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NASA Grant NAG5-338

FINAL REPORT

For the period 1 July 1983 through 30 June 1985

Principal Investigator

Dr. Mario D. Grossi

July 1985

Prepared for
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics

The NASA Technical Officer for this Grant is Mr. Jean E. Welker, Code 921, Earth Survey Applications Division, Goddard Space Flight Center, Greenbelt, Maryland 20771



RESEARCH RELATIVE TO THE DEVELOPMENT OF A CRYOGENIC MICROWAVE CAVITY
GRADIOMETER FOR ORBITAL USE

NASA Grant NAG5-338

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Summary

The highlights of the study performed under Grant NAG5-338 have been the conceptual design of a free-fall ground-based testing approach for gravity gradiometers, and the joint study and development with IFSI/CNR of the single-axis sensor that will be tested at the NASA-MSEC's 300' drop-tower facility. Through the sponsorship of the NASA Grant, the project has reached now a point that we can undertake hardware development for these tests. SAO will submit to USAF-AEGL, on or before July 29, 1985, a proposal to continue under DoD support the R&D activity that started with a two-year support from NASA-GSEC. The plan envisions a joint testing activity NASA/USAF on the gradiometer, with AEGL supporting SAO for the required hardware development, and MSEC making available the drop-tower facility and providing assistance in personnel and equipment for the tests, at no cost to SAO or to AEGL.

SAO has published three Semiannual Reports (as well as this Final Report), to illustrate the accomplishments of the project: the 1st is dated December 1983 (Fuligni and Grossi, 1983); the 2nd, July 1984 (Fuligni and Grossi, 1984a); and the 3rd, December 1984 (Lorenzini and Grossi, 1984b). These three reports, together with the present one (dated July 1985), give a fairly complete account of the results obtained in the course of the study. The present report focuses on the activity from January 1985 to June 1985. This last semester of the 2-year project has aimed at identifying technical approaches to increase the sensitivity of a non-cryogenic gradiometer toward the goal of 10^{-3} EU/ $\sqrt{\text{Hz}}$, with solutions that have the potential of achieving an even more ambitious threshold, such as 10^{-4} EU/ $\sqrt{\text{Hz}}$. This goal can be achieved with a gradiometer design in which the proof masses are each suspended from two small arms, the torsion of which is directly related to the displacement of the sensing element. A negative-spring action, aimed at reducing the resonance frequency, is provided in this design by means of an external electrostatic field. This configuration of the instrument is also suitable for use in a tensorial arrangement.

1.0 INTRODUCTION

The investigation carried out by SAO in the two-year span, 1983-to-1985, had the primary objective of ascertaining feasibility and practicality of gradiometer schemes characterized by a sensitivity of the order of 10^{-2} -to- 10^{-3} EU/ $\sqrt{\text{Hz}}$, that could be designed, constructed and tested in a relatively short time-frame, such as before the decade of the '80s is over. First, a key to the success of this undertaking was judged by SAO to be the direct transfer to the gradiometer design of high-sensitivity displacement sensing techniques, already developed, or under development, by the community of gravity radiation antenna designers (Grossi, 1981). Devices of particular interest were found to be the condenser probe and the microwave cavity, of the cryogenic and of the non-cryogenic variety. Second, it was considered crucial to the success, the ability to test the sensitive gradiometer on the ground, in an environment free from man-made vibrations and seismic oscillations. The best way (perhaps the only possible way) to achieve this goal is, in SAO opinion, the adoption of a free-fall approach, using possibly (in order to save money) an existing facility, such as the drop-tower available at NASA-MSFC, Huntsville, Alabama. This approach was introduced in SAO Semiannual Report #2, July 1984 (Section 2.9, pages 43-51). An air-tight, sealed, cylindrical container, with inside pressure $\leq 10^{-3}$ torr, housing in its interior the gravity gradiometer under test, would fall inside an elevator cabin in rapid descent (free-fall drop is 293.8', and fall time is 4.3 seconds, during which data can be collected), thus simulating for the instrument a vibration-free, in-vacuo, orbit-like, condition. It would be impractical to use bulky cryostats in free-fall tower tests, such as the ones that can be conducted at NASA-MSFC. This was one of the reasons why SAO, with NASA concurrence, concentrated its efforts on the design and construction of a gradiometer that uses a non-cryogenic, condenser-probe displacement-sensor, in-

strument. The plan for the construction of the overall test package is illustrated in Section 2.3 (page 12-18) of Semiannual Report #3 (December, 1984). The plan calls for a joint effort of SAO and IFSI-CNR, Frascati, Italy. The latter would construct the sensing element, using their condenser probe consisting of a rectangular plate attached to a rigid frame by crank-shaped suspensions, all machined from a single block. The former would assemble in a suitable container the overall test package, by adding to the sensing element the required ancillary instrumentation such as a power amplifier to feed an existing modulator/transmitter for wireless transfer of data, and a gyro package to measure the package's angles and angular rates during the free-fall. Data from the gyros would be time-correlated to the data from the gradiometer. Correction of errors due to attitude variations would be performed in the post-test analysis of the observations.

In the last six months of project performance, SAO has done the following:

- a) further analysis of the non-cryogenic gradiometer configuration, to ascertain the possibility of improving the instrument sensitivity of about an order of magnitude;
- b) investigation of the sensitivity improvement that could be expected from an operation of the sensor at cryogenic temperatures;
- c) study of a tensorial configuration;
- d) evaluation of the response of a single-axis, off-line, gradiometer to the field of a spherical mass, in a situation such as the one to be encountered in the free-fall, drop-tower tests planned at the facility available in Huntsville, Alabama.

2.0 TECHNICAL DISCUSSION

2.1 General

The design philosophy that evolved in the course of our study favored a simple, non-cryogenic instrument, that could be designed and constructed in a two-year time frame and could be tested on the ground, using an existing free-fall, drop-tower facility. Under the circumstances, it was of concern to verify that, notwithstanding the instrument simplicity, the design is advanced enough to provide attractive sensitivity values, and is characterized by a good potential of further improving on the threshold, without major rework of the configuration. Our most recent effort has addressed this specific issue. We found confirmation of the advisability to proceed in the development of a simple, non-cryogenic instrument that is sensitive enough to satisfy NASA-OSSA spaceborne gravity gradient measurement requirements, in terms of minimum detectable gravity anomaly, and at the same time is able of making use of orbital flight opportunities that are far more numerous than the ones suitable for bulkier and heavier cryogenic apparatus. For instance, the instrument of our conception could be flown in the second mission of the Tethered Satellite System (TSS), scheduled to be launched in late 1989, while the tethered subsatellite could not easily accommodate the large cryostat needed with a cryogenic gradiometer.

In the following sections, we discuss the rationale for our design choices and we further define our proposed free-fall testing approach. If for the latter all goes as expected, this approach may represent a real breakthrough in the development of a gradiometer for orbital flight, possibly saving years of efforts in the elimination of vibrations and seismic oscillations, that would otherwise totally mask the signals in ground-based testing.

2.2 Non Cryogenic Gravity Gradiometer

Preliminary tests conducted at IFSI (Bordoni et al., 1985) on a model sensor allow us to draw some conclusions about the performances and potentialities of the non cryogenic approach to gravity gradiometry. This sensor, combined properly with the other identical sensors, will eventually make it possible to build a full tensorial instrument. The general concept of this force transducer has been already described in Semiannual Report #3. The main feature is that the proof mass is suspended through two small arms, the torsion of which is directly related to the displacement of the sensing element and then to the modulation of the pick off capacitors.

Length and cross section of the suspension arms, together with the moment of inertia of the proof mass with respect to the rotation axis, determines the frequency of the fundamental mode of the sensor. Other modes of vibration, which are present, have much higher proper frequencies, and this is one of the main merits of the solution that we have adopted. One further point is that torsion allows, fairly easily, to reach low resonance frequencies.

This is a very important matter as far as the mechanical behavior of the sensor is concerned. In fact this frequency has direct influence on sensitivity, high sensitivity requiring low resonance frequency. On the other hand, possible adverse dynamic conditions of the environment where measurements are to be performed call for a high dynamic range and strength of the instrument.

To achieve this it would be desirable to adopt the conflicting solution of a high resonance frequency, or, better, to change the strength of the equivalent harmonic oscillator, depending on the dynamic and environmental conditions.

Within reasonable limits this is possible by using an artificial negative spring, as it is obtained by an electrostatic field. In our case this is accomplished by adding two additional capacitor plates on opposite sides of the proof mass, electrically insulated from those of the pick off capacitor. In this way half of the surface of the sensor is used to detect the signal, and half to decrease the mechanical frequency through a dc voltage regulated by a proper feedback loop.

It is easy to estimate the effectiveness of the negative spring.

As we use two plates on the opposite sides of the moving one, the electrical forces, if of proper value, will not change the equilibrium position of the proof mass, and the effect of the applied electrostatic fields will be that of decreasing the stiffness of the mechanical spring. Such negative elastic constant is obtained by taking the second derivative of the electrostatic energy in the capacitor

$$K_e = \frac{d^2}{dx^2} \left(\frac{1}{2} c v^2 \right) = c E_0^2 \quad (1)$$

where c is the total capacitance, v the applied DC voltage, and E_0 the electric field between plates. So the resulting spring constant, k_γ , is

$$k_\gamma = k_m - K_e \quad (2)$$

where k_m is the mechanical elastic constant.

