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PROPOSAL FOR A SATELLITE TEST OF THE CORIOLIS PREDICTION OF GENERAL RELATIVITY*

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PROPOSAL FOR A SATELLITE TEST OF THE CORIOLIS PREDICTIONS OF GENERAL RELATIVITY[a]

Abstract

A technique is proposed to use the gyroscopic stability of a spinning artificial satellite to measure the apparent Coriolis force (Lense–Thirring effect) predicted by general relativity. It is established that the primary satellite ought to be shielded from atmospheric buffeting by a secondary or tender satellite that would accompany the primary test vehicle.

Other perturbations considered are interaction with the magnetic field of the earth, and interaction of any gravitational quadrupole moment of the satellite with the gradient of the earth's gravitational field. These interactions are sufficiently small that design of a vehicle to avoid excessive interaction should be possible.

The spinning shielded satellite technique proposed here could make possible a rather accurate measurement of the curvature of space near the earth. This curvature manifests itself in a precession of the spin (the de Sitter–Fokker effect), which is about a factor of 12 larger than the Lense–Thirring effect and thus could provide a logical first step for such a program.

Development of the exterior, or tender, satellite alone would offer a number of subsidiary advantages. It could be used with a dummy interior satellite ot obtain drag-free trajectories and thus provide a very accurate tool to study air drag, as well as gravitation and geodetics. By using an interior satellite with very different nuclear composition the tender could be used to establish the equivalence of gravitational and inertial mass to greater accuracy.

WSEG RESEARCH MEMORANDUM NO. 11 PROPOSAL FOR A SATELLITE TEST OF THE CORIOLIS PREDICTION OF GENERAL RELATIVITY

Introduction

1. The purpose of this proposal is to call attention to the fact that the development of satellite technology will soon allow an experimental verification of the "induced Coriolis force," or Lense–Thirring effect predicted by general relativity. In discussing this prediction for the theory, Einstein remarked that the magnitude of this effect (which amounts to about 2×10^{-6} radians per year near the surface of the earth) "is so small that confirmation by laboratory experiments is not to

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be thought of." However, artificial satellites can provide an almost force-free environment that cannot be approached in surface laboratories. This new environment makes the experimental confirmation of the prediction a distinct possibility.

2. Conceptually, the experiment can be described very simply. A satellite is launched into a nearly circular polar orbit which is high enough to be almost free of the earth's atmosphere, but close enough to the earth that induced Coriolis forces will not be too strongly attenuated. The satellite is then given a large angular momentum or spin about an axis nearly perpendicular to the plane of the orbit. The direction of this axis of angular momentum relative to the fixed stars is accurately determined and recorded for a period of a year or more. Neglecting minor perturbations, the prediction of classical physics is that this angular momentum axis will not rotate relative to the fixed stars. However, relativity predicts a well-defined rotation or precession of this axis in the direction of rotation of the earth. In effect, space itself near the earth should appear to rotate very slowly with the earth.

3. If, on the other hand, the satellite is launched again in a polar orbit but with its spin axis in the plane of the orbit and parallel to the spin axis of the earth, then the Lense–Thirring effect on the orientation of the spin axis should vanish, and another relativistic effect known as the de Sitter–Fokker effect should be observed.[b]

4. This second effect which appears to be a factor of twelve larger than the first is a result of the curvature of space near a massive object. As a consequence of this curvature, a vector, such as the angular momentum vector when displaced parallel to itself around a Schwartzschild field, will be found to be no longer parallel to its initial orientation ofter the circu is complete.

Measurement of Orientation

5. In order to get useful results from the experiment it is essential to have a technique for measuring very accurately the orientation of the spin axis with respect to the distant stars. It seems likely that a number of ways for accomplishing this could be devised. However the following very simple method is offered to demonstrate that the problem of measurement in the experiment is basically solvable.

6. A telescope is mounted in the satellite looking along the angular momentum axis. As the satellite spins, each star in the field of view traces a circle on the recording apparatus. The totality of circles thus generated provides a characteristic signature indicating with high accuracy the exact orientation of the angular momentum axis. The resolution angle α of a 25 cm telescope using visible light is given by

$$\alpha = 1.22 \frac{\lambda}{D} = \frac{1.22 \times 5.5 \times 10^{-5}}{25} = 2.7 \times 10^{-6}$$

[b]The author is grateful to Prof. P. G. Bergmann for calling his attention to the importance of this effect in the experiment.

