CRYOMAGNETICS, INC.

FACTORY INSPECTION AND TEST REPORT

AND

FINAL REPORT

FOR THE THIRD FLIGHT MAGNET

SERIAL # C-654-M

TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

GREENBELT ROAD

GREENBELT, MARYLAND 20771

CONTRACT #NAS5-98073



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## Certification

Final Report
for The Third Flight Magnet
Serial # C-654-M

Contract #NAS5-98073
Nasa Goddard Space Flight Center

All the test results in this report is certified by : R. Wayne McGhee
Senior Engineer
Cryomagnetics Inc.

R. Wayne McGhee ______ Date 8-28-98

8-28-98

## Introduction:

A self-shielded superconducting magnet was designed for the NASA Goddard Space Flight Center Adiabatic Demagnetization Refrigerator Program. This is the third magnet built from this design. The magnets utilize Cryomagnetics' patented ultra-low current technology. The magnetic system is capable of reaching a central field of two tesla at slightly under two amperes and has a total inductance of 1068 henries.

This Final Report details the requirements of the magnet, the specifications of the resulting magnet, the test procedures and test result data for the third magnet (Serial # C-654-M), and recommended precautions for use of the magnet.

## 1.0 Magnet Design

The end use of the superconducting magnet is the generator of magnetic fields to be used in an Adiabatic Demagnetization Refrigerator (ADR) System. Two magnets were originally made both space flight approved. This order is for a third magnet too be used as a backup magnet.

The design requirements for the magnet call for them to have a maximum central field of 2.0 tesla with a field to operating current ratio of higher than 1.0 tesla/ampere. The magnets are to be actively shielded; that is, stray magnetic fields are to be minimized through the use of reverse windings on the ends and over the outside of the main solenoid. The magnets are to be fabricated on an aluminum coil former whose bore is sealed on one end. This former will be furnished by NASA.

The preliminary magnet design is shown in Table 1. All coils are indicated in this table including the active shield coils. The magnet was designed such that rectangular cross-section coils were to be used due to ease of modeling and computer simulation.

Criteria used for the coil design were:

1) Magnetic field at Z=+/- 6.6 centimeters should be greater than one half the field at Z = zero.
2) Central field equals 2 tesla at less than 2 amperes.
3) Magnetic field at Z =+/-22.5 centimeters or greater to be 10 gauss or less.
4) Magnetic field to be less than 500 gauss at all radial locations of 8.9 centimeters or greater.

Nominal coil design geometries and number of turns are indicated in Table 1. The finished magnet computer generated field profile is shown in Figures 1 and 2. Also shown is the actual measured field profiles (Figure 4,5, and 6).

It was anticipated that the superconducting wire to be used should be 0.003 inches bare diameter (0.004 inches on top of insulation) to achieve the 1.00 tesla/ampere field to current ratio. Expected packing of winding was approximately 7000 turns per square centimeter. At two amperes this means an overall current density in the windings of approximately 14,000 amps/cm.

Peak fields on the superconducting wire were anticipated to be 2.12 tesla at 2 amperes and 2 tesla central field. Present state-of-the-art superconducting wire technology suggests that 0.003 inch diameter multifilament NbTi wire with a 1.5:1 copper to superconductor ratio would have the capability to pass roughly 5.4 amperes at 4.2 kelvin and 2 tesla. This wire was chosen for this magnet. The ratio of copper to superconductor was changed on this order from 1.35:1 to 1.5:1 and 54 filaments to 18 filaments because of a quicker delivery. All other wire specifications are the same or better than the 1.35:1 wire used on previous magnets.

Inductance computations on the design coil indicated that an overall magnet inductance of 1068 henries would be present in the magnet. This corresponds to a full field (2 tesla) stored energy of roughly 2 kilojoules. Cryomagnetics' patented ultra low current quench protection was designed into the magnet to maintain tolerable voltage, temperature and strain levels in the event of a magnet quench. The magnet is to be fully epoxy impregnated both to prevent training and as a quench propagation accelerator. The magnetic field decay constant for the magnet was designed to be approximately 0.6 seconds ( although this will certainly vary some due to the multiple coil geometry of the magnet).

Forces on each of the magnets' "end" reverse winding sections were computed to be on the order of 170 pounds axially at full field. These forces were designed to be easily restrained through the aluminum coil former. Net axial forces on the "outer" reverse windings were, of course, zero.

## 2.0 Final Magnet Specifications

The final resulting magnet is shown in Figure 9. Table 2 indicates actual coil dimensions and turns. The final coils were wound with the appropriate number of turns and geometries to achieve the desired field profile. Final calculations indicated that a 1068 henry inductance could be expected upon testing the system. Mutual and self inductances of all coils are detailed in Figure 7.

Computer simulations indicated that an operating field to current ratio of 1.0428 tesla/ampere coil should be expected in the central field region.

Two temperature sensors supplied by NASA where epoxied into the flanges of the magnet. The location are shown in Figures 8 and 9. The sensor located at the large flange end is serial # FP44. The other, serial # FP42, is located on the end with the closed bore tube. It was found that sensor FP44 was open on all leads after the test. NASA decided not to replace because of the risk factor involved.

## 3.0 Test Procedures

The finished magnet's room temperature resistance was not recorded because the high inductance prevented obtaining a correct reading.

Cryomagnetics' testing procedures involved tests performed on three different days. On all the test the magnet was lowered into a bucket-style dewar with the mounting flange at the top. The liquid helium was left at atmospheric pressure and at a temperature of 4.2 Kelvin during all test.

Initial cool-down of the magnet occurred on 8 August 1998. Pre-cooling of the magnet using liquid nitrogen was accomplished by lowering the tail side of the magnet until it was in contact with the surface of an Ln2 pot. Eventually (within about 2 hours), the magnet was allowed to become immersed in Ln2 to insure a thorough pre-cool.

The magnet was then lifted from the liquid nitrogen bath and transferred to the helium dewar. Helium was introduced at a slow rate. It took approximately one hour to cool from 77k to 4.2k. The magnet was then three fourth covered with liquid helium.

Powering of the magnet was performed using one of Cryomagnetics' IPS-100 Superconducting Magnet Power Systems. A cryogenic hall sensor was utilized to monitor the axial magnetic field profile in the bore of the magnet.

| Sensor | Location |
|---|---|
| BHA-921, Shop Sensor supplied by Cryomagnetics | Axial Sensor set up to monitor axial component of the field. |

The magnet was charged at 3 volts to 0.68 amperes. The inductance was checked and found to be approximately 3200 henries. This would result if the outside null windings were reversed. This was verified by computer modeling. The magnet was discharged and warmed up. The leads for the outside null was then reversed.

The second test occurred on 19 August 1998. The magnet was mounted with the mounting flange up and 3/4 covered with helium. The magnet was charged at 3 volts to 1.978 amps. The inductance was measured at 1055 henries. The design was 1068 henries.

The axial field scan was then done. The magnet was discharged and the hall sensor offset rechecked. The scan data is shown in Figure 3. The data was for a central field of 20,391 gauss. Figures 4,5, and 6 are graphs of the data.

The magnet could not be scanned at 8.9 centimeters radial location because of the magnet flanges. To confirm the field a hall sensor mounted at a radial location of 8.9 centimeters and an axial location of 7.0 centimeters. This data was compared to the calculated data shown in Figure 2. The results shows the measured field Bz to be slightly higher than the calculated field data but well within specifications. The calculated current is 1.920 amperes and the measured current for 2 tesla is 1.918 amperes. The test results showed the field at less than 10 gauss at +22.5 centimeters on axis. The specification was 10 gauss.

