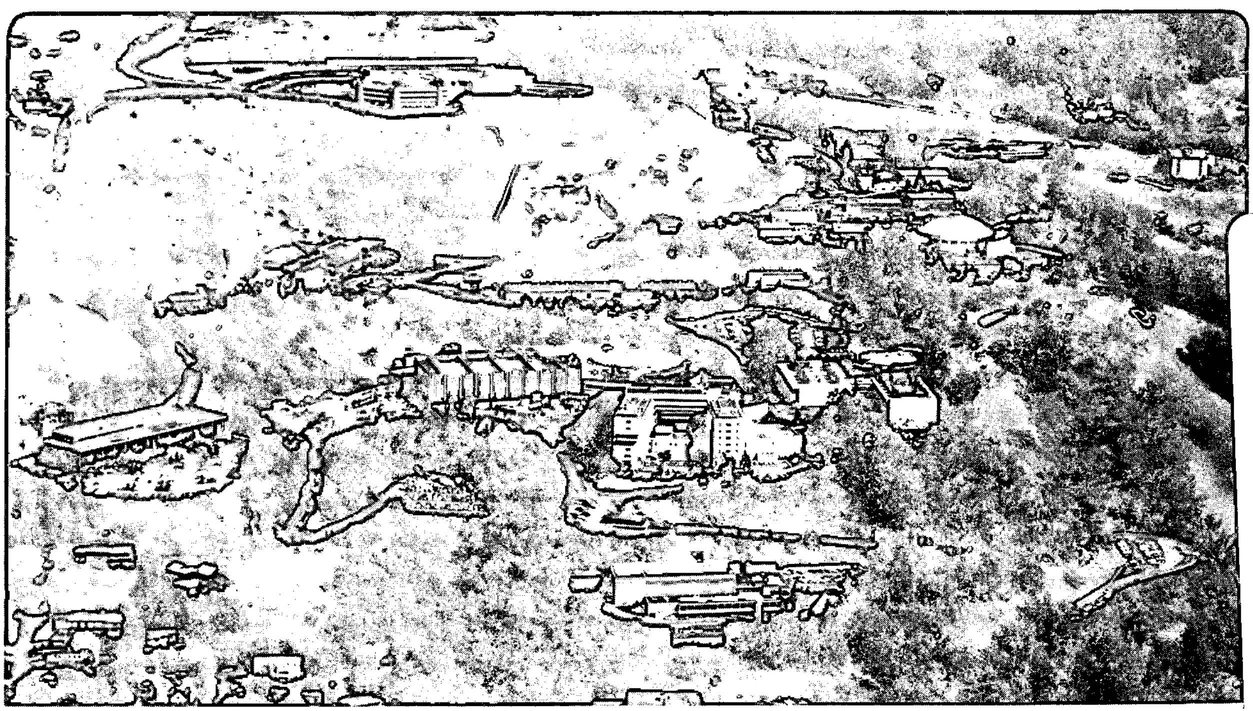

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ABSTRACT

This Report compares the Space Station version of ASTROMAG with free-flyer versions of ASTROMAG which could fly on an Atlas IIa rocket and a Delta rocket. Launch with either free-flyer imposes severe weight limits on the magnet and its cryogenic system. Both versions of ASTROMAG magnet which fly on free-flying satellites do not have to be charged more than once during the mission. This permits one to simplify the charging system and the cryogenic system. The helium II pump loop which supplies helium to the gas cooled electrical leads can be eliminated in both of the free-flyer versions of the ASTROMAG magnet. This report describes the superconducting dipole moment correction coils which are necessary for the magnet to operate on a free-flying satellite.

BACKGROUND

The Space Sciences and Applications Advisory Committee (SSAAC) and NASA Headquarters recommended investigating the option of a free-flying satellite version of the Space Station Freedom-borne ASTROMAG Facility. The Astromag Project conducted a study of the various launch vehicles, orbits, and spacecraft as well as those for the magnet and experiment configurations. During that study the Atlas IIAs and a 57-degree inclination orbit was determined to be feasible and desirable in terms of meeting the original scientific objectives[1] and as part of this study a new configuration for the magnet system was developed[2]. During the early portion of the study several options and designs were explored and proved interesting. We report here on a configuration roughed out for a Delta II launched satellite showing how it would differ from the Space Station facility[3,4] and the compromises that would result from descoping the ASTROMAG facility to a smaller, simpler, less expensive, and less capable Delta II version.

Moving ASTROMAG from Space Station Freedom to a satellite launched by an expendable launch vehicle requires that all components of the superconducting magnet system be simplified and have their mass reduced.[2,3] The launch vehicle chosen by the project is the Atlas IIA which can launch up to 5812 kg into a low earth orbit at 57 degrees. The Atlas IIA will accommodate a satellite 3.63 meters in diameter and 7.46 meters long including the antenna. The ASTROMAG satellite was designed to fit in this space. The Atlas IIA version of ASTROMAG weighs just over 5257 kg and the the length of the two experiments attached to the magnet module is 3.94 meters.[1]

The Atlas IIA is not the only choice for a launch vehicle. If one wants to save money at the expense of the physics objectives, one could launch a version of ASTROMAG using a Delta II. With the Delta II vehicle, one is not restricted to a launch from the Kennedy Space Flight Center with a maximum orbital inclination of 57 degrees. The Delta II can be launched from Vandenburg Air Force Base in high inclination orbits such as the sun synchronous orbit at 98.7 degrees. For such an orbit, a Delta can put between 2500 and 3500 kg into orbit depending on the type of Delta II rocket and the altitude of the final orbit.[5] A Delta II with a 10 foot diameter fairing could launch an ASTROMAG satellite which is 2.79 meters in diameter and 5.73 meters long. Using the standard 8 foot fairing, the satellite diameter would be 2.54 meters and its length would be 5.50 meters. If the Delta II is used as a launch vehicle, the size of the ASTROMAG satellite will have to be reduced by about 30 percent and the satellite mass will have to be reduced about just over 40 percent.