However, with good optics it is normally not difficult to measure differences in angle equal to about one third the nominal resolution. The de Sitter–Fokker effect at the end of one month is about equal to the telescope resolution so a measurable effect should be available in two weeks. As the duration of the experiment increases the percentage accuracy should increase so that theoretically at the end of one year an answer could be available to 5 per cent accuracy. However, improvements in measuring technique or a larger telescope could reduce this time.

7. It is worth noting that this method of determining the spin axis does not require that the spin axis be aligned with the telescope axis with high accuracy. It is only required that the spin axis be included in the field of view of the telescope.

8. There remain, of course, a number of difficult engineering problems. The telescope must be focused, and the image must be recorded and transmitted. However, it is too early to become deeply involved in the engineering problems of the experiment.

Significance of Experiment

9. Quite aside from the implications to any particular theory, the history of science has demonstrated that when experiments are conducted which either open new fields, or greatly increase accuracy in old familiar fields, the chance of learning things new and basic is very great. The experiment proposed here represents an improvement of about a factor of 10^3 in the determination of the locally non-rotating frame of reference near the earth. It also provides a first feasible technique to measure the curvature of space near the earth.

10. Actually some implications of the curvature of space near massive objects have already been observed. The bending of light near the sun and the precession of the perihelion of mercury have botah been determined experimentally to an accuracy that requires this curvature or some equivalent effect in the theory to account for the observations.

11. However, the experiment proposed here offers an independent confirmation at this effect and should provide higher accuracy than was obtained in the previous experiments.

12. However, no implication of the rotation of space near a heavy rotating massive object has ever been observed. Thus, the measurement of this rotation (the Lense–Thirring effect) could be of crucial theoretical importance to the theory of relativity.

13. While the curvature of space or the equivalent of it is contained in almost any theory that can patch up the apparent internal inconsistencies of special relativity, the rotation effect is a higher order prediction of relativity and alternative theories making different predictions for this effect are still experimentally allowed.

14. Yilmaz has recently exhibited several alternative formulations of relativity which predict the three classical experiments and appear to preserve general covariance but do not predict the Lense–Thirring effect or predict it in lesser degree.

(Phys. Rev. III, 1417 (1958)). At the 1959 New York meeting of the American Physical Society, he suggested a hypothetical test of these predictions using the orbit of a satellite appear feasible as a definitive test because of the extremely large magnitude of perturbations that are not accurately known, such as the quadrupole and higher order moments of the earth's gravitational field. However, the spin of a satellite is much less influenced by such effects and may provide a feasible technique for the experiment.

15. The origin of the different predictions is fundamental in our understanding of physical laws. When Einstein devised his General Theory, he was forced by the evidence of the Michaelson Moreley experiment to construct the theory in such a way that physical laws were invariant to a translation of coordinates. On the basis of mathematical simplicity, and as a logical generalization of this invariance, he also assumed that the laws should be independent of a *rotation* of coordinates and in fact any other coordinate transformation. This latter assumption is deeply embedded in the structure of the theory and represents an additional departure from classical theory not specifically required by the experimental evidence.

16. Once this postulate is accepted, rotation has meaning only when defined *relative* to other massive bodies. Consequently, a spinning satellite will measure its rotation relative to both the earth and the distant stars; i.e., both will contribute to the determination of a "non-rotating" angular momentum axis. To the extent that the earth contributes to this determination, the local "non-rotating axis" will actually rotate relative to the distant stars. Thus the Coriolis prediction in a qualitative way follows directly from the basic assumptions of the theory. (On the other hand, the formal mathematics of the theory appears to be consistent with the existence of a "preferred" or non-rotating coordinate system, which can be imposed through boundary conditions at infinity.)

17. The practical significance of the theory of relativity in the field of physics is much greater than would be implied by the very small size of the physical effects it predicts for microscopic objects of limited size. The predictions of relativity become crucial in the interpretation of cosmological problems. Moreover, the structure of relativity provides a powerful guide in the selection of new theories concerning the basic structure of matter. Consequently, it is very important that the theory of relativity itself be provided with as rigorous an experimental foundation as is possible.