Equation (2) can be written as

$$\omega_\gamma^2 = \omega_m^2 \left(1 - \frac{c E_0^2}{m \omega_m^2} \right) = \omega_m^2 (1 - \beta_0) \quad (3)$$

where m is the mass of the equivalent harmonic oscillator.

In this way, in principle, the resonance frequency of the proof mass can be made as low as one wants, by proper choice of β_0 .

After this brief premise, we are now in the position to evaluate the practical limits of the sensitivity of the non cryogenic instrument, in a realistic, even if a bit idealized, situation.

For a gradiometer having a resulting resonance frequency of the sensor ω_γ , as given by equation (3), much greater than the signal frequency ω_s , we have for the sensitivity of the generic gravity tensor component Γ

$$\Gamma^2 = \frac{\omega_\gamma^4}{mL^2} \frac{\Delta f}{\omega_s} K \left[\frac{4T}{Q} \frac{\omega_s}{\omega_\gamma} + 2T_n \right] \quad (4)$$

providing proper mechanical and electrical matchings. This appears to be possible in our case. This expression for sensitivity assumes that the only noise sources are the internal ones, that is the thermal source (first term in parenthesis) and amplifier source (second term in parenthesis).

As high Q materials, like Aluminum 6061, are available, the brownian motion term in equation (4) can be kept sufficiently low to disregard it with respect to T_n , the noise temperature of the electronic amplifier. So, given the mechanical configuration and parameters, the true limiting factor is the noise of the amplifier.

We now ask the question: given the best (from the point of view of noise) available room temperature amplifier, let's find a minimum limit for sensitivity assuming a reasonable and practical mechanical configuration of the sensor.

By equation (3) we can in principle decrease the resonance frequency till zero. This however set an upper limit to the mass of the sensor

$$m \leq \frac{cE_0^2}{\omega_s^2} \quad (5)$$

E_0 must not exceed 10^7 volts/m, in order to prevent discharge, and a reasonable figure for c is around 1000 pF. As it was discussed previously, it is wise not to have a too low mechanical resonance frequency. 30 Hz appears a reasonable compromise that meets the requirements of mechanical strength, dynamic range, and reliable construction. With these parameters, the mass cannot be greater than 2.8 kg (by equation 5).

We may now assume to be able to decrease at will the frequency of the oscillator and so to be in a position opposite to that considered in equation (4), i.e., $\omega_s \ll \omega_r$.

In this assumption of quasi-free motion of the proof mass, the equation (4) for the sensitivity is modified as follows.

$$\Gamma^2 \simeq \frac{\omega_s}{mL^2} \Delta f \left[\frac{4KT}{Q} + 2KT_n \right] \quad (6)$$

By assuming the signal frequency at $\omega_s \simeq 0.1 \text{ rad sec}^{-1}$, and by adopting a limit mass, as given by equation (5), of 2.8 kg and a baseline of 1 m, we obtain

$$\Gamma = 3 \times 10^{-4} \text{ EU}/\sqrt{\text{Hz}} \quad (7)$$

provided $Q > 10^4$, which can be obtained even working at room temperature. T_n was taken equal to 0.1 K, as it is allowed by a FET amplifier.

The sensitivity (equation 7) corresponds to a limiting situation which is rather difficult to reach in practice. For example, a field of 10^7 volts/m, as used to estimate the mass limit of the sensor, is rather unsafe, as discharges can be started. We are however confident that sensitivities an order of magnitude worse than stated in equation 7 could in principle be obtained with more realistic room temperature instruments.

To be specific, let us discuss what can be obtained by pushing as far as possible the performance of the instrument now under development at IESI/CNR. The first prototype of the sensor has a mass of 0.3 kg and a resonant frequency of 59 Hz. Tests on this sensor to assess the performance of the electrostatic field as a negative spring have shown that with an applied voltage of 50 volts, the frequency was decreased to 48 Hz. This result makes us confident that with a second prototype, now under construction, having a mechanical resonance at 30 Hz, an approximately 0 frequency will be reached.

The first gradiometer prototype will have a baseline of 0.5 m. From these parameters one could expect a theoretical sensitivity of

$$\Gamma = 2 \times 10^{-3} \text{ EU}/\sqrt{\text{Hz}} \quad (8)$$

To reach effectively this sensitivity one must however solve a number of experimental problems, whose solutions are not at all obvious. One problem, to be carefully investigated, is the evaluation of noise which will be eventually produced by the feedback system. This is needed not only to adjust the scale factors of the sensors and regulate their dynamic range, but also to restore the equilibrium position of these quasi free proof masses. We feel that it will be strongly reduced by the configuration of the system, where forces are exerted on opposite direction of the sensor plate, providing a zero net effect.

Another source of noise, which was not taken into account in the previous discussion, is the voltage and phase noise of the a.c. supply to the bridge of the pick up circuit.

Previous experience with gravity wave-antenna transducers suggests to us that this noise too should be strongly reduced by the geometrical configuration we are using.

2.3 Cryogenic Instruments

In the previous section we have discussed the performance to be expected by a non cryogenic instrument and we have found that the most important limitation to sensitivity comes out from the noise temperature of the preamplifier. Present day technology does not allow, at the frequencies of some kHz of interest to us, noise temperatures much lower than 0.1 K.

This is not true for cryogenic temperatures where SQUIDS, or cooled GAs, very high frequency amplifiers, in connection with microwave cavity resonators, can be used.

One further point is that when the amplifier noise temperature is sufficiently low, the thermal noise contribution may become important, thus requiring increase of Q or decrease of temperature of the bath or both. This in turn can be accomplished by going to a cryogenic environment with the instrument.

One question which deserves some consideration is that of exploring the possibility of using the proposed non cryogenic instrument at liquid He temperatures, with some minor modifications.

The mechanical assembly does not pose particular problems as geometries similar to that under discussion have been already successfully used in connection with a cryogenic gravity wave antenna.

The only substantial changes required concern the pick up electric circuit where the FET amplifier has been replaced by a SQUID. This in principle implies only to change the coupling of transducer output to amplifier input. This can be done with a superconducting transformer. The construction of this transformer, however, may be difficult in practice because a very stringent electric-

cal matching condition are to be met. In addition, in presence of high mechanical Q's, instabilities may develop in the pick up circuit.

It seems to us, in any case, that this line of future development is worth of deeper investigations.

2.4 The Tensorial Configuration

The sensor we have discussed is the building block of the gravity gradiometer. A one axis configuration is presently under construction at IFSI/CNR. It is expected to have a resonance frequency of approximately 30 Hz and a mass of about 0.4 kg. The total length is 0.5 m. The geometry chosen is such that the sensor measures the off line component Γ_{ij} of the gravity gradient tensor.

The reason for this choice for the first prototype is twofold:

(1) It has been proposed (Grossi, 1984) to make such a test in free-fall, in order to overcome the great difficulties of insulating the gradiometer from acoustic and seismic noise when testing its performance. The drop tower at NASA/MSFC will be used. Both at the start and at the end of the fall the gradiometer will experience large accelerations. Their effect on the sensors will be greatly reduced, and perhaps, will become unimportant, if the resulting inertial forces are constrained in a direction normal to that of the sensitive axis of the gradiometer. This, in connection with possible rotational motions of the instrument which can be started at the beginning of the free fall, have suggested to us, at least in the very first test, the above geometry. In addition, if the gradiometer axis remains vertical during the fall, the instrument will be insensitive to the earth field gradient. The expected response of

this geometry to a spherical mass simulating a gravity anomaly is discussed in Section 2.5 here below.

(2) Precise geometrical relationships (both alignments and orthogonalities) between sensor sensitive axes and baseline directions are of primary importance. The geometry we have decided to use as a first step allows us to reach great precision in a relatively simple way and at low cost. The full one-axis instrument is in fact obtained by machining a single plate of Aluminum. It is possible in this way to keep the centers of the sensing masses within a few microns with respect to the geometrical axis of the gradiometer.

From this one-axis instrument it is easy to build a partial tensorial instrument by mounting three of them along three mutually perpendicular directions. With proper orientation of the sensor axes all the three off-line components can be measured.

To get an in-line one-axis instrument does not appear, in principle, to be particularly difficult. It can still be obtained from a single block of material by machining, but it will be more expensive. We expect also that precision in alignments will be a bit worse than the above one for the off-line device.

We do not expect temperature changes to affect seriously the instrument performance. This requires essentially some care in attaching the gradiometer to its frame in order to avoid differential expansion or contraction which could result in deformations. Temperature gradients may be more important. Due to the geometry of the gradiometer, we expect that this temperature gradient will be possibly larger along the axis of the baseline. As the instrument is completely made of the same material except for the insulator of the capacitors, the only effect caused by a strong difference in temperature between the two sensors is a variation in the value of the capacitances of the same fractional

order as the fractional variation of thickness of the insulators. This is estimated to be 1 part in 10^4 for a difference of 1°C . This may affect the scale factors and may require correction.

We think however that this particular point will be better evaluated, by performing measurements on the instrument itself and by testing its behavior as a function of temperature and of temperature gradients.

