43

AD 667803

AFCRL-67-0158
DECEMBER 1967
AIR FORCE SURVEYS IN GEOPHYSICS, NO. 201

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Positive Ion Sensing System for the Measurement of Spacecraft Pitch and Yaw, Air Force D-10 Experiment Flown on Gemini X and XII

R. C. SAGALYN
M. SMIDDY

OFFICE OF AEROSPACE RESEARCH
United States Air Force

61

AFCRL-67-0158
DECEMBER 1967
AIR FORCE SURVEYS IN GEOPHYSICS, NO. 201

UPPER ATMOSPHERE PHYSICS LABORATORY PROJECT 8617

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Positive Ion Sensing System for the Measurement of Spacecraft Pitch and Yaw, Air Force D-10 Experiment Flown on Gemini X and XII

R. C. SAGALYN
M. SMIDDY

OFFICE OF AEROSPACE RESEARCH

United States Air Force

Abstract

An attitude sensing system utilizing the properties of ambient positive ions was developed and successfully flown on Gemini Spacecrafts X and XII. In this device the outputs of two planar electrostatic analyzers mounted symmetrically about the appropriate axis are combined to give directly pitch and yaw angles. Comparison of the flight results with those obtained simultaneously with an on-board inertial guidance system shows that over the angular range for which the ion sensing system was designed, ± 20 deg, the average values are in good agreement. The in-flight results also provided a unique description of the distribution of charged particles around the spacecraft, including the wake region, and new information on the motion of the neutral winds and the mean ion drift motion in the upper atmosphere relative to the earth's rotation.

The system could be readily adapted or modified for automatic control of manned or unmanned rockets, satellites, or supersonic aircraft. Significant reductions in required weight, power, volume, warm-up time, response time, and cost make this a potentially valuable tool for future space flight.

Contents

Contents

Illustrations

Tables

Positive Ion Sensing System for the Measurement of Spacecraft Pitch and Yaw, Air Force D-10 Experiment Flown on Gemini X and XII

1. INTRODUCTION

A system for measuring spacecraft pitch and yaw with respect to the spacecraft's velocity vector, utilizing the properties of positive ions, was developed by scientists and engineers at the Air Force Cambridge Research Laboratories. It was flown successfully on Gemini Spacecrafts X and XII.

The primary purpose of this experiment was to determine the feasibility of measuring spacecraft pitch and yaw angles by using the properties of environmental positive ions and the appropriate electrostatic probe configuration.

Secondary objectives included: (a) measuring the distribution of ambient thermal ions along the satellite trajectory; (b) measuring the distribution of the charged particles in the satellite wake (also mapping the distribution of charged particles around the spacecraft from results obtained during controlled maneuvers); and (c) determining the relative motion of the upper-air ion drift with respect to the neutral winds and to the rotation of the earth.

The results have shown that environmental positive ions can be utilized to measure spacecraft angular position or attitude with respect to the orbital plane and direction of motion. By adding a horizon detector to give the local vertical, a complete earth-centered attitude determination system can be realized. By adding a command mechanism at the output for the control of reaction jets or

(Received for publication 28 September 1967)

reaction wheel, etc., this instrumentation could be converted to an automatic attitude-control device. It would also largely eliminate the need for telemetry instrumentation as well as the errors introduced in data transmission to and from ground stations.

This technical report contains a discussion of the theory, background, and development of this device as well as the most significant results and general conclusions concerning the utilization of such a system.

2. BACKGROUND

For several years, members of the Space Electricity Group at AFCRL have been studying the properties of charged particles in the upper atmosphere. The work has included investigations in the ionosphere, exosphere, magnetospheric cavity transition region, and interplanetary gas. The results have shown that in the region from 60 miles to at least 10 earth radii, the random thermal velocity of the positive ions is 3 to 10 times less than the average spacecraft velocity. The measurement of environmental positive ions and their properties is, therefore, highly dependent on spacecraft attitude.

We have provided information to various Department of Defense Groups (including SSD, NASA personnel concerned with spacecraft control, and private companies interested in attitude sensing) during the past 4 years. Both environmental data and the specific properties of planar electrostatic analyzers relevant to attitude sensing were discussed. For example, we showed analytically that two sensors properly located with respect to the direction of motion and the axis of interest of the spacecraft could be used to make precision measurements of pitch and yaw angles. During May and June 1964, representatives from the Research and Technology Directorate, SSD, Los Angeles, requested that we develop such a system and integrate it for flight on two Gemini spacecrafts. A number of factors entered into the Air Force interest in the development and "in-flight" evaluation of such a system. These included yaw-measurement weaknesses in the inertial system, and the high cost, weight, power consumption, inadequacy to some missions, etc., of existing inertial systems.

2.1 Schedule

We were given official authority to develop this experiment in April 1964; the first flight on Gemini X was flown in August 1966. The second flight, Gemini XII, was flown in November 1966. There were approximately 27 months between the initiation of the development of the experiment and its operation in-flight.

The principal constraints imp ·· ' by the schedule were those associated with working with a spacecraft that ha been fully designed before we entered the program. For example, we considered it desirable on the initial tests of the experiment to extend the boom at least 3 ft from the spacecraft, because of various protuberances on the spacecraft. This could not be implemented since a "major" redesign would be involved.

Because of our previous experience with low-current measuring devices, and our studies concerning the properties of environmental positive ions, we were able to complete the design and development, testing, integration, etc., of the ion sensing system in the time allotted.

2.2 Testing

The testing procedures for the experiment were worked out at AFCRL, consistent with both our own experimental practices and the special requirements imposed by working with the Gemini spacecraft system. The specific documents giving us operating constraints, environmental conditions at the spacecraft during flight, launch conditions, electrical tests, etc., were supplied to us by Detachment 2, SSD, at the Manned Space Flight Center. They included both McDonnell Aircraft and Manned Space Flight Center documents.

After the initial laboratory development was completed, Pre-Delivery Acceptance tests (PDA), Pre-Installation Acceptance tests (PIA), and mechanical and electrical specifications were imposed on the subcontractors.

The time allotted for integrating the equipment on the spacecraft was approximately 3 days. This period was not continuous as other spacecraft operations had higher priority. The specific integration test included: the optical alignment of the experimental apparatus to insure that it would be pointing along the appropriate axis with a precision of 0.25 deg; the electrical interface, including power and telemetry tests; and testing of the pyrotechnics used for boom extension and deployment of the protective cover on the sensor. It also included mechanical integration of the equipment on the spacecraft.

The major environmental testing was conducted at the integration plant (McDonnell Aircraft Corp.). At Cape Kennedy, tests were performed to demonstrate that the experiment package was functioning properly and to provide final preflight electrometer calibrations.

2.3 Technical Problems Encountered

Two types of problems arose as the experiment was developed: those involving interface with the spacecraft which could jeopardize the objectives of the experiment, and those common to the development of any new experimental system.

One interface problem that arose concerned the length of the booms on which the experimental equipment was mounted. We requested that the booms be approximately 3 ft long to minimize spacecraft interference with the sensors, but due to the positioning of the doors on the spacecraft their length had to be decreased to about 15 to 17 in. Some realignment and interchange of sensors was necessary to maximize the "look" angle of the experiment.

Another problem that had to be solved was that of protecting the sensors mounted in the aft section of the spacecraft against contamination from the prelaunch and launch environment. This problem was solved by retracting the experiment inside the aft section before orbital injection. A special container built to protect the sensors opened in flight after boom deployment.

2.1 Technical Contributions Related to Development

The principal technological developments realized from the design of this experiment are extremely stable electrometers that are capable of obtaining an accuracy of 0.25 deg, and the logic and operational circuits that do not drift under wide temperature variations, the launch environment, etc.

3. THEORY

In the altitude range from 60 miles to 10 earth radii, positive ions and electrons produced primarily by photoionization exist in equal concentrations. The number density varies greatly in space and with time; for example, the charge density reaches a maximum of the order of 10^6 per cc in the vicinity of the F region maximum at approximately 350 km and decreases to approximately 10^2 per cc at about 10 earth radii. There are also great variations in the number densities on the day and night side of the earth, in the vicinity of the geomagnetic equator, and in the lower ionosphere below approximately 1000 km.

Very rapid increases in ion and electron concentrations occur at sunrise due to photoionization and dissociation of the neutral atmosphere constituents. More gradual decreases in density occur at local sunset when recombination and diffusion become important. This is illustrated in Figure 1 which gives the results of positive ion measurement we obtained with spherical electrostatic analyzers on a Discoverer satellite (Sagalyn et al., 1965).

The average energy of the charged particles varies from about 0.01 eV at 100 km to approximately 4.0 eV at 10 earth radii. The kinetic temperature of the charged particles in the altitude range covered by the Gemini spacecraft varies from approximately 250° K to about 3000° K (Sagalyn et al, 1965; Dalgarno et al, 1963).

It has been demonstrated by the authors and other experimenters that the charged particles in the upper atmosphere have an essentially Maxwellian velocity distribution. The average thermal velocity of the particles may be given by the relation:

$$v = \left(\frac{8kT}{\pi m}\right)^{1/2} \qquad (1)$$

where

k = Boltzman's constant

T = temperature in degrees Kelvin

m = mass in grams

v = thermal velocity in centimeters per second.

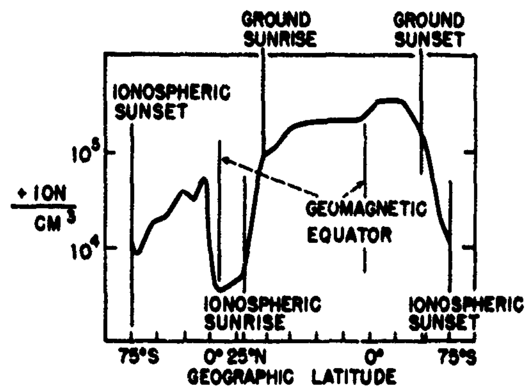

Figure 1. Variation of Positive Ions in the F Region on One Complete Orbit

Substituting in Eq. (1) representative values for temperature and mass of the positive ions, one finds that their random thermal velocity varies between 0.8 and 1 km/sec over the altitude range of the Gemini spacecraft orbit. Satellites orbiting in the upper ionosphere have varying average velocities, depending upon the nature of the orbit; however, typical satellite speeds vary between 7 and 11 km/sec. The spacecraft velocity is, therefore, approximately 10 times greater than the average thermal velocity of the positive ions.

Relative to the spacecraft, the positive ions possess negligible velocity (Sagalyn 1967). It should be noted that the situation is very different for electrons since their average mass is approximately 10^4 times less than that of the ions. Applying Eq. (1) one calculates that the average electron velocity is about 30 times greater than the vehicle velocity. The fact that positive ions may be considered stationary with respect to the spacecraft velocity is fundamental to the operation of the ion attitude sensing system.