THE LIMITS IMPOSED BY THE ATLAS AND THE DELTA LAUNCH VEHICLES

Table 1 shows the mass which can be launched in a number of different orbits for three types of Delta II launch vehicles. The mass which can be put into a 833 km sun synchronous orbit varies from 2567 kg to 3261 kg depending on the type of delta used to launch the satellite. The Atlas IIa can only be launched from the Kennedy Space Flight Center in Florida. This limits the maximum orbital inclination to 57 degrees, which does increase the number of lower energy particles into the detectors. The maximum mass which can be put into a 500 km circular orbit at an inclination of 57 degrees by an Atlas IIa is 5808 kg. A Delta II launched satellite put into a similar orbit would have a mass from 3400 to 4300 kg into orbit depending on the type of Delta rocket used for the launch. The Delta II rocket can be launched from Vandenburg Air Force Base in California. From here, polar and sun synchronous orbits can be obtained. ASTROMAG would benefit from being launched into a sun synchronous orbit. A large number of lower energy particles would impinge on the ASTROMAG detectors making up for, in part, the loss of detector area caused by the reduced size of the experiments. (See Figure 1.)

The weight limits for the ASTROMAG experiment launched by an Atlas affects the LISA experiment more than the WiZard experiment. The total area of the LISA experiment is reduced by a factor of three, but the bending strength of the magnet in the Atlas version is similar to the Space Station version. The mass limits imposed by the Delta II launch vehicle reduces the area of LISA even more as the mass is reduced. Because launch mass must be reduced, the integrated field of the magnet must also be reduced. This is not good for the momentum resolution of the high-Z particles of the iron group that LISA wants to analyze. A Delta-launched ASTROMAG will not be able to do the iron-group physics which has been proposed for the Space Station version of ASTROMAG This area of cosmic ray physics is in part retained by the Atlas IIA version of ASTROMAG. The area of the WiZard experiment is also reduced further in the Delta versions of the experiment, but this is in part compensated for by the increased flux of low energy particles one gets in a polar or sun synchronous orbit. Except for the effects of reduced area, the physics in WiZard is hardly affected by the use of a Delta launch vehicle.

Table 1
Delta II Mission Capabilities with Various Types of Delta Rockets (See Reference 4)

	Spacecraft Mass (kg)		
Type of Delta II Rocket	**6925**	**7925**	**Enhanced**
Type of Mission			
1) GPS, 20183 km circular*	839	998	1134
2) GTO, 185 x 35786 km*	1447	1615	1819
3) Molniya, 370 x 40094 km*	962	1111	1275
4) Sun Synchronous			
833 km circular, α = 98.7 deg.	2567	2889	3261
5) LEO, 185 km circular, α = 28.7 deg.	3983	4459	5039
6) LEO, 185 km circular, α = 90 deg.	3025	3397	3819
7) Pathfinder, 448 km circular, α = 38 deg.	3615	4051	4577
8) TOPEX, 1333 km circular α = 63.4 deg.	2263	2572	2921
9) Escape with Injection at 185 km*	1025	1148	1293

*Third stage required in the nose cone.