2.5 Response Of One-Axis, Off-Line, Gradiometer, To The Field Of A Spherical Mass

We set the mass generating the field to be tested at a certain height of the drop tower, and we take it as origin of the coordinates of the reference frame. We assume that the y axis, downward oriented, is along the vertical. The xz plane is the horizontal one, containing the center of mass. The gradiometer axis is oriented parallel to the vertical and lies on the yz plane, which contains also the sensitive axes of the accelerometers (see Figure 1a).

In this way the yz component with respect to our system of coordinates is measured. It is related at every point during the fall to the components $\bar{\Gamma}$ along the principal axis by a rotation around the x axis. This gives for the output signal, S, of the gradiometer

$$S = [\bar{\Gamma}_{yy} - \bar{\Gamma}_{zz}] \sin 2\theta + \bar{\Gamma}_{yz} \cos 2\theta$$

and, being $\bar{\Gamma}_{yz} = 0$,

$$S = \frac{GM}{r^3} \sin 2\theta$$

or, by eliminating θ ,

$$S = \frac{2GM}{R_0^3} \frac{h}{R_0} \left[\frac{1}{1 + (h/R_0)^2} \right]^{5/2}$$

This is zero when the gradiometer crosses the xz plane and has, in absolute value, two maxima at $h = \pm R_0/2$, corresponding to

$$S = \pm 0.57 \text{ GM}/R_0^3.$$

If $R_0 = 2\text{m}$, $M = 10 \text{ kg}$, S corresponds to $4 \times 10^{-2} \text{ EU}$.

The form of the signal, as a function of time, is shown in Figure 2.

In the test it is desirable to contain the signal as seen from the gradiometer in a narrow range of frequencies starting from zero. We can obtain an estimate of this range by considering that the duration Δt of the signal is of the order of the time the gradiometer takes to span a distance R_0 , as it is clear from Figure 1b,

$$\Delta t = R_0 / \sqrt{2gh_0}$$

where h_0 is the height above the xz plane at which the free fall is started. We must then keep R_0 as large as possible and h_0 small.

With a mass of 10^3 kg we get a signal of 10^{-1} EU at 7 m . By assuming $h_0 = 10 \text{ m}$, we get approximately for the frequency within which the bulk of the signal is contained

$$\Delta f = 2 \text{ Hz}.$$

An enhancement, due to the form of the signal, is to be expected at a frequency $f_0 = 1/(2t_0)$, where t_0 is the time needed to travel the distance between the two peaks, which gives $f_0 \simeq 1 \text{ Hz}$.

Figures 3, 4 and 5 give the spectrum of the signal at the output of the gradiometer. The spectrum was obtained by FFT'ing the simulated instruments's output in the geometric situation of Figure 1. Figure 3 is the most informative of the three Figures and provides the Power Spectral Density (PSD) of the signal. It can be seen that the peak of PSD is at about 0.5 Hz. Figure 4 and Figure 5 give the real and the imaginary part of the signal spectrum.

Appendix I contains the software code that was used in computing the graphs of Figures 3, 4 and 5. Appendix II contains the print-out of the calculations.

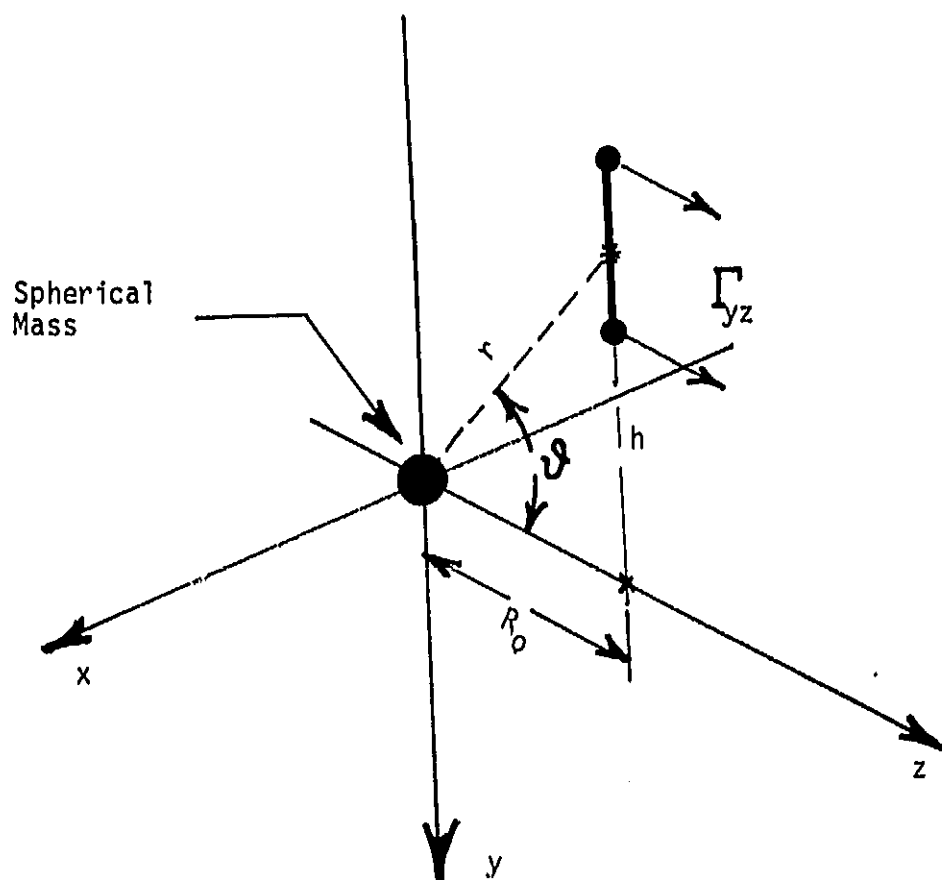


Figure 1 a
Geometry of free-fall measurements

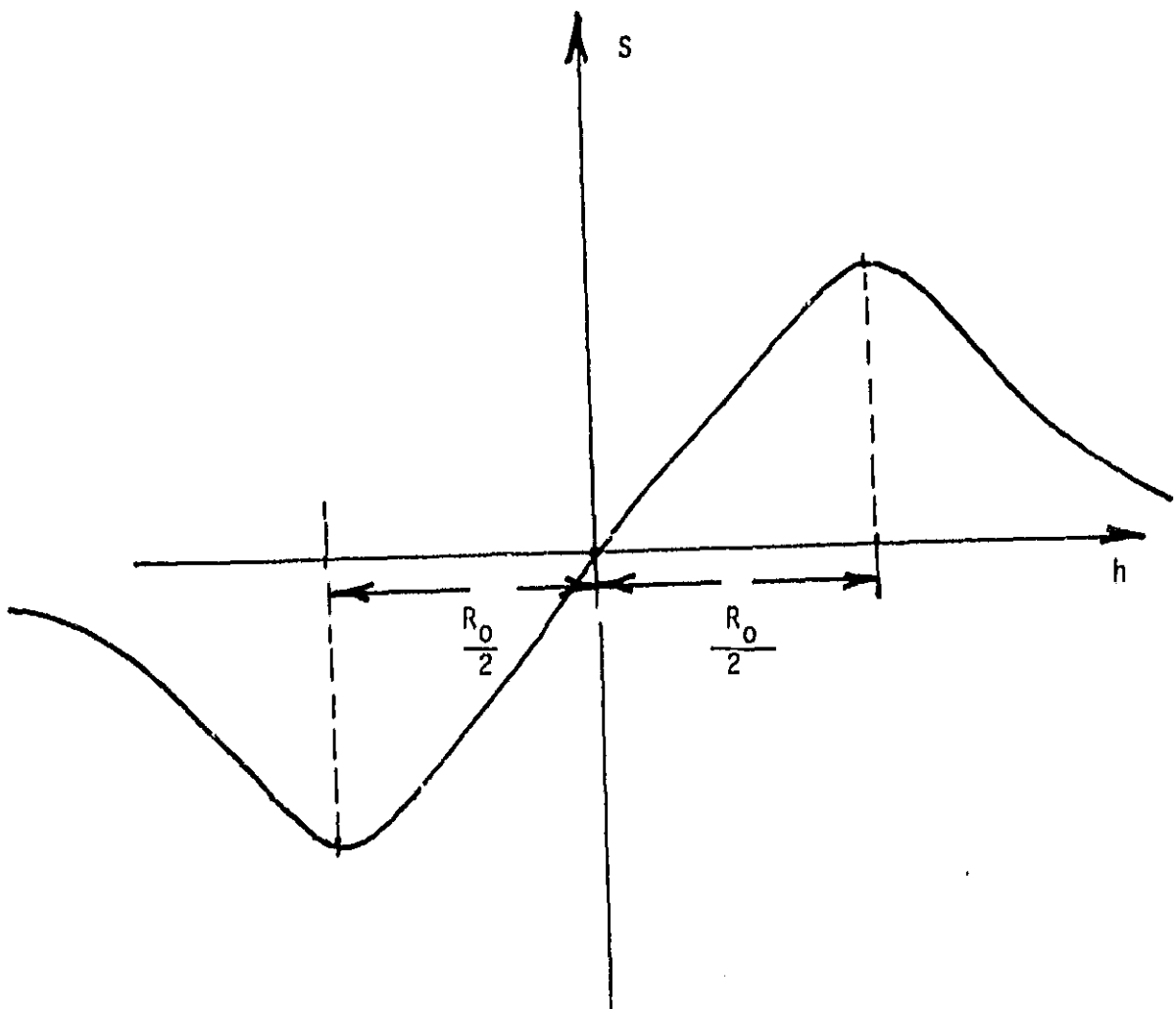


Figure 1 b

Graph of Signal S as a function of distance h
 (See Figure 1 a, for meaning of symbols R_0 and h)