If one uses a planar electrostatic analyzer of the type illustrated in Figure 2, it can be shown that the current to the collector is simply related to both the positive ion density in the medium and to the angle between the normal to the plane of the sensor and the vehicle velocity vector. As shown by Sagalyn (1967), when the ratio of the satellite velocity to the random velocity of the ions is greater than or equal to 2, and with grid and collector voltages as indicated in Figure 2, the current i to the collector is given by:

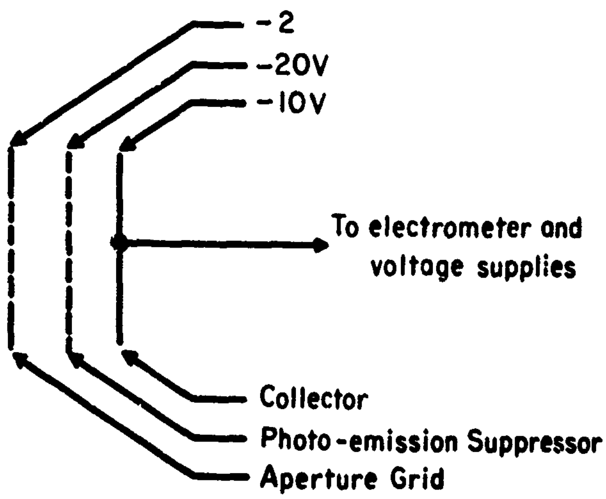

Figure 2. Example of Electrode Arrangement and Voltages Applied to the Planar Electrostatic Analyzer

$$i = ANe\ |V|\ f(v)\ \alpha$$

where

- A = aperture area
- N = the positive ion density
- e = the particle charge
- $|V|$ = magnitude of the ion velocity, a function of the satellite velocity and position of the sensor with respect to the direction of motion
- f(v) = a function of the vehicle potential with respect to the undisturbed plasma
- α = an experimentally determined transmission factor for the grid electrodes.

The manner in which these principles were applied to the attitude experiment flow on Geminis X and XII are described in the next section of this report.

The system was designed to transmit the output angles to the ground via telemetry (both on tape and in real time) and to the flight director's indicator. In addition, the outputs of the individual electrometers of the system were recorded and transmitted to give: charged particle density along the satellite orbit, the distribution of charged particles around the spacecraft including the wake, and information concerning the relative drift motion of positive ions at the Gemini orbital altitudes. The most important operational result is the comparison of the pitch and yaw angular measurements with the outputs of the inertial system.

4. EXPERIMENT

4.1 General Description

Two planar electrostatic analyzers with a sensor configuration as indicated in Figure 3 were utilized in this experiment.

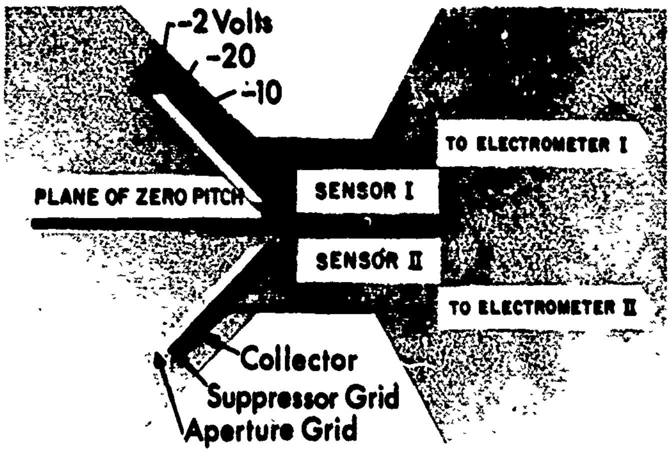

Figure 3. Pitch System Sensor Arrangement and Applied Voltages

As mentioned above under THEORY, when the ratio of the satellite velocity to the random velocity of the ions is greater than or equal to 2, and with grid and collector voltages as indicated in Figure 3, the current i to the collector of a planar electrostatic analyzer is given by:

$$i = ANe \, |V| \, f(v) \, \alpha \tag{3}$$

where

- A = aperture area
- N = positive ion density
- e = particle charge
- $|V|$ = magnitude of the ion velocity, a function of the satellite velocity and position of the sensor with respect to the direction of motion
- f(v) = a function of the vehicle potential with respect to the undisturbed plasma
- α = experimentally determined transmission factor for the grid electrodes.

In the ionosphere the satellite velocity is 6 to 10 times greater than the random ion velocity; therefore, the ions are considered fixed and the magnitude of the velocity $|V|$ is equal to $v_s \cos\theta$, where v_s is the spacecraft velocity and θ is the angle between the direction of motion of the vehicle and normal to the plane of the sensor. Equation (3) then becomes:

$$i = ANev_s \cos\theta \, f(v) \, \alpha \quad . \tag{4}$$

It is seen from Eq. (4) that the planar sensor current is highly dependent on its orientation with respect to the direction of motion. This fact is fundamental to the understanding and operation of the ion attitude sensor. For yaw measurement, two identical sensors are aligned at 45 deg with respect to the plane of zero yaw. An identical sensor system, mounted symmetrically about the zero pitch plane, is used to measure pitch angles. These two independent systems are mounted on booms approximately 2 ft long in the aft section of the spacecraft. They are extended on command by the astronaut at the appropriate time after orbital injection. The location of the booms and sensors on Gemini Spacecrafts X and XII is shown in Figure 4. The location of the sensors and the boom lengths are set to minimize the influence of spacecraft wake, contamination, and space charge effects.

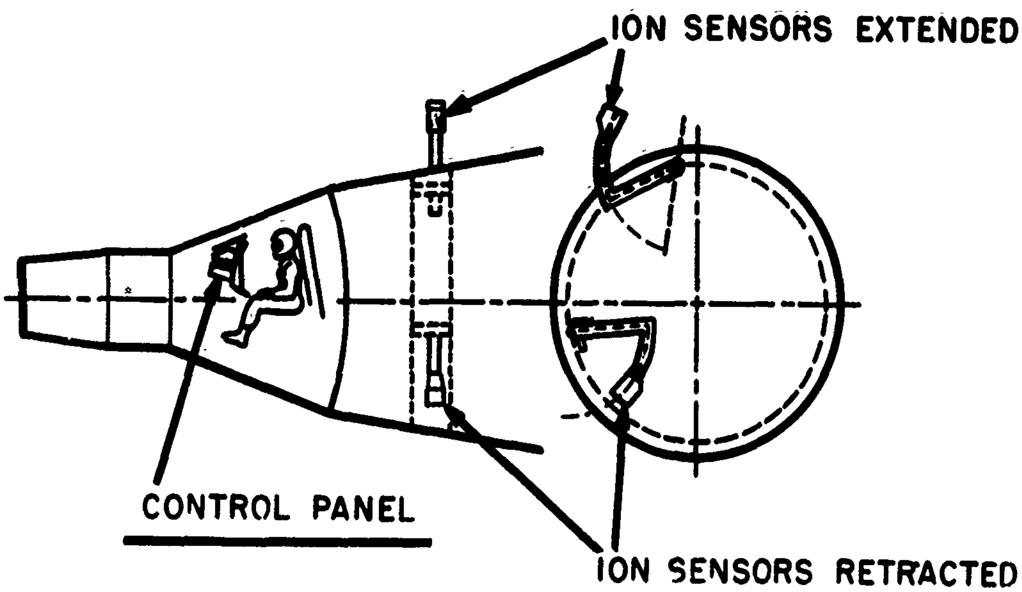

Figure 4. Location of Experiment D-10 Pitch and Yaw Experiment on Gemini Spacecraft

The principle of operation of the ion attitude sensor can best be understood by first considering the measurement of pitch. Except for the change in alignment as indicated above, the analysis of the yaw measurement is identical. With two sensors aligned symmetrically about the pitch axis as shown in Figure 2, the current to the collector of each sensor is given by:

$$i_1 = Nev_s \alpha A \cos(45-\theta) \quad (5)$$

$$i_2 = Nev_s \alpha A \cos(45+\theta) \quad (6)$$

where

i_1 = current to sensor 1

i_2 = current to sensor 2

θ = pitch angle (in degrees).

Solving Eqs. (5) and (6) for θ one obtains:

$$\text{Tan}\,\theta = \frac{i_1 - i_2}{i_1 + i_2} \quad . \quad (7)$$

For θ less than or equal to 20 deg, tangent θ is equal to θ, in radians.

From Eq. (7) it is seen that the output of the sensors may be displayed on a meter calibrated directly in degrees "θ" for small angles and in "tangent θ" in general for all angles. It should also be observed that changes in charge density N or satellite velocity V_s do not affect the angular measurement.

A block diagram of a given system (pitch or yaw) is shown in Figure 5. The output of each sensor is amplified by electrometers 1 and 2. In order to obtain the desired accuracy over the current range of 10^{-6} to 10^{-11} A, linear amplifiers with range switching covering five current decades are employed. The outputs of electrometers 1 and 2 are then electronically added, subtracted, integrated, and compared. The final output tangent θ, referred to as the compared output, is sent to the flight directors's indicator, to an on-board magnetic tape that is periodically transmitted to ground stations, and in real time to a few ground stations.

In order to fully evaluate the experimental system, to obtain information on the ambient ion densities and on the distribution of positive ions in the wake of the vehicle, the direct outputs of electrometers 1 and 2, the range analog indicator, and calibration monitors are also transmitted through telemetry. These latter

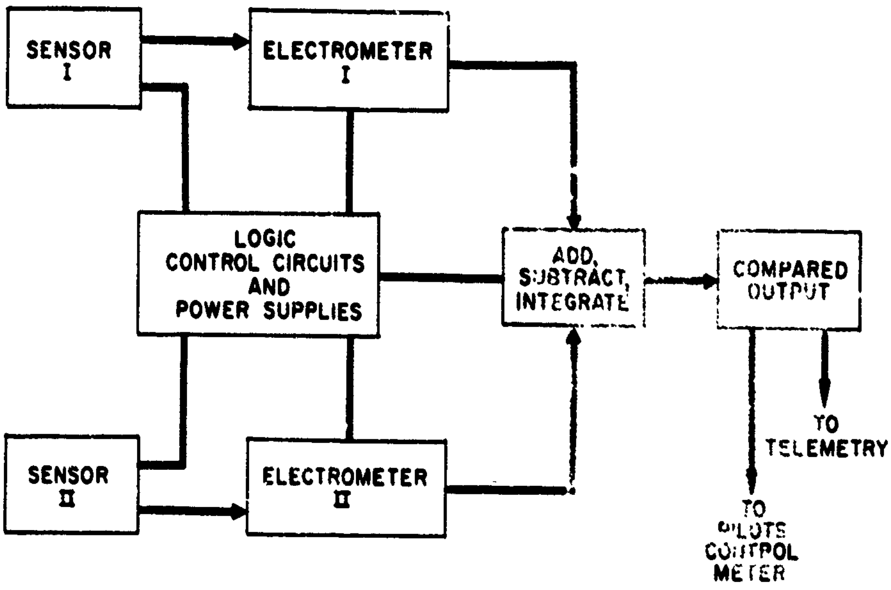

Figure 5. Block Diagram of Ion Yaw/Pitch Sensing System

outputs would not be required in an operational system. It should be noted that while the Gemini D-10 experiment was designed for precise pitch and yaw angular measurements over the range ± 20 deg, there is no basic limitation to the magnitude of the angle to be measured. The required resolution, response time, and so forth, vary with the specific application of the system. A simple engineering modification of the ratio circuits would be involved for varying systems requirements.

