FACILITY FORM 602

N65-29385 (ACCESSION NUMBER) | (THRU)
22 (PAGES) | 1 (CODE)
TMX-51950 (NASA CR OR TMX OR AD NUMBER) | 07 (CATEGORY)

NASA SPACE ELECTRONICS RESEARCH

to be presented at

THE INTER-AMERICAN SYMPOSIUM ON SPACE RESEARCH

Buenos Aires, Argentina

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

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Washington, D. C.

INTER-AMERICAN Sym. on Space RESEARCH,
BUENOS AIRES, Aug. 3-7, 1964

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ABSTRACT

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Recent research in space electronics, by NASA, will be discussed under two categories: 1) Guidance and Control, and 2) Communications; Instrumentation and Data Processing. In the first category, subjects such as the cryogenic gyroscope, the electrostatic accelerometer, gravity gradient stabilization and flight simulation will be discussed. In the second category, the discussion will concern advances in astrophysical instrumentation, on board and ground data processing, laser communications and data transmission and reception.

author

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Gentlemen, this morning I would like to guide you through a description of some technical ... of NASA's ... electronics and control program, as ... in Figure 1. Included are ... guidance and control functions in accomplishing a space or aeronautical vehicle mission. ... here in diagrammatic form is the flow of information and commands in a navigation, guidance and control system.

First navigation is performed, deciding what final actions are desired, and with sensors measuring the end point and where you are, relative to each other. The guidance system, with its sensors, then determines the best path to follow to arrive at the destination. Control then keeps the vehicle on this flight path by means of actuators, acting on the vehicle. We will see examples of research and development in each of these blocks, aimed at contributing to the technology of the vehicle navigation, guidance and control for use by future space and aeronautical projects.

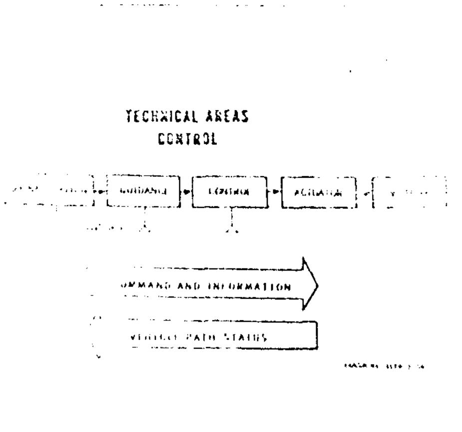

Fig. 1

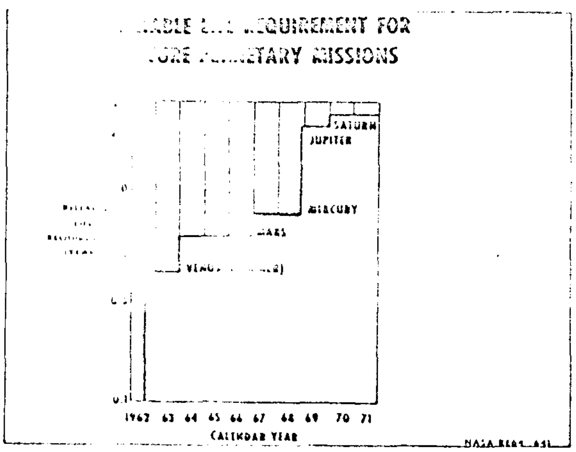

Fig. 2

Important to such research work is the establishment of technical requirements—goals, if you will—for our program efforts. How these requirements influence the emphasis on specific devices can be traced in the following sequence. First, as Figure 2 shows, the mission time demands reliable operating life of our subsystems. Shown are representative high thrust missions of the future, and the associate reliable life requirements in years. Not included of course, is the amount of confidence one must place on each of the subsystems...is it a primary system, a secondary or backup, is it manned...all of which will then determine the required reliability for the subsystem.

Both the requirements for very long life in navigation and guidance systems, and the desire to have simple backup schemes lead to consideration of manned navigation systems, illustrated in Figure 3.

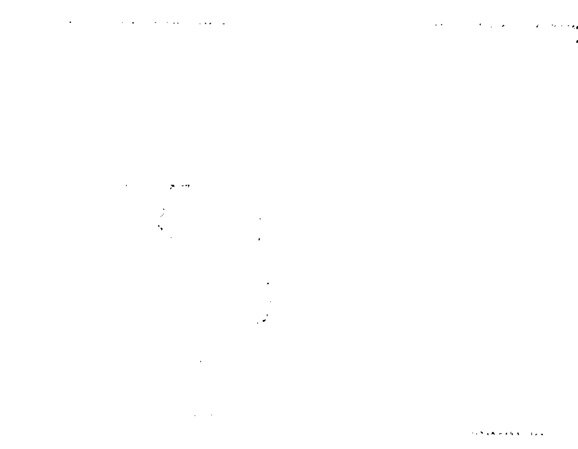

Fig. 3

Prior to the availability of an advanced space flight guidance simulation facility being developed for Ames Research Center, an interim simulator is being used effectively. The simulator consists of a [illegible] crew compartment supported on an air-bearing table to provide free [illegible] motion. The spacecraft and hand-held optical instruments are provided a planetary and [illegible], and the compartment itself is controlled by a cold gas [illegible] controlled system.

Studies with this sim[illegible] at Ames of the accuracy obtainable with crew-operated manual [illegible] tion instruments have been underway. The studies are investigating the use of both hand-held and spacecraft mounted instruments. Experienced Air Force navigators and Ames Research C[illegible] engineering personnel are participating in these studies. Results of the studies to date show that readings with hand-held backup instruments, plus a navigation table, can be obtained with [illegible] accuracies. As an example, other factors being equal, the use of a manual system as backup would degrade the Earth landing footprint area on a lunar return mission by only a factor of [illegible] compared with the use of instruments of the accuracy spec[illegible] for Apollo.

In addition to these studies, research on a variety of navigational instrument techniques is [illegible] way in-house at Ames. Devices being investigated include manually-operated sextants using advanced filters, fiber optics, and special electronics, and a photographic system in which planetary discs are photographed against the star background. Navigational measurements are ma[illegible] directly from the resulting photographs.

Mi[illegible]ion considerations also lead us to requirements fo[illegible] future gyroscope devices, Figure 4. For each of [illegible] indicated applications—a job within a mis-si[illegible] [illegible]ft rates and other requirements are derived. Shown are the principal unmet requirements in each case. For example, for capsule maneuvers, drift stability is an unmet requirement. However, achieving long life for this particular application is not a problem today. Future gyros should cer-tainly require no temperature oven control for stability. They should have no external magnetic field to interfere with other space instrumentation and should require a minimum associated com-puter capability. These requirements have led us to both research and development tasks related to the cryogenic gyro, Figure 5. Here a super-conducting sphere is supported in a vacuum by a frictionless magnetic field, and the position of the spacecraft relative to this sphere is read out optically. The superconductivity is maintained by imersing the unit in the very cold liquified gas fuel cell of the spacecraft.

FUTURE GYRO REQUIREMENTS

APPLICATION	DRIFT RATE °/hr.	OTHER PRINC[illegible]
MANEUVER ANGLE REFERENCE	0.5 to 0.1	TORQUER [illegible] STABILITY
ORBITAL REFERENCE ANGLE STORAGE	0.5	LONG LIFE
ORBITAL PLANE DETERMINATION (GYROCOMPASSING)	0.1 to 0.01	LONG LIFE
CAPSULE MANEUVERS (REENTRY, ETC.)	0.1 to 0.001	DRIFT STABILITY

GYRO SHOULD REQUIRE NO TEMPERATURE CONTROL, HAVE NO EXTERNAL MAGNETIC FIELD AND MINIMUM COMPUTER REQUIREMENTS.