The magnet was then raised in the cryostat approximately 2 feet to obtain a quench. The magnet was then lowered slowing back into the liquid. It was confirmed the magnet had survived the quench okay and the magnet was removed from the cryostat.

The third test was on 20 August 1998. This gives three complete cycles from room temperature to helium temperature. The magnet was only covered with 6 centimeters of helium on the small diameter end. The magnet was charged at 1 volt to 2.065 tesla then ramped down and removed from the cryostat.

## 4.0 Recommended Precautions

The magnet represents one of the highest inductances achieved in a superconducting magnet. This high inductance, although protected by shunt devices built into the magnet, should be handled with care or potentially fatal voltages could occur. The following precautions should always be observed to protect personnel, ancillary equipment, and the magnet itself:

1) Never disconnect the magnet's power leads while current is present.
2) Never touch the power leads while current is present unless a 30 kV insulated tool is used.
3) Never "quench-cool" the magnet. Cool down should be slow enough that large thermal gradients across the magnet do not occur or one runs the risk of breaking a wire.
4) Never connect a non-quench-protected power supply to the magnet or else it and/or the magnet may be damaged.

**Table 1**

**NASA GSFC**
**AXAF Magnet Design Data**

| Coil Number | A(0) | A(1) | B | Z(0) | Turns |
|---|---|---|---|---|---|
| | | | | | |
| 1 | 4.000 | 5.900 | 6.500 | 0.000 | 190197 |
| 2 | 4.710 | 5.140 | 0.635 | 10.177 | -4205 |
| 3 | 4.710 | 5.140 | 0.635 | -10.177 | -4205 |
| 4 | 7.500 | 7.770 | 9.000 | 0.000 | -37422 |
| 5 | 7.770 | 8.000 | 6.500 | 0.000 | -23023 |
| 6 | 8.000 | 8.200 | 4.500 | 0.000 | -13860 |

**Table 2**

**NASA GSFC**
**AXAF Magnet Actual Winding Data**
**Magnet Serial Number** C-654-M

| Coil Number | A(0) | A(1) | B | Z(0) | Turns |
|---|---|---|---|---|---|
| | | | | | |
| 1A | 4.0234 | 4.9936 | 6.4897 | 0.000 | 98324.8 |
| 1B | 4.9936 | 5.9347 | 6.4897 | 0.000 | 91269.5 |
| 2 | 4.7244 | 5.3340 | 0.6223 | 10.188 | -5701.5 |
| 3 | 4.7244 | 5.3340 | 0.6223 | -10.188 | -5701.5 |
| 4 | 7.5121 | 7.7724 | 8.9941 | 0.000 | -35046 |
| 5 | 7.7724 | 8.0010 | 6.9184 | 0.000 | -24121 |
| 6 | 8.0010 | 8.1547 | 4.5847 | 0.000 | -10045 |
| 7 | 8.1547 | 8.2131 | 1.5316 | 0.000 | -670 |

Notes:
**All dimensions are in centimeters.**
**A(0) = Inside radius of the coil.**
**A(1) = Outside radius of the coil.**
**B = 1/2 Length of the coil.**
**Z = Axial position of the coil center.**
**Dipole Moment =** 98.2 A-M2
**Weight = 20.25 lbs**

Table #3
Computer Field Data Generated From Finished Magnet Data

| RHO (cm) | Z (cm) | BR (gauss) | BZ (gauss) | BMOD (gauss) |
|---|---|---|---|---|
| .0000E+00 | -3.0000E+01 | .0000E+00 | 3.4939E+00 | 3.4939E+00 |
| .0000E+00 | -2.9000E+01 | .0000E+00 | 3.5567E+00 | 3.5567E+00 |
| .0000E+00 | -2.8000E+01 | .0000E+00 | 3.5643E+00 | 3.5643E+00 |
| .0000E+00 | -2.7000E+01 | .0000E+00 | 3.4897E+00 | 3.4897E+00 |
| .0000E+00 | -2.6000E+01 | .0000E+00 | 3.2945E+00 | 3.2945E+00 |
| .0000E+00 | -2.5000E+01 | .0000E+00 | 2.9241E+00 | 2.9241E+00 |
| .0000E+00 | -2.4000E+01 | .0000E+00 | 2.3012E+00 | 2.3012E+00 |
| .0000E+00 | -2.3000E+01 | .0000E+00 | 1.3159E+00 | 1.3159E+00 |
| .0000E+00 | -2.2000E+01 | .0000E+00 | -1.8609E-01 | 1.8609E-01 |
| .0000E+00 | -2.1000E+01 | .0000E+00 | -2.4182E+00 | 2.4182E+00 |
| .0000E+00 | -2.0000E+01 | .0000E+00 | -5.6636E+00 | 5.6636E+00 |
| .0000E+00 | -1.9000E+01 | .0000E+00 | -1.0265E+01 | 1.0265E+01 |
| .0000E+00 | -1.8000E+01 | .0000E+00 | -1.6536E+01 | 1.6536E+01 |
| .0000E+00 | -1.7000E+01 | .0000E+00 | -2.4441E+01 | 2.4441E+01 |
| .0000E+00 | -1.6000E+01 | .0000E+00 | -3.2634E+01 | 3.2634E+01 |
| .0000E+00 | -1.5000E+01 | .0000E+00 | -3.5828E+01 | 3.5828E+01 |
| .0000E+00 | -1.4000E+01 | .0000E+00 | -1.8318E+01 | 1.8318E+01 |
| .0000E+00 | -1.3000E+01 | .0000E+00 | 5.9732E+01 | 5.9732E+01 |
| .0000E+00 | -1.2000E+01 | .0000E+00 | 2.8397E+02 | 2.8397E+02 |
| .0000E+00 | -1.1000E+01 | .0000E+00 | 8.0179E+02 | 8.0179E+02 |
| .0000E+00 | -1.0000E+01 | .0000E+00 | 1.7994E+03 | 1.7994E+03 |
| .0000E+00 | -9.0000E+00 | .0000E+00 | 3.4280E+03 | 3.4280E+03 |
| .0000E+00 | -8.0000E+00 | .0000E+00 | 5.7235E+03 | 5.7235E+03 |
| .0000E+00 | -7.0000E+00 | .0000E+00 | 8.5452E+03 | 8.5452E+03 |
| .0000E+00 | -6.0000E+00 | .0000E+00 | 1.1554E+04 | 1.1554E+04 |
| .0000E+00 | -5.0000E+00 | .0000E+00 | 1.4321E+04 | 1.4321E+04 |
| .0000E+00 | -4.0000E+00 | .0000E+00 | 1.6545E+04 | 1.6545E+04 |
| .0000E+00 | -3.0000E+00 | .0000E+00 | 1.8144E+04 | 1.8144E+04 |
| .0000E+00 | -2.0000E+00 | .0000E+00 | 1.9179E+04 | 1.9179E+04 |
| .0000E+00 | -1.0000E+00 | .0000E+00 | 1.9751E+04 | 1.9751E+04 |
| .0000E+00 | .0000E+00 | .0000E+00 | 1.9933E+04 | 1.9933E+04 |
| .0000E+00 | 1.0000E+00 | .0000E+00 | 1.9751E+04 | 1.9751E+04 |
| .0000E+00 | 2.0000E+00 | .0000E+00 | 1.9179E+04 | 1.9179E+04 |
| .0000E+00 | 3.0000E+00 | .0000E+00 | 1.8144E+04 | 1.8144E+04 |
| .0000E+00 | 4.0000E+00 | .0000E+00 | 1.6545E+04 | 1.6545E+04 |
| .0000E+00 | 5.0000E+00 | .0000E+00 | 1.4321E+04 | 1.4321E+04 |
| .0000E+00 | 6.0000E+00 | .0000E+00 | 1.1554E+04 | 1.1554E+04 |
| .0000E+00 | 7.0000E+00 | .0000E+00 | 8.5452E+03 | 8.5452E+03 |
| .0000E+00 | 8.0000E+00 | .0000E+00 | 5.7235E+03 | 5.7235E+03 |
| .0000E+00 | 9.0000E+00 | .0000E+00 | 3.4280E+03 | 3.4280E+03 |
| .0000E+00 | 1.0000E+01 | .0000E+00 | 1.7994E+03 | 1.7994E+03 |
| .0000E+00 | 1.1000E+01 | .0000E+00 | 8.0179E+02 | 8.0179E+02 |
| .0000E+00 | 1.2000E+01 | .0000E+00 | 2.8397E+02 | 2.8397E+02 |
| .0000E+00 | 1.3000E+01 | .0000E+00 | 5.9732E+01 | 5.9732E+01 |