The analytical expression for S is:

$$S = \frac{2 G M}{R_0^3} \frac{h}{R_0} \left[\frac{1}{1 + (h/R_0)^2} \right]^{5/2}$$

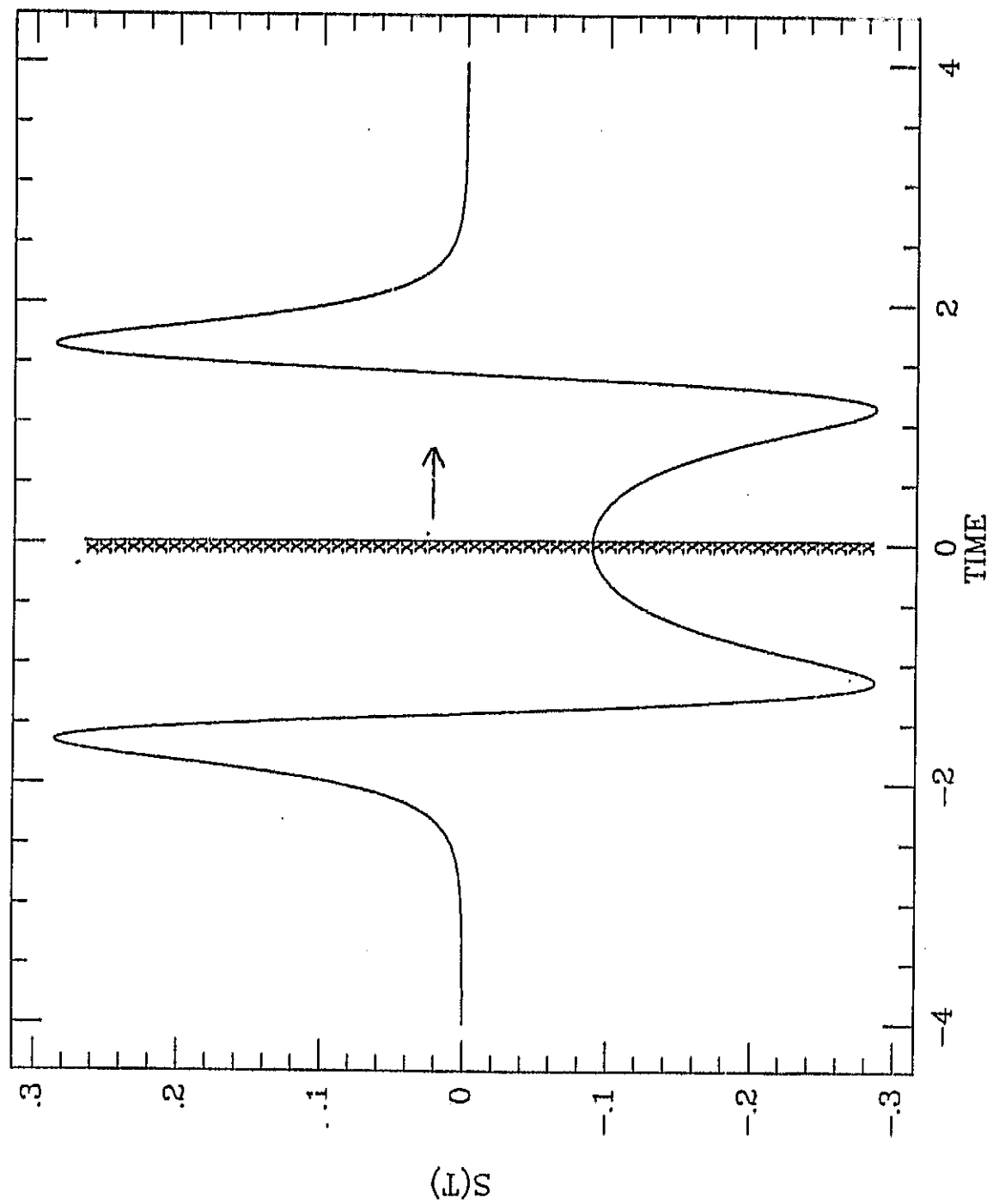


Figure 2. Signal at the output of the gradiometer as a function of time.

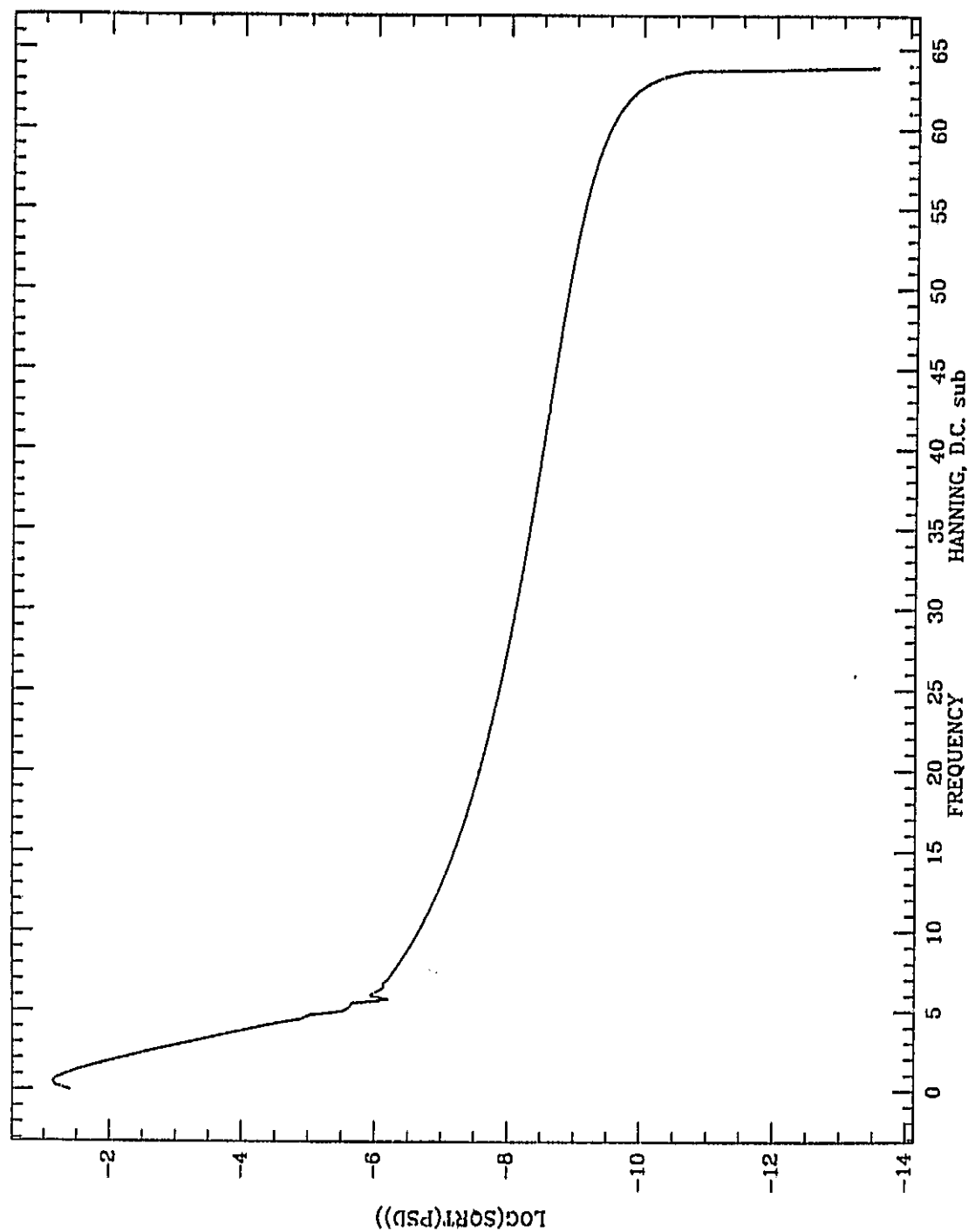


Figure 3. Power spectral density of the signal, d.c. level subtracted.