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Fig. 4

Progress is shown by the very low drift rate achieved, matching the drift requirement of Figure 4, and the long run-down time constant. This time constant indicates the potential for long life, if the very serious heating problem and con-sequent loss of superconductive properties in the superconducting sphere can be solved.

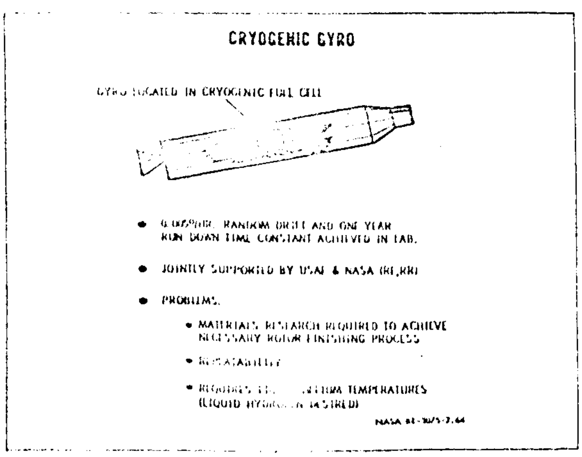

Fig. 5

Problems remaining to be solved include the rotor finishing to get an extremely smooth and accurate surface on the sphere, which promises to be a solution to the very severe heating problem; repeatability of fabrication, because of the finishing process primarily; and the fact that superconducting materials available today require liquid helium temperatures. Helium as a fuel has a specific impulse of precisely zero. We want to go to liquid hydrogen temperatures at 21° above absolute zero—this is desired and we hope to be able to make that.

Another gyroscope development aimed at the long-life medium accuracy required (Figure 4), is the laser gyro, Figure 6. In this case a four-sided laser system has light going in both directions around the ring. Please remember that light travels at a constant velocity without regard to the velocity of the medium through which it is passing. If we imagine this ring rotating, then light passing in the direction of the rotation will have to travel a longer distance and will have a longer wavelength and a lower frequency than light going in the other direction, against the rotation. If a sample of both light beams is taken out and compared by conventional microwave techniques, the angular rate is measured, and we have an angular rate sensor useful both in guidance and control.

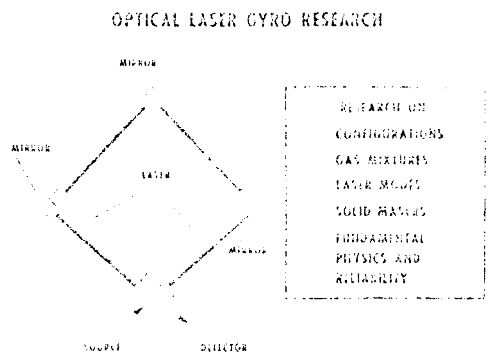

Fig. 6

The potential for long-life reliability can be seen from a complete lack of moving parts. Research is now going on at Ohio State University and at other places towards optimum configurations and optimum gas mixtures, the achievement of a single mode of oscillation within the masers, and solid state rather than gaseous masers or lasers. Even some fundamental physics is not yet understood, and of course all of it pointed towards greater reliability of this type of sensor.

Earlier trajectory studies of Mars and Venus Orbiter missions, Figure 7, using electrically propelled spacecraft, indicated the sensitivity of these trajectories to relatively small guidance errors. For example, in a 415-day Mars Orbiter mission, one-half degree error in thrust angle could result in 200,000 miles position error at the target planet. It was concluded that

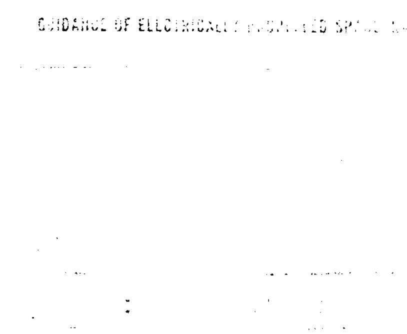
Fig. 7

repetitive trajectory determinations throughout the flight and corrective guidance maneuvers would be required for the low thrust propulsion system mission. In fact, in this repetitive mode it is rather [illegible] to distinguish between navigation and guidance. This work is currently being followed by more detailed studies of specific techniques for guidance of low thrust spacecraft trajectories, which should lead to the formulation of statistically optimal guidance procedures. In parallel with the guidance studies, are [illegible] studies directed toward the application of advanced mathematical techniques to the calculation of trajectories for vehicles having one or more low-thrust stages. This work is an extension of a major activity at MSFC on the performance of trajectory studies for high-thrust missions.

Although considerable analytical work remains to be completed, it has been recognized that sensor technology applicable to low-thrust guidance should be developed. Particularly needed, are accelerometers having sensitivities in linearities for accelerations several orders of magnitude lower than those used in current high-thrust applications. Unfortunately the lack of available manpower has precluded the initiation of requirement and specification work in this area. There is of interest, however, a procurement [illegible] of an electrostatically suspended, accelerometer developed by Bell Aerosystems for the Air Force. This accelerometer is to be used for thrust measurement of ion engines in future orbital engineering flights. This [illegible], [illegible] with suitable modifications for increased sensitivity, can give early insights into the problems of measuring low accelerations.

A research task underway at Ames, Figure 8, combines guidance and control studies aimed at solving the zero zero landing problem of the short haul commercial airliner when operating into relatively small airports not equipped with all of the paraphernalia available to today's jet transports. The concept uses rather precise on-board inertial navigation equipment, forward looking and doppler radars, and digital computer equipment in the airplane, combined with unattended, simple, accurately located radar repeaters placed near the approach end of the runway. The pilot, having complete and precise knowledge of the runway position presented to him, flies the aircraft in a pseudo-visual mode to a blind landing.

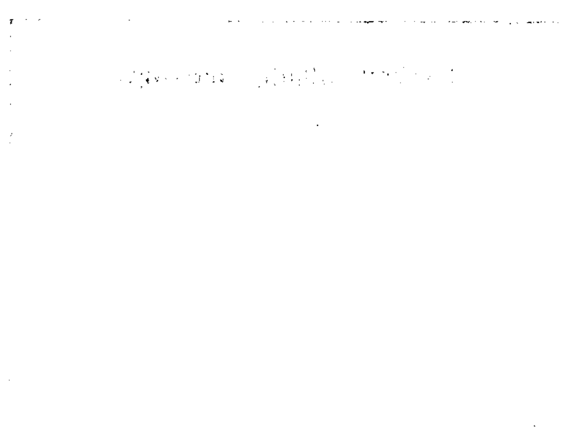

Fig. 8

System simulation results have been quite encouraging and flight tests of a representative system will be conducted soon.

The part which a pilot may play in controlling a vehicle is always of interest. If a pilot, equipped with a full set of instruments, is aboard a large space booster being sent on a space mission, what role can the pilot play in making more effective the controls in that booster? To answer this question it was postulated that a pilot could control during boost and might even perform better than a completely automatic autopilot in cases of partial failure of the electronic system.

A preliminary demonstration was mounted by Marshall scientists, using an Ames simulator at Ames, and with the aid of Ames and Flight experience in manned flight control. The demonstration showed that the pilot could control the vehicle, given properly displayed information, [illegible] could in addition reduce structural loads due to wind gusts. The Pilot must, however, be given aid from some portions of the automatic system, so he doesn't replace the autopilot, but simply makes the system as a whole more effective.