| | | | | |
|---|---|---|---|---|
| .0000E+00 | 1.4000E+01 | .0000E+00 | -1.8318E+01 | 1.8318E+01 |
| .0000E+00 | 1.5000E+01 | .0000E+00 | -3.5828E+01 | 3.5828E+01 |
| .0000E+00 | 1.6000E+01 | .0000E+00 | -3.2634E+01 | 3.2634E+01 |
| .0000E+00 | 1.7000E+01 | .0000E+00 | -2.4441E+01 | 2.4441E+01 |
| .0000E+00 | 1.8000E+01 | .0000E+00 | -1.6536E+01 | 1.6536E+01 |
| .0000E+00 | 1.9000E+01 | .0000E+00 | -1.0265E+01 | 1.0265E+01 |
| .0000E+00 | 2.0000E+01 | .0000E+00 | -5.6636E+00 | 5.6636E+00 |
| .0000E+00 | 2.1000E+01 | .0000E+00 | -2.4182E+00 | 2.4182E+00 |
| .0000E+00 | 2.2000E+01 | .0000E+00 | -1.8609E-01 | 1.8609E-01 |
| .0000E+00 | 2.3000E+01 | .0000E+00 | 1.3159E+00 | 1.3159E+00 |
| .0000E+00 | 2.4000E+01 | .0000E+00 | 2.3012E+00 | 2.3012E+00 |
| .0000E+00 | 2.5000E+01 | .0000E+00 | 2.9241E+00 | 2.9241E+00 |
| .0000E+00 | 2.6000E+01 | .0000E+00 | 3.2945E+00 | 3.2945E+00 |
| .0000E+00 | 2.7000E+01 | .0000E+00 | 3.4897E+00 | 3.4897E+00 |
| .0000E+00 | 2.8000E+01 | .0000E+00 | 3.5643E+00 | 3.5643E+00 |
| .0000E+00 | 2.9000E+01 | .0000E+00 | 3.5567E+00 | 3.5567E+00 |
| .0000E+00 | 3.0000E+01 | .0000E+00 | 3.4939E+00 | 3.4939E+00 |

Current Required 1.920 amperes (computer generated)

| | | | | |
|---|---|---|---|---|
| .0000E+00 | 1.4000E+01 | .0000E+00 | -1.8318E+01 | 1.8318E+01 |
| .0000E+00 | 1.5000E+01 | .0000E+00 | -3.5828E+01 | 3.5828E+01 |
| .0000E+00 | 1.6000E+01 | .0000E+00 | -3.2634E+01 | 3.2634E+01 |
| .0000E+00 | 1.7000E+01 | .0000E+00 | -2.4441E+01 | 2.4441E+01 |
| .0000E+00 | 1.8000E+01 | .0000E+00 | -1.6536E+01 | 1.6536E+01 |
| .0000E+00 | 1.9000E+01 | .0000E+00 | -1.0265E+01 | 1.0265E+01 |
| .0000E+00 | 2.0000E+01 | .0000E+00 | -5.6636E+00 | 5.6636E+00 |
| .0000E+00 | 2.1000E+01 | .0000E+00 | -2.4182E+00 | 2.4182E+00 |
| .0000E+00 | 2.2000E+01 | .0000E+00 | -1.8609E-01 | 1.8609E-01 |
| .0000E+00 | 2.3000E+01 | .0000E+00 | 1.3159E+00 | 1.3159E+00 |
| .0000E+00 | 2.4000E+01 | .0000E+00 | 2.3012E+00 | 2.3012E+00 |
| .0000E+00 | 2.5000E+01 | .0000E+00 | 2.9241E+00 | 2.9241E+00 |
| .0000E+00 | 2.6000E+01 | .0000E+00 | 3.2945E+00 | 3.2945E+00 |
| .0000E+00 | 2.7000E+01 | .0000E+00 | 3.4897E+00 | 3.4897E+00 |
| .0000E+00 | 2.8000E+01 | .0000E+00 | 3.5643E+00 | 3.5643E+00 |
| .0000E+00 | 2.9000E+01 | .0000E+00 | 3.5567E+00 | 3.5567E+00 |
| .0000E+00 | 3.0000E+01 | .0000E+00 | 3.4939E+00 | 3.4939E+00 |

Current Required 1.920 amperes (computer generated)

Table #4
Computer Field Data Generated From Finished Magnet Data

Field Point TAble

| RHO Centimeter | Z Centimeter | BR Gauss | BZ Gauss | BMOD Gauss |
|---|---|---|---|---|
| 8.9000E+00 | -1.2500E+01 | -7.9764E+00 | 6.0904E+01 | 6.1424E+01 |
| 8.9000E+00 | -1.1500E+01 | -2.3601E+01 | 6.5316E+01 | 6.9449E+01 |
| 8.9000E+00 | -1.0500E+01 | -2.0671E+01 | 6.0544E+01 | 6.3976E+01 |
| 8.9000E+00 | -9.5000E+00 | 1.4892E+01 | 1.0949E+02 | 1.1050E+02 |
| 8.9000E+00 | -8.5000E+00 | -8.1206E+01 | 2.2666E+02 | 2.4076E+02 |
| 8.9000E+00 | -7.5000E+00 | -2.1971E+02 | 1.8707E+02 | 2.8856E+02 |
| 8.9000E+00 | -6.5000E+00 | -3.4242E+02 | 1.6826E+02 | 3.8153E+02 |
| 8.9000E+00 | -5.5000E+00 | -4.3276E+02 | -4.7036E+01 | 4.3531E+02 |
| 8.9000E+00 | -4.5000E+00 | -2.8734E+02 | -1.3011E+02 | 3.1542E+02 |
| 8.9000E+00 | -3.5000E+00 | -2.9335E+02 | -1.6032E+02 | 3.3430E+02 |
| 8.9000E+00 | -2.5000E+00 | -2.3115E+02 | -2.2861E+02 | 3.2510E+02 |
| 8.9000E+00 | -1.5000E+00 | -1.6632E+02 | -2.8617E+02 | 3.3099E+02 |
| 8.9000E+00 | -5.0000E-01 | -6.0315E+01 | -3.2886E+02 | 3.3434E+02 |
| 8.9000E+00 | 5.0000E-01 | 6.0315E+01 | -3.2886E+02 | 3.3434E+02 |
| 8.9000E+00 | 1.5000E+00 | 1.6632E+02 | -2.8617E+02 | 3.3099E+02 |
| 8.9000E+00 | 2.5000E+00 | 2.3115E+02 | -2.2861E+02 | 3.2510E+02 |
| 8.9000E+00 | 3.5000E+00 | 2.9335E+02 | -1.6032E+02 | 3.3430E+02 |
| 8.9000E+00 | 4.5000E+00 | 2.8734E+02 | -1.3011E+02 | 3.1542E+02 |
| 8.9000E+00 | 5.5000E+00 | 4.3276E+02 | -4.7036E+01 | 4.3531E+02 |
| 8.9000E+00 | 6.5000E+00 | 3.4242E+02 | 1.6826E+02 | 3.8153E+02 |
| 8.9000E+00 | 7.5000E+00 | 2.1971E+02 | 1.8707E+02 | 2.8856E+02 |
| 8.9000E+00 | 8.5000E+00 | 8.1206E+01 | 2.2666E+02 | 2.4076E+02 |
| 8.9000E+00 | 9.5000E+00 | -1.4892E+01 | 1.0949E+02 | 1.1050E+02 |
| 8.9000E+00 | 1.0500E+01 | 2.0671E+01 | 6.0544E+01 | 6.3976E+01 |
| 8.9000E+00 | 1.1500E+01 | 2.3601E+01 | 6.5316E+01 | 6.9449E+01 |
| 8.9000E+00 | 1.2500E+01 | 7.9764E+00 | 6.0904E+01 | 6.1424E+01 |