These boom-mounted experiments were extended on astronaut command after orbital injection. An additional command was subsequently given to expose the sensors. The principal operations in flight were the astronaut maneuvers outlined below under FLIGHT TEST I. The astronauts were also requested to periodically examine the inertial and ion sensor outputs, as shown on the flight director's meters, and transmit their comments about the operation through the onboard voice tape recorders.

1.2 Instrumentation

Two independent systems were flown on each vehicle, one for the measurement of pitch and one for the measurement of yaw. Each system was identical except for its orientation to the plane of zero pitch or yaw. Each system included an electronics package and a sensor unit placed in a single container and mounted on a boom that was extended approximately 2 ft from the aft section after orbital injection. This in not a necessary configuration for obtaining pitch and yaw measurements. The best configuration for the electronics section and sensor unit is dependent upon the shape of the satellite and on the space and weight distribution possibilities available.

The electronics package, which measured 4X6X5 in. and weighed 2.5 lb, was contained in a magnesium box as shown in Figure 6. The wiring of the circuit boards in the electronic section is shown in Figure 7.

A photograph of the sensor unit is shown in Figure 8. Its overall dimensions were 3X6X5 in.and it weighed 4 lb, including an alignment fixture.

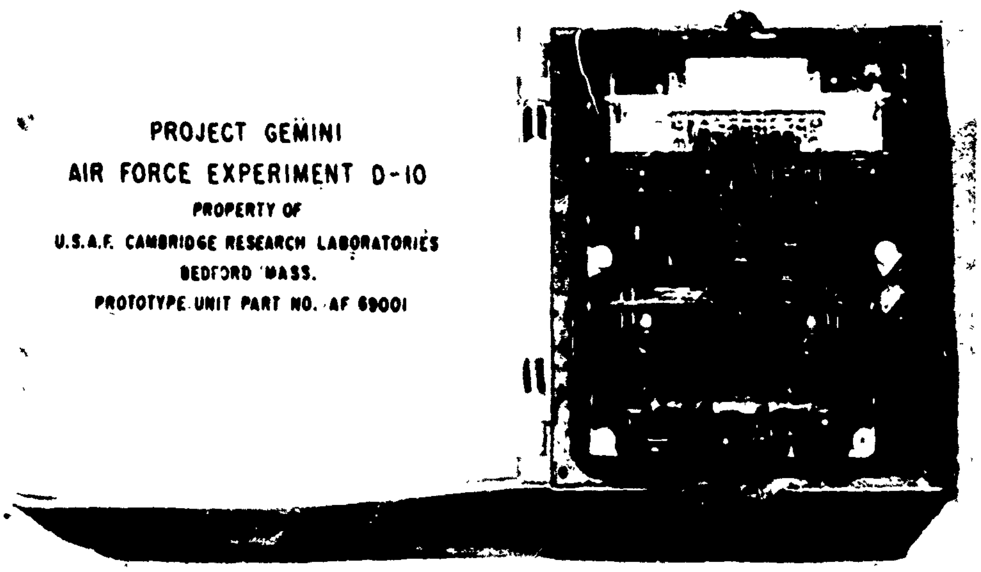

Figure 6. Positive Ion Attitude Sensor Package With View of Electronics Section

The input to the experiment was the positive ion current flow to the sensors. There were seven outputs from each system. For the pitch system these included: pitch angle; electrometer 1 output; electrometer 2 output; calibration monitors for electrometers 1 and 2; electrometer range indicator; and temperatures monitored at two positions on the electronics package to give the operating temperature of the unit.

The logic circuit in the electronics package was designed to apply an internal calibration to electrometers 1 and 2 at intervals of approximately 50 min. Outputs were also designed to indicate that the pitch boom had deployed.

Figure 7. Wiring of Circuit Boards in Electronics Section

Figure 8. Ion Attitude Sensor With Alignment Fixture

The yaw system outputs were similar to those described above for the pitch system. In an operational device only the angular values would be required. Additional photographs of the equipment are given in Figures 9 and 10.

Photographs of the equipment mounted on the aft section of the spacecraft are shown in Figures 11 and 12.

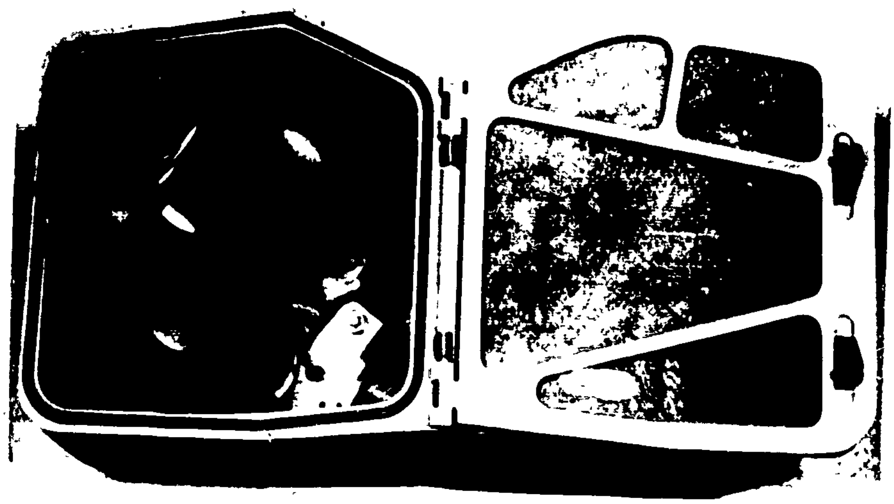

Figure 9. Experiment Package with Sensors Exposed

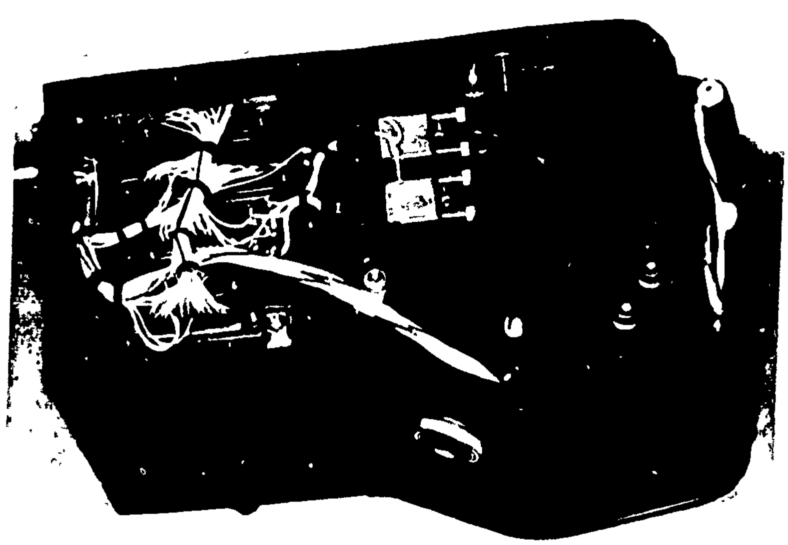

Figure 10. Experiment Package With Back Plate Removed

Figure 11. D-10 Experiment Package Mounted on Boom Extended From Aft Section of Spacecraft

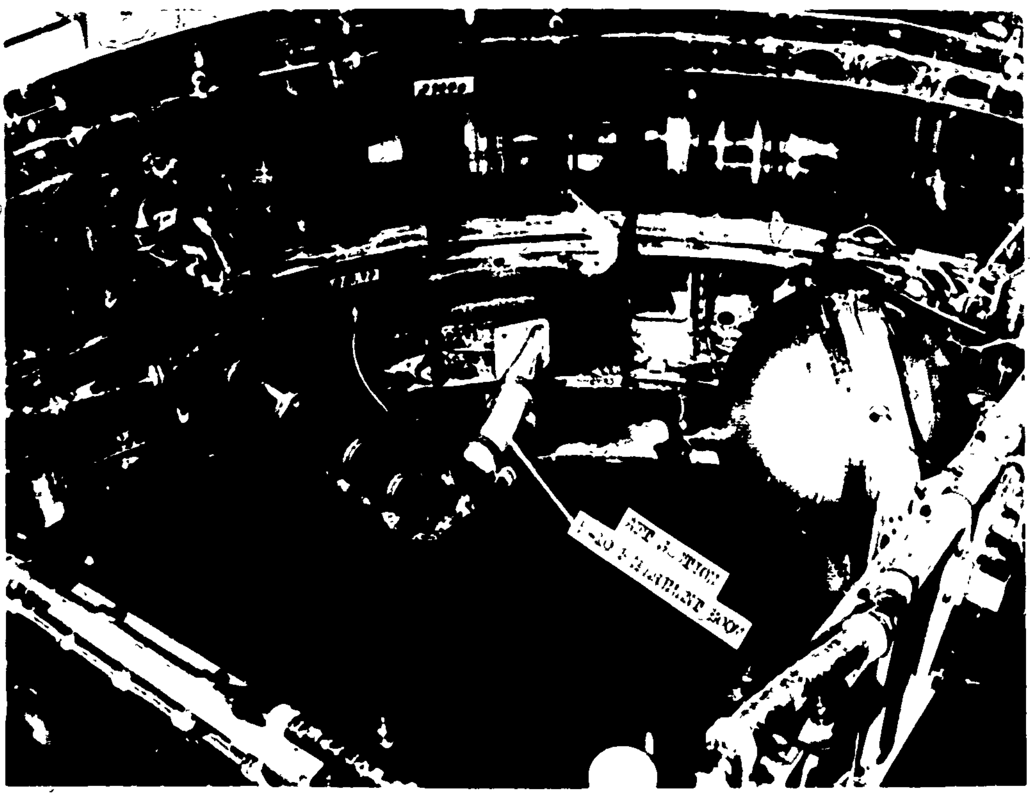

Figure 12. D-10 Experiment Boom Inside Aft Section of Spacecraft

5. FLIGHT TEST I–FLIGHT PLAN

The first flight test of Experiment D-10 took place on Gemini X in August 1966 to determine the feasibility of orbital pitch and yaw determination by ion sensing. Outlined below is pertinent information regarding Flight Test I.

5.1 Mission as Planned

5.1.1 OPERATIONAL PROCEDURES

These included turn-on procedures which required the astronauts to supply commands for boom deployment and removal of the protective covers on the sensors after orbital injection and application of power to the experiment. The principal astronaut activities with respect to the D-10 experiment were the in-flight maneuvers outlined below to accomplish the primary and secondary objectives of the experiment.

SPACECRAFT SYSTEMS CONFIGURATION

1. Undocked.
2. Agena power C/B - Closed.
3. Other systems are dependent on particular sequences.

NOTE: The experiment must be completed during a continuous period of time involving no firing of the vertical and lateral thrusters. Firing of these thrusters may severly degrade the sensors once their covers are released. Firing of any other thrusters should not affect the sensors.

PROCEDURES

MODE A - Equipment Extension and Activation

1. Bus Arm Switch - EXP
2. Ion sensor seq. switch - SEQ. 1
3. Wait 1 to 2 min for booms to fully extend

NOTE: Opening of the sensor covers prior to full boom extension may cause the booms to jam inside the retro adapter section.

4. Ion Sensor mode switch - ON (Must remain ON or FDI until completion of exp.)
5. Ion sensor seq. switch - SEQ-2
6. Bus Arm switch - SAFE.