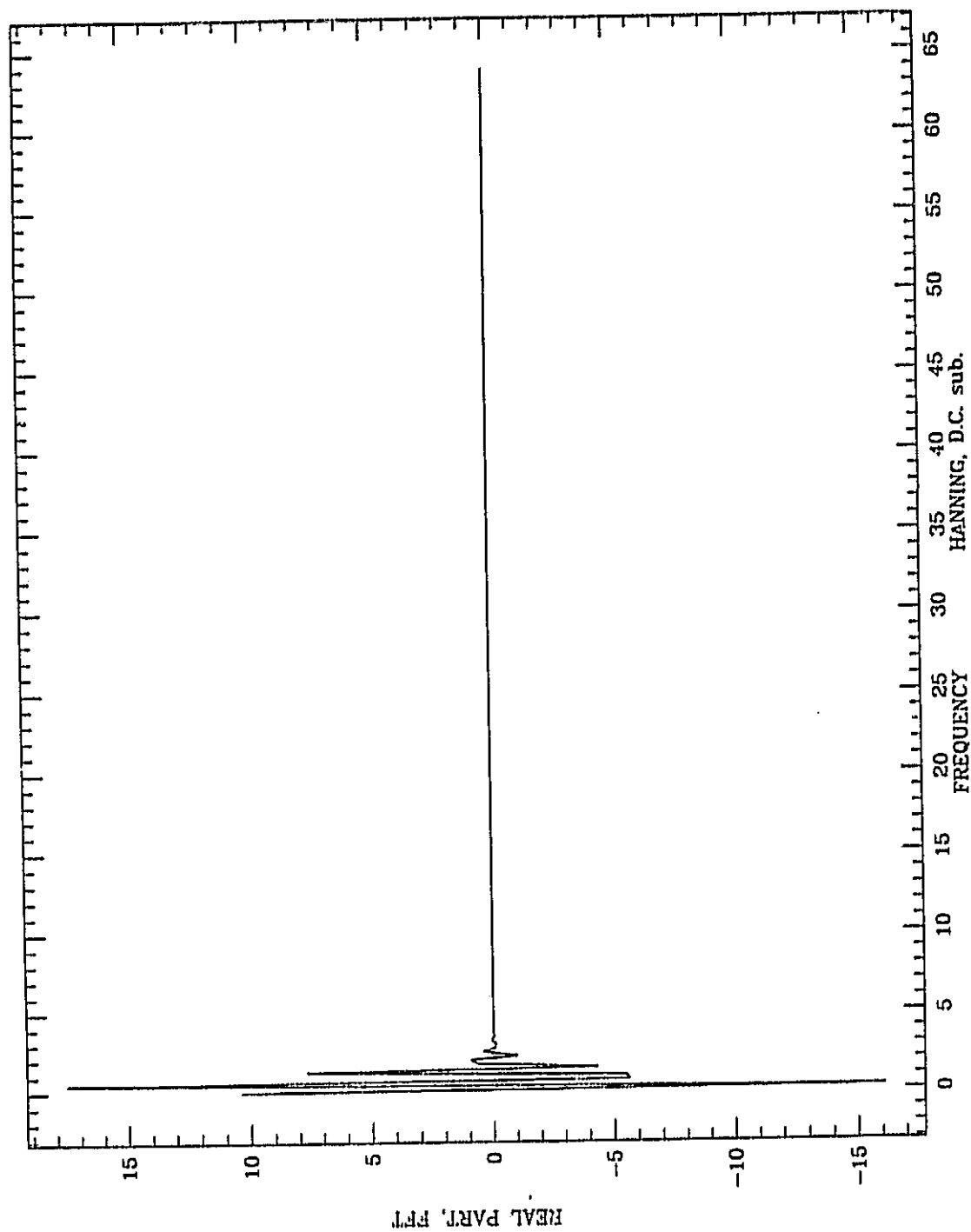


Figure 4. Real part of signal spectrum.

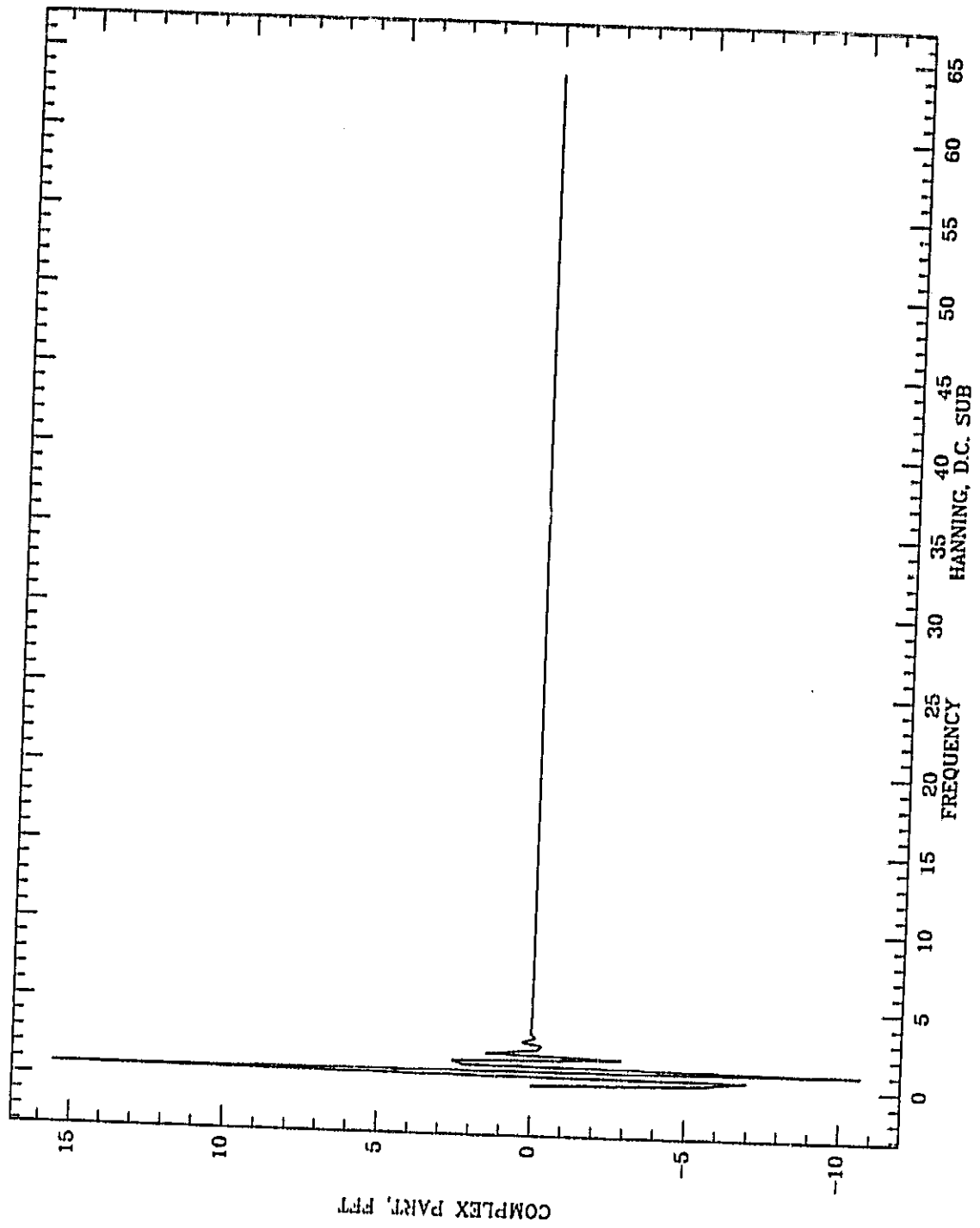


Figure 5. Imaginary part of signal spectrum.

3.0 CONCLUSIONS AND RECOMMENDATIONS

We conclude on the advisability of a follow-on program based on the construction by SAO of a non-cryogenic gradiometer package that uses the displacement sensor developed at IFSI/CNR, and on the free-fall testing of such a package at the drop-tower facility available at NASA/MSEC, Huntsville, Alabama. It is our understanding that NASA-OSSA and USAF-AEGL have already formulated a joint activity plan, with AEGL providing financial support to SAO for the instrument hardware effort, and NASA-OSSA providing support for the in-house activity at MSEC. We recommend that such a plan be implemented without delay; we actually expect that this follow-on phase will start in October 1985. If this is the case, there will be time enough to prepare for a 1989 flight, or even for an earlier flight.

It appears that NASA Grant NAG5-338 has made it possible for SAO to achieve enough progress in gradiometer design, that hardware development is now on the verge to be initiated. If the events in Fall 1985 will confirm this expectation, the Grant would have fully accomplished its scope.

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Appendix I

Software Code for the Computation of the Spectrum of the
Expected Signals in Free-Fall Experiments

GRADSPEC.FOR/2

29-MAR-1985 17:34

PAGE 1

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PROGRAM GRADSPEC
IMPLICIT REAL*8(A-H,O-Z)

C      GRADIOMETER RESPONSE FUNCTION.

C      COMPUTE THE FFT AMPLITUDE.
C      PRINT THE RESULT, WITH THE FREQUENCY.
C      NOTE THIS IS THE SQUARE ROOT OF THE PSD.

C      WE SUBTRACT OFF THE D.C. COMPONENT BEFORE FFT'ING.
C      IN 'ANAL1' THERE MAY BE PROBLEMS DUE TO THE HANNING WHEN WE
C      IGNORE THE D.C. POST-FFT AS BEING COMPONENT FFT(1).