Central Field 2 tesla

FIGURE #1 CALCULATED FIELD DATA GENERATED FROM FINISHED MAGNET WINDING DATA

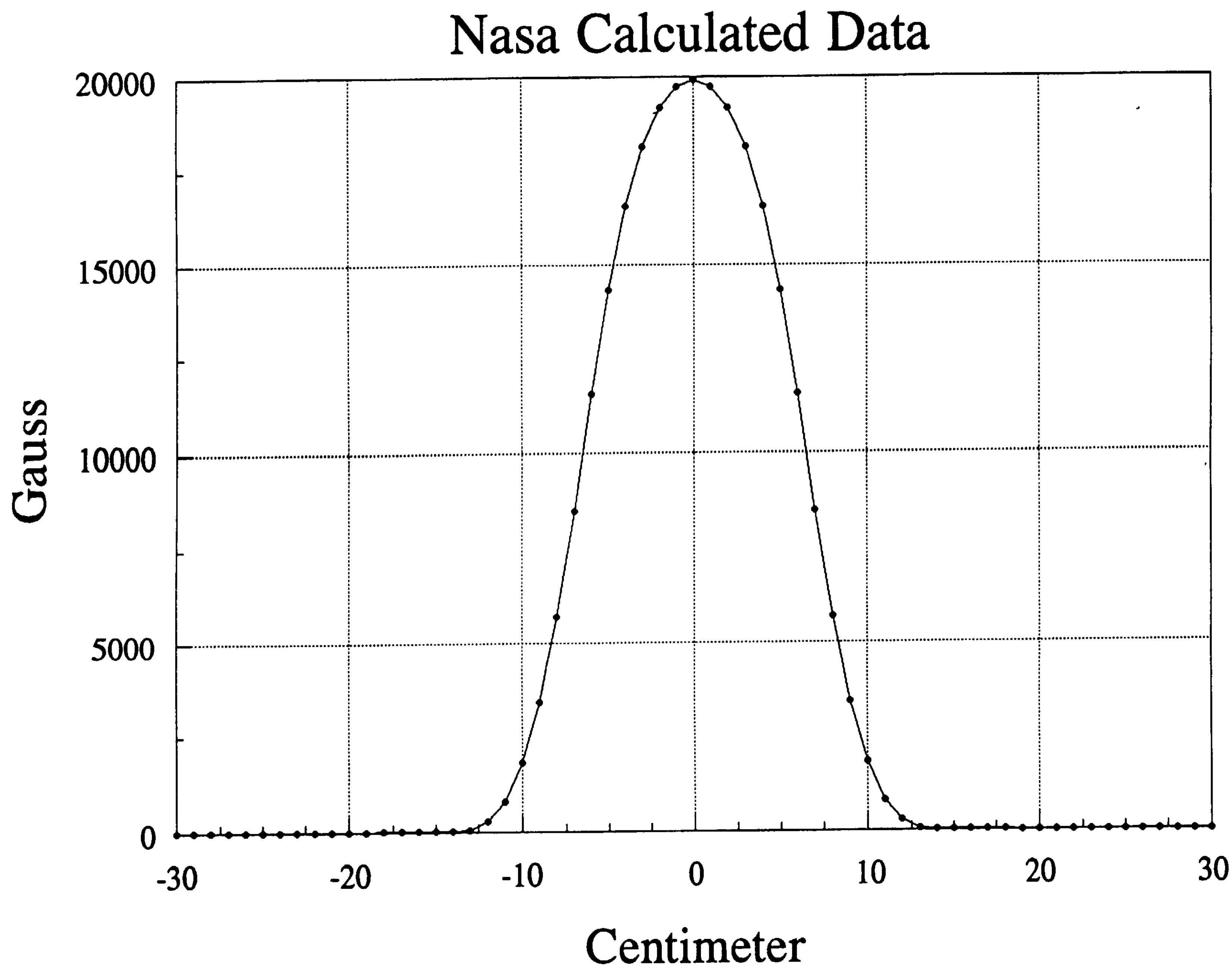


FIGURE #2 CALCULATED FIELD DATA GENERATED FROM FINISHED MAGNET DATA AND ONE MEASURED POINT

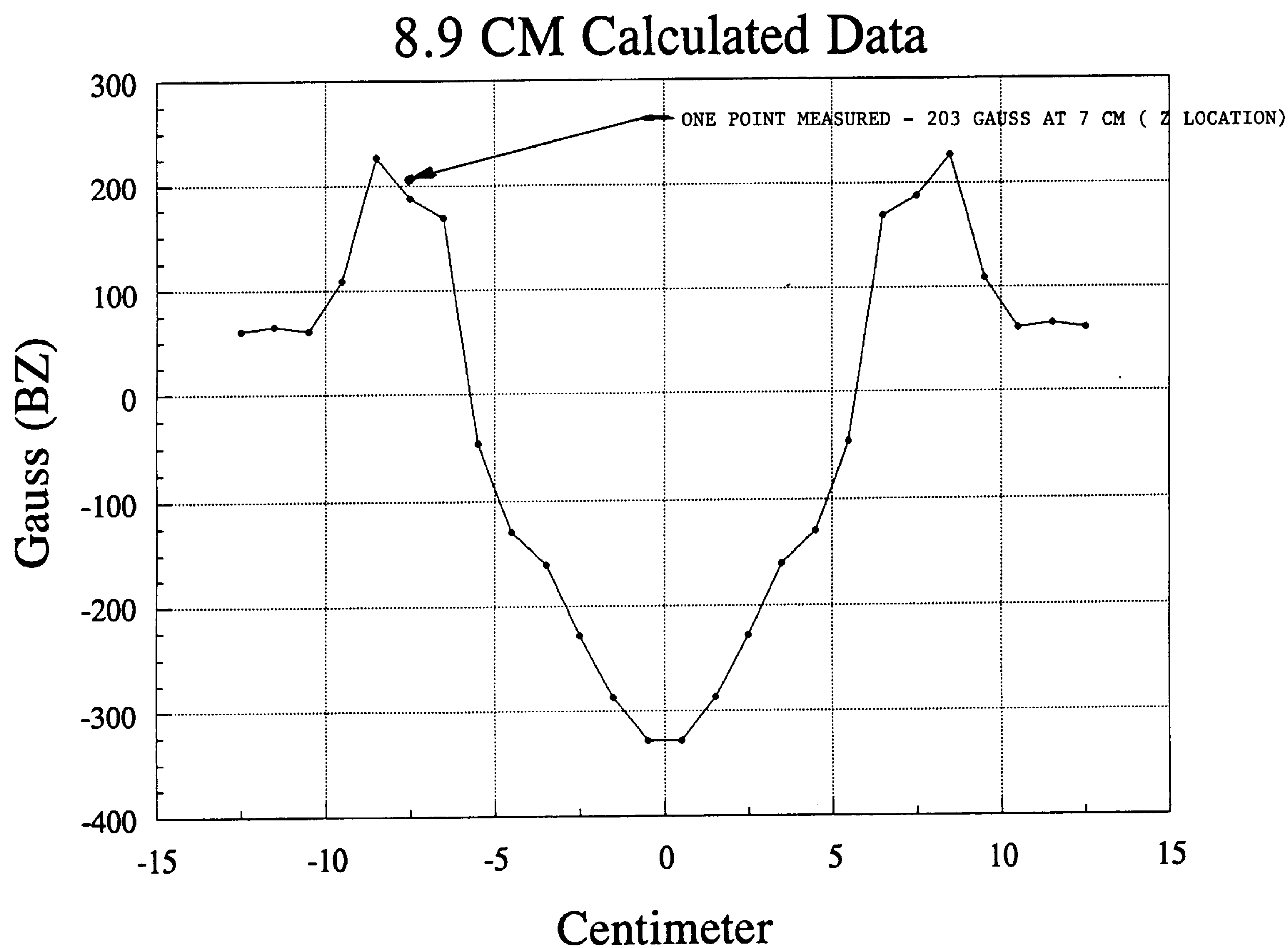


FIGURE #3

MEASURED AXIAL DATA

| CM | millivolt | Gauss |
|---|---|---|
| -11.000000 | 0.560600 | 733.500000 |
| -10.000000 | 1.393800 | 1.8237E03 |
| -9.000000 | 2.641200 | 3.4559E03 |
| -8.000000 | 4.565600 | 5.9739E03 |
| -7.000000 | 6.778000 | 8.8687E03 |
| -6.000000 | 9.058900 | 1.1853E04 |
| -5.000000 | 0.000000 | 1.4656E04 |
| -4.000000 | 13.040600 | 1.7063E04 |
| -3.000000 | 14.317200 | 1.8733E04 |
| -2.000000 | 15.148800 | 1.9821E04 |
| -1.000000 | 15.584000 | 2.0391E04 |
| 0.000000 | 15.740000 | 2.0595E04 |
| 1.000000 | 15.600900 | 2.0413E04 |
| 2.000000 | 15.119100 | 1.9782E04 |
| 3.000000 | 14.326700 | 1.8745E04 |
| 4.000000 | 12.986100 | 1.6991E04 |