MODE B - Ambient data accumulation

1. Platform - ORB Rate and aligned
2. Computer - PRE LN
3. Attitude Control - PLAT
4. ION Sensor mode switch - FDI

5. FDI Scales - HI
6. Hold spacecraft attitude at zero in all axes for 10 min

NOTE: Mode B should be done three times; once each at the northernmost orbital latitude, the southernmost orbital latitude, and at an equatorial crossing.

MODE C - Roll attitude study

1. Platform - ORB RATE and aligned
2. COMPUTER - PRE LN
3. Attitude control - PULSE
4. Ion Sensor mode switch - FDI
5. FDI Scales - HI
6. Roll 720 deg at about 3 deg per sec, holding pitch and yaw to zero
7. Voice record crew commentary about FDI needle movements

NOTE: Mode C should be done twice: once in daylight, once in darkness.

MODE D - Pitch attitude study

1. Platform - ORB RATE and aligned
2. Computer - PRE LN
3. Attitude control - PULSE
4. Ion Sensor mode switch - FDI
5. FDI scales - HI
6. Holding both yaw and roll to zero deg pitch from 20 deg down to 40 deg up at ≈ 0.1 deg per sec
7. Holding yaw at 5 deg left and roll to zero, pitch from 40 deg up to 20 deg down at ≈ 0.1 deg per sec
8. Holding yaw at 5 deg right and roll to zero, pitch from 20 deg down to 20 deg up at ≈ 0.1 deg per sec
9. Voice record crew commentary about FDI needle movements.

NOTE: Mode D should be done three times.

MODE E - Yaw attitude study

1. Platform - ORB RATE and aligned
2. Computer - PRE LN
3. Attitude control - PULSE
4. Ion Sensor mode switch - FDI
5. FDI scales - HI
6. Holding both pitch and roll to zero deg, yaw from 20 deg right to 40 left at ≈ 0.1 deg per sec
7. Holding pitch at 5 deg down and roll to zero, yaw from 40 deg left to 20 deg right at ≈ 0.1 deg per sec
8. Holding pitch at 5 deg up and roll to zero, yaw from 20 deg left to 20 deg right at ≈ 0.1 deg per sec
9. Voice record crew commentary about FDI needle movements.

NOTE: Mode E should be done three times.

MODE F - Photo emission effects

1. Platform - ORB RATE and aligned
2. Computer - PRE LN
3. Attitude control - PLAT
4. Ion Sensor mode switch - FDI
5. FDI Scales - HI
6. Hold spacecraft attitude at zero about all three axes from 5 min before sunrise to 15 min after sunrise
7. Voice record crew commentary on FDI needle movements.

NOTE: Mode F should be done twice.

MODE G - Random data accumulation

1. Ion Sensor mode switch - ON
2. At least 6 hr of data acquisition is requested. Drifting flight is preferred.

MODE H - Translation thruster effects

1. Platform - ORB RATE and aligned
2. Computer - NAV (CTCH-UP)
3. Enter the following into the computer:
   25:00000
   26:00000
   27:00000
4. Attitude control - PULSE
5. Ion sensor mode switch - FDI
6. FDI scales - HI
7. Control S/C attitudes to 0°, 0°, 0°
8. START COMP - PUSH
9. Holding 0°, 0°, 0°, Fire the UP/DWN and LEFT/RIGHT translation thursters briefly
10. Read address 80 from the computer
11. Translate aft to null address 80
12. Voice record crew commentary on FDI needle movements.

NOTE: The thruster firings in this sequence will probably destroy the sensing system. Hence, this mode will be the last performed.

5.1.2 INTEGRATION OF OPERATIONAL PROCEDURES INTO THE FLIGHT PLAN

The procedures for power turn-on, extension of booms, etc., were submitted to the Detachment 2 Office, SSD, approximately one year before flight. At the same time the desired in-flight maneuvers were also submitted together with information on the priority of the various operations. A number of discussions were held between representatives of SSD Det. 2 Office and AFCRL scientists and engineers. Certain compromises were made concerning the duration and time sequencing of the in-flight tests which we are not in a position to comment on.

5.1.3 INTEGRATION OF EXPERIMENT INTO MISSION PLAN

Apart from our original submission designating the most desirable spacecraft maneuvers and their priority for the evaluation of the D-10 experiment, we had a few brief discussions with our representatives at the SSC Det. 2 Office, Houston, on the mission plan.

5.2 Astronaut Training

5.2.1 SCHEDULE AND DISCUSSION OF FORMAL BRIEFINGS

A formal briefing, of approximately one hour duration, was conducted with the Astronauts by one of the D-10 experimenters approximately one month before flight.

5.2.2 SCHEDULE AND DISCUSSION OF FORMAL TRAINING

We are not aware of any formal training given to the Astronauts relevant to the D-10 experiment.

5.2.3 INFORMAL DISCUSSIONS AND TRAINING

The D-10 experimenter group had an opportunity to discuss for about one-half hour following the formal briefings, the specific maneuvers and their objectives with the Astronauts as well as to answer their questions.

5.2.4 USE OF MOCKUPS, TRAINING EQUIPMENT, TRAINERS AND SIMULATORS

While the Astronauts had seen the model of the D-10 experiment, no trainer or simulator was used. We do feel, however, that for future flights a much better contact between the scientists and the Astronauts concerning the operations and the consequences of their modification in flight, a better understanding of the objectives, and the use of simulators or other training equipment would be very helpful to both the Astronauts and to the success of the experiment.

5.2.5 PARTICIPATION IN PRE-LAUNCH FLIGHT SIMULATION

Members of the experimenters group were present at pre-launch flight simulations of the total spacecraft.

5.3 Mission as Flown

The procedures in flight differed considerably from the planned mission procedures outlined above. This was due to a variety of factors; for example, certain of the experiments, such as the EVA (Extra-Vehicular Activities), and other maneuvers not associated with the D-10 experiment consumed more time than originally planned. Minor difficulties that occurred in flight also affected the sequence of the operations for the mission. This type of flexibility will always be necessary on a manned flight; it is essential to the welfare of the Astronauts and to the success of the mission.

The pre-flight Gemini X mission called for approximately 11 hours of D-10 experiment time with approximately 3 hours of controlled maneuvers. The in-flight period was very close to this; the total number of operating hours for D-10 was 12, with 4 hours of controlled maneuvers. The equipment performed very well in flight.

6. FLIGHT TEST I-RESULTS

The ion attitude sensing system was flown initially on the Gemini X spacecraft in August of 1966. The experiment functioned very well. It was operated for approximately 12 hours, including 3 1/2 hours when the inertial platform was also operating. The mission, as planned, is given in the previous section; it can be seen that it consisted of many specific in-flight maneuvers, including:

a. Yaw angle study which consisted of maintaining roll and pitch fixed and varying yaw from 0 to +40 deg right to 40 deg left at a rate determined by the bandwidth of the telemetry system and the ability of the Astronauts to control the spacecraft motion.

b. A pitch study similar to the yaw study.

c. A roll study similar to the yaw study.

d. Investigation of the vehicle wake properties as well as the measurement of the ion density as a function of position around the spacecraft.

e. Determination of effect of spacecraft thruster firings on the experiment outputs.

f. The determination of the influence of the environmental factors on the measurements, such as photoemission. Photoemission effects can best be determined near local sunrise and sunset.

g. The determination of the environmental positive ion concentrations along the spacecraft orbit.

Both the post-flight analysis of the transmitted data, examples of which are given in Figures 13 through 15, and the Astronauts' in-flight comparison of the ion sensing system with the inertial guidance system on the flight director's indicator show that the two systems agreed in absolute magnitude very well in both pitch and yaw. This statement holds for the conditions (including angular range) for which the D-10 experiment was designed.

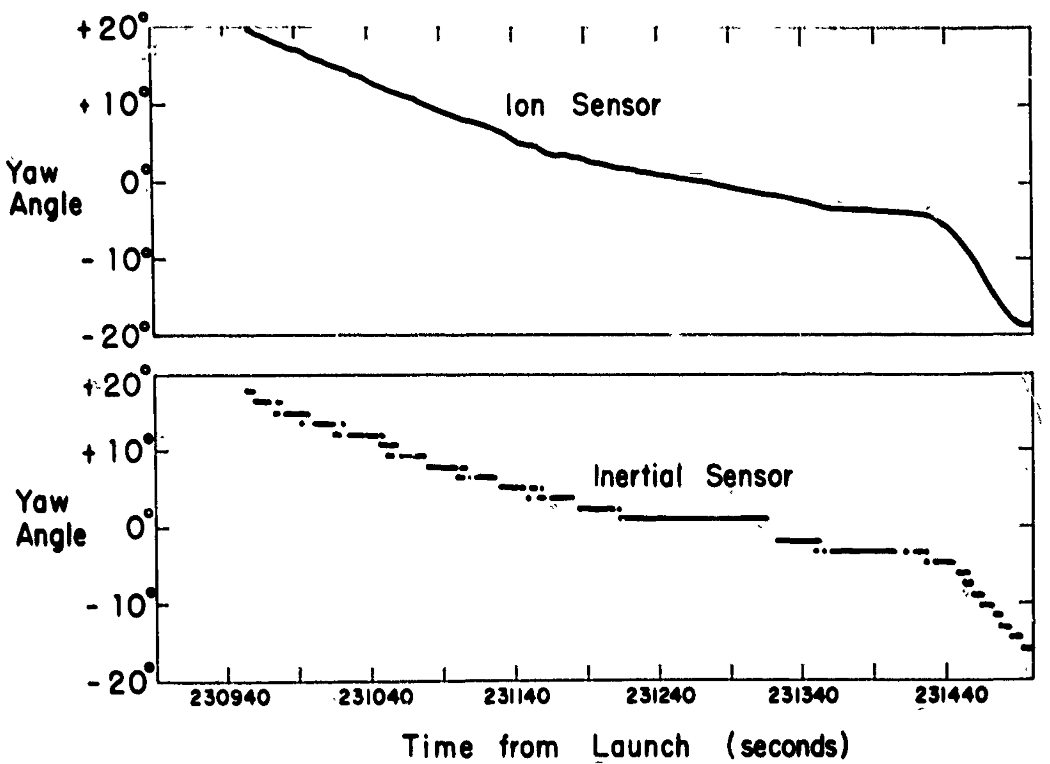

Figure 13. Example of Simultaneous Measurement of Yaw Angles by Means of the Ion and Inertial Systems vs Time From Launch (sec) - Gemini-10

In particular, the response of the Air Force D-10 Experiment to variations in angular position was extremely rapid, of the order of milliseconds. The yaw measurement results, as illustrated in Figures 13, 14, and 15, show that the magnitudes of the angles at a given time agree within the experimental error of the systems. The inertial yaw measurement accuracy is of the order of 2 deg. With the angular range of ± 20 deg, the ion yaw accuracy for the Gemini D-10 is of the order of ± 0.5 deg. The inertial data shown on Figures 13, 14, and 15 also illustrate characteristics that introduced difficulties in the manual control of the spacecraft. For example, when the yaw angle was varied, an 8-sec delay occurred.