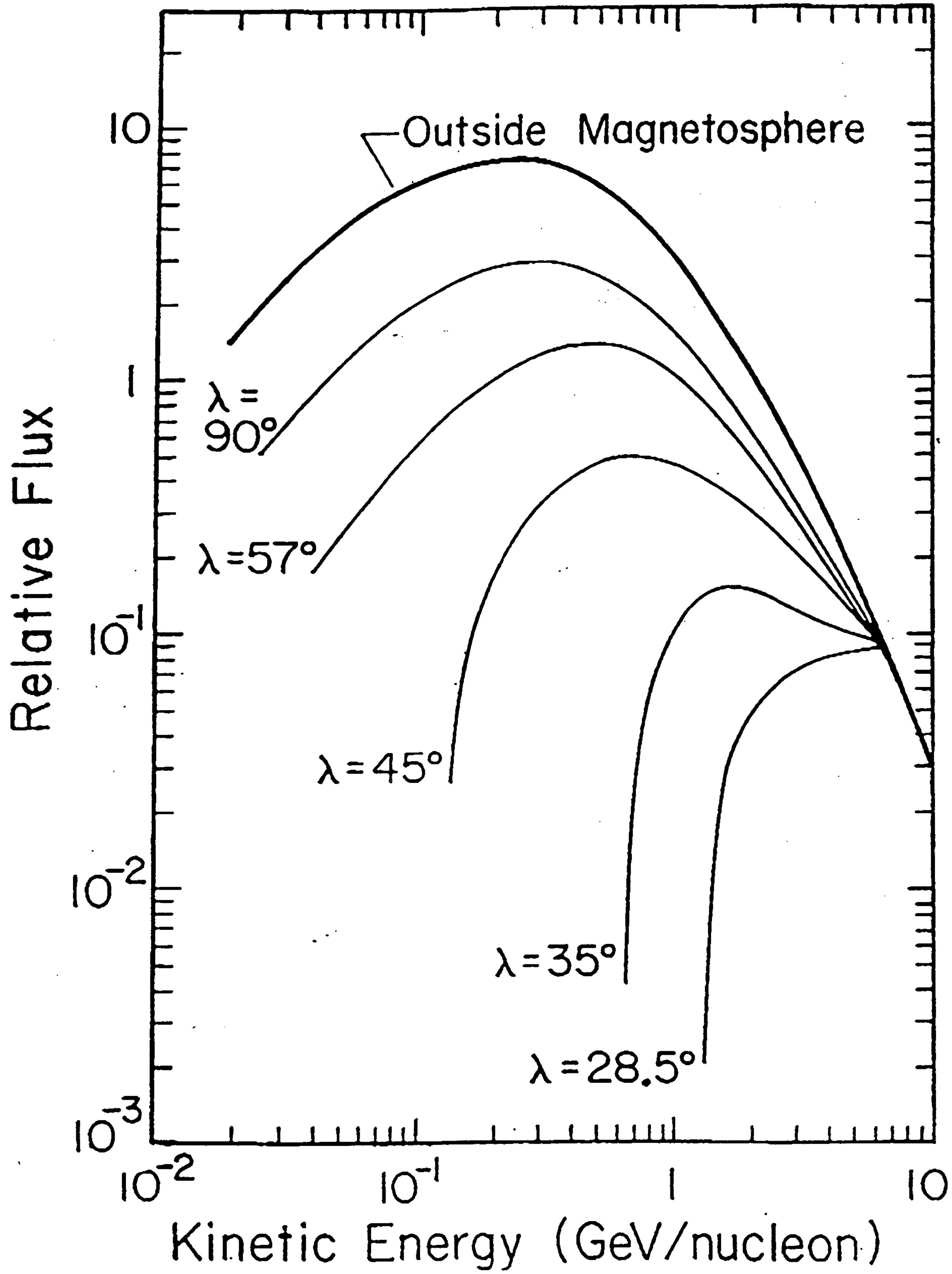


Fig. 1 The Relative Flux of Various Charged Particles in a 500 km Earth Orbit as a Function of Kinetic Energy per Nucleon and Orbital Inclination. (The orbital inclination of the space station is 28.5 °; an Atlas IIa orbit has a maximum inclination of 57°; and a Delta II sun synchronous orbit has an inclination of about 90°.)

Figure 2 shows a version of ASTROMAG satellite launched by an Atlas IIa rocket which has been deployed. The Delta launched ASTROMAG would look somewhat similar but solar collector panels for the Delta launched ASTROMAG would be about a factor of two smaller because Delta launched ASTROMAG would be in a more favorable sun synchronous orbit. The solar panels can be used to shade the magnet cryostat to reduce the vacuum shell temperature somewhat, which in turn permits increasing the dewar life. The effect of shading the cryostat vacuum vessel has not been factored into the tank size calculations for the Delta launched magnet.

A reduced size WiZard experiment appears to be a feasible proposition. The Atlas version of the WiZard experiment will almost fit within the Delta II fairing. The WiZard experiment will become smaller as the magnet coil diameter goes down. This reduction in diameter is enough to allow WiZard to fit within the Delta fairing. Further reduction of the size of the WiZard experiment is expected because its weight must be reduced about 40 percent compared to the Atlas version. The part of WiZard which has the greatest effect on overall experiment mass is the calorimeter. The WiZard experiment mass will have to be reduced from 1134 kg to about 600 kg.

The LISA experiment, however, must be reduced in length by about 30 percent (from 3.55 m to about 2.60 m) in order to fit into the Delta fairing. A 15 percent reduction of the LISA dimensions can be expected to occur because of the reduction of the magnet coil diameter, but this is not enough of a cut to permit LISA to fit in the Delta fairing. Weight should not be a problem with LISA if the dimensions of the experiment can be cut so that LISA will fit in the Delta fairing. The LISA experiment mass will have to be reduced from 885 kg to about 470 kg.

The use of a Delta launch vehicle also affects the placement of the main communications antenna, the pitch momentum wheels and the folding solar panels. The space available for these functions is about 2.20 m as compared to about 3.30 m for the Atlas version. The total mass allowed for the satellite, which carries the magnet and the LISA and WiZard detectors will have to be about 900 kg for the Delta version. If the total launch mass for the Delta IIA into a sun synchronous orbit is 3000 kg, about 1030 kg can be allocated to the superconducting solenoid magnet.

THE DELTA LAUNCHED MAGNET DESIGN

The goal of the design process for a Delta launched ASTROMAG magnet is to reduce the Atlas magnet mass from 1590 kg to about 1000 kg. The mass of the magnet coils must be reduced while retaining as much of the integrated field in the detectors as possible. If one simply reduces the volume of the magnet coil package to 62 percent of the Atlas magnet volume, and scales the dimensions of the package accordingly, one finds that the length of the magnet cryostat would be just over 2.00 m and the cryostat outside diameter would be just over 1.55 m. These two dimensions define the basic envelope size for the Delta ASTROMAG magnet coil system.