| 5.000000 | 11.152000 | 1.4591E04 |
| 6.000000 | 9.057500 | 1.1851E04 |
| 7.000000 | 6.541500 | 8.5593E03 |
| 8.000000 | 4.279400 | 5.5994E03 |
| 9.000000 | 2.622500 | 3.4314E03 |
| 10.000000 | 1.368800 | 1.7910E03 |
| 11.000000 | 0.574600 | 751.800000 |
| 12.000000 | 0.178900 | 232.900000 |
| 13.000000 | 0.068800 | 90.000000 |
| 14.000000 | 0.045800 | 61.300000 |
| 15.000000 | 0.036900 | 48.300000 |
| 16.000000 | 0.032500 | 42.500000 |
| 17.000000 | 0.024300 | 31.800000 |
| 18.000000 | 0.016800 | 22.000000 |
| 19.000000 | 0.011200 | 14.700000 |
| 20.000000 | 0.006900 | 9.000000 |
| 21.000000 | 0.004000 | 5.200000 |
| 22.000000 | 0.001900 | 2.500000 |
| 23.000000 | 0.000300 | 0.400000 |
| 24.000000 | -0.000500 | -0.700000 |
| 25.000000 | -0.001500 | -2.000000 |
| 26.000000 | -0.002000 | -2.600000 |
| 27.500000 | -0.002100 | -2.700000 |
| 28.500000 | -0.002100 | -2.700000 |
| 29.500000 | -0.002100 | -2.700000 |
| 30.500000 | -0.002100 | -2.700000 |