PARAMETER (IMAX = 2048, IMAX2 = 1025)      IMAX2=IMAX/2+1

DIMENSION ST(IMAX),STDC(IMAX),POW(IMAX2),
1         FREQ(IMAX2)

PARAMETER (ISIZE=1024)      !HALF THE MAXIMUM N
COMPLEX*16 Z(ISIZE+1)
COMMON /FFTCON/Z              !MAKE FULL FFT ACCESSIBLE OUTSIDE
LOGICAL HANNING                !FLAG IN COMMON = SET TO DO HANNING.
COMMON /FFTCON2/HANNING

PRINT *, ' ( P1* T**2 - P2)/P3 '
PRINT *, 'ENTER P1,P2,P3:'
READ *, P1,P2,P3

PRINT *, ' TIME INTERVAL: TMIN,TMAX'
READ *, TMIN,TMAX
PRINT *, ' NUMBER OF INTERVALS:'
PRINT *, ' (MUST BE EVEN; 2**K IS MOST EFFICIENT)'
READ *, NPTS
H = (TMAX-TMIN)/(NPTS-1)

DO I = 1, NPTS
    T = TMIN + (I-1)*H
    X = (P1*T*T-P2)/P3
    ST(I) = X / ( (1.0+X**2)**2.5 )
END DO

WRITE(12,101) P1,P2,P3,TMIN,TMAX,NPTS
101  FORMAT(' PARAMETERS 1', 3F10.3, ' INTERVAL:', 2F10.3, ' * POINTS',
1      15)
C      PRINT *, 'ENTER NUMBER OF POINTS IN INTERVAL'
C      READ *, NINT
NINT = NPTS

PRINT *, ' ENTER 1 IF HANNING IS TO BE DONE'
READ *, IHAN
IF (IHAN.EQ.1) THEN
    HANNING = .TRUE.
    WRITE(12,*) ' HANNING DONE'
ELSE
    HANNING = .FALSE.
    WRITE(12,*) ' HANNING *NOT* DONE'
ENDIF

PRINT *, ' ENTER 1 IF D.C. LEVEL SHOULD BE SUBTRACTED:'

```

GRANDSPEC, FOR/2

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```

READ *, IDC
IF (IDC.EQ.1) THEN
    CALL SUBDC(ST,NINT,STDC)
    CALL FFTAMP(STDC,NINT,POW)
    WRITE(12,*) ' D.C. LEVEL SUBTRACTED'
ELSE
    CALL FFTAMP(ST,NINT,POW)
    WRITE(12,*) ' D.C. LEVEL SUBTRACTED'
ENDIF

NP = NINT/2+1

DF = 1./(NINT*H)  ! ASSUME EQUAL INTERVALS
WRITE(12,*) 'FREQUENCY INTERVAL:', DF, ' (HERTZ)'
DO I = 1, NP
    FREQ(I) = (I-1)*DF
END DO

WRITE(12,*) ' F,P, REAL, COMPI,'
WRITE(12,215)
1   (FREQ(I),POW(I),Z(I), I=1,NP)
FORMAT('0', //
1   (F15.7,5X,G16.8,5X,2G16.8) )

END

SUBROUTINE SUBDC(A,N,B)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A(1),B(1)

AMEAN = 0.
DO I = 1,N
    AMEAN = AMEAN + A(I)
END DO
AMEAN = AMEAN / N

DO I = 1,N
    B(I) = A(I)-AMEAN
END DO

RETURN
END

```

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FFTAMP,FOR/12

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```

SUBROUTINE FFTAMP(A,N,XAMP)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A(1),XAMP(1)

PARAMETER (ISIZE=1024)  !HALF THE MAXIMUM N
COMPLEX*16 Z(ISIZE+1)
COMMON /FFTCON/Z          !MAKE FULL FFT ACCESSIBLE OUTSIDE
LOGICAL HANNING           !FLAG IN COMMON - SET TO DO HANNING.
DATA HANNING/,TRUE./      ! DEFAULT SET ON
COMMON /FFTCOM2/HANNING
INTEGER IWK(6*ISIZE+150)
REAL*8 WK(6*ISIZE+150),AA(2*ISIZE)
PARAMETER (PI=3.141592653589793,PI2=2*PI)

```

```

C      INPUT:
C          A(1..N)      SEQUENCE TO BE TRANSFORMED
C          N            SIZE OF SEQUENCE --
C                      MUST BE EVEN & POSITIVE, UP TO 1024.
C      OUTPUT:
C          XAMP(1.. N/2+1) AMPLITUDE OF RESULTING DFT
C          XPHASE( " )    PHASE      " " " "

```

```

C      COMPUTES A PROPERLY NORMALIZED D.F.T. OF THE REAL INPUT A().
C      OUTPUTS, RATHER THAN REAL AND COMPLEX COMPONENTS, THE
C      AMPLITUDE; NOTE THAT PHASE IS LOST.
C      BEFORE COMPUTING DFT, APPLY A HANNING
C      FUNCTION MULTIPLIER TO REDUCE "LEAKAGE" (SEE BRIGHAM, "THE
C      FAST FOURIER TRANSFORM", P.140); THIS REDUCES FAKE BASELINE AND
C      SHARPENS UP LINES AT FREQUENCIES "BETWEEN" THE DISCRETE
C      FREQUENCIES OUTPUT, BUT SLIGHTLY BROADENS LINES PRECISELY AT AN
C      OUTPUT FREQUENCY. TO GET POWER IN A LINE, SUM THE AMPLITUDES
C      ACROSS THE LINE BEFORE SQUARING.
C      USE IMSL ROUTINE FFTRC(); LINK WITH SYS$IMSL;IMSL9D/LIB.
C      N IS NOT REQUIRED TO BE A POWER OF 2, THOUGH MORE EFFICIENT IF SO.

```

```

C      APPLY HANNING:
C      SCALE = PI2/N
C      DO I = 1,N
C          IF (HANNING) THEN
C              AA(I) = A(I)*0.5*( 1-COS( (I-1)*SCALE ) )
C          ELSE
C              AA(I) = A(I)
C          ENDF
C      END DO

```

```

C      TRANSFORM:
C      CALL FFTRC(AA,N,Z,IWK,WK)

```

```

C      GET AMPLITUDE:
C      INP = N/2 + 1
C      SCALE = 2.0/N
C      DO I = 1,INP
C          XAMP(I) = ABS(Z(I))*SCALE
C      END DO

```