The results, Figure 9, then show that with a typical manned booster trajectory, shown here schematically, in the normal all systems "Go" mode the pilot could adapt to changing wind conditions as they develop during flight, minimizing structural loads, could guide by alternate paths during the ascent, and could materially aid in precise injection control. When malfunctions were simulated, the pilot could correct for many of these, or in case of abort, could take the safest course of action. In fact the pilot's ability to adapt to new conditions rivals that of advanced digital adaptive autopilots being developed now for booster use,

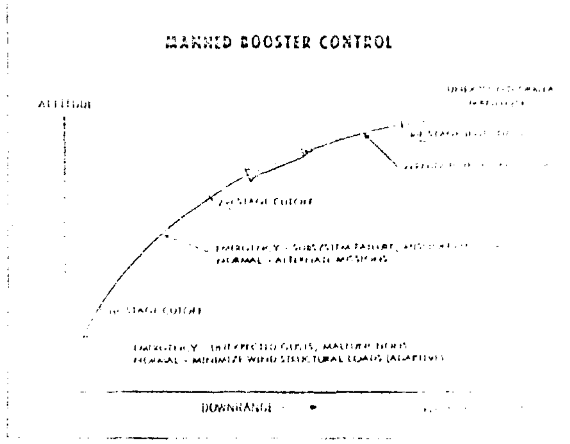

Fig. 9

The booster characteristics used in the simulation [illegible], were those of the Saturn V. It appears feasible to incorporate manned booster control in manned Saturn V launchings with very little change in the vehicle. This mode of operation is being considered by Saturn V project engineers, although much remains to be done before a decision can be made [illegible] control.

Future simulation work along these lines is planned to extend this analysis to piloted recoverable booster concepts, where pilot control may greatly simplify guidance and control equipment requirements.

Turning our attention from flight systems to some tools of the flight control investigator, Figure 10, the simulator shown is used for some related work. The interchangeable pilot enclosures—the one here is a Gemini enclosure—will house one or two men, mounted on a ten-foot diameter gimbal ring, hydraulically driven by a computer, not shown. The computer has within it the equations of motion of the simulated vehicle, and in turn is driven by the pilot's controls. Where the simulation can be done with a fixed-base simulator, where the pilot

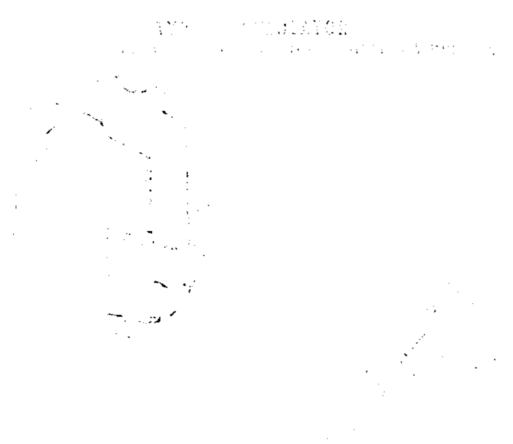

Fig. 10

does not move in correspondence with the simulated vehicle's motions, it certainly is to be preferred.

Figure 11 shows two conditions of flight: Launch and climb, and reentry, in which fixed-base simulation results were compared with X-15 flight results, the line showing satisfactory correlation. The experimental points (shaded area) show satisfactory correlation for launch and climb, but not for reentry. Because of these sorts of comparisons, reentry and other flight regimes must be simulated by moving base simulators, while launch and climb can be simulated by fixed base simulators. Our ability to judge between the complexity and cost of these two types to accomplish a specified task simulation is increasing, but is greatly dependent on the ability to measure human performance in flight control situations.

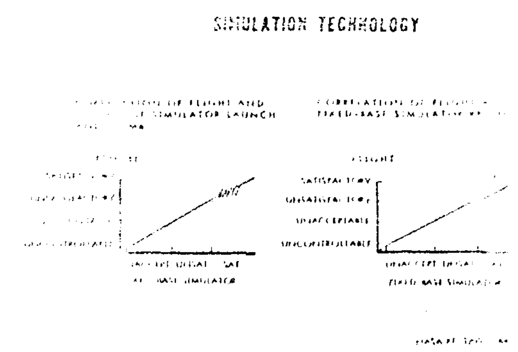

Fig. 11

Figure 12 further notes that the ability to reliably measure human performance in a flight control loop leads directly to better control systems through our ability to utilize a rational design procedure. Presently three methods are used in measuring this control system performance.

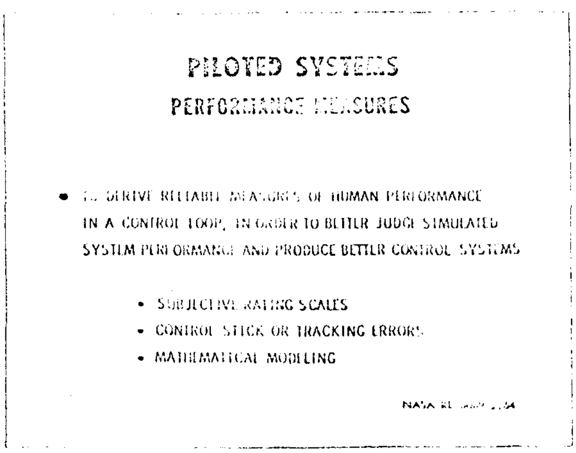

Fig. 12

The first of these, subjective rating scales, suffers from the usual difficulty with subjective scales in that the pilot is seldom able to describe objectively what he has done, but it is still quide useful for acceptability—test pilot—sorts of judgments.

Second, control stick errors are sometimes used as measures. Many parameters of the simulated flight are recorded, usually as parallel pen tracings, and an evaluation is made of the complex interrelations between such tracings. Often thirty or more are required. The important thing is the mass of data. Even with this mass of data, certain conclusions seldom can be drawn regarding the suitability of the control system design. Experienced flight control engineers can intuitively derive much information from such a record, and of course many successful vehicles are now flying based on such intuitive analyses. But the method leaves much to be desired. Measures derived from these instantaneous errors, such as integrated absolute error and RMS error, do not correlate between themselves, and an even less reliable correlation is obtained between these measures and the design being tested.

We desire instead, a rational design procedure for manned flight control systems in which the actions of the man can be predicted accurately. True, we can predict pilots' actions in the simplest cases, single axis control, linear operations, non-time variant, single task. But the real value of pilot in a flight control situation is where he is adaptive, nonlinear, making control decisions about multiple axes and multiple tasks. Mathematical models are being sought for these more complex, real cases, drawing on the extensive control theory available today in [illegible] systems, optimized systems, sampled data models, and so forth.

[illegible] the method of mathematical modeling, figure 13 shows a method used at Langley, in which a pilot is placed in a typical simulated control loop, being asked to command the vehicle according to the commands and errors fed to him through his display. If now a computer, actually a part of an adaptive autopilot, is given the same information and is driven to adapt to give the same output as the man, after the run is over the characteristics of the adaptive autopilot can be [illegible] out and are a measure of the pilot performance on this task using this control and display. Note that the autopilot is not driving the vehicle. It is simply adapting itself to null the difference between its performance and the pilot's. Extensions of this technique to multiaxis and [illegible] operations promise to yield useful models, such as sampled data models, for the design of [illegible] flight control systems, which will make the most of the immense capability of the pilot.

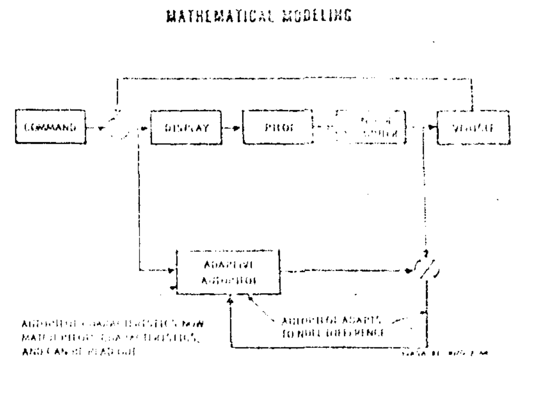

Fig. 13

Let's consider a satellite attitude control system whose very virtue is the fact that it depends on the vehicle shape rather than an overt control system. First let's look at the principle involved, Figure 14, in gravity gradient attitude stabilization. Here we have a representative spacecraft with an upper and lower end represented by the dumbbell. The lower end, because it is closer to the Earth, has a slightly higher gravity force acting on it, therefore it weighs more. The effect is to rotate the dumbbell so that the heavy end points toward the Earth. This force exists. It has been seen many times in orbit. But without a further step it would result in a pendulum action, swinging about the neutral position. Damping must be provided, and therein lies the engineering problem.