Feasibility of the Experiment

18. Aside from data collection, the prime requirement for feasibility of the experiment is that the external torques acting about the center of mass of the satellite with a component *perpendicular* to the spin axis must be very small. The following three interactions appear to be the most important factors that might contribute to a change in the diction of the angular momentum axis:

(a) The earth's atmosphere acting through the translation of the satellite to produce torques with a component perpendicular to the spin.

(b) The gradient of the gravitational field interacting with the mass moments of the satellite.

(c) The magnetic field of the earth interacting with electric currents on or in the satellite or with any magnetization of the satellite.

19. The relative importance of these effects depends in large degree on the specific for of the experiment that is to be selected. The final choice of an experiment (involving actual selection of the orbit and spin axis; the mass, volume and moments of inertia for the satellite; and the external shield and internal stabilization mechanism (if any); together with recording and telemetering techniques) will depend on a large number of specific harware considerations that cannot be discussed now. Consequently, one cannot attempt to calculate perturbations on a realistic basis. However, to provide a basis for the discussion we will consider a specific idealized version of the experiment.

20. Table I summarizes the parameters assumed for these calculations.

21. The satellite mass and radius were selected to be consistent with a reasonable launching capability. The moment of inertia, $1/2mr^2$, falls between the moments for a hollow or solid sphere. The spin was chosen to give a maximum internal acceleration not exceeding 10 G.

22. With appropriate theoretical interpretation the orbit could be equatorial, polar, or intermediate; however, we will discuss only the equatorial and polar orbits because it simplifies visualization and calculations. The orbit radius is selected in round numbers to give a reasonable altitude where air drag would not be excessive. Higher altitudes might well produce significantly less interaction; however, data on air densities above 600 km are too incomplete to be very useful.

23. The Lense–Thirring precession on the surface of the earth is shown together with an estimate of the effect at the chosen orbit radius. The precession of 6×10^{-14} rad/s corresponds to an applied "torque" on the satellite discussed here of 1.0×10^{-10} N · m. This pseudo-torque will be compared with other actual torques that might alter the spin axis.

24. The corresponding parameters for the de Sitter–Fokker effect are also shown. However, the experimental perturbations will be compared primarily against the more stringent requirements of the Lense–Thirring effect. The requirements for the de Sitter–Fokker effect are, of couse, always about a factor of twelve less severe.

Major Atmospheric Perturbations

25. Classically, air drag at high altitudes (where mean free paths are sufficient that collective air motion can be ignored) is divided into two components:

(a) A specular reflection component in which incident particles bounce elastically like light from a mirror.

Table 1. Summary of Parameters

Mass of Statellite	
Mass of Statellite	$= 10^3$ kg $= m$
Radius of Satellite	$= 0.5$ m $= r$
Moment of Inertia	$= \frac{1}{2} mr^2 = I$
Spin	$= 14.14$ rad/s $= \omega$
Max Acceleration at Rim	$= 100$ m/s^2 $\cong 10$ **G**
Instrumentation	$=$ one telescope of 25.4 cm of diameter and associated recording and transmitting equipment

Orbit Data	
Radius of Orbit	$= 7 \times 10^6$ m
Altitude	$= 632$ km
Acceleration (g)	$= 8.15$ m/s^2
Period	$= 97$ min
Velocity	$= 7560$ m/s
Atmospheric Density	$= 10^{-15}$ g/cm^3

Relativistic Precession

Lense–Thirring Effect

$\dfrac{d\phi}{dt} = 2.7 \times 10^{-6}$ rad/year on surface of earth[a]

$\cong 2.0 \times 10^{-6}$ rad/year at orbit altitude

or 6×10^{-14} rad/s

Equivalent Torque $= I\omega \dfrac{d\phi}{dt} = 1.0 \times 10^{-10}$ N $\cdot$ m

de Sitter–Fokker Effect

$\dfrac{d\phi}{dt} = 3.3 \times 10^{-5}$ rad/year for indicated orbit[b]

or $\cong 1.0 \times 10^{-12}$ rad/s

Equivalent Torque $= I\omega \dfrac{d\phi}{dt} = 1.7 \times 10^{-9}$ N $\cdot$ m

[a] Based on a calculation by H. Yilmaz

[b] Based on a calculation by F. Pirani

(b) A thermalized component in which incident particles stop to be thermalized and then either rebound with a thermal distribution of velocities or remain attached to the surface.