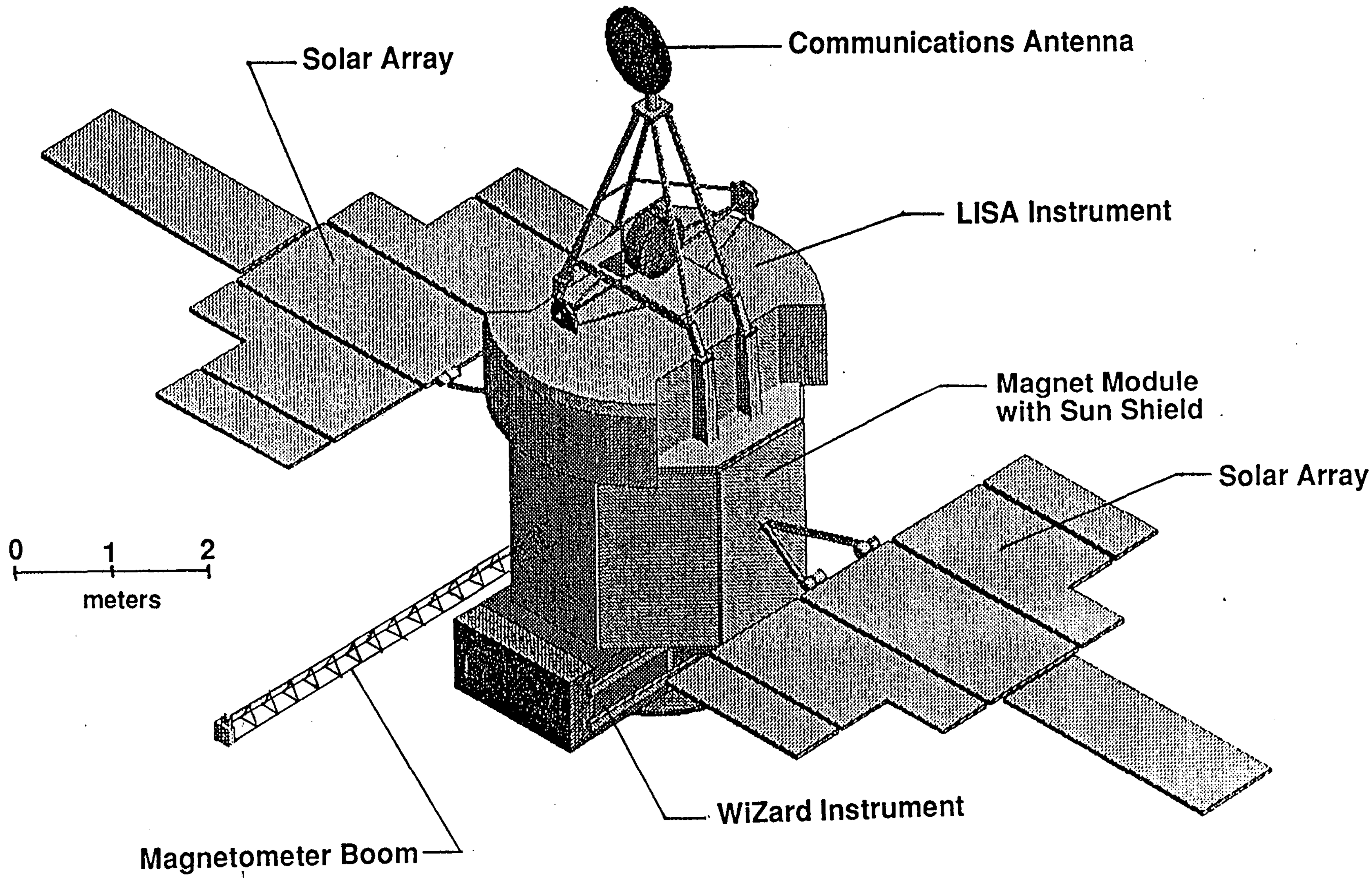


Fig. 2 The Atlas IIa ASTROMAG Satellite in the Fully Deployed Position.

Figure 3 shows the magnet coil cross-section for the proposed Delta II launched ASTROMAG coil. The table below Fig. 3 presents the basic parameters for the coil cross-section shown in the figure. The mass of the two magnet coils represents just over 25 percent of the total magnet mass including the liquid helium. This is comparable with the Atlas launched free-flyer. The stored energy per unit coil mass of the Delta free-flyer magnet (25.2 joules per gram) is lower than for the Atlas free-flyer magnet (about 28 joules per gram). The coil design current is limited by the current carrying capacity of the superconductor which is the same conductor proposed for the Atlas version. Optimization of the coil shape becomes even more important for the Delta version of ASTROMAG than it is for the Atlas version of ASTROMAG.