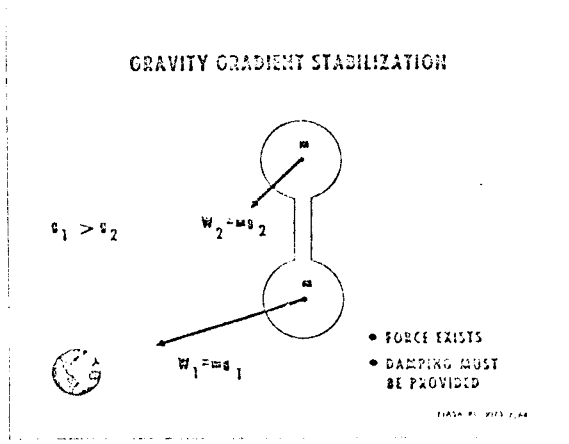

Fig. 14

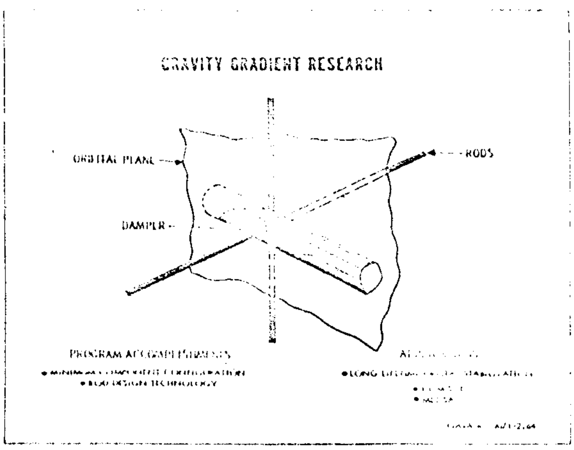

Fig. 15

Practical implementation of gravity gradient attitude control takes a form like the configuration shown in Figure 15, developed at the Ames Center, and worked on by others, in which long rods are paid out from the satellite body to increase the satellite's rotational inertia. The satellite is skewed with respect to the orbital plane so that it goes along in a skid all the time in order to cross couple the motion about the three axes. Due to this cross coupling we can use a single damper about one axis, cross coupling its damping into the other axes, making a minimum component configuration. In addition, we have been working on the technology required for these very long rods, sometimes 30 to 500 feet in length, working towards rod configuration and materials so that the rod bending due to solar heating will not materially affect the operation.

The ultimate aim is development of technology applicable to a variety of spacecraft, operation up to synchronous altitudes, and cost effective long-life stabilization for communications satellites, meteorological satellites or any other kind of satellite that needs to point towards the Earth.

Moving on to the actuators, Figure 16, which execute the commands of the guidance and control system, we have supported the development, by American Standard Radiators' Advanced Technology Laboratory, of a micro-power thrustor for mass expulsion attitude control of spacecraft which utilizes gaseous hydrogen as a propellant. This may be available from boil-off of the hydrogen system. Hydrogen under pressure is introduced into a pipe within the pressure chamber. When a control system demands it, the electrical

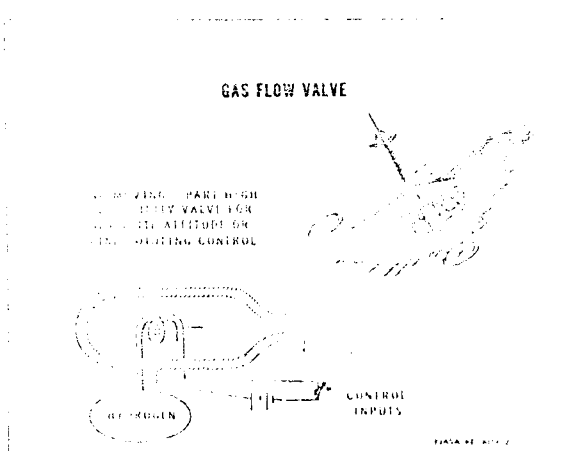

Fig. 16

system heats the pipe. The pipe is made of a peculiar metal, palladium, which when [illegible], allows the hydrogen to diffuse through the palladium [illegible] into the pressure chamber, [illegible] through th[illegible]rust nozzle, exerting attitude control on the spacecraft. Thus a no moving [illegible] valve for [illegible]itude thrust control, at least for a large, slowly perturbing orbital spac[illegible] obtain[illegible] which has a potential reliability much greater than now available.

The NASA research activities I will discuss cover the technical areas shown in Figure 1. These technical areas range from the instrumenting of the physical phenomena to the experimenter, including some discussion of the interactions of data processing with the experimenters themselves. These technical areas are: Instrumentation, On-board data processing, Transmission, Information concerning the channel itself, the Receiver and Ground-based data processing. The basic objectives of the research conducted in these technical areas is to improve the efficiency with which the experimenter gathers the required data concerning physical phenomena.

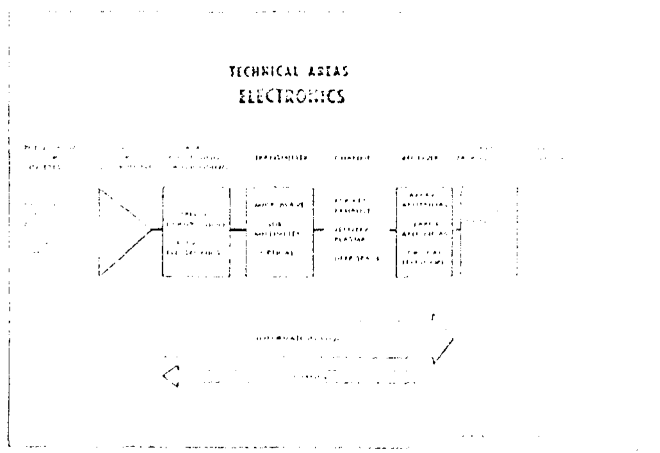

Fig. 1

I will highlight selected items from each of these technical areas to illustrate (a) the requirements we are striving to meet, (b) the existing state of technology, (c) the progress being made, (d) future prospects.

Instrumentation

The first technical area is that of the sensor or instrument, which is probably the most important in that it is the first contact with the physical phenomena of interest. The instrumentation requirements are many and diverse. However, they may be readily summarized as shown in Figure 2, the most important requirement being that of extending the sensor dynamic range and thus increasing the utility of the sensor. The requirements listed in Figure 2 apply with uniform force to the three primary instrumentation categories—astrophysical, biomedical, and engineering.

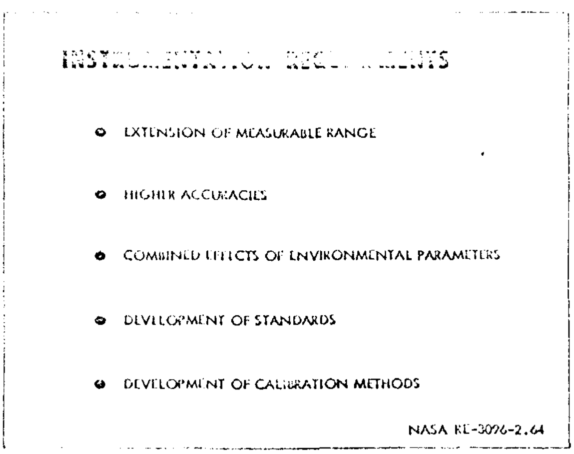

Fig. 2

In the astrophysical instrumentation area, one of the most important instruments is that of the charged particle instrument. Shown in Figure 3 are two types of charged particle instruments. Our research efforts are directed primarily toward the individual particle detection and counting approach. Previously, instruments for detecting charged particles performed a velocity or an energy filtering as shown in Figure 3, using electrical or magnetic fields and then indicating the number of particles on an average basis.