The step-like variations in yaw angle giving jumps of the order of 1 to 1.5 deg in the inertial measurement were partly due to the synchronous detectors used in

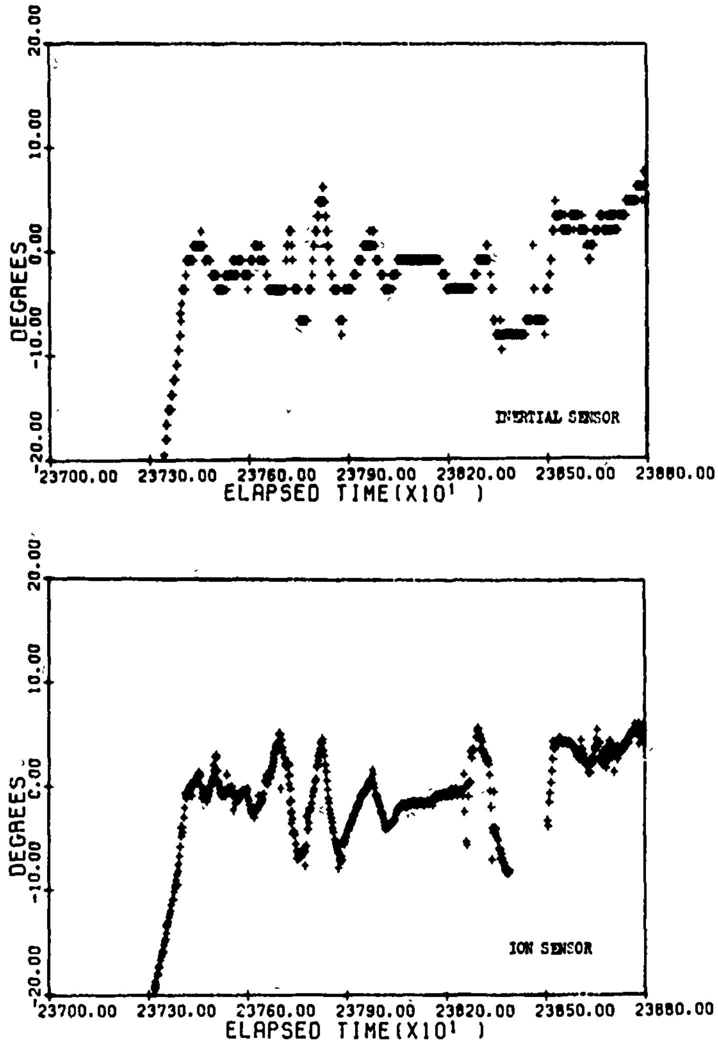

Figure 14. Comparison of Simultaneous Measurement of Yaw Angles by Means of Ion and Inertial Sensors vs Time From Launch (sec) - Gemini-10

the inertial guidance system and partly due to the manner in which the data was digitized through the telemetry system.

It is obvious that the addition of an ion yaw sensor would significantly improve existing attitude systems, primarily because of the slow response time and the relatively large inaccuracies in the present inertial yaw measuring techniques. The existing inertial system requires about 40 min to stabilize and warm-up after power turn-on. This is partly due to the electronic circuitry and to the necessary

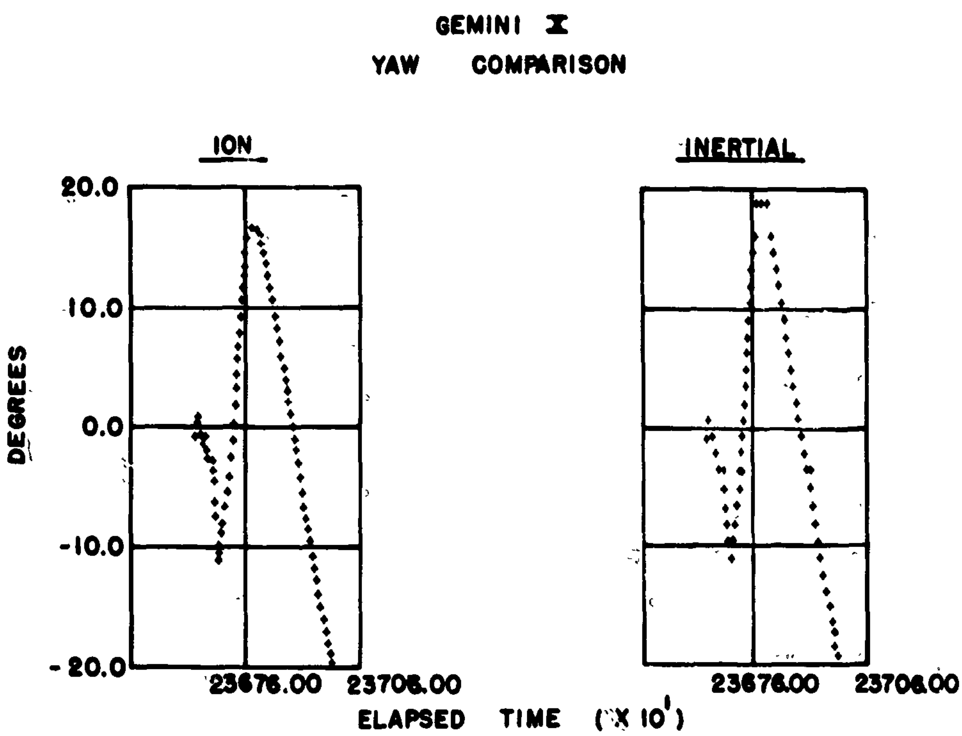

Figure 15. Comparison of Simultaneous Measurement of Yaw Angles by Means of the Ion and Inertial Sensors vs Time From Launch (sec) - Gemini-10

adjustments of the inertial platform. On the Gemini X mission, the Astronauts found that using the ion yaw angluar measurements decreased the time for the platform alignment by about two thirds.

Illustrations of the simultaneous measurements of pitch angles obtained from the ion and inertial systems are given in Figures 16 and 17. It is seen that the absolute values of the angles agree within 1. 5 deg over the angular range ± 20 deg. If one restricts the yaw angle to under 13 deg, the agreement is within 0. 5 deg. This is because of the location of the sensors on the spacecraft; when the yaw angular position was beyond +13 deg, an error was introduced due to shadowing from the vehicle.

The mounting limitations imposed by a fully designed spacecraft were discussed prior to flight by the AFCRL experimenters and SSD-Det No. 2 coordinators at the Manned Spacecraft Center. This result does illustrate that the proper mounting of ion sensors is very important for precise angular measurement.

A good example of the relative response time for these systems is seen in Figure 15 between 66 hr 0 min and 66 hr 5 min. While the individual maximum and minimum pitch agree very well, the fast response of the ion sensor makes it

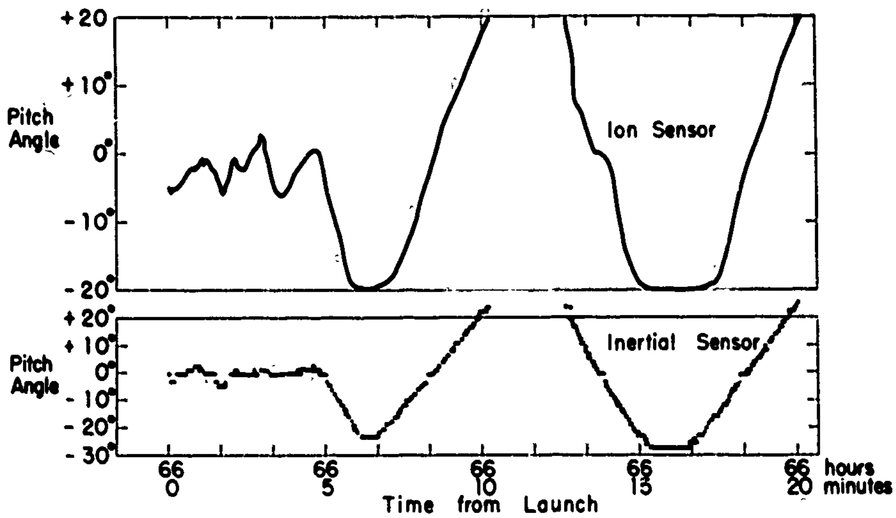

Figure 16. Comparison of Simultaneous Measurement of Pitch Angles by Means of the Ion and Inertial Sensor vs Time From Launch (sec) - Gemini-10

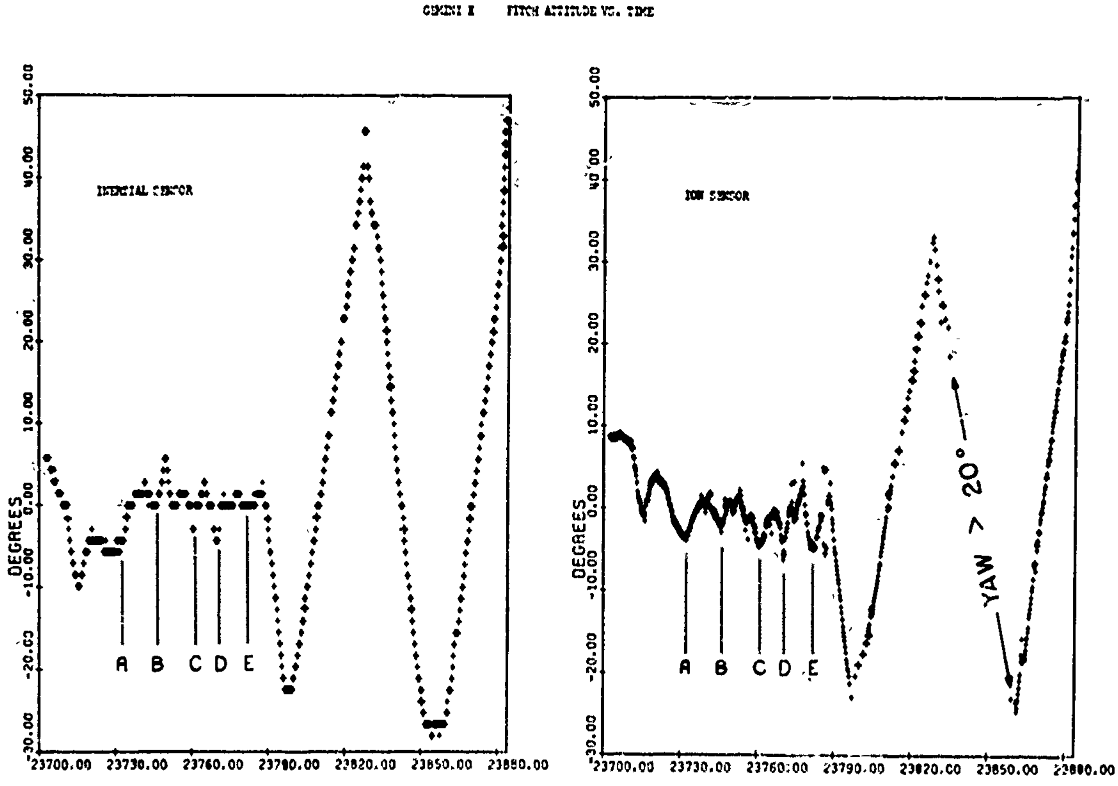

Figure 17. Comparison of Simultaneous Measurement of Pitch Angles by Means of the Ion Sensor and Inertial Sensor vs Time From Launch (sec) - Gemini-10

easy to detect angular changes. Operationally, this should be of particular importance in conserving thruster fuel and under conditions where rapid angular determinations are necessary.

As illustrated in Figure 18, which gives $\Delta\theta$ (the difference between the inertial and ion sensor measurements as a function of the roll angle, variations in roll do not affect yaw or pitch measurements. This is consistent with the theory and the design of the D-10 experiment.

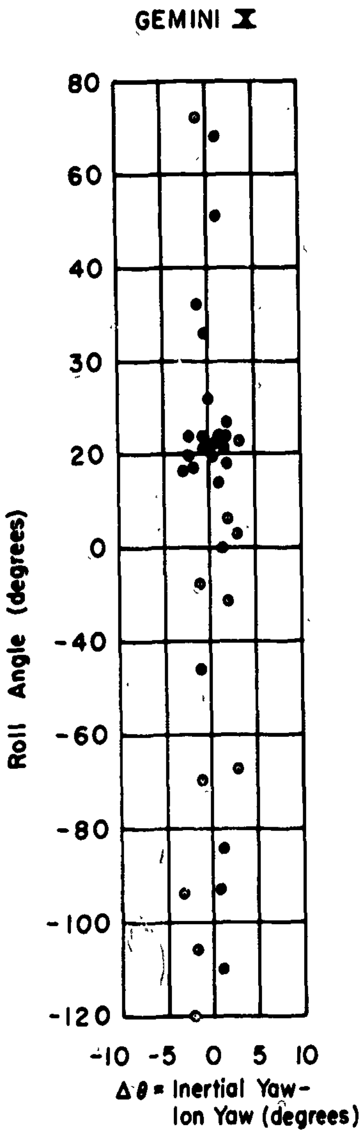

Figure 18. Illustration of Independence of Ion Sensor Yaw Measurements on Variations in Roll Angle

The results given in Figure 19 show that within the range 180 ± 20 deg, the experiment also functions; that is, there is good agreement between the ion sensors and the inertial guidance output. The experiment can, therefore, operate in the forward or aft direction. This will be discussed further in the discussion of Gemini XII results where a greater amount of this type of data was obtained.

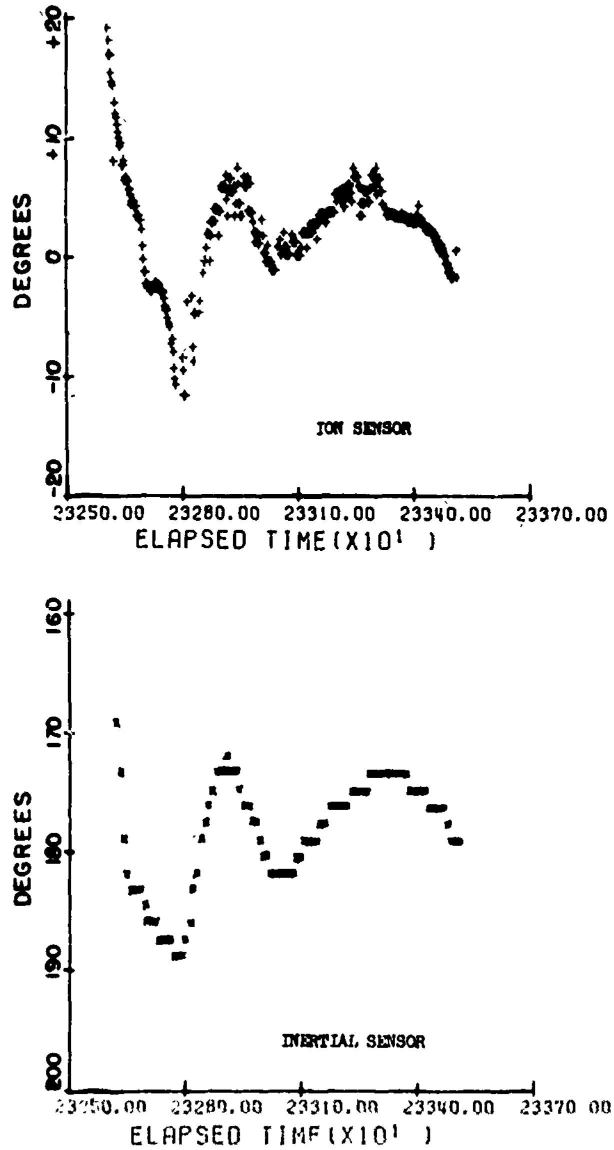

Figure 19. Comparison of Simultaneous Measurements of Pitch Angles by Means of the Ion and Inertial Sensors in the Vehicle Wake (180 ± 20 deg)

The environmental positive ion density along the satellite orbit was also obtained continuously on this flight. Four simultaneous measurements were obtained from the four electrometer outputs. The charge density is determined from the relation

$$N = \frac{i}{\alpha A e |V| \cos \theta} \qquad (8)$$

where

- i = electrometer current
- α = transmission loss of the grid system, experimentally determined
- A = aperture area
- e = particle charge
- V = vehicle velocity
- θ = the angle between direction of motion and the normal to the plane of the sensor.

θ was determined independently from the inertial measurements. Eight independent calculations of N were therefore obtained. The eight density calculations obtained simultaneously show remarkable agreement, as indicated in Figures 20A thru 20H. This held true independent of the direction of motion with respect to the position of the D-10 experiment. A discussion of the dependence of the charge density on latitude and altitude will be given in the discussion of Gemini XII results.

One of the experimental operations (Mode G) was to fire critical thrusters that were pointing most closely in the direction of the pitch and yaw sensors to determine whether thruster firings affected the D-10 operation. As illustrated in Figure 21, the thruster firing did vary the attitude of the spacecraft, as expected, and consistent with the simultaneous inertial guidance measurement changes. The measured charged density also varied for a fraction of a second; however, no deterioration of the D-10 experiment sensors occurred as a result of the firings.

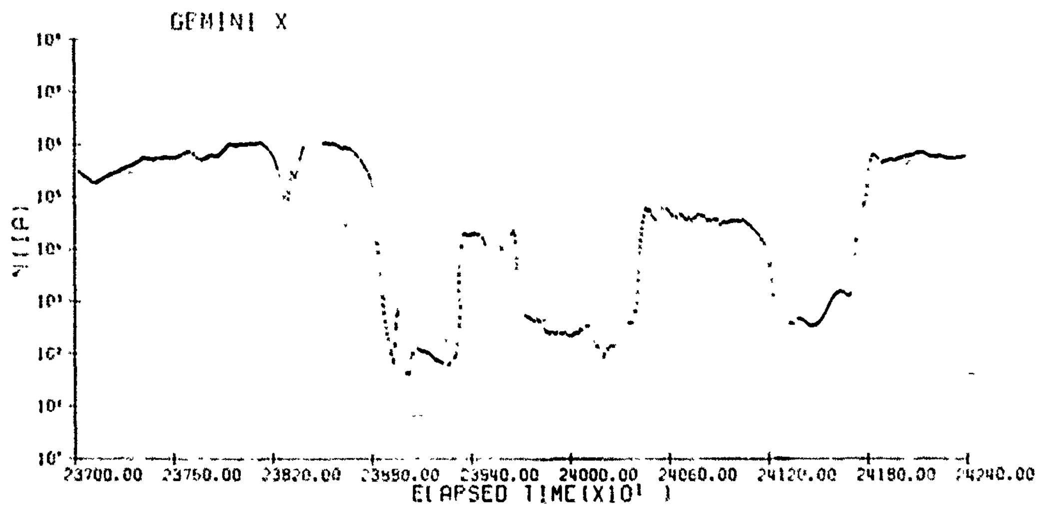

Figure 20 A. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Electrometer IA and Ion Sensor Yaw Angles

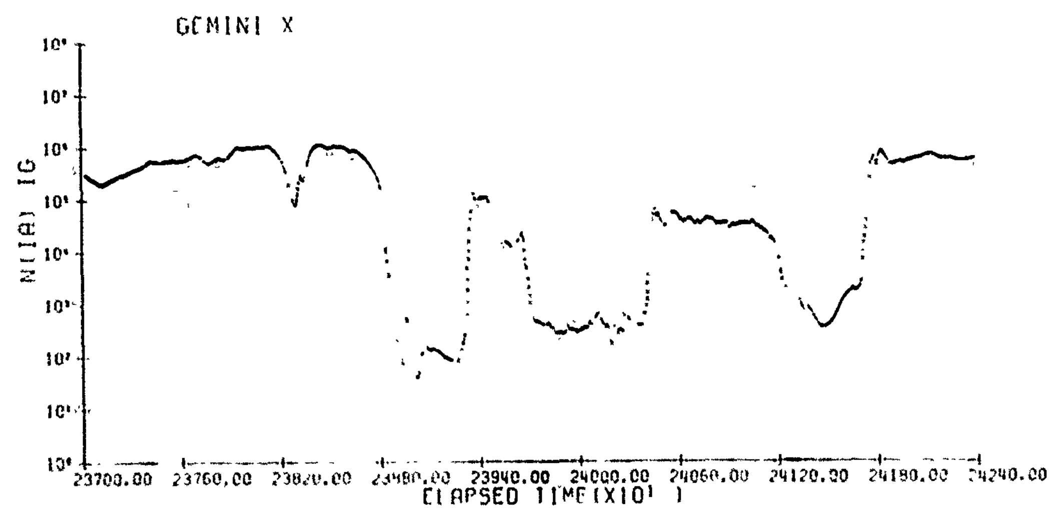

Figure 20 B. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Ion Sensor Electrometer IA and Inertial Yaw Angles IG

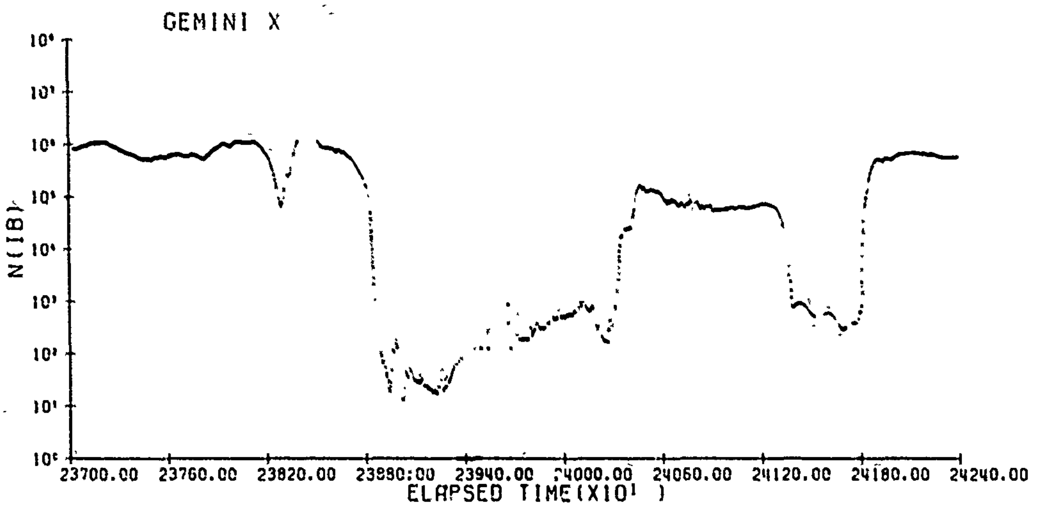

Figure 20 C. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Electrometer IB and Ion Sensor Yaw Angles

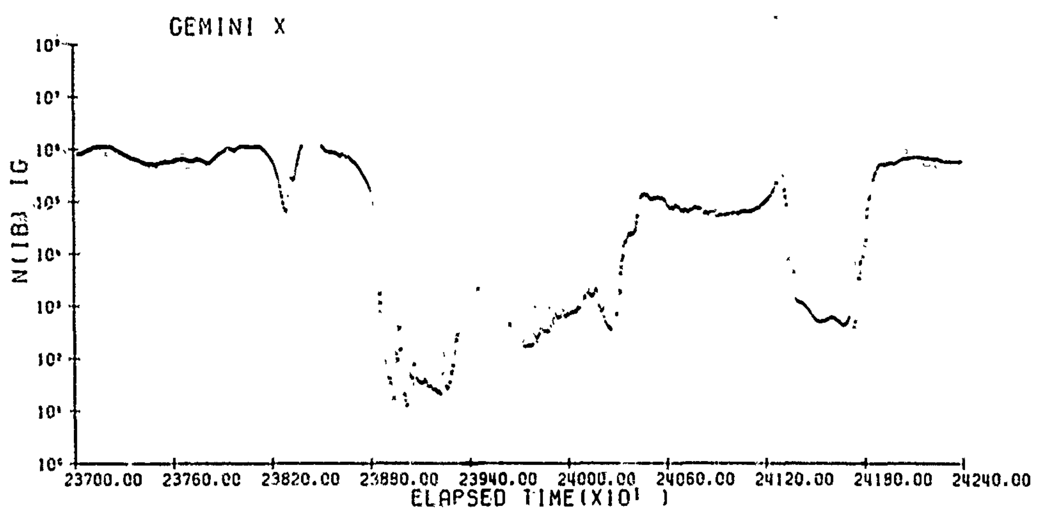

Figure 20 D. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Ion Sensor Electrometer IB and Inertial Yaw Angles IG

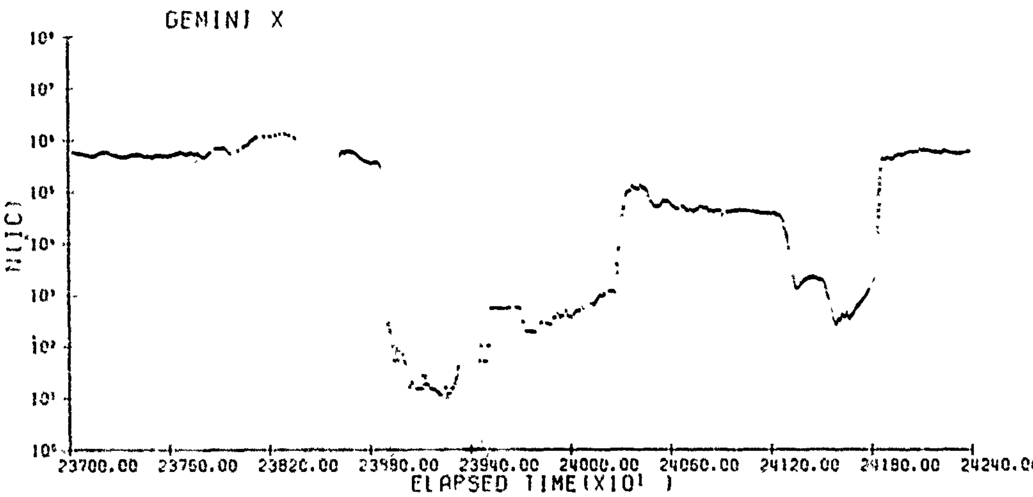

Figure 20 E. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Electrometer IC and Ion Sensor Pitch Angles

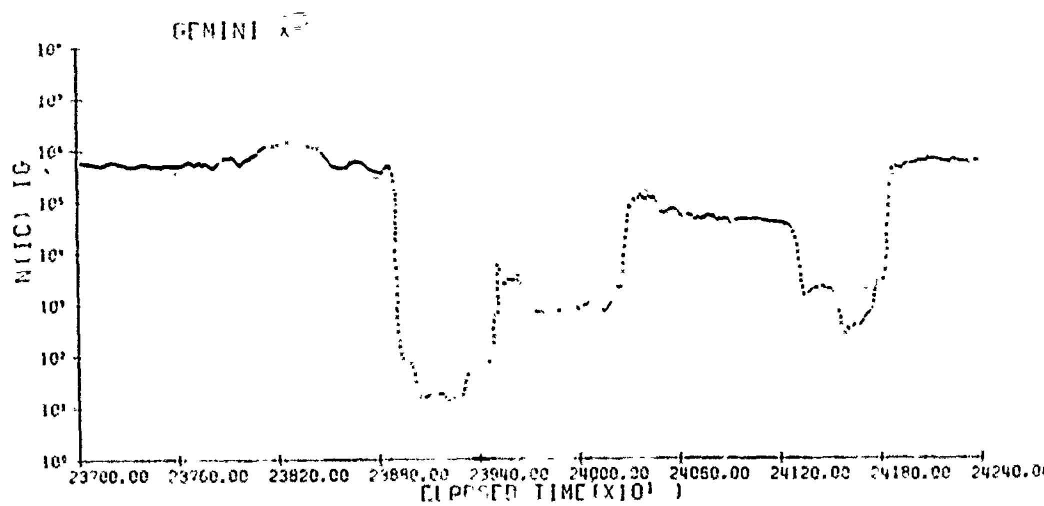

Figure 20 F. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Ion Sensor Electrometer IC and Inertial Pitch Angles IG

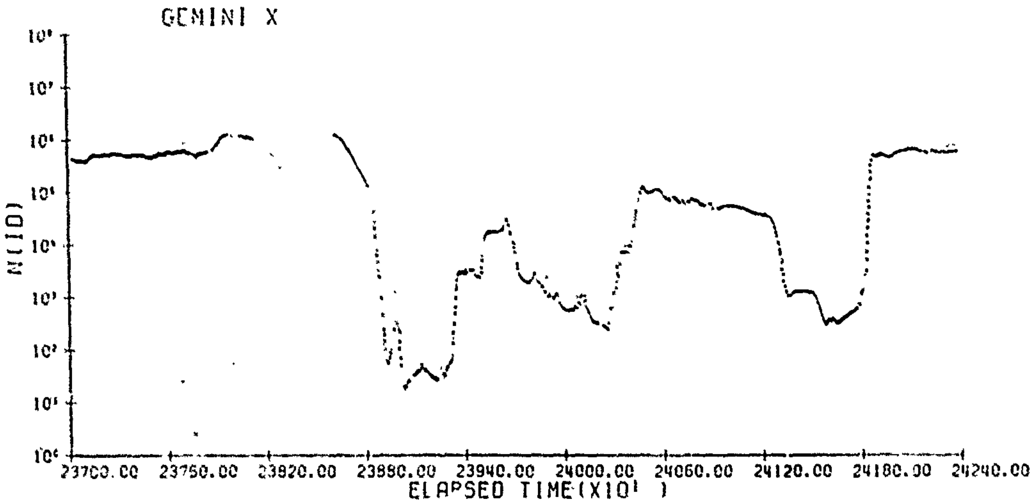

Figure 20 G. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Electrometer ID and Ion Sensor Pitch Angles

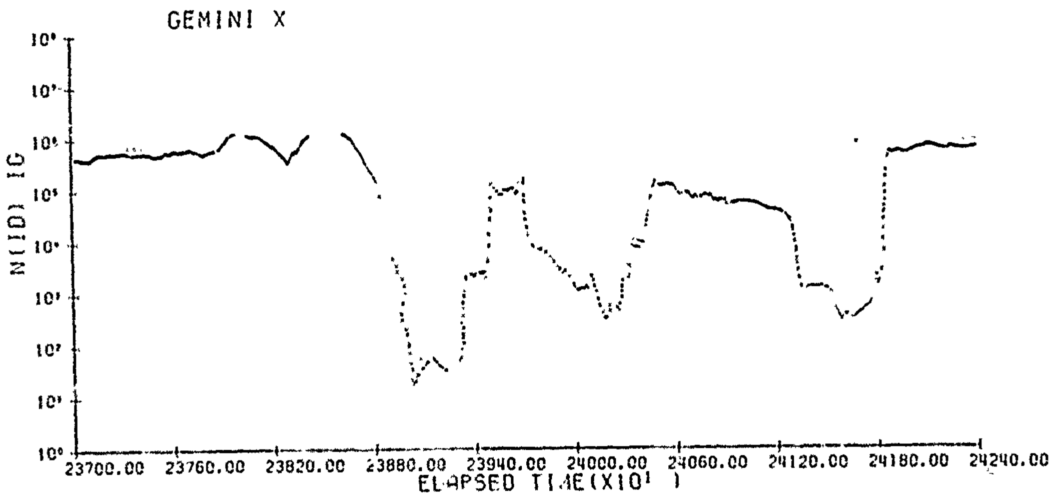

Figure 20 H. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Ion Sensor Electrometer ID and Inertial Pitch Angles IG

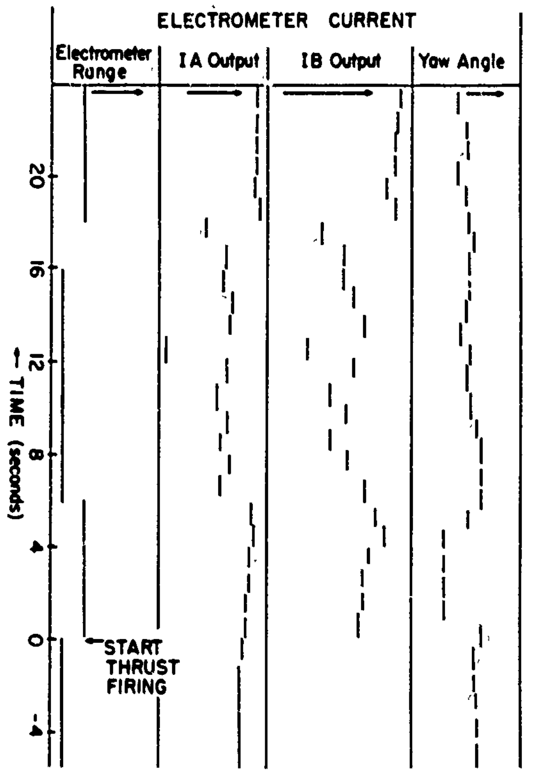

Figure 21. The Effect of Thruster Firings on Yaw Angular Measurements and Yaw Current Measurements as a Function of Time. Form of data determined by the real-time telemetry system - Gemini-10

7. FLIGHT TEST II - FLIGHT PLAN

The second flight test of the D-10 experiment took place on Gemini XII, the last flight of the Gemini series, in November 1966.

The mission as planned and the astronaut training were identical to those described in 5.1 and 5.2 for Flight Test I on Gemini X and will not be repeated here.

7.1 Mission as Flown

The experiment was operated for over 30 hours in flight, considerably longer than the planned experiment time (see discussion of the mission plan for Flight Test I). This came about partly to aid the ground crew in ascertaining the attitude of the vehicle during the periods when the inertial guidance system was turned off.

A real time station for D-10 was set up at Mission Control for the Gemini XII flight. The experimenter was on hand to evaluate the system in real time and to give inputs to the mission control at times when the inertial guidance could not be operated. This also allowed for real time comparison of the inertial and ion attitude sensing system. The real time data link worked very well.

Deviations in the planned maneuvers were due partly to loss of critical thrusters, reduction in the fuel capacity, and the usual flexibility that must be allowed for in any manned flight. After the flight, it was difficult to deduce the actual sequence of flight maneuvers for Gemini XII. However, according to the Astronaut's in-flight log, on-board voice tapes, and the magnetic data tapes, the experiment was operated for approximately 33 hours. Specific maneuvers for comparison of the inertial and the ion attitude sensing system were conducted for at least 6 hours. The equipment worked very well throughout the flight.

8. FLIGHT TEST II—RESULTS

The second test of the D-10 ion attitude sensing system was made on Gemini XII in November 1966. Power was applied to the experiment for slightly over 30 hours on Gemini XII; for 13 hours the inertial guidance system was also operative. Thus, on Gemini XII a great deal of data was obtained, including a comparison of the pitch and yaw angles on the ion attitude and inertial systems, the distribution of environmental positive ion along the spacecraft orbit, and an accurate description of the charge particle distribution around the spacecraft including the vehicle wake. The Gemini XII flight data were also analyzed to determine the relative motion of the earth with respect to the mean ion drift motions.

Specific in-flight maneuvers included yaw, pitch, roll studies, effects of photo-emmission, and other environmental factors on the sensors. The effect of spacecraft thruster firings on the experiment was determined. The Gemini X (Flight Test I) mission outline given above provides an outline of these operational procedures.

The experiment operated extremely well throughout the power-on period. Over the angular range for which the ion attitude experiment was designed, the pitch and yaw measurements obtained by both the ion sensor system and the inertial guidance system were within the experimental error of both systems. Post-flight analysis showed that the pitch angle results agree within ± 0.5 deg. Comparison of yaw angles over the same angular range indicates an agreement within ± 1.5 deg. It should be noted that the inertial guidance system has an accuracy in yaw of the order of ± 2 deg.

Examples of yaw measurements obtained simultaneously by both the ion sensor and the inertial system are illustrated in Figures 22 and 23. The time is given as elapsed time from launch. The faster response of the ion sensor can be seen in these figures. The same interpretation of this effect holds as that given for the experiment flown on Gemini X.

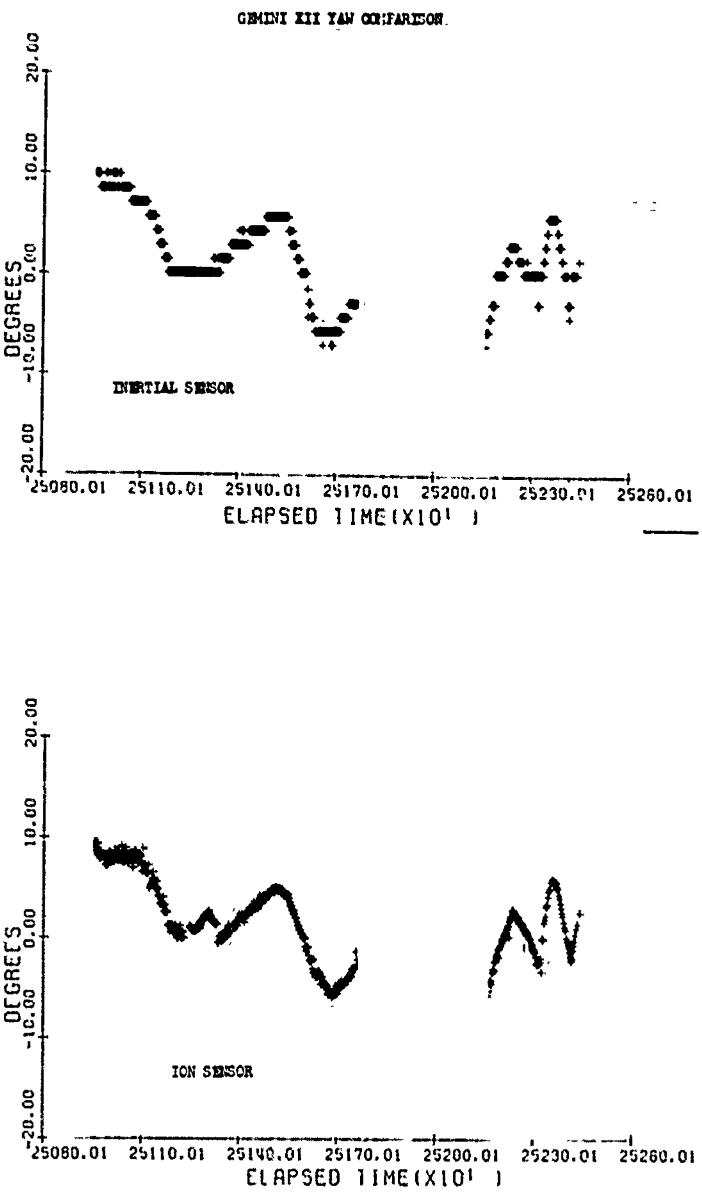

Figure 22. Comparison of Simultaneous Yaw Angular Measurements by Means of the Ion and Inertial Sensors vs Time From Launch (sec)-Gemini-12

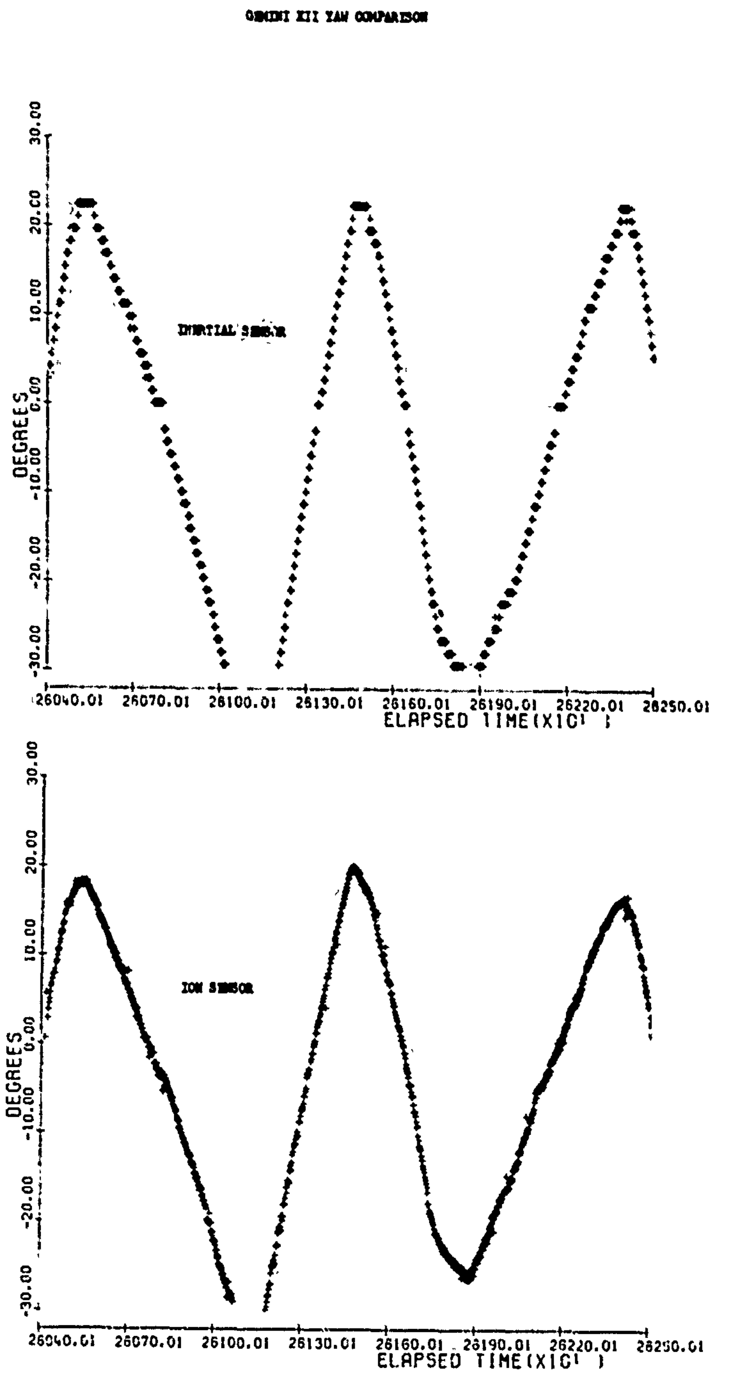

Figure 23. Comparison of Simultaneous Yaw Angular Measurements by Means of the Inertial and Ion Sensors vs Time From Launch (sec)- Gemini-12

Examples of pitch-angle measurements obtained simultaneously by the inertial and ion sensors are given in Figures 24 and 25 for the Gemini-XII flight. At a given time it can be seen that the agreement between the two systems is of the order of ± 0.5 deg over the range ± 20 deg.

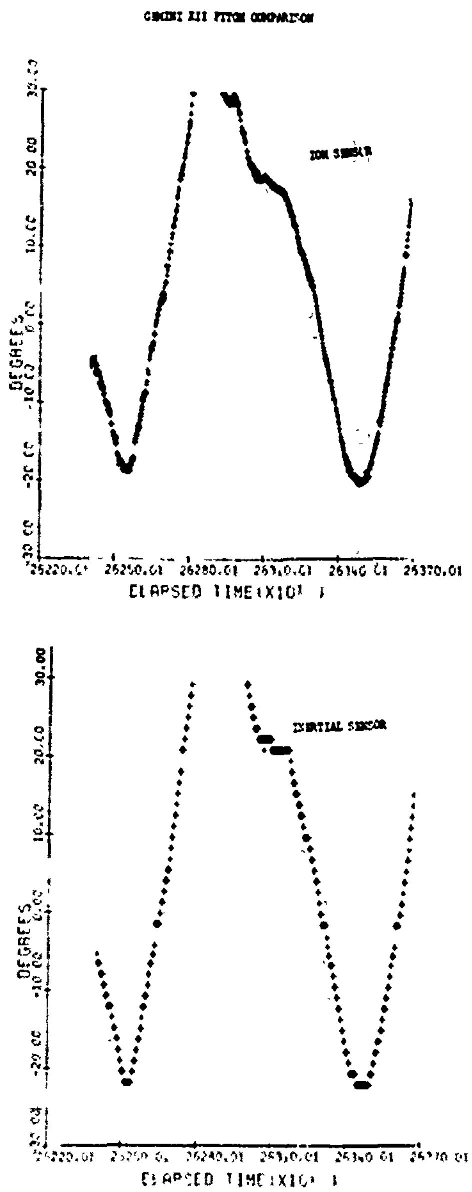

Figure 24. Comparison of Simultaneous Measurements of Pitch Angles by Means of the Inertial and Ion Sensors vs Time From Launch (sec) - Gemini-12