```

RETURN
END

```


Appendix II

Numerical Results Obtained with the Software Code

Illustrated in Appendix I

PARAMETERS : 5.000 10.000 7.000 INTERVAL: 0.000 4.000 * POINTS 512
HANNING DONE
D.C. LEVEL SUBTRACTED
FREQUENCY INTERVAL: 0.24951171H7500000 (HERTZ)
F,P, REAL, COMPI,

F	F	Real [F]	Im [F]	unnormalized
0.0000000	0.40634849E-01	10.402571	0.00000000E+00	
0.2495117	0.66489533E-01	-15.078007	-5.5877591	
0.4990234	0.73955782E-01	17.602378	-6.9715619	
0.7485352	0.64706461E-01	-5.6288586	15.519164	
0.9980469	0.46849091E-01	-5.5049787	-10.669736	
1.2475586	0.31343033E-01	7.7074557	2.2108651	
1.4970703	0.19667618E-01	-4.3245741	2.5784453	
1.7465820	0.11780176E-01	0.67176413	-2.9400066	
1.9960938	0.69201520E-02	0.97730122	1.4776005	
2.2456055	0.39320017E-02	-0.99200155	-0.17076590	
2.4951172	0.21959892E-02	0.45471487	-0.33056486	
2.7446289	0.12262843E-02	-0.40106965E-01	0.31135623	
2.9941406	0.65676502E-03	-0.10650490	-0.13009621	
3.2436523	0.35821648E-03	0.91223041E-01	0.93741103E-02	
3.4931641	0.19460239E-03	-0.36741348E-01	0.33644133E-01	
3.7426758	0.97406492E-04	0.10888160E-02	-0.24912279E-01	
3.9921875	0.56004079E-04	0.94852570E-02	0.10750848E-01	
4.2416992	0.28192607E-04	-0.71805686E-02	0.72729601E-03	
4.4912109	0.13010192E-04	0.25904195E-02	-0.20934861E-02	
4.7407227	0.96227872E-05	0.82558010E-04	0.24620497E-02	
4.9902344	0.30653551E-05	-0.75390459E-03	-0.21778535E-03	
5.2397461	0.24188112E-05	0.51577835E-03	0.34263792E-03	
5.4892578	0.22174284E-05	-0.16711278E-03	0.54250631E-03	
5.7387695	0.62653308E-06	-0.16925054E-04	0.15949698E-03	
5.9882813	0.11944462E-05	0.55702732E-04	0.30066181E-03	
6.2377930	0.92940080E-06	-0.34771651E-04	0.23537205E-03	
6.4873047	0.74072486E-06	0.10135571E-04	0.18435449E-03	
6.7368164	0.74724356E-06	0.19002461E-05	0.19128491E-03	
6.9863281	0.62982481E-06	-0.38683414E-05	0.16118874E-03	
7.2358398	0.57334661E-06	0.22693843E-05	0.14675919E-03	
7.4851516	0.52400097E-06	-0.55618235E-06	0.13414310E-03	
7.7348633	0.46926818E-06	-0.14907876E-06	0.12013256E-03	
7.9843750	0.42928601E-06	0.27780671E-06	0.10989647E-03	
8.2338867	0.39123772E-06	-0.12572344E-06	0.10015678E-03	
8.4833984	0.35737398E-06	0.43725738E-07	0.91487729E-04	
8.7329102	0.32805401E-06	0.24513908E-07	0.83981822E-04	
8.9824219	0.30137547E-06	-0.70960083E-08	0.77152120E-04	
9.2319336	0.27765416E-06	0.17176390E-07	0.71079464E-04	
9.4814453	0.25637675E-06	0.64292170E-08	0.65632449E-04	
9.7309570	0.23716733E-06	0.62185576E-08	0.60714816E-04	
9.9804688	0.21985812E-06	0.76211606E-08	0.56283677E-04	
10.2299805	0.20418372E-06	0.54281440E-08	0.52271033E-04	
10.4794922	0.18996154E-06	0.54588893E-08	0.48630154E-04	
10.7290039	0.17703224E-06	0.49710811E-08	0.45320252E-04	
10.9785156	0.16524732E-06	0.44039091E-08	0.42303313E-04	
11.2280273	0.15448510E-06	0.41161259E-08	0.39548185E-04	
11.4775391	0.14463677E-06	0.37408759E-08	0.37027012E-04	
11.7270508	0.13560701E-06	0.34313126E-08	0.34715395E-04	
11.9765625	0.12731284E-06	0.31632093E-08	0.32592087E-04	
12.2260742	0.11968074E-06	0.29078780E-08	0.30638268E-04	
12.4755859	0.11264595E-06	0.26841539E-08	0.28837364E-04	
12.7250977	0.10615121E-06	0.24803199E-08	0.27174708E-04	
12.9746094	0.10014564E-06	0.22947453E-08	0.25637284E-04	

13.2241211	0.94584064E-07	0.21270008E-08	0.24213520E-04
13.4736328	0.89426189E-07	0.19739401E-08	0.22893104E-04
13.7231445	0.84636039E-07	0.18344614E-08	0.21666876E-04
13.9726563	0.80181417E-07	0.17071384E-08	0.20526443E-04
14.2221680	0.76033449E-07	0.15906254E-08	0.19464563E-04
14.4716797	0.72166193E-07	0.14839074E-08	0.18474545E-04
14.7211914	0.68556293E-07	0.13859902E-08	0.17550411E-04
14.9707031	0.65182688E-07	0.12960164E-08	0.16686768E-04
15.2202148	0.62026351E-07	0.12132315E-08	0.15878746E-04
15.4697266	0.59070064E-07	0.11369527E-08	0.15121938E-04
15.7192383	0.56298720E-07	0.10665788E-08	0.14412344E-04
15.9687500	0.53696652E-07	0.10015683E-08	0.13746343E-04
16.2187617	0.51252475E-07	0.94143841E-09	0.13120633E-04
16.4677734	0.48953960E-07	0.88575678E-09	0.12532214E-04
16.7172852	0.46790409E-07	0.83413377E-09	0.11978345E-04
16.9667969	0.44752053E-07	0.78621951E-09	0.11456526E-04
17.2163086	0.42829962E-07	0.74169942E-09	0.10964470E-04
17.4658203	0.41015955E-07	0.70028865E-09	0.10500084E-04
17.7153320	0.39302535E-07	0.66173046E-09	0.10061449E-04
17.9648438	0.37682820E-07	0.62579234E-09	0.96468019E-05
18.2143555	0.36150484E-07	0.59226349E-09	0.92545239E-05
18.4638672	0.34699708E-07	0.56095280E-09	0.88831252E-05
18.7133789	0.33325130E-07	0.53168637E-09	0.85312333E-05
18.9628906	0.32021808E-07	0.50430646E-09	0.81975827E-05
19.2124023	0.30785176E-07	0.47866882E-09	0.78810051E-05
19.4619141	0.29611018E-07	0.45464184E-09	0.75804206E-05
19.7114258	0.28495432E-07	0.43210656E-09	0.72948305E-05
19.9609375	0.27434805E-07	0.41095224E-09	0.70233100E-05
20.2104492	0.26425787E-07	0.39107920E-09	0.67650015E-05
20.4599609	0.25465273E-07	0.37239523E-09	0.65191099E-05
20.7094727	0.24550376E-07	0.35481623E-09	0.62848963E-05
20.9589844	0.23678415E-07	0.33826434E-09	0.60616742E-05
21.2084961	0.22846895E-07	0.32266889E-09	0.58488050E-05
21.4580078	0.22053492E-07	0.30796385E-09	0.56456939E-05
21.7075195	0.21296042E-07	0.29408944E-09	0.54517867E-05
21.9570313	0.20572526E-07	0.28098967E-09	0.52665666E-05
22.2065430	0.19881059E-07	0.26861329E-09	0.50895510E-05
22.4560547	0.19219880E-07	0.25691306E-09	0.49202894E-05
22.7055664	0.18587345E-07	0.24584507E-09	0.47583604E-05
22.9550781	0.17981914E-07	0.23536872E-09	0.46033699E-05
23.2045898	0.17402144E-07	0.22544689E-09	0.44540488E-05
23.4541016	0.16846685E-07	0.21604379E-09	0.43127515E-05
23.7036133	0.16314272E-07	0.20712841E-09	0.41764537E-05
23.9531250	0.15803717E-07	0.19867006E-09	0.40457515E-05
24.2026367	0.15313903E-07	0.19064116E-09	0.39203592E-05
24.4521484	0.14843784E-07	0.18301548E-09	0.38000087E-05
24.7016602	0.14392374E-07	0.17576962E-09	0.36844479E-05
24.9511719	0.13958748E-07	0.16888050E-09	0.35734394E-05
25.2006836	0.13542032E-07	0.16232761E-09	0.34667602E-05
25.4501953	0.13141406E-07	0.15609148E-09	0.33642000E-05
25.6997070	0.12756096E-07	0.15015382E-09	0.32655606E-05
25.9492188	0.12385372E-07	0.14449770E-09	0.31706552E-05
26.1987305	0.12028546E-07	0.13910737E-09	0.30793077E-05
26.4482422	0.11684967E-07	0.13396782E-09	0.29943515E-05
26.6977539	0.11354022E-07	0.12906542E-09	0.29066296E-05
26.9472656	0.11035131E-07	0.12438705E-09	0.28249935E-05
27.1967773	0.10727745E-07	0.11992071E-09	0.27463027E-05
27.4462891	0.10431345E-07	0.11565453E-09	0.26704244E-05
27.6958008	0.10145441E-07	0.11157860E-09	0.25972330E-05
27.9453125	0.98695675E-08	0.10768239E-09	0.25266093E-05
28.1948242	0.96032835E-08	0.10395624E-09	0.24584406E-05

28.4443359	0.93461714E-08	0.10034205E-09	0.23426199E-05
28.6938477	0.90978355E-08	0.96980979E-10	0.23290459E-05
28.7431594	0.88578997E-08	0.93175364E-10	0.22676223E-05
29.1928711	0.86260076E-08	0.90587803E-10	0.22082579E-05
29.4423828	0.84018202E-08	0.87591477E-10	0.21508660E-05
29.6918945	0.81850159E-08	0.84719524E-10	0.20951641E-05
29.9414063	0.79752887E-08	0.81466498E-10	0.20416739E-05
30.1909180	0.77723478E-08	0.79125806E-10	0.19847210E-05
30.4404297	0.75759165E-08	0.76792520E-10	0.19344346E-05
30.6899414	0.73857315E-08	0.74361306E-10	0.18907473E-05
30.9394531	0.72015420E-08	0.72027074E-10	0.18435947E-05
31.1889648	0.70231091E-08	0.69785836E-10	0.17979160E-05
31.4384766	0.68502058E-08	0.67632362E-10	0.17536527E-05