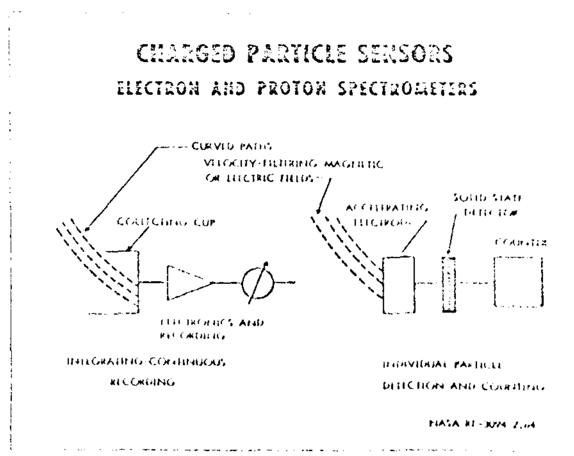

Fig. 3

Langley Research Center and Goddard Space Flight Center seek to provide resolution in the detection process so that individual particles can be detected. This approach which utilizes high-speed amplifiers shows promise of meeting the requirements of a dynamic range from a few particles per second to tens-of-thousands of particles per second. Illustrated in Figure 3 is a solid-state technique; however, other approaches such as electron multipliers are being pursued as charged particle detectors.

In the area of engineering instrumentation, one of the more important sensors is that of the ablation sensors. Research at Langley Research Center is pursuing three different types of ablation sensors as indicated in Figure 4. The optical ablation sensor operates as follows. As the material ablates, a sapphire rod is exposed to the light generated by the plasma. The sapphire rod transmits the light generated by the plasma and this light is detected by the photo diodes. An output from the photo diode is an indication that the material has ablated to the end of the sapphire rod.

The second approach takes advantage of the electrical conduction of the charred material to short two wires imbedded in the ablating material. As the material ablates, the ends of the wires are exposed to charred material which causes a short between the wires and thus indicates the material has ablated to expose the wires. The instrument shown on the far right in Figure 4 illustrates an ablation instrument which indicates in a more general sense the status of an ablating heat shield. The molybdenum tube is exposed to the heat and is weakened and thus loses its structural strength. Since the tube is under tension from the spring, it collapses and shorts, or [illegible] a microswitch, indicating the status of the ablated materials.

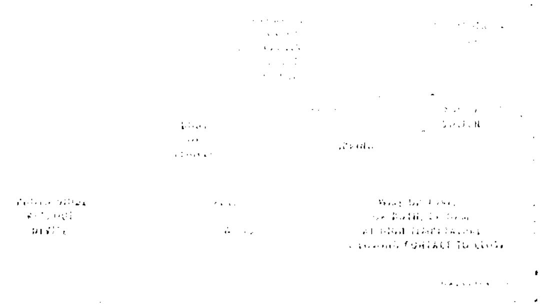

Fig. 4

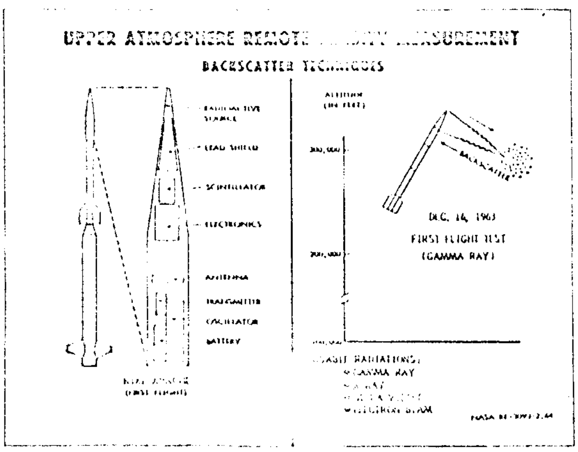

Fig. 5

[illegible] Langley Research Center has performed a flight experiment evaluating gamma rays as the source for a backscattering device. (Figure 5) Gamma rays are emitted and the number reflected back provides a measure of the atmospheric density. Results of the flight test indicate that we can accurately measure atmospheric densities at altitudes in excess of 300,000 feet. Effort is being pursued using X-ray and ultra-violet, as well as electron beams, as the source for a backscattering instrument to measure atmospheric densities at altitudes in excess of 400,000 feet.

On-Board Data Processing or Encoding

The next technical area is that of on-board data processing or encoding. This is an area in which we feel substantial improvement can be made in the efficiency of data transfer and handling by the spacecraft. For example, pre-processing of data on board the spacecraft can be employed to eliminate much of the redundancy of data and thereby decrease the amount of data to be transmitted. Shown in Figure 6 are two spacecraft, one transmitting all the data and the other transmitting only

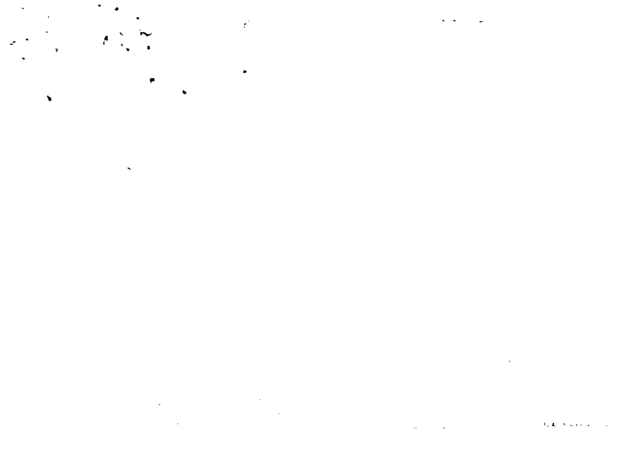

Fig. 6

the pre-processed data. In conjunction with the pre-processing of data, there is a large amount of data storage to allow the experimenter to command the spacecraft to transmit the raw data if more resolution in the experiment is needed to resolve some ambiguity.

To illustrate this type of system, consider a weather satellite whose primary mission is to provide hurricane warnings. As shown in Figure 7, the pre-processing of the data would take the form of pattern recognition. Pattern recognition provides the answer to the important question—Is there a hurricane? The critical data concerning the location and size of the eye, as well as the motion of the eye, can also be provided by pattern recognition or pre-processing of the data. At the same time, one or two pictures of the hurricane could be stored for later confirmation by the Weather Bureau. Transmitting only the critical parameters which describe the hurricane would represent a large reduction in the amount of data needed and thus achieve a considerable increase in the efficiency of the data channel.

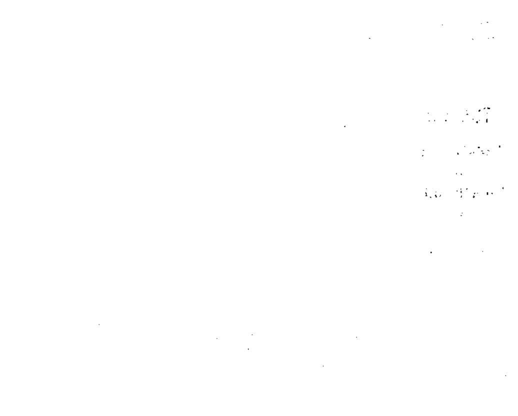

Fig. 7

The on-board data processing or encoding equipments require a large number of electronic components. It is the reliability of these components which, in the final analysis, determines the reliability and life expectancy of the spacecraft. As a result, considerable research is being [illegible] in the area of electronic component reliability. Our approach is first to determine the behavior of the components in the environments shown in Figure 8.