26. It is clear that neither component of itself could give rise to a net torque (if we neglect the spin of he satellite). Specular reflections produce a change in momentum which is by definition perpendicular to the surface; consequently, in bouncing from a spherical surface each individual reflection results in zero net torque. For thermalizing collisions, on the other hand, while the average torque or rebound

is zero, the torque associated with the initial stopping of the incident particles is finite. If only thermalizing collisions occured this net torque for the collision would be cancelled by similar collisions on the opposite side of the satellite. However, the ratio of thermalizing to specular collisions is normally temperature dependent. Thus if one hemisphere of the satellite were warmer than the other, (as the side facing the sun almost surely would be) one would exect a number of thermalizing collisions in one hemisphere which would not be balanced by thermalizing collisions in the other hemisphere. For a satellite moving at high velocity perpendicular to its spin axis, this could result in a significant torque perpendicular to the spin axis.

27. To estimate the magnitude of this effect we consider an air density ρ of about 10^{-15} g/cm^3 at 600 km. (This is just about a factor of two higher than the estimate by T. S. Stern, Physics of Fluids, 1, 165 (1958)).

28. Then the total material μ swept out by the satellite in orbit is given by

$$\mu = \rho v A = 10^{-9} \times 7560 \times \frac{\pi}{4} = 5.9 \times 10^{-6} \text{ g/s}$$

If all particles bounced elastically this would result in change of velocity of

$$2v\frac{\mu}{m} = 9 \times 10^{-8} \text{ m/s}$$

which corresponds to a total drag force of 9×10^{-5} N. Of course, the direct drag is far too small to be of concern in the experiment. Even after ten years the change in orbit radius would be negligible.[c]

29. However, it is large compared to the size torques allowed. For this force to produce a torque equal to the Lense–Thirring relativistic torque of 1.0×10^{10} N · m. it is only necessary that the center of effort for the torque be displaced by $(1.0 \times 10^{-10}) \times (9 \times 10^{-5})$ or 1×10^{-7} m. An effect of this magnitude might be expected if as much as one collision in 50000 on one hemisphere was not matched by a corresponding collision on the opposite hemisphere.

30. It is, of course, possible that the temperature coefficient for thermalized vs. specular reflection could be made very low or that the temperature could be kept very uniform. However, where possible in an experiment of this type it is better to remove perturbations that might tend to throw doubt on the results.

A Technique to Minimize the Atmospheric Perturbations

31. As it turns out, it is probably not very difficult to shield the satellite from the larger atmospheric forces. Moreover, such shielding has a number of subsidiary benefits associated with other perturbations. To provide the shield, the primary experimental satellite can be encased in a larger hollow sphere or "tender" satellite

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[c]At these high altitudes the ionization is considerable and electro-magnetic contributions to drag are probably more important (especially for a slightly charged body) than the direct Newtonian collisions. However, in the calculation of torques these electro-magnetic effects do not appear to be very important.

having the center of mass. The tender satellite could be equipped with light beams or other sensing mechanism to monitor the position of the primary satellite *without* exerting significant forces or torques on the primary satellite. The use of *external* vernier rocket jet would allow minor repositioning of the tender with respect to the primary satellite so that the two would not collide during the course of the experiment.

32. Two additional advantages of the use of the "tender" are immediately apparent:

(a) It provides a shield against micro-meteorites that might otherwise defeat the experiment.

(b) it shields the satellite against the direct rays of the sun, thus allowing better temperature control and minimizing difficulties with thermal expansion.

Other advantages of the tender will become clear when we take up other perturbations.

33. There would also be a number of useful by-products from the development of a shielded satellite. Such a satellite would provide means for obtaining very accurate gravitational data since atmospheric to keep the tender in position might provide very accurate data on atmospheric drag. It is even possible that data resulting from such orbits might allow one to correct for classical perturbations in orbital-type relativistic experiments.

Remaining Atmospheric Perturbations

34. Having now disposed of the high-relative velocity of the satellite and the atmosphere by placing the satellite in a container so that the local atmosphere moves with the satellite, we now consider the remaining atmospheric perturbations. These perturbations will be the result of transfer of angular momentum from the tender to the satellite wia the residual gas contained in the tender.