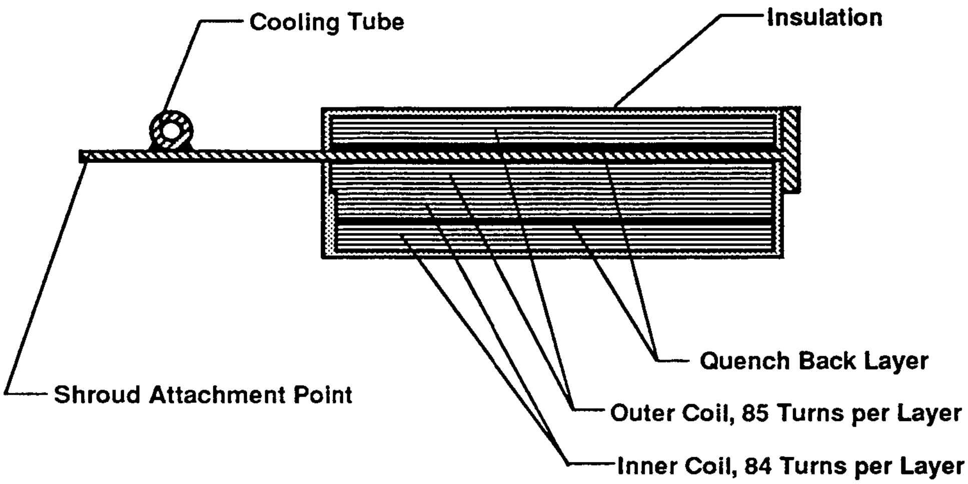
Table 2 compares the parameters of the Delta launched version of the ASTROMAG coil with the baseline Space Station version and the Atlas IIA version of the ASTROMAG magnet. The Atlas version of the ASTROMAG coil has already undergone considerable optimization. As a result, the physics possible for the Atlas version is comparable with the baseline Space Station version. The coil cross-section shown in Fig. 3 also reflects this optimization process. As the magnet weight is reduced, so is the integrated magnetic field in the LISA and WiZard detectors. The mass of the Delta launched version of the ASTROMAG superconducting magnet may be reduced further when its cryostat design is optimized. The magnet system mass represents about 33 percent of the total Delta launched satellite mass as compared to 30 percent for the Atlas version and 27 percent for the Space Station version. Further optimization and magnet weight reduction would be a clear benefit for the Delta launched magnet system.

Figure 4 shows a proposed cross-section of the Delta launched magnet and its cryostat. Shown in Fig. 4 are the two magnet coils, the helium tank, the shroud connecting the coils to the tank, the persistent switch, the gas cooled electrical leads and the magnetic dipole moment correction coils. The cryostat shown in Fig. 4 will have a helium lifetime of greater than 2 years, which is comparable to the Atlas magnet cryostat. Figure 5 shows an electrical circuit diagram for the Delta version of the ASTROMAG magnet. Figure 5 includes the self and mutual inductances of the primary elements of the magnet circuit as well as the resistance and power supply parameters.

THE EFFECT OF A FREE-FLYER SATELITE OPTION ON THE CRYOGENIC SYSTEM FOR ASTROMAG

A change of ASTROMAG from the Space Station to a free-flying satellite does affect the magnet and its cryogenic system. The most important changes are as follows; 1) The launch weight constraints of the free-flyers mean that weight is critical. The magnet, the cryogenic system and the various subsystems should be optimized for minimum system weight.. 2) There is no set limit on the charge time. The ASTROMAG magnet is only charged once during the mission instead of four times a year as the Space Station version requires. The charge time should be optimized so that the weight of the persistent switch, the charging system power supply, the solar panels needed to provide power for charging, and the helium used during the

Fig. 3 A Free-flyer Aluminum Matrix Superconducting Coil with a Pure Aluminum Quench Back Circuit to be launched in a Delta Rocket .



FREE-FLYER ALUMINUM MAGNET PARAMETERS

Number of Magnet Coils	2
Number of S/C Layers per Coil	24
Number of QB Layers per Coil	2
Number of Turns per Layer	84 or 85
Number of S/C Turns per Coil	2028
Number pf QB Turns per Coil	169
Coil Outside Diameter (m)	1.232
Coil Inside Diameter (m)	1.128
Space Between the Coils (m)	1.400
Outer Coil Width (mm)	178.50
Inner Coil Width (mm)	176.40
Magnet Self Inductance (H)	15.08
6.45 MJ Design Current (A)	925.0
Coil Peak Induction (T)*	6.63
Intercoil Tensile Force (kN)*	235#
S/C Matrix Current Density (A/ sq mm)*	325
Quench Energy at 1.8 K (micro-joules)*	400
Coil Package Mass (kg)	127.2