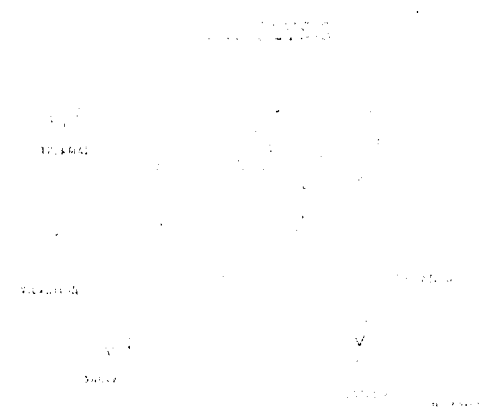

Fig. 8

After determining the failure modes exhibited by the components in these environments, the [illegible] is oriented toward excluding or minimizing [illegible] failure mechanisms and orienting our research to devising components which will be completely immune to that type of damage mechanism.

To illustrate, let's look at radiation damage. Figure 9 shows the tolerance to proton radiation of conventional electronics, semi-conductors and thin film devices. Semi-conductors have less tolerance than conventional devices such as resistors and capacitors, as well as less tolerance than that predicted for the thin film devices. One of the reasons

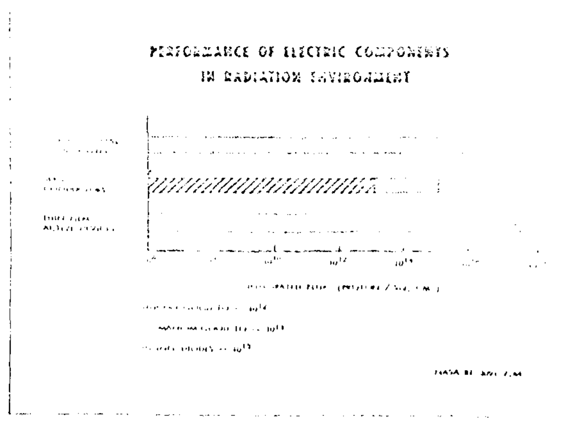

Fig. 9

the semi-conductor is more susceptible to radiation damage is because it is made of a single crystal structure. Dislocations or imperfections in the crystal lattice will cause it to deteriorate. Proton radiation can cause such dislocations in the lattice of a semi-conductor and thus cause a degradation in the performance.

The thin film device (Mead Triode) shown in Figure 10 is polycrystalline and disturbances to its lattice structure should not affect its performance. The Mead Triode utilizes tunneling phenomena to provide the source of electrons, the number of electrons being determined by the voltage applied. Controlling the flow of electrons with the signal voltage allows us to achieve a power gain or an amplifying device.

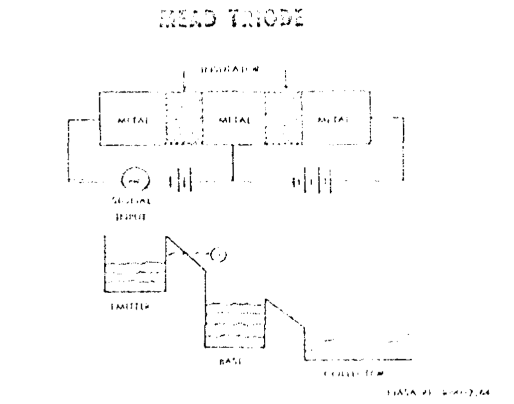

Fig. 10

Devices receiving considerable attention, due to their predicted immunity to radiation as well as long life expectancy, are the pneumatic devices.

Fig. 11

Studies conducted by Marshall Space Flight Center indicate that using these and other pneumatic devices, it will be possible to construct computer systems with clock rates of tens of kilocycles per second, component densities of hundreds per cubic inch and power required per logic element of a few milliwatts. It is interesting to note that the commerical fall-out is expected to be high for devices of this type because they are not only immune to radiation, but also have potential of extremely long life and reliability. Some manufacturers tell us that we can expect to see pneumatic timers and switches on washing machines and dishwashers.

Research is being conducted on speech processing to reduce the data required to transmit speech from deep space. Our approach is two-fold. First, on a long range basis, the objective is to study ways and means to strip speech of all its redundant characteristics, such as speaker recognition and emotional state, and just transmit the spoken words. Theoretically, it is possible to transmit speech stripped of all redundancy using only 60 bits per second as opposed to the present requirement of one to two thousand bits per second.

The second approach in speech processing is to achieve a means of transmitting speech using existing equipments that serve other functions, such as transmitting speech using the beacon transponder. AVCO, under contract to NASA, is working on a speech processing system which is extremely simple in theory, but could very easily be used in conjunction with a beacon transponder. The speech processing technique being perfected by AVCO is shown in Figure 12. The speech is filtered with emphasis on the high, hard-clipped and then differentiated. The differentiated, hard-clipped wave gives a pulse for each crossing. These pulses indicating the zero crossings are transmitted. When these pulses

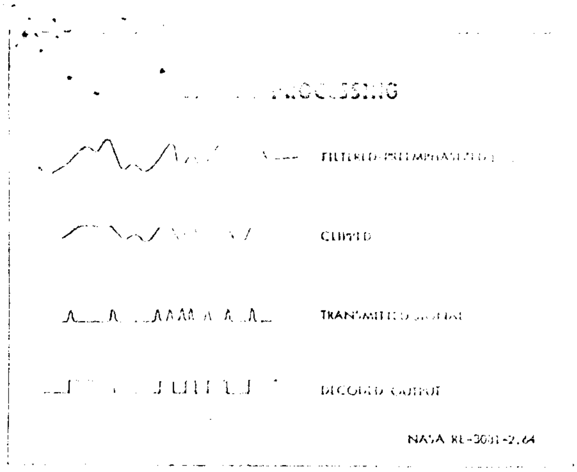

Fig. 12

receiver, the hard-clipped speech wave ... reconstructed and if played through ... will be very intelligible.

It should be emphasized that this is not a data rate ... system. ... technique to put speech in ... which we can incorporate speech on a C-band beacon. If such a system had been available ... Mercury flights, it could have been ... primary ... of communication during the blackout period because the C-band beacon did not suffer blackout. Considerable work remains to be done to make such a speech system compatible with the tracking system.

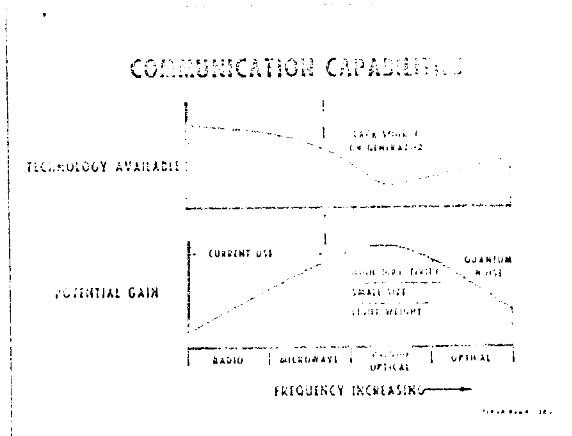

Fig. 13

Transmitter

The next technical area is that of the transmitter. I would like to discuss, as indicated in Figure 13, the technology available and the potential as a function of frequency for a transmission system. At the radio and microwave frequencies we feel there is an abundance of technology. In the region between microwave and optical, which is the submillimeter, there is a definite lack of technology. The primary reason for a dearth of technology in this frequency range is the lack of a source of coherent frequencies. At the optical end of the spectrum there is also an abundance of technology largely because of the work of astronomers and more recently the discovery of the laser.