1.978 AMPERES

FIGURE #4  MEASURED FIELD DATA CENTRAL FIELD AT 2.06 TESLA

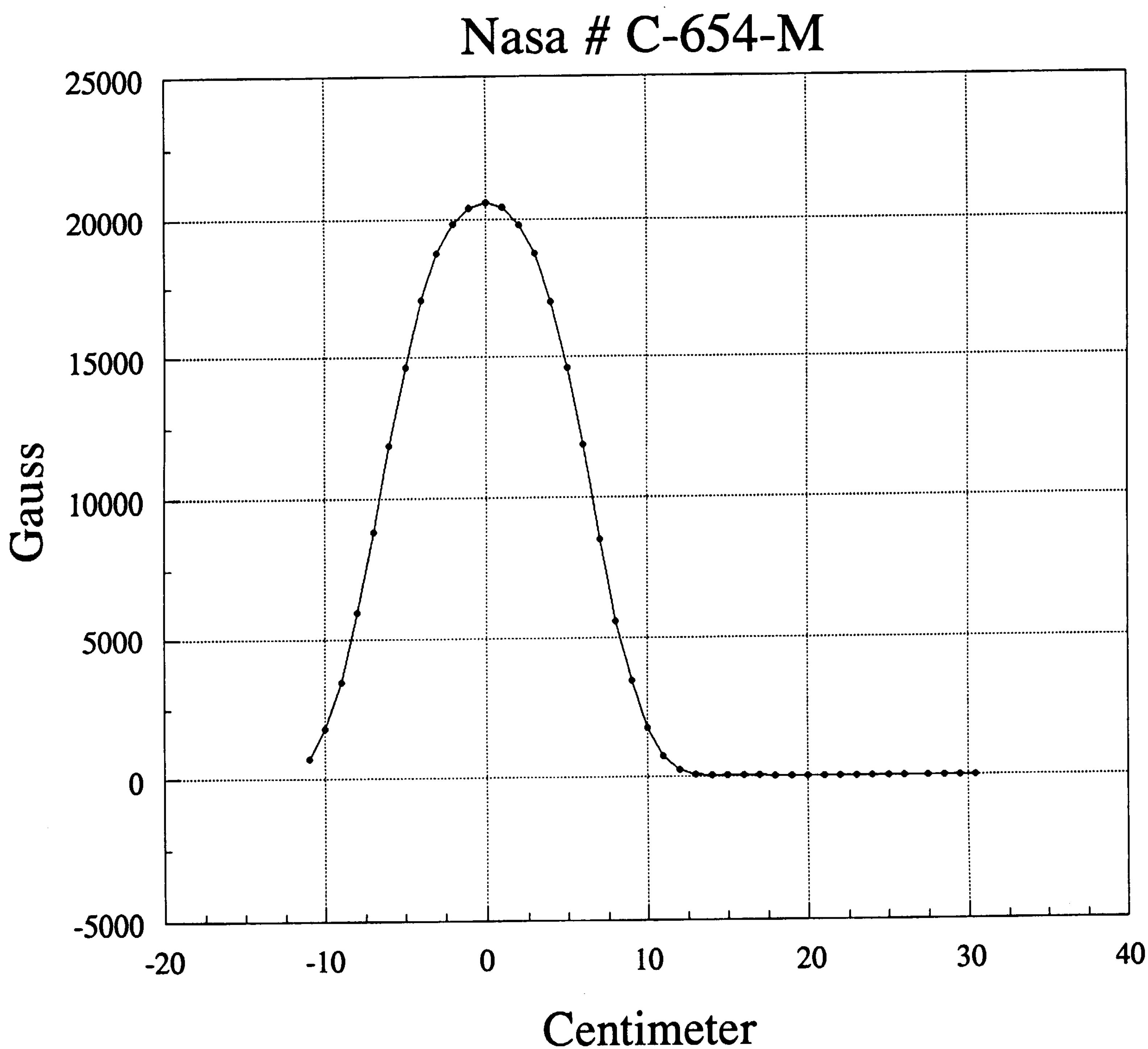


FIGURE #5 MEASURED FIELD DATA CENTRAL FIELD AT 2.06 TESLA

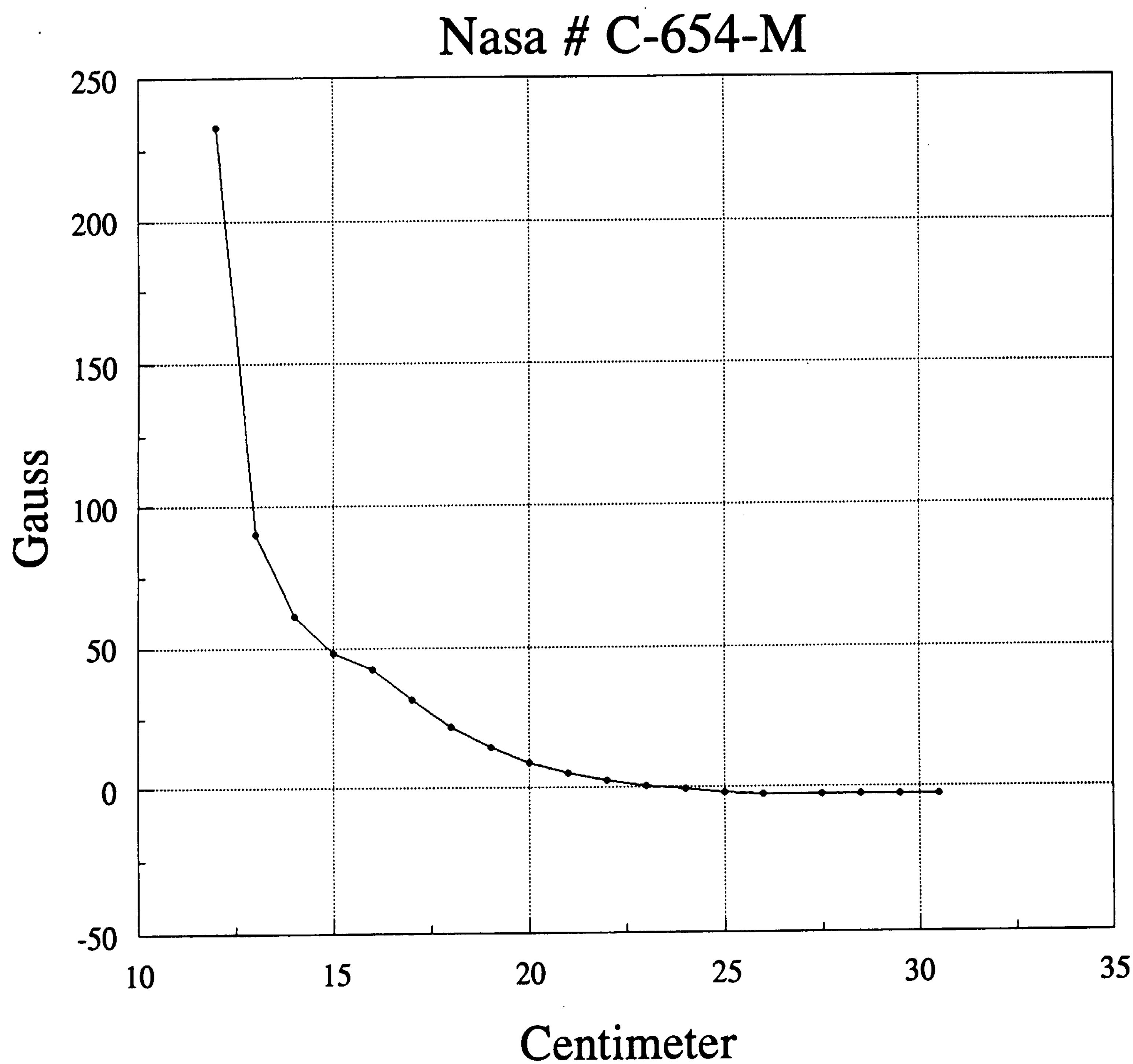


FIGURE #6  MEASURED FIELD DATA CENTRAL FIELD AT 2.06 TESLA

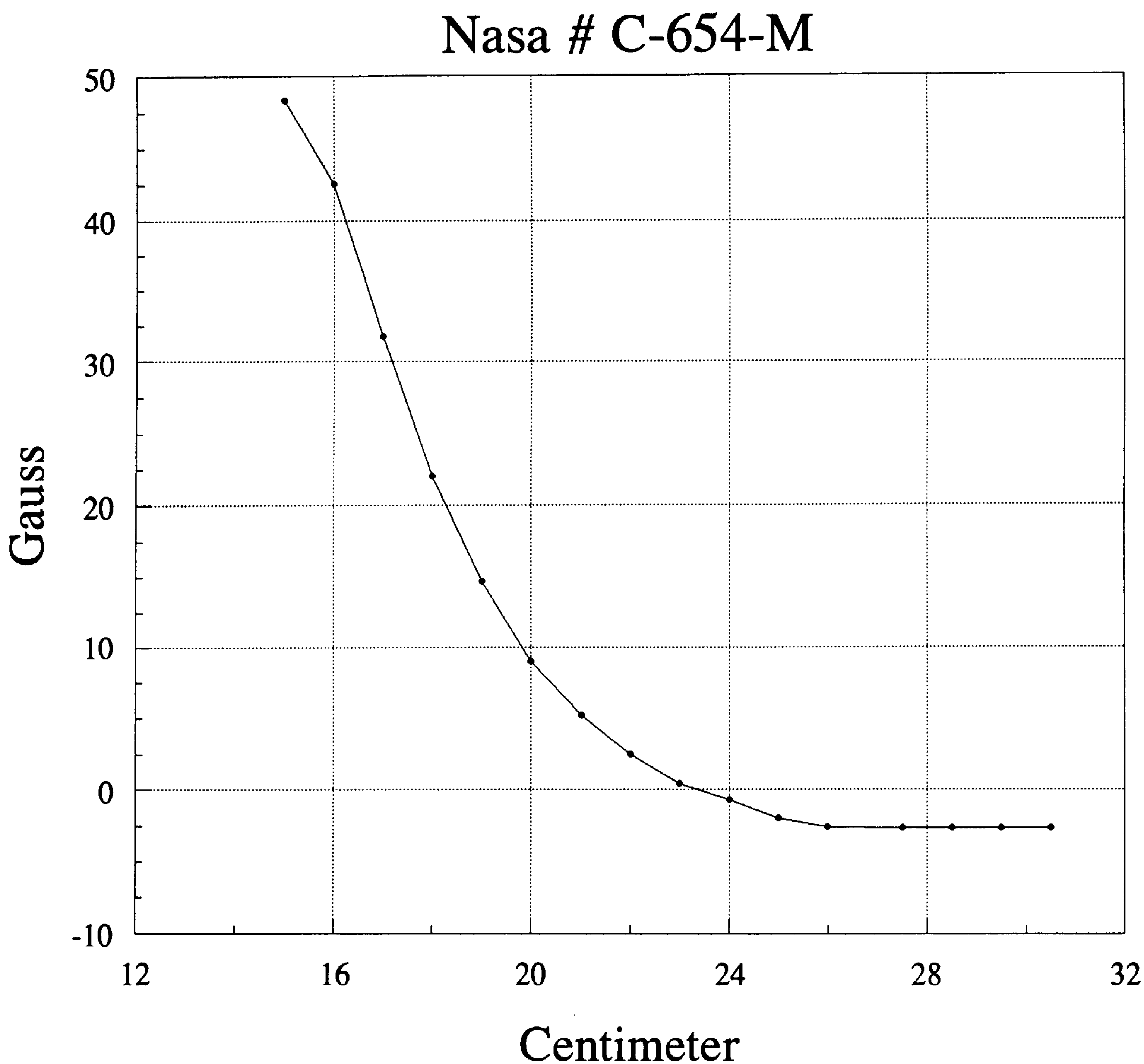


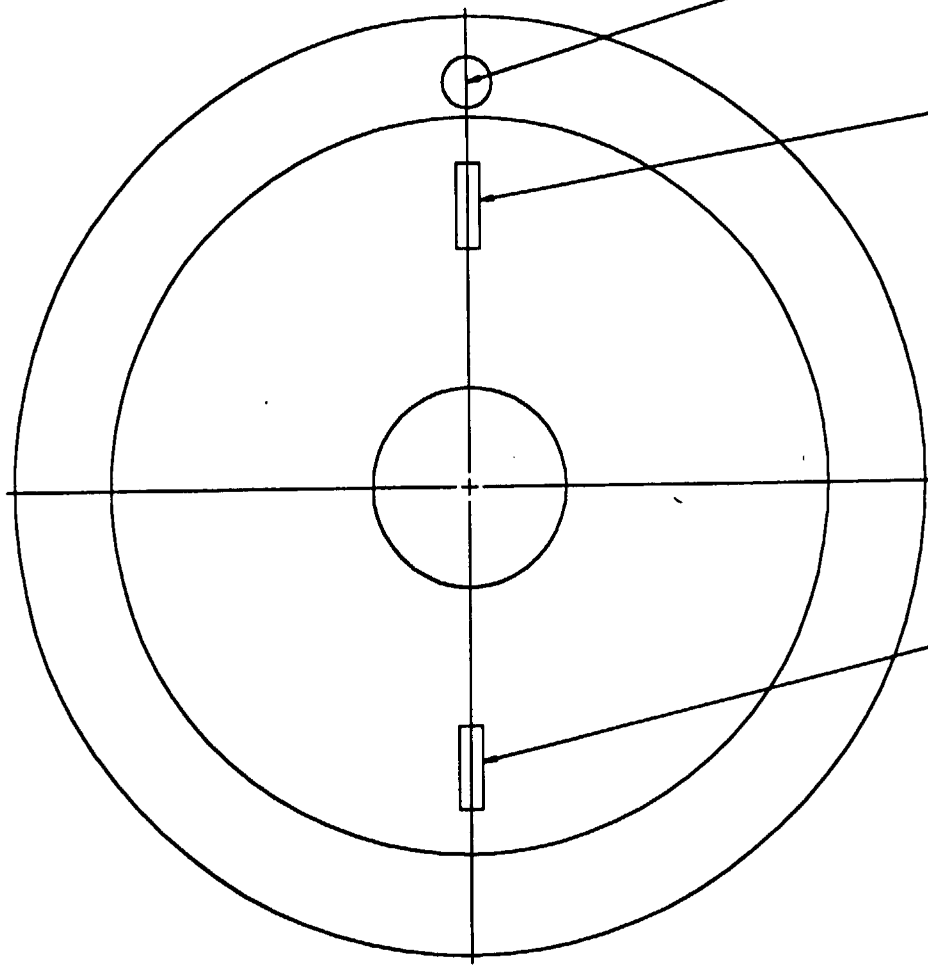
FIGURE 7

MUTUAL AND SELF INDUCTANCE MATRIX

| coil # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 416 | | | | | | | |
| 2 | 391.7 | 507.9 | | | | | | |
| 3 | -5.06 | -6.1 | 5.3 | | | | | |
| 4 | -5.06 | -6.1 | 0.04 | 5.3 | | | | |
| 5 | -112.9 | -155.7 | 0.04 | 4.14 | 112 | | | |
| 6 | -84.7 | -117.4 | 2.4 | 2.39 | 81.6 | 67.1 | | |
| 7 | -37.8 | -52.5 | 0.86 | 0.86 | 34.8 | 29.9 | 15.6 | |
| 8 | -2.6 | -3.7 | 0.052 | 0.052 | 2.36 | 20 5 | 1.13 | 0.12 |

TOTAL INDUCTANCE = 1068 HENRIES

| REV. | DATE | BY | DESC. |
|---|---|---|---|




SENSORS MOUNTED IN FLANGE AGAINST MAIN COIL WINDING SEE FIGURE 10 FOR LOCATION.

CRYOMAGNETICS, INC.

Magnet Assembly Top View
Large Flange End

TOLERANCES UNLESS OTHERWISE INDICATED, TOLERANCES TO BE

0.000 = ±.005

UNLESS OTHERWISE INDICATED, BREAK ALL SHARP EDGES. PARTS TO BE BURR FREE.

TITLE
NASA
TEMPERATURE SENSOR ROTATIONAL LOCATION
Figure #8

| | | | | | |
|---|---|---|---|---|---|
| REF. DWG. | - | DRAWN BY | RWM | DRAWING NO. | D-20569-A |
| CAD/CAM FILE NAME | D20569A | DATE | 8-24-98 | | |
| DISK NO. | 20-12 | APPROVAL | - | SCALE none | REV. 0 |