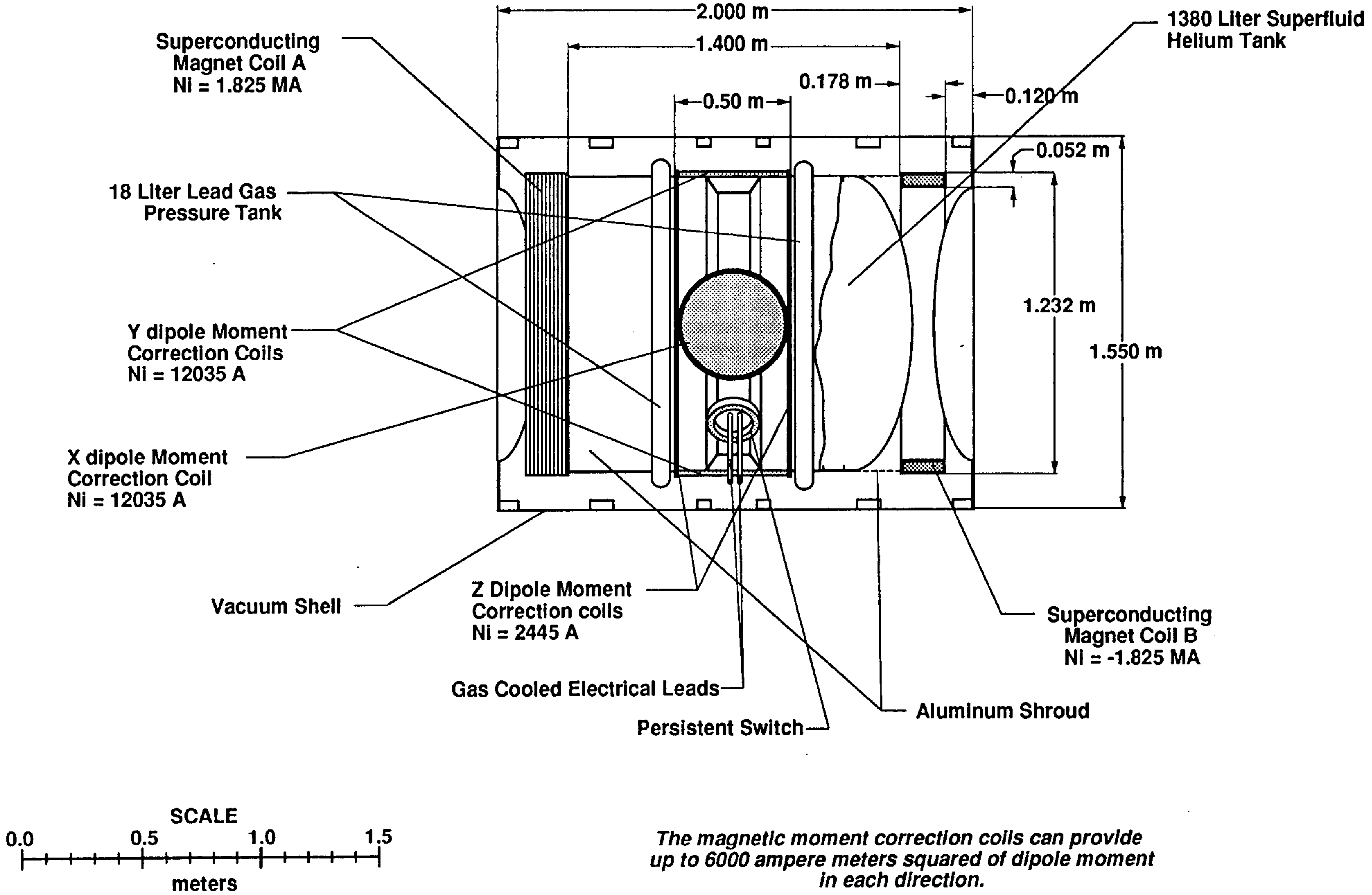
* At the 6.45 MJ Design Coil Current
\# 24.0 metric tons

Table 2
A Comparison of the Delta and Atlas Free-flyer ASTROMAG Magnets with the Baseline Space Station Magnet

	Baseline Space Station Version	Atlas Free-flyer Version	Delta Free-flyer Version
Cryostat OD (m)	2.120	1.820	1.550
Cryostat Length (m)	2.608	2.350	2.000
Helium Tank Volume (liters)	3440	2250	1380
Coil OD (m)	1.660	1.440	1.232
Coil Length (m)	0.184	0.220	0.178
Coil Thickness (m)	0.050	0.058	0.052
Coil Separation (m)	2.000	1.670	1.400
Number of Turns per Coil	2440	2928	2028
Design Current (A)	810	800	925
Magnet Stored Energy (MJ)	11.0	11.6	6.4
Physics Factor##	0.987	1.000	0.700
Coil Mass (kg)	661	414	254
Switch & Corrector Mass (kg)	30*	22	13
Helium Mass (kg)	500	327	203
Dewar Mass (kg)	935	724	470
Charging System Mass # (kg)	150**	104	~65
Total Magnet Mass (kg)	2276	1591	1005
Magnet Weight Factor##	1.431	1.000	0.632
Overall Mass (kg)	~8500	5257	~3000

This includes the electronics.
The Atlas version has a factor of 1.000.
* There are no magnetic moment correction coil in the space station version.
** Estimated, this was not included in the space station version.

Fig. 4 A Delta Launched Version of the ASTROMAG Free-flyer Magnet with Superconducting Dipole Moment Correction Coils and the Main Magnet Persistent Switch.



The magnetic moment correction coils can provide up to 6000 ampere meters squared of dipole moment in each direction.