As we look at the potential or applicability of these various frequencies for long range cummunications, we see that the curve is essentially the inverse of the technology curve. The characteristic desired for a transmitter is high directivity, small size, and light weight, and this is characteristic of the submillimeter and optical frequencies; in fact, the higher the frequency, the better.

The potential curve of Figure 13, on a theoretical basis, should continue to have a positive slope, because more directivity can be achieved at the higher frequencies. However, there is a limit to how much directivity can actually be used due to the limitation of how accurately the spacecraft equipment can point the transmitter. That, coupled with the fact that quantum noise becomes predominant as opposed to the type of noise at the microwave frequency, forces the curve to fall off as shown.

Figure 14 illustrates the gains achieved by high directivity. When a laser beam is compared with a microwave beam, due to the spread of the beam, the energy at the receiver is spread over a much

Fig. 14

larger area in the microwave case than in the optical case and thus less signal will be received by the microwave receiver than the optical receiver.

In order to take advantage of these narrow beams in space applications, we must devise techniques for accurate pointing. Sylvania, under contract to Marshall Space Flight Center, is looking into the approaches of electronically steering or pointing a laser beam. Figure 15 shows a laser beam being deflected by applying a voltage across a KDP crystal. It turns out that a KDP crystal, with voltage applied will, indeed, deflect a laser beam and the deflection can be controlled by controlling the amount of voltage applied.

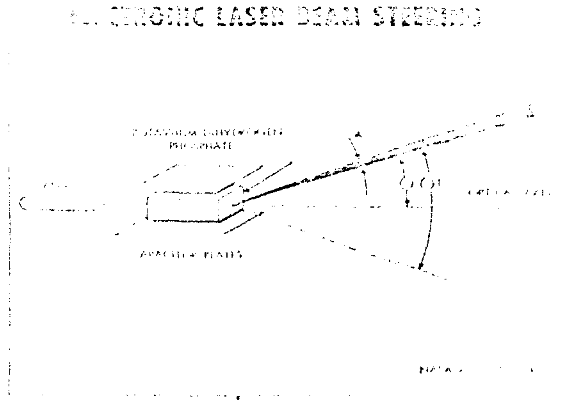

Fig. 15

Figure 16 is another illustration of what can be achieved with a highly directive transmitter. Figure 16 is a picture taken at Hughes Research Laboratory across Santa Monica Bay of a laser located about 18 miles away. The important thing to notice is how bright the laser light is compared to the other lights. It should be noted that the red laser light is actually white in the center because the film is saturated. This laser beam is about one-millionth the power of the other lights shown in the picture. It is very interesting to see this set-up at Hughes. If you walk a few feet either way, you are out of the laser beam and you can no longer see it.

Fig. 16

Channel

The next technical area I would like to discuss is that of the channel. The principal activity we have in this area is that of determining the effects of plasmas generated during reentry on communications. Figure 17 shows the areas during reentry where communications blackout will occur due to the plasma effects. Any vehicles having a velocity and altitude to the right of the VHF blackout line will suffer VHF blackout. Similarly, any vehicle to the right of the channel blackout line will suffer blackout of C-band. For instance, a vehicle travelling at 20,000 fps at a hundred thousand feet altitude will be blacked out at both the C-band and VHF frequency. A typical or possible Apollo reentry trajectory is also shown on Figure 17, which indicates that Apollo will suffer both VHF and C-band blackout during the early portion of reentry.

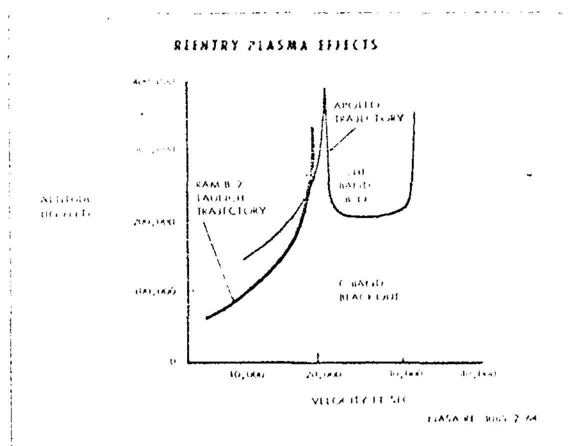

Fig. 17

Shown in Figure 19 is an optical technique being pursued, which does not appear to fall specifically into any of the technical areas but is a cross between a receiver and a transmitter so it will be discussed now. This device is a Modulation Inducing Retrodirective Optical System (MIROS), which acts as a passive relay. The operation is as follows. The laser beam with modulation hits the corner reflector, as does the laser beam without modulation. The modulation appearing on the one beam appears also on the other beam after it has been reflected by the corner reflector. Since the corner reflector returns the light beam to the source, a communications relay has been accomplished.

Fig. 19

Research effort at Goddard Space Flight Center, and also at Langley Research Center, is on the same principle except the corner reflector itself is modulated. The sum total of these techniques will allow us to consider accomplishing optically such things as lunar surface communications over the horizon; and, for some applications, to leave the transmitter off the spacecraft and in its place put a modulatible corner reflector and interrogate it with a laser beam. Another application might be where an astronaut, exploring the lunar surface, puts a corner reflector on his helmet, and the mother ship could listen to him talk by shining a beam at his helmet.

Receivers

The next technical area is that of the receiver. Figure 20 shows our present receiving capability. With the present 85-foot antenna receiver system, we have a good capability to receive average quality TV pictures from lunar distances. With the 210-foot antenna, NASA will have a good capability for high quality TV pictures at a two or three pictures per second transmission rate from lunar distances. However, the planetary capability, even with the 210-foot dish is still meager.

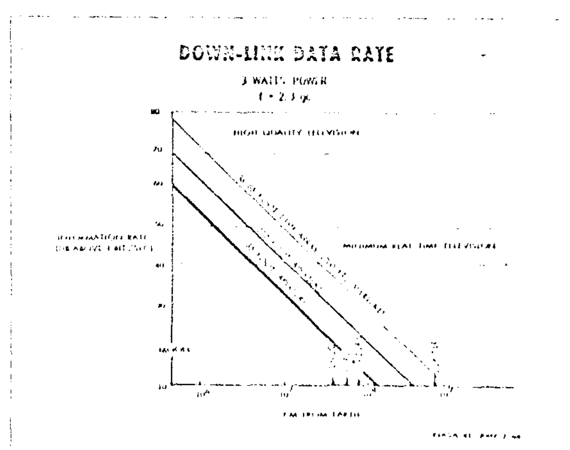

Fig. 20

Our research activity has been to achieve even larger apertures and thus improve our communications capability. Both Goddard Space Flight Center and Langley Research Center are doing techniques work in arraying of antennas to increase the aperture. For example, an array of thirty-six 85-ft. antennas would roughly give the same type of improvement over the 210-ft. antenna as was obtained from going from an 85-ft. to a 210-ft. aperture antenna.

Work in multiple feeds at the Cambridge Research Laboratory recently came to our attention and we plan to devote some effort in FY 1965 to determine the applicability of their effort to achieving inexpensive large apertures. The Air Force is interested in swinging the beam maybe four or five beam widths off beam center by varying the phase of the different feeds (see Figure 21) instead of moving the dish. These same techniques show promise as an approach to compensate for a sag or deformation in the antenna reflector. We plan to look at these techniques as a way of achieving a larger aperture at a much cheaper cost. For instance, instead of thirty-six 85-ft. antennas, at the same price we might be able to achieve thirty-six 120-ft. or 150-ft. antennas.

