

a report on the NASA Conference on

EXPERIMENTAL TESTS OF THEORIES OF RELATIVITY

By L. I. Schiff

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A CONFERENCE on experimental tests of theories of relativity, sponsored by the National Aeronautics and Space Administration, was held at Stanford University on July 20 and 21, 1961. The chairman of the conference was the late H. P. Robertson* (California Institute of Technology), and local arrangements were managed by R. T. Jones (NASA). About 35 scientists attended, representing half as many different institutions. The group was small enough so that all sessions could be handled quite informally. Only six papers were prepared in advance, and most of those present participated in discussion of these and related matters.

In his introductory remarks, Robertson stated that NASA had asked that a conference be held by those interested in the possible uses of satellites and rockets for testing theories of relativity, in order that NASA might be advised on the value of various proposals. He expressed the opinion that, with present techniques, tests of the special theory of relativity could best be performed on the surface of the earth, and that rockets would be more useful for tests of the general theory of relativity and other possible theories of gravitation. He then reviewed the present experimental basis of general relativity: the red shift follows from more elementary considerations and is not really a test of general relativity, and the deflection of light by the sun has not been measured with great precision; only the precession of the perihelion of the orbit of the planet Mercury provides an accurate test of Einstein's theory, and fortunately this includes the lowest-order nonlinearity.

The first paper was given by R. V. Pound (Harvard), who described his now-famous terrestrial experiments which measured the gravitational shift of Mössbauer radiation. For the available vertical height of 70 ft, the fractional shift is 2.3×10^{-15} in each direction, whereas the fractional line width is about 10^{-12} . In spite of this disparity, the ratio of the observed to the theoretically expected shift now stands at 0.97 ± 0.035 . He remarked

that the cost of the entire series of experiments was about one percent of that of the fuel for a single large rocket; but he hopes to improve the accuracy by an order of magnitude without interfering with the satellite program.

In the discussion, O. H. L. Heckmann (Universities of California and Hamburg) said that solar red-shift measurements cannot be expected to be reliable for the present because of large violet shifts from granulations. On the other hand, terrestrial observations of 40 Eridani B and Sirius B are improving, and satellite observations, both of the red shifts from these stars and of the solar deflection of starlight, offer great promise. J. G. King (Massachusetts Institute of Technology) reviewed the studies that had been made of a possible satellite measurement of the combined gravitational and Doppler shifts. This work stopped about a year ago, and his group has no plans to propose a satellite experiment. N. G. Roman (NASA) mentioned the status of the similar experiments considered by Hughes Aircraft and the National Bureau of Standards, and stated that neither of these is now being funded by NASA. There was general agreement with Robertson's conclusion that a satellite effort is not worth while for this experiment.

R. H. Dicke (Princeton) described various ways in which current ideas about gravitation, which are based on Einstein's theory, might be modified. He stressed the importance of null experiments, such as those of Eötvös on the equivalence of gravitational and inertial mass, which are now being improved at Princeton. He then referred to Dirac's cosmology, with its possible connection between the values of natural "constants" and the age of the universe. A possible new theory, similar to one proposed by Jordan, would replace the Newtonian gravitational "constant" by a scalar field that would depend on the proximity of matter. Some of the predictions made by these theories might be subject to experimental test, although numerical estimates of the effects to be expected cannot be made with definiteness, since the theoretical parameters are

* See page 90 of this issue.

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not determined in advance. In the discussion, W. A. Fowler (California Institute of Technology) and Heckmann questioned some of the estimates that had been used for the age of the universe; no conclusion was reached on the connection between the theoretical parameters and existing cosmological observations.

J. Siry (Goddard Space Flight Center), who gave the third paper, described the minitrack (radio) and optical methods for tracking satellites. The optical system has errors of about 7" of arc along the track, and about 2" at right angles. The minitrack system can be of comparable accuracy when freshly calibrated, and in addition gives altitude errors of a few hundred meters and radial-velocity errors of about 10 cm/sec. C. W. Sherwin (Aerospace Corp.) suggested in the discussion that the motion of a satellite be slaved to a freely falling test object so that the latter is always at the center of the satellite. In principle, this test object could be free of all forces except that arising from the gravitational field of the earth, moon, etc. The satellite would then be constrained to follow its motion, and at the same time would protect it from environmental disturbances such as radiation and atmospheric gas. The trajectory of such a slaved satellite would be truly representative of the gravitational field, and might supply very high quality information from which the mass multipole moments of the earth could be computed. This concept of a slaved satellite was proposed in 1959 by G. E. Pugh.