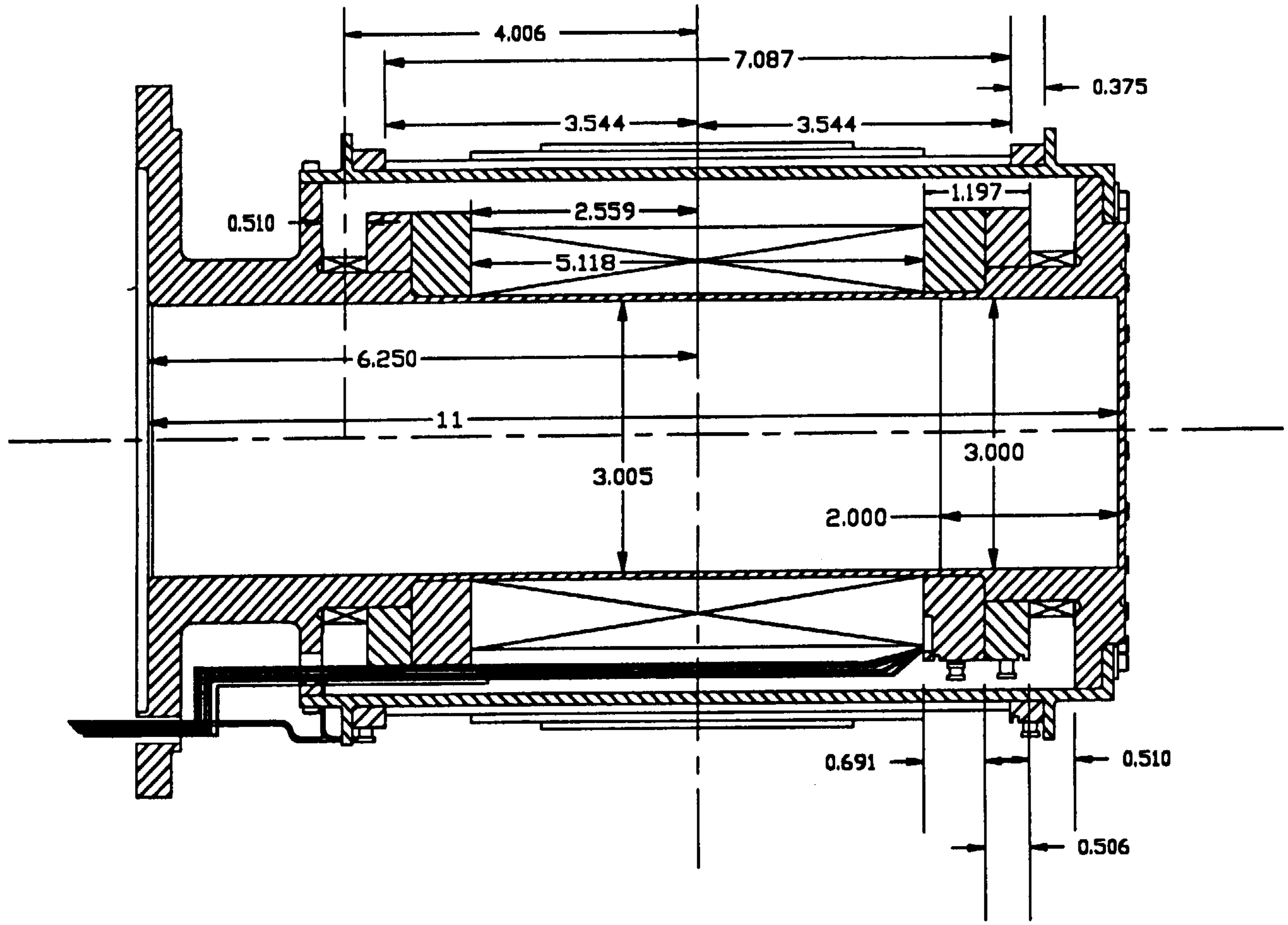



Figure #9

| REV. | DATE | BY | DESC. |
|---|---|---|---|
| 1 | 7/1/98 | rvm | Modified current lugs |

CRYOMAGNETICS, INC.

NASA GODDARD SPACE FLIGHT CENTER
LOW CURRENT SUPERCONDUCTING MAGNET
WO-3465

| | | | | |
|---|---|---|---|---|
| DRAWN BY | RVM | DATE | 8-24-98 | D-20418-C |
| SCALE | FULL | REV. | 2 | |

# TEMPERATURE SENSOR WIRING

| SENSOR | CONNECTOR WIRE COLOR |
|---|---|
| SENSOR (A) FP42 | |
| V+ | GREEN |
| V- | BLUE |
| I+ | YELLOW |
| I- | RED |
| SENSOR (B) FP44 | |
| V+ | BLACK |
| V- | BLUE |
| I+ | YELLOW |
| I- | RED |

for 3rd Flight
Magnet

Calibration Curve for FP42

| T (K) | R (Ohms) |
|---|---|
| 1.20915 | 51426.6 |
| 1.30082 | 47400.5 |
| 1.39983 | 43836.5 |
| 1.4999 | 40811.2 |
| 1.59983 | 38295.6 |
| 1.69988 | 36159.2 |
| 1.79987 | 34330.8 |
| 1.89984 | 32721.6 |
| 1.99994 | 31315.6 |
| 2.19969 | 28992.5 |
| 2.39963 | 27124.4 |
| 2.59957 | 25585.3 |
| 2.79965 | 24320.4 |
| 2.99964 | 23233.1 |
| 3.19971 | 22310.8 |
| 3.39961 | 21517.4 |
| 3.59956 | 20834.8 |
| 3.79961 | 20212.3 |
| 4.00006 | 19668.2 |
| 4.19967 | 19181.4 |
| 4.4998 | 18539.1 |
| 4.99949 | 17662.6 |
| 5.49938 | 16952.5 |
| 5.99946 | 16366.9 |
| 6.49911 | 15885.7 |
| 6.99809 | 15470.2 |
| 7.49773 | 15116.3 |
| 7.99753 | 14803.9 |
| 8.49736 | 14536.9 |
| 8.99673 | 14293.2 |
| 9.49637 | 14077.4 |
| 9.99505 | 13884. |
| 10.4943 | 13711.2 |
| 10.994 | 13557.1 |
| 11.4933 | 13416.4 |
| 11.9926 | 13279.8 |
| 12.992 | 13050.1 |
| 13.9949 | 12847. |
| 14.9944 | 12675. |
| 15.9939 | 12517.8 |
| 16.9936 | 12383.2 |

Calibration Curve FP42 page 2

| | |
|---|---|
| 17.9931 | 12264.9 |
| 18.9926 | 12159.1 |
| 19.9906 | 12062. |
| 20.993 | 11970.2 |
| 21.9905 | 11892.3 |
| 22.9914 | 11814.5 |
| 23.9894 | 11745.7 |
| 24.9906 | 11683.6 |
| 25.9877 | 11626.6 |
| 26.9895 | 11569.8 |
| 27.9888 | 11522.4 |
| 79.37 | 10545.4 |
| 88.65 | 10480.4 |

for 3rd Flight
Magnet

Calibration Curve for FP44

| T (K) | R (Ohms) |
|---|---|
| 1.20919 | 50934.8 |
| 1.30078 | 46995. |
| 1.39973 | 43453.4 |
| 1.49985 | 40484.2 |
| 1.59981 | 38016.2 |
| 1.6998 | 35908.9 |
| 1.79981 | 34072. |
| 1.89977 | 32494.1 |
| 1.99979 | 31115.2 |
| 2.19969 | 28789.8 |
| 2.39963 | 26941.7 |
| 2.59954 | 25425.6 |
| 2.79953 | 24187.4 |
| 2.99968 | 23117.5 |
| 3.19977 | 22194.7 |
| 3.39958 | 21408.6 |
| 3.59955 | 20722.9 |
| 3.7996 | 20122. |
| 3.99969 | 19572.5 |
| 4.1997 | 19087.3 |
| 4.49988 | 18458.2 |
| 4.99951 | 17577.9 |
| 5.49948 | 16883.7 |
| 5.99927 | 16304.4 |
| 6.49919 | 15820.9 |
| 6.99811 | 15412.9 |
| 7.49784 | 15054.3 |
| 7.99756 | 14749.6 |
| 8.49758 | 14481.2 |
| 8.99659 | 14247.9 |
| 9.49626 | 14030.9 |
| 9.99491 | 13839.1 |
| 10.4942 | 13670.1 |
| 10.9942 | 13509.8 |
| 11.4931 | 13373. |
| 11.9926 | 13241.9 |
| 12.9918 | 13008.8 |
| 13.9949 | 12807.7 |
| 14.9941 | 12633.9 |
| 15.9937 | 12486.4 |

Calibration Curve FP 44 page 2

| | |
|---|---|
| 16.9936 | 12350.6 |
| 17.9937 | 12233.4 |
| 18.9928 | 12127.4 |
| 19.9912 | 12028. |
| 20.9937 | 11941.1 |
| 21.9921 | 11860.3 |
| 22.9913 | 11786.7 |
| 23.99 | 11720. |
| 24.9903 | 11659.3 |
| 25.9869 | 11599.3 |
| 26.99 | 11541.6 |
| 27.9887 | 11496.1 |
| 79.29 | 10540.8 |
| 88.55 | 10479.6 |