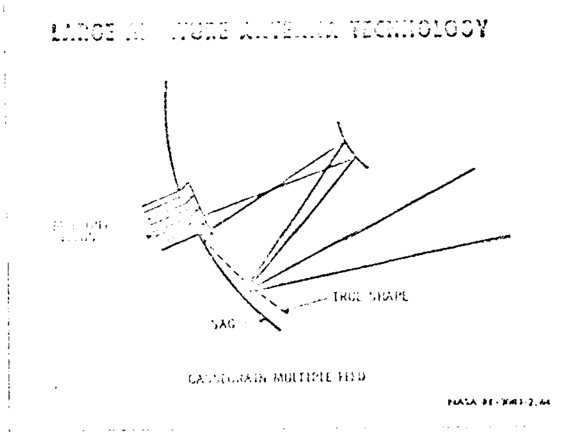

Fig. 21

Also, the same technique could possibly be applied to extending the frequency range of the present antennas. If, in the future, NASA goes to X-band frequencies, the present antennas will not have the required surface tolerance in the main reflectors. The multiple feed system might be a way of compensating for the lack of the required surface tolerance.

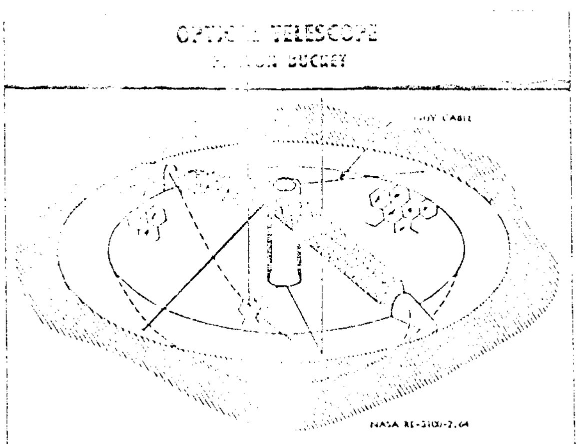

Fig. 22

Study effort in FY 1965 is planned to determine means of achieving large receiving apertures for optical systems. We are not interested in a large receiving area for coherent detection, but for non-coherent detection. Essentially, what is needed is a large photon bucket to gather in as many of the photons transmitted as possible. A possible construction of the photon bucket is shown in Figure 22. It is composed of many individual reflectors, but the tolerances on the reflectors are not stringent since the system is used for non-coherent detection.

Data Processing

The next technical area is ground data processing. Here substantial change is taking place, both in techniques and equipment. This can be illustrated by looking at the computer complex shown in Figure 23. On the left are shown the arithmetic and memory units which are the basic elements of a computer. In the center are the standard input-output equipments. The equipment on the extreme right is the equipment which is making it possible to achieve easy access to the computer.

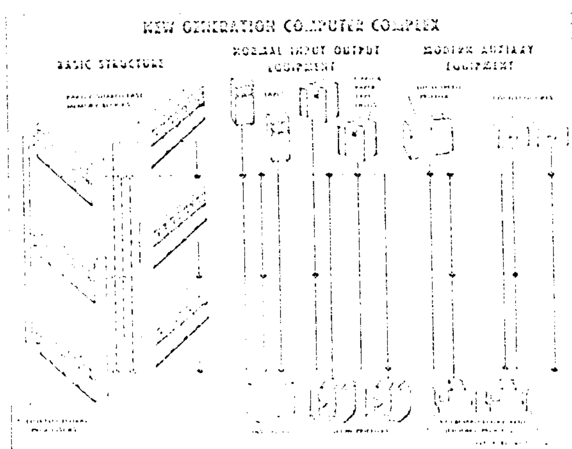

Fig. 23

Our efforts in the computer systems area are to perform studies and conduct experiments to increase [illegible] efficiency of the computing complex, to point the way to more reliable systems design, [illegible] the man-computer communications capability and, thereby, increase the utility and flexibility of the computer system.

We are trying to achieve ways and means to allow many people to work simultaneously with a computer. These people shown in Figure 24 will solve complex problems simultaneously with the computer. This is possible because the latest computer systems tie more than one arithmetic and memory unit together. Our long range goal is to achieve a computing system whereby many scientists would use a computer simultaneously to solve a complex problem, much in the same way an engineer uses a slide rule today to solve some of the more mundane engineering problems.

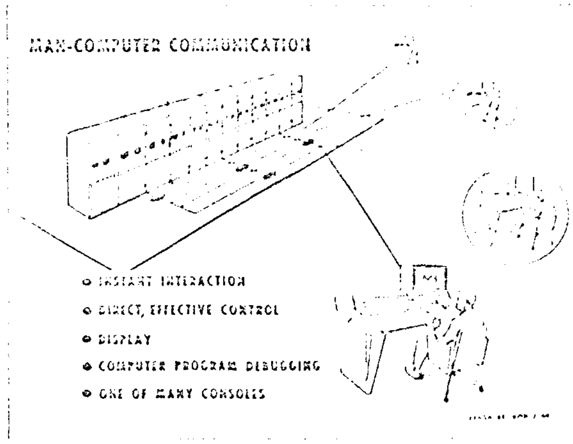

Fig. 24

Considerable research effort is being expended in evolving computer components. Figure 25 shows the status of the computer memory capability. It turns out that NASA's interest is in the area which is a compromise between high speed and large core capability. Research over the years in core memory, as shown in Figure 26, indicates that we are at the end of the development cycle in cores. The next generation of memories will probably be continuous ferrite plates and RCA is under contract to NASA to continue research on ferrite plate structures.

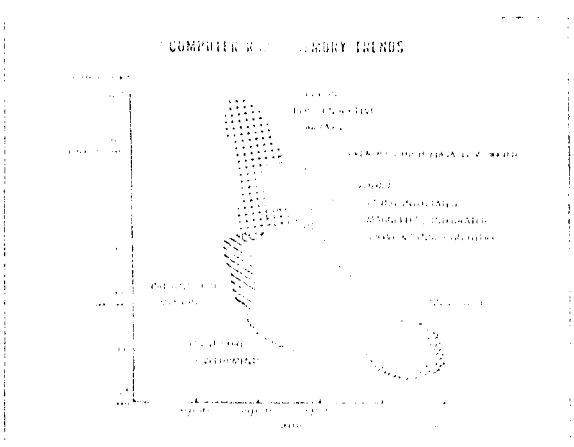

Fig. 25

Using either the continuous ferrite plate approach, magnetic films or films on wire, and other components being developed, we feel it will be possible to build computers in the size and weight allowed on spacecraft with the same capability as our present day large ground computers. This, coupled with the results of the man-computer communications effort should result in providing the astronauts or space scientists on the moon or other planets with a high performance computer which could be used with ease to either solve a complex navigation problem or a complex scientific equation.

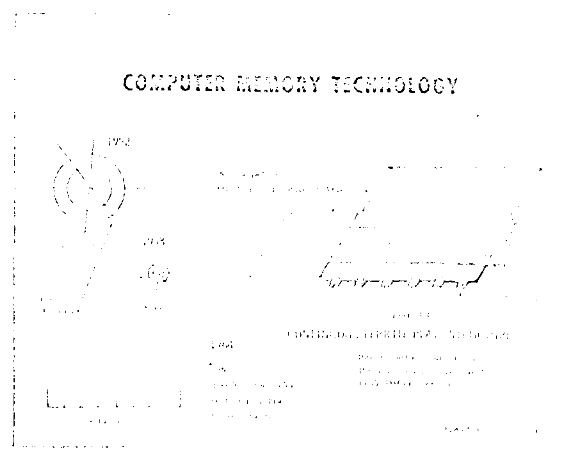

Fig. 26

Summary

I have discussed examples which illustrate NASA's research activities in the technical areas from the instrumenting of the phenomena to the experimenter, and also interaction between the

...transfer and data processing. Successful development of these techniques, as well as others being pursued but not discussed today, should enhance the capability of experimenters to gather more meaningful data as well as consider new types of experiments in space.