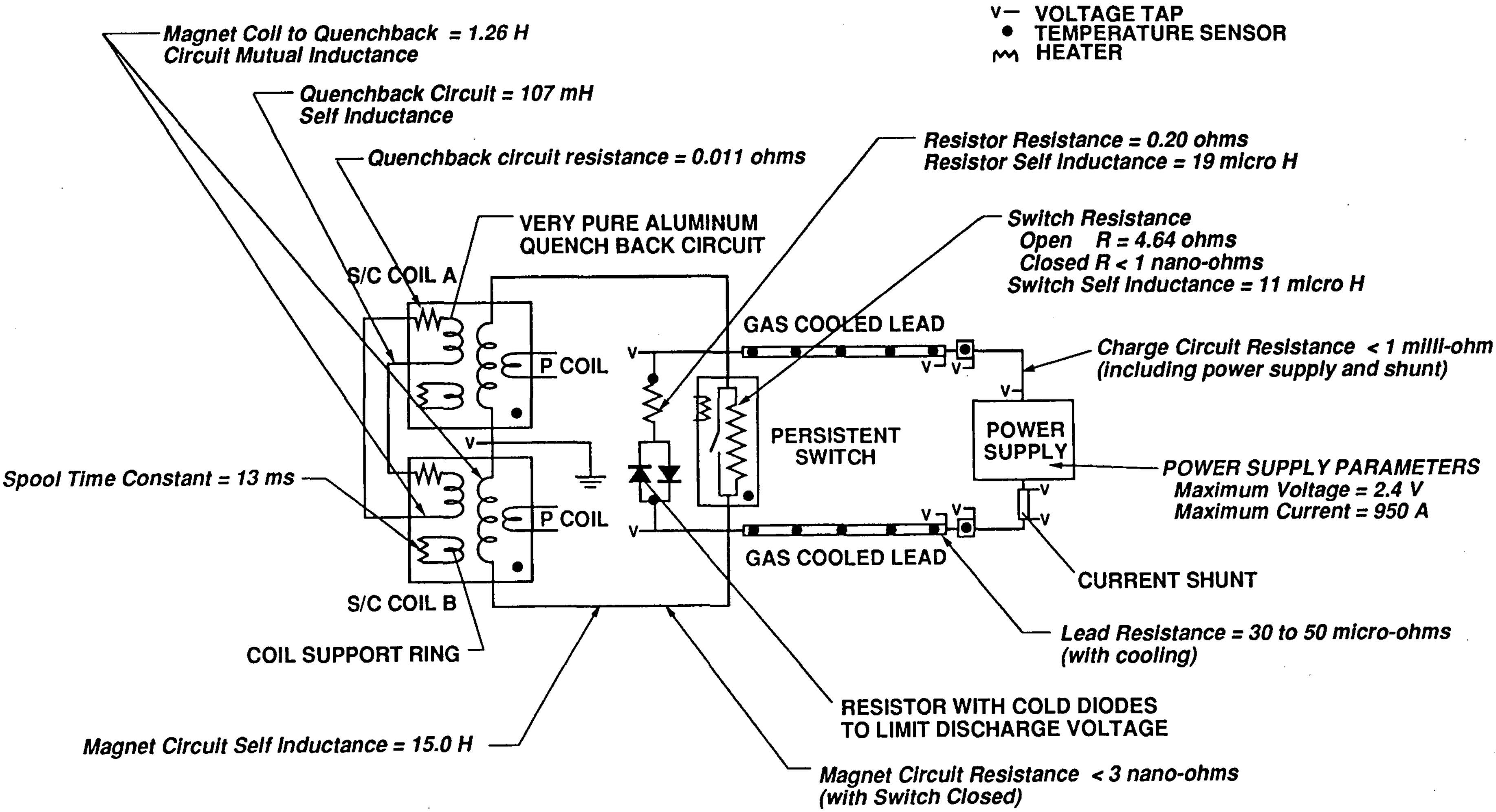


Fig. 5 The Electrical Circuit Diagram for the Delta Version of the ASTROMAG Superconducting Magnet. (The persistent switch mass is 6 kg; the maximum discharge voltage is 172 volts; the optimum charge time is 2.5 to 3 hours; and about 35000 joules will be deposited into the superfluid helium tank during charging.)