In a companion paper, J. Mitchell (NASA) described the capabilities of existing and anticipated satellite vehicles. Comparison of a typical current satellite with the OAO (orbiting astronomical observatory) of a few years hence shows an increase in weight from 100 to 1000 pounds, an increase in available electrical power from 10 to 100 watts, and the replacement of single-axis spin stabilization with 10° precision by three-axis stabilization with precision better than 1' of arc. He also emphasized, for the edification of physicists unfamiliar with the realities of satellite experimentation, that conditions are radically different from those that obtain in a laboratory. The experimenter is dependent on many other persons for crucial components, he must make his plans two years ahead of launching and then meet definite schedules, and he must be prepared for failure to orbit. Frustrations occur repeatedly, but the rewards of a successful shot are high.

The next paper, by L. I. Schiff (Stanford), described the predictions of the Einstein theory with regard to the motion of the spin axis of a gyroscope that is either at rest in an earth-bound laboratory, or in a free-fall orbit about the earth. In either case, the Newtonian theory predicts no precession of the spin axis if the gyroscope is spherically symmetric. General relativity theory, however, predicts both the geodetic precession arising from motion through the earth's gravitational field, and the Lense-Thirring precession that represents the difference between the gravitational field of the rotating and the nonrotating earth. If the gyroscope is at rest with respect to the earth, it is carried around

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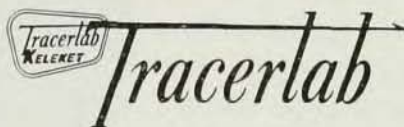
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the earth once a day by the rotation of the earth, and its weight must also be supported by a nongravitational force; the latter gives rise to an additional Thomas (special-relativistic) precession. In this case, all three terms are of the same order of magnitude, and the total precession is about 0.4" of arc per year. If the gyroscope is in a satellite at moderate altitude, the geodetic precession is about 7" per year, the Lense-Thirring precession is about 0.1" per year, and the Thomas precession is zero.

The discussion was devoted mainly to two possible satellite-gyroscope experiments. W. A. Little (Stanford), representing W. M. Fairbank who was unable to attend the conference, described a proposed gyroscope that consists of a superconducting sphere supported stably on a static magnetic field. The difference between the local acceleration of gravity g and the true acceleration of the satellite arises mainly from atmospheric gas and should be of the order of $10^{-7} g$ at moderate altitudes; this greatly simplifies the problem of supporting the spinning sphere. Ambient electric and magnetic fields can be greatly reduced by using a superconducting shield, and the low temperature required also decreases thermal distortion since all coefficients of thermal expansion are very small. A temperature of around 4°K can be maintained for a year by sublimation of a hundred pounds of solid hydrogen, and an additional five liters of liquid helium would keep the temperature below 1°K. The orientation of the spin axis would be observed by putting a spot of a suitable radioactive material on the sphere, and using the Mössbauer effect to align the spin axis of a synchronously rotating absorber with that of the sphere. Experiments are under way on all aspects of this system.

A different kind of extreme-precision gyroscope was described by A. Nordsieck (University of Illinois and General Motors). It consists of a conducting sphere which is supported by an electric field with the help of a feedback loop. It is in an advanced stage of development, and drift rates are now being held to less than 3×10^{-8} rad/sec when it is supported against normal earth gravity; it is expected that this can be reduced by a factor 30. (Note that 1" of arc per year is equal to 1.5×10^{-13} rad/sec.) Satellite operation at $10^{-7} g$ would certainly lower the drift rate by several orders of magnitude. Reading out the orientation of the spin axis is accomplished by an optical method; this can now be done with an accuracy of 0.2", and improvement by a factor 10 should be possible.

Discussion continued on both the superconductive and electric gyroscopes. The possibility of using a satellite slaved to the gyroscope was also mentioned; this would replace the problem of gyro support by the problems of gyro sensing and satellite control. However, it would also give the satellite a true gravitational orbit, which would be of interest for other reasons. In response to the suggestion that the general relativistic perihelion precession of such an orbit might be measured (as with Mercury), Schiff pointed out that for an