35. Again using a density of 10^{-5} g/cm^3 the total net torque resulting from this effect assuming the worst situation with 100 per cent thermalizing collisions is about 1×10^{-9} N · m. This torque is about ten times the Lense–Thirring relativistic effect. However, it should have no net effect on the experiment because the torque involved has no component perpendicular to the spin. One practical problem in the design of the tender will be to provide an adequate opening to the outside (probably out the back of the rocket) to allow sufficient "pumping speed" to maintain the good vacuum in the tender, despite outgassing problems, and nevertheless keep the primary satellite shielded from high-velocity molecules outside the tender. On the other hand, it is possible that the speed of the tender could be utilized as a vacuum pump to attain an even better vacuum in the satellite than exists in the exterior atmosphere.

36. We turn now to a consideration of other perturbations that might influence a shielded satellite.

The Gravitational Perturbation

37. As we noted earlier, the interaction of the gravitational gradient with the mass moments of the satellite can priduce torques that would alter the angular momentum axis. Of course, if the satellite were perfectly spherical the quadrupele and all higher order moments would vanish and there would be no perturbation. To estimate the magnitude of the effect, however, let us assume that a small mass ring (total mass ℓ) is placed on the equator of the satellite in addition to the intrinsic mass of the spherical satellite. (In some concepts such a ring might be considered desid=rable as a technique to fix the principal axis and stabilize the angular momentum axis in the body of the satellite.) If we let θ represent the angle between the axis of the mass ring and the gravitational gradient, then the torque produced will be given by:

$$\text{Torque} = \frac{4}{\pi} \left(\frac{\ell}{1g} \right) \frac{r}{R} \sin\theta \cos\theta$$

Thus, if the resulting precession is to be small compared to the Lense–Thirring relativistic effect, we have the requirement that

$$\frac{\ell}{m} \sin\theta \cos\theta \ll \frac{1.0 \times 10^{-10}}{3.7 \times 10^{-4}} = 0.27 \times 10^{-6}.$$

Consequently, if no restriction is placed on θ we have the requirement that

$$\ell \ll 0.4 \text{ g}$$

38. However, the limitation may not be so severe. For instance, in polar orbit, if the spin axis is always perpendicular to the plane of the orbit, the value of $\sin\theta \cos\theta$ is zero. Of course, any error in the initial alignment of the spin angle would result in some net torque, but this effect should be easily calculable, to the accuracy that the satellite moments are known.

39. Fortunately, it should be possible to measure the ratio of the satellite's moments of inertia very accurately in flight. It is only necessary to record with the telescope the period of the classical precession of the spin axis in the body of the satellite. Once the period is known, classical corrections for the gravitational interaction of the moments with the earth's gravitational field should be possible with high accuracy.

40. There is, of course, no essential reason for using an intentionally nonspherical satellite. It is probable that the drift of the rotation axis in the body of a spherical satellite would be so slight that it would not interfere with measurements. Indeed, in a truly spherical satellite the drift rate is zero. However, any irregularities in the body resulting from uneven temperatures or other causes would define a new major axis, so that in practice some drift would exist even if it were almost vanishingly small. This problem is, of curse, considerably simplified by the use of the tender satellite to stabilize temperatures and shield from the direct rays of the sun.

41. One strategy to overcome any drift would be to use a number of adjustable moment-shims that would allow one to define the major axis at will. These shims

could then be used toward the end of the experiment to realign the spin axis in the body of the satellite.

The Magnetic Perturbations

42. The magnetic field of the earth can interact with magnetic moments of the satellite. Such magnetic moments might result from induced currents in the satellite, electronic current loops in the instrumentation of the satellite, magnetization of materials in the satellite, or rotation of the satellite as a charged sphere.

43. It is clear that the use of ferro-magnetic materials in the satellite must be avoided, and that other materials should be as non-magnetic as possible. However, if these precautions are followed on would not expect serious trouble from magnetic materials.

44. Any electrical circus in the satellite should be designed to minimize the effective area of D. C. current loops. Indeed, where possible the circus should be turned off during the course of the experiment. To estimate the magnitude of these interactions conside a current loop around the equator of the satellite. The resulting torque τ is given by

$$\tau = I\vec{B} \times \vec{A} = 4 \times 10^{-5} \times \frac{\pi}{4}I = 3.2 \times 10^{-5}I$$

Thus, if the resulting torque is to be less than 1×10^{-10} the current in such a loop would have to average less than 0.3×10^{-5} A or alternatively, a one-ampère circu would have to be restrictd to an effective area of less than 0.03 cm. Of course, it is the component of the circu area-vector parallel to the spin axis that counts. The component of area perpendicular to the spin axis does not result in a net torque unless the current is very large.