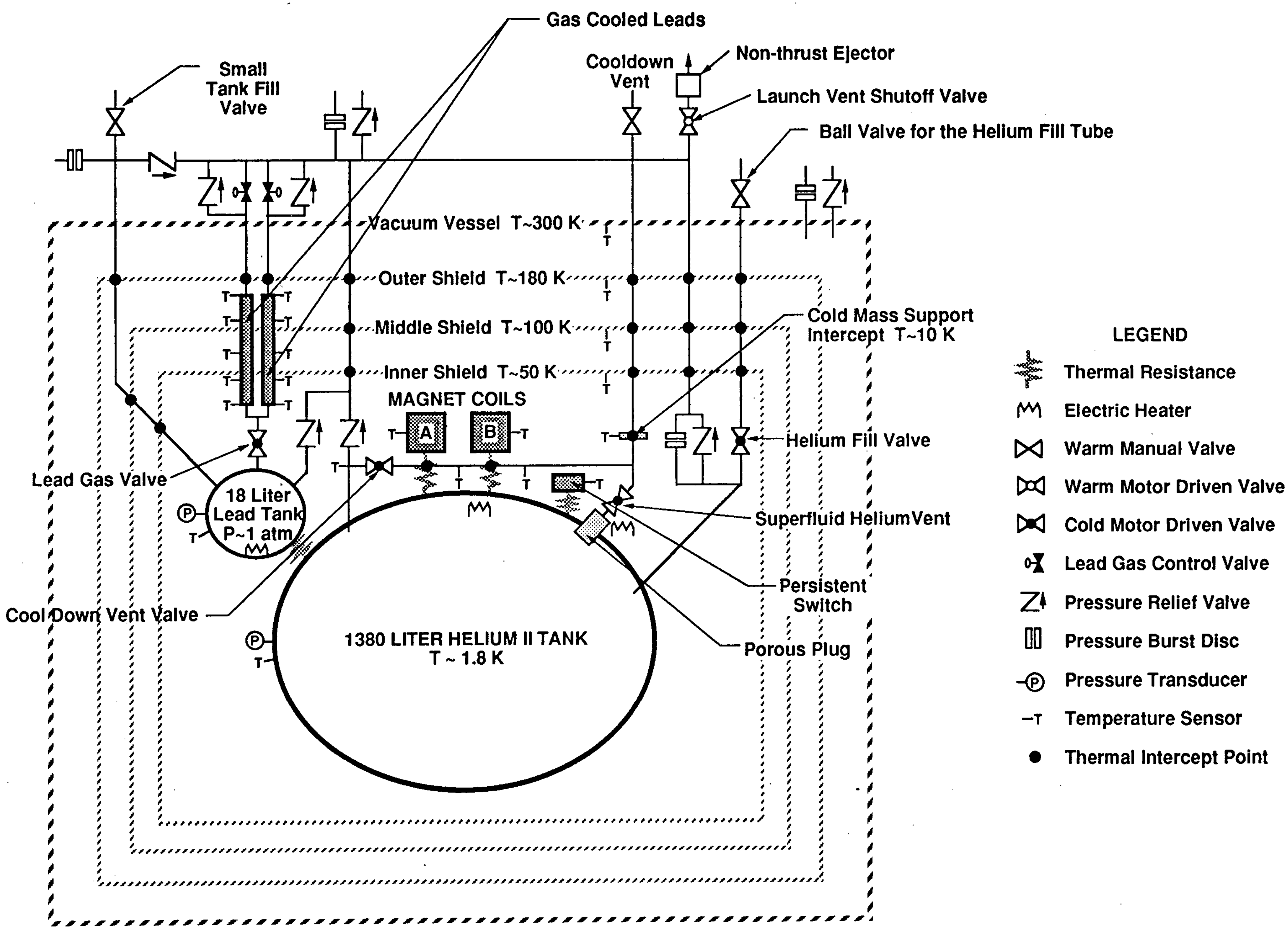
charging process is minimized [6]. 3) The magnet coils and the persistent switch can be cooled by conduction. The need for a superfluid helium pump to cool the coils and the switch is eliminated. 4) Cooling gas for the gas cooled leads need not be supplied by a superfluid helium pump because the magnet is charged only once during the mission. Lead cooling gas can be supplied by heating a separate tank of helium to provide the pressure to force helium through the gas cooled electrical leads. 5) The lead disconnect can be at the warm end of the leads instead of the cold end of the leads. One trade off the helium needed to cool the leads while charging the magnet with a reduction of the weight of the leads. 6) Superconducting dipole moment correction coils are required in addition to the fact that the two main coils in the solenoid are of opposite polarity in order to make the net magnetic dipole moment as close to zero as possible [7,8]. The presence of magnetic dipole moment in causes torque to be applied to the space craft due to interaction with the earth's magnetic field lines. The space station version does not require any additional dipole moment correction.

Figure 6 shows a simplified cryogenic system which could be applied to either the Atlas or the Delta version of the ASTROMAG magnet. The weights and volumes quoted apply to the Delta version of ASTROMAG. The cryogenic system shown in Fig. 6 shows all of the components being cooled by conduction. Lead cooling is supplied by pressurizing at separate helium tank with a heater. The dipole moment correction coils are not shown in Fig. 6; they are attached to the superfluid helium tank directly. The physical location of the solenoid persistent switch and the three sets of orthogonal dipole moment correction coils are shown in Figure 4. The dipole moment correction coils will be superconducting and they will operate in persistent mode. The correction coil current will be low (about 10 amperes) and the charge time will be short, so that gas cooled correction coil leads are not required. The dipole moment correction coils and their persistent switches have to be optimized to minimize the total dipole moment correction coil system mass and the amount of helium needed when the correction coils are charged. The small amount of magnetic dipole moment which remains will be eliminated using conventional torquer bars used on many satellites today.

CONCLUSIONS

An ASTROMAG magnet, for launch by an Atlas IIa or a Delta II, can be made using available technology. Using improved aluminum matrix conductor technology, the performance of a 1600 kg Atlas launched superconducting magnet appears to be comparable to the magnet proposed for the space station version of ASTROMAG. The weight goal of 1000 kg for the Delta launched magnet system appears to be feasible, using the technology proposed for the Atlas-launched magnet system. The magnet design presented in this report will produce about 70 percent of the integrated field of the Atlas launched magnet. The cryostat will provide cooling for the magnet coils for a period of at least two years. The cryogenic cooling system for the free-flyers will be much simpler than the cryogenic system that was proposed for the space station version of ASTROMAG. The free-flyer versions of ASTROMAG require additional orthogonal dipole moment correction coils in order to minimized the torque put into the space craft by interaction with the earth's magnetic field lines.

Fig. 6 The Delta Free-flyer ASTROMAG Magnet 1.8 K Cryogenic System.



ACKNOWLEDGEMENT

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