31.6879883	0.66826146E-08	0.65563530E-10	0.17107493E-05
31.9375000	0.65201290E-08	0.63574701E-10	0.16691530E-05
32.1870117	0.63625516E-08	0.61662422E-10	0.16288132E-05
32.4365234	0.62096942E-08	0.59823073E-10	0.15896117E-05
32.6860352	0.60613770E-08	0.58053958E-10	0.15517125E-05
32.9355469	0.59174284E-08	0.56351068E-10	0.15148617E-05
33.1850586	0.57776844E-08	0.54712140E-10	0.14790872E-05
33.4345703	0.56419883E-08	0.53133917E-10	0.14443490E-05
33.6840820	0.55101902E-08	0.51613884E-10	0.14106087E-05
33.9335938	0.53821468E-08	0.50144736E-10	0.13778296E-05
34.1831055	0.52577212E-08	0.48738630E-10	0.13459766E-05
34.4326172	0.51367821E-08	0.47378563E-10	0.13150162E-05
34.6821289	0.50194203E-08	0.46067435E-10	0.12849162E-05
34.9316406	0.49048664E-08	0.44802944E-10	0.12556458E-05
35.1811523	0.47936544E-08	0.43583456E-10	0.12271755E-05
35.4306641	0.46854576E-08	0.42406421E-10	0.11994771E-05
35.6801758	0.45801701E-08	0.41271090E-10	0.11725235E-05
35.9296875	0.44776905E-08	0.40174934E-10	0.11462788E-05
36.1791992	0.43779214E-08	0.39116740E-10	0.11207479E-05
36.4287109	0.42807696E-08	0.38094692E-10	0.10958770E-05
36.6782227	0.41861455E-08	0.37107802E-10	0.10716533E-05
36.9277344	0.40939631E-08	0.36154231E-10	0.10480546E-05
37.1772461	0.40041398E-08	0.35232754E-10	0.10250598E-05
37.4267578	0.39165962E-08	0.34342406E-10	0.10026486E-05
37.6762695	0.38312562E-08	0.33481406E-10	0.98080159E-06
37.9257813	0.37480465E-08	0.32644230E-10	0.95949991E-06
38.1752930	0.36668968E-08	0.31844367E-10	0.93872558E-06
38.4248047	0.35877393E-08	0.31065797E-10	0.91846125E-06
38.6743164	0.35105088E-08	0.30312684E-10	0.89869025E-06
38.9238281	0.34351428E-08	0.29584026E-10	0.87939655E-06
39.1733398	0.33615809E-08	0.28879002E-10	0.86056470E-06
39.4228516	0.32897650E-08	0.28196158E-10	0.84217985E-06
39.6723633	0.32196394E-08	0.27535649E-10	0.82422768E-06
39.9218750	0.31511500E-08	0.26895869E-10	0.80669441E-06
40.1713867	0.30842451E-08	0.26276371E-10	0.78956675E-06
40.4208984	0.30188747E-08	0.25676273E-10	0.77283193E-06
40.6704102	0.29549906E-08	0.25095078E-10	0.75647759E-06
40.9199219	0.28925463E-08	0.24532048E-10	0.74049185E-06
41.1694336	0.28314971E-08	0.23986308E-10	0.72486324E-06
41.4189453	0.27717996E-08	0.23457607E-10	0.70958070E-06
41.6684570	0.27134123E-08	0.22945133E-10	0.69461354E-06
41.9179688	0.26562948E-08	0.22448266E-10	0.68001147E-06
42.1674805	0.26004084E-08	0.21966771E-10	0.66570454E-06
42.4169922	0.25457154E-08	0.21499837E-10	0.65170315E-06
42.6665039	0.24921797E-08	0.21046970E-10	0.63799801E-06
42.9160156	0.24397663E-08	0.20607848E-10	0.62458017E-06
43.1655273	0.23884413E-08	0.20182148E-10	0.61144096E-06
43.4150391	0.23381720E-08	0.19768656E-10	0.59857202E-06

ORIGINAL LIST OF FOOD COUNCIL

43.664550H	0.27889268E-0H	0.19367970E-10	0.58546525E-0h
43.9140625	0.22406751E-0H	0.18479226E-10	0.57161283E-0h
44.1635742	0.21933875E-0H	0.18602091E-10	0.56150719E-0h
44.4130859	0.21470351E-0H	0.18235688E-10	0.54964100E-0h
44.6625977	0.21015905E-0H	0.17880598E-10	0.53800717E-0h
44.9121094	0.20570267E-0H	0.17535751E-10	0.52659884E-0h
45.1616711	0.20133179E-0H	0.17201682E-10	0.51540438E-0h
45.4111328	0.19704388E-0H	0.16876774E-10	0.50443234E-0h
45.6606445	0.19283652E-0H	0.16560978E-10	0.49366150E-0h
45.9101563	0.18870735E-0H	0.16254933E-10	0.48309081E-0h
46.1596680	0.18465407E-0H	0.15957700E-10	0.47271443E-0h
46.4091797	0.18067445E-0H	0.15669331E-10	0.46252668E-0h
46.6586914	0.17676643E-0H	0.15389140E-10	0.45252205E-0h
46.9087031	0.17292787E-0H	0.15117227E-10	0.44269522E-0h
47.1577148	0.16915664E-0H	0.14853606E-10	0.43304100E-0h
47.4072266	0.16545093E-0H	0.14596765E-10	0.42355438E-0h
47.6567383	0.16180878E-0H	0.14348426E-10	0.41423047E-0h
47.9062500	0.15822834E-0H	0.14106549E-10	0.40506455E-0h
48.1557617	0.15470781E-0H	0.13872125E-10	0.39605201E-0h
48.4052734	0.15124546E-0H	0.13644362E-10	0.38718838E-0h
48.6547852	0.14783959E-0H	0.13423055E-10	0.37846934E-0h
48.9042969	0.14448954E-0H	0.13208655E-10	0.36989066E-0h
49.1538086	0.14119072E-0H	0.13000137E-10	0.36144824E-0h
49.4033203	0.13794457E-0H	0.12797819E-10	0.35313809E-0h
49.6528320	0.13474857E-0H	0.12601591E-10	0.34495633E-0h
49.9023438	0.13160125E-0H	0.12411054E-10	0.33689920E-0h
50.1518555	0.12850118E-0H	0.12226018E-10	0.32896301E-0h
50.4013672	0.12544695E-0H	0.12046694E-10	0.32114419E-0h
50.6508789	0.12243721E-0H	0.11872523E-10	0.31343926E-0h
50.9003906	0.11947063E-0H	0.11703534E-10	0.30584482E-0h
51.1499023	0.11654593E-0H	0.11540083E-10	0.29835757E-0h
51.3994141	0.11366183E-0H	0.11380712E-10	0.29097429E-0h
51.6489258	0.11081712E-0H	0.11226749E-10	0.28369183E-0h
51.8984375	0.10801060E-0H	0.11077339E-10	0.27650713E-0h
52.1479492	0.10524109E-0H	0.10932798E-10	0.26941719E-0h
52.3974609	0.10250747E-0H	0.10792123E-10	0.26241911E-0h
52.6469727	0.99808606E-0H	0.10656253E-10	0.25551003E-0h
52.8964844	0.97143426E-0H	0.10524556E-10	0.24868717E-0h
53.1459961	0.94510862E-0H	0.10397092E-10	0.24194781E-0h
53.3955078	0.91909879E-0H	0.10273658E-10	0.23528929E-0h
53.6450195	0.89333945E-0H	0.10154060E-10	0.22870902E-0h
53.8945313	0.86798612E-0H	0.10038620E-10	0.22220445E-0h
54.1440430	0.84286366E-0H	0.99268247E-11	0.21577310E-0h
54.3935547	0.81801771E-0H	0.98188052E-11	0.20941253E-0h
54.6430664	0.79343897E-0H	0.97144531E-11	0.20312038E-0h
54.8925781	0.76911831E-0H	0.96135315E-11	0.19689429E-0h
55.1420898	0.74504680E-0H	0.95167585E-11	0.19073198E-0h
55.3916016	0.72121569E-0H	0.94224247E-11	0.18463122E-0h
55.6411133	0.69761639E-0H	0.93320822E-11	0.17858980E-0h
55.8906250	0.67427404E-0H	0.92450461E-11	0.17260556E-0h
56.1401367	0.65107968E-0H	0.91614885E-11	0.16667640E-0h
56.3896484	0.62812587E-0H	0.90800682E-11	0.16080022E-0h
56.6391602	0.60537106E-0H	0.90027677E-11	0.15497499E-0h
56.8886719	0.58280742E-0H	0.89288981E-11	0.14919870E-0h
57.1381836	0.56042724E-0H	0.88573455E-11	0.14346937E-0h
57.3876953	0.53822291E-0H	0.87888972E-11	0.13778507E-0h
57.6372070	0.51618698E-0H	0.87233446E-11	0.13214387E-0h
57.8867188	0.49431208E-0H	0.86609600E-11	0.12654389E-0h
58.1362305	0.47259096E-0H	0.86012799E-11	0.12098329E-0h
58.3857422	0.45101649E-0H	0.85445237E-11	0.11546022E-0h
58.6352539	0.42958161E-0H	0.84902205E-11	0.10997289E-0h

58.8847656	0.40827436E-09	0.84386629E-11	0.10451952E-06
59.1342773	0.38710288E-09	0.83411019E-11	0.99098317E-07
59.3837891	0.36604539E-09	0.83440228E-11	0.93707619E-07
59.6333008	0.34510016E-09	0.83009664E-11	0.88345641E-07
59.8828175	0.32426059E-09	0.82604690E-11	0.83010710E-07
60.1323242	0.30352009E-09	0.82227739E-11	0.77701141E-07
60.3818159	0.28287217E-09	0.81870565E-11	0.72415275E-07
60.6313477	0.26211039E-09	0.81533990E-11	0.67151459E-07
60.8808594	0.24182837E-09	0.81238731E-11	0.61908067E-07
61.1303711	0.22141978E-09	0.809457090E-11	0.56681462E-07
61.3798828	0.20107832E-09	0.80701175E-11	0.51476051E-07
61.6291945	0.18079777E-09	0.80470977E-11	0.46284230E-07
61.8789063	0.16057191E-09	0.80266974E-11	0.41106412E-07
62.1284180	0.14039461E-09	0.80092252E-11	0.35941020E-07
62.3779297	0.12025970E-09	0.79918849E-11	0.30786482E-07
62.6274414	0.10016107E-09	0.79807827E-11	0.25641233E-07
62.8769531	0.80042670E-10	0.79685702E-11	0.20503722E-07
63.1264648	0.60048383E-10	0.79598550E-11	0.15372384E-07
63.3759766	0.40022234E-10	0.79483007E-11	0.10245689E-07
63.6254883	0.20008119E-10	0.79474205E-11	0.51220723E-08
63.8750000	0.31054152E-13	0.79498630E-11	0.00000000E+00