45. Probably induced currents in the satellite resulting from rotation in the earth's magnetic field will be one of the more serious problems. The forces resulting from these currents can be made to vanish either by making the satellite a perfect conductor or a perfect insulator. Barring major breakthroughs in superconductors, the latter alternative appears the easiest to approximate.

46. To get a feeling for the size of effects one can expect from induced currents, let us consider a conducting loop on the surface of the satellite that passes through both poles. The induced voltage in such a loop is given by $E = d(\vec{B} \cdot \vec{A})/dt$ or $E = \omega BA \cos\theta = 4.4 \times 10^{-4}$ V. Thus, if the resistance of the loop were less than 50 Ω, the torque would exceed the Lense–Thirring relativistic "torque".

47. However, in any proposed experiment, most of the torque so generated would primarily be directed toward slowing the rotation. Because of time integration over spin and orbit, the net effect perpendicular to the spin axis will tend to be quite small.

48. In addition, one must avoid large conducting bodies in the satellite. The use of laminated and high resistance components is desirable. Probably even the telescope mirrors should be laminated. This is illustrated by fact that the maximum

torque resulting from a solid rectangular piece of material is given approximately by

$$\tau \cong \omega B^2 \frac{V}{\rho} W^2 \, .$$

where V is volume of the material, ρ is the resistivity, and W is the width or second largest dimension of the rectangle. For example, a copper bar 2 cm × 1 cm × 1 cm would produce a torque just about equal to the relativistic torque. It is clearly advantageous keep W as small as possible. Again, the tender can simplify the problem by making it possible to put all or almost all electronic equipment in the tender.

49. A negligible torque will result from the rotation of the satellite even if one assumes it to be charged to about 12 Volt (which seems very unlikely in a shielded satellite). The total charge on such a satellite is about 3×10^{-9} C.

Thus, with a rotation about 2.3 cycles per second, the total "current" is less than 10^{-8} A. This is a factor of 10^{-3} smaller than would be required for a serious perturbation.

Useful By-Products of the Experiment

50. Development of the technique required to use the tender satellite concept would also open the door to a number of other useful experiments which will be mentioned briefly.

51. The fact that the interior satellite is almost completely shielded from external forces implies that the trajectory of the entire satellite will be essentially a pure geodesic without any atomspheric perturbation. The trajectory, therefore, might be useful to improve international geodetic data. A modified version to provide higher sustained thrust for the tender could be used to investigate gravitational anomalies at low altitudes where air drag would usually preclude such measurements entirely.

52. On the other hand, if a technique can be developed to monitor the total thrust required to maintain the tender in position, then this information might be useful to provide a minute-by-minute evaluation of the drag on the tender.

53. If such a satellite and tender were constructed using very different materials having different "packing fractions" (such as copper vs. beryllium) then the technique could be used to provide a check of the equivalence of gravitational and inertial mass. For this purpose it would probably be good to use a high orbit where the air drag is exceptionally low.

54. The accuracy obtainable in this experiment depends entirely on the accuracy of the tender sensing and control mechanism. For instance, discrepancy of one part in 10^6 in the ratio for inertial to gravitational mass would result in a seven meter difference in the radius for a stable orbit. If instrumentation were accurate enough to permit detection of a 7 cm difference in radius then a discrepancy of one part in 10^8 might be observable.

Summary

55. Assuming no major interactions have been ignored, it appears that there is no single perturbation of such magnitude that it would make the experiment non-feasible. The physical design of a satellite to avoid all interactions with the desired level of confidence may be difficult, but can probably be done within a few years. Considerable work should be done both to improve the theoretical understanding of the relativistic problem and to determine more accurately the size of the classical interactions and the difficulties of practical design within the limitations imposed.

56. A reasonable program to investigate the relativistic effects would probably begin by checking out techniques in the simpler classical gravitation and inertial mass could probably be carried out in the process of checking out the gyroscopic techniques. The first real gyroscopic experiment should probably be measurement of the large de Sitter–Fokker effect. Measurement of the Lense–Thirring effect, while of greater interest, should probably be postponed until all techniques are fully established.

57. The experiments is an important one which appears to be within the responsibilities of the NASA. It would be, in the most literal sense a direct measurement of space itself.

Acknowledgments