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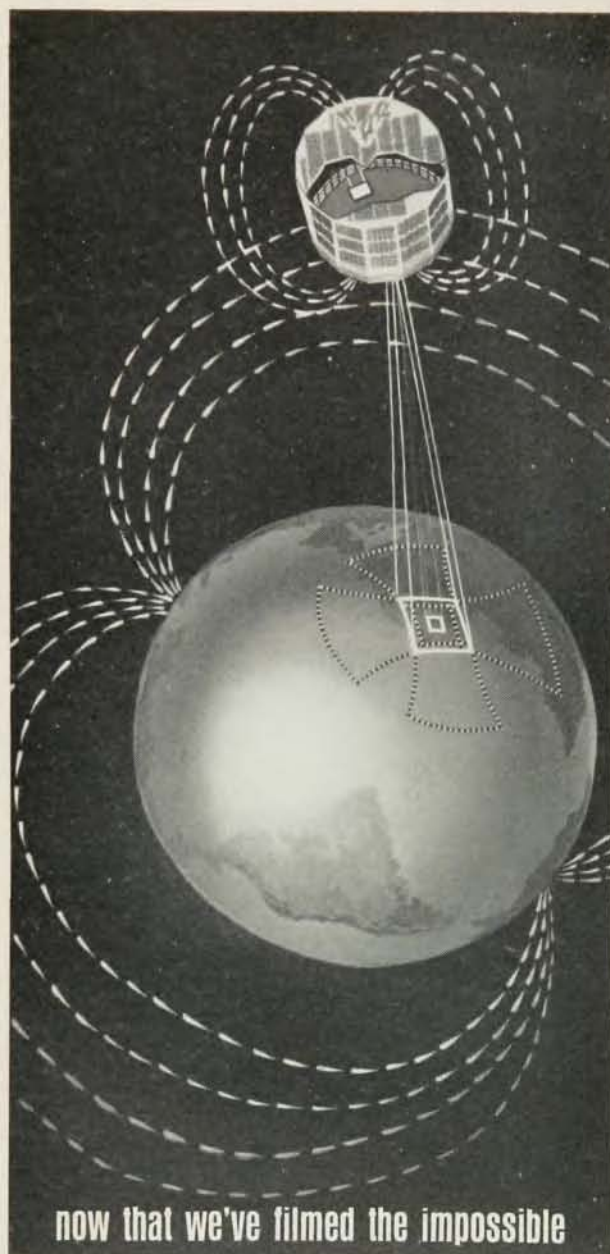
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equatorial orbit this effect is only about a millionth of the precession caused by the earth's equatorial bulge. Roman remarked that NASA would like to be kept informed of plans and progress along all three of these lines. Reservations for space aboard a satellite cannot be made until an experiment is quite certain to succeed, and then must be made a year or two in advance of launching. In response to a question, she stated that a 36-inch telescope might be in orbit by the end of 1965, and that orientations could probably be held to 0.1°.

The last paper was presented by J. Weber (University of Maryland), on the detection and production of gravitational waves. He first discussed natural receivers such as the earth and the moon. Excitation of vibration and rotation of the earth by gravitational waves from outside would be very difficult to detect because of noise arising from winds. The moon would be much better in this respect, and a moon-crust strain detector might be a useful object to send there. Laboratory detectors of gravitational waves would best be constructed of piezoelectric crystals operating in high modes; these would also make the most efficient generators of gravitational waves. Preliminary experiments on these are now under way.

Weber, Dicke, and P. G. Bergmann (Syracuse University) discussed the measurability of various components of the Riemann tensor and the need for an invariant formulation of the results of particular experiments. Bergmann also commented on the maximum radiation that could be expected from double-star systems. He felt that solutions of the Einstein equations for the radiation problem are far from complete, so that if a measurement could be made, it would have theoretical significance.

Robertson asked for general comments before concluding the conference. An apparently new experiment was proposed quite tentatively by Nordsieck. This would consist of sending a very precisely periodic source of radio signals into the sun; analysis of the record of these signals, together with knowledge of the orbit, might make it possible to measure components of the metric tensor that are known only imperfectly.

In closing, Robertson summarized those parts of the conference that are of greatest interest to NASA. There was general agreement with his conclusion that some or all of the three types of gyroscope precession experiments (superconductive, electric, slaved satellite) are promising enough to warrant encouragement by NASA. Cosmological experiments should also be kept in mind as they develop. Roman and Jones expressed appreciation on behalf of NASA for the participation of those present. NASA would like to supply vehicles that can be used for significant scientific experiments, and it hopes for further feasibility studies and, eventually, for definite proposals.

To this reviewer, the conference demonstrated the value of a short meeting of a small number of specialists to discuss a closely related group of topics that could lead to still another fruitful union of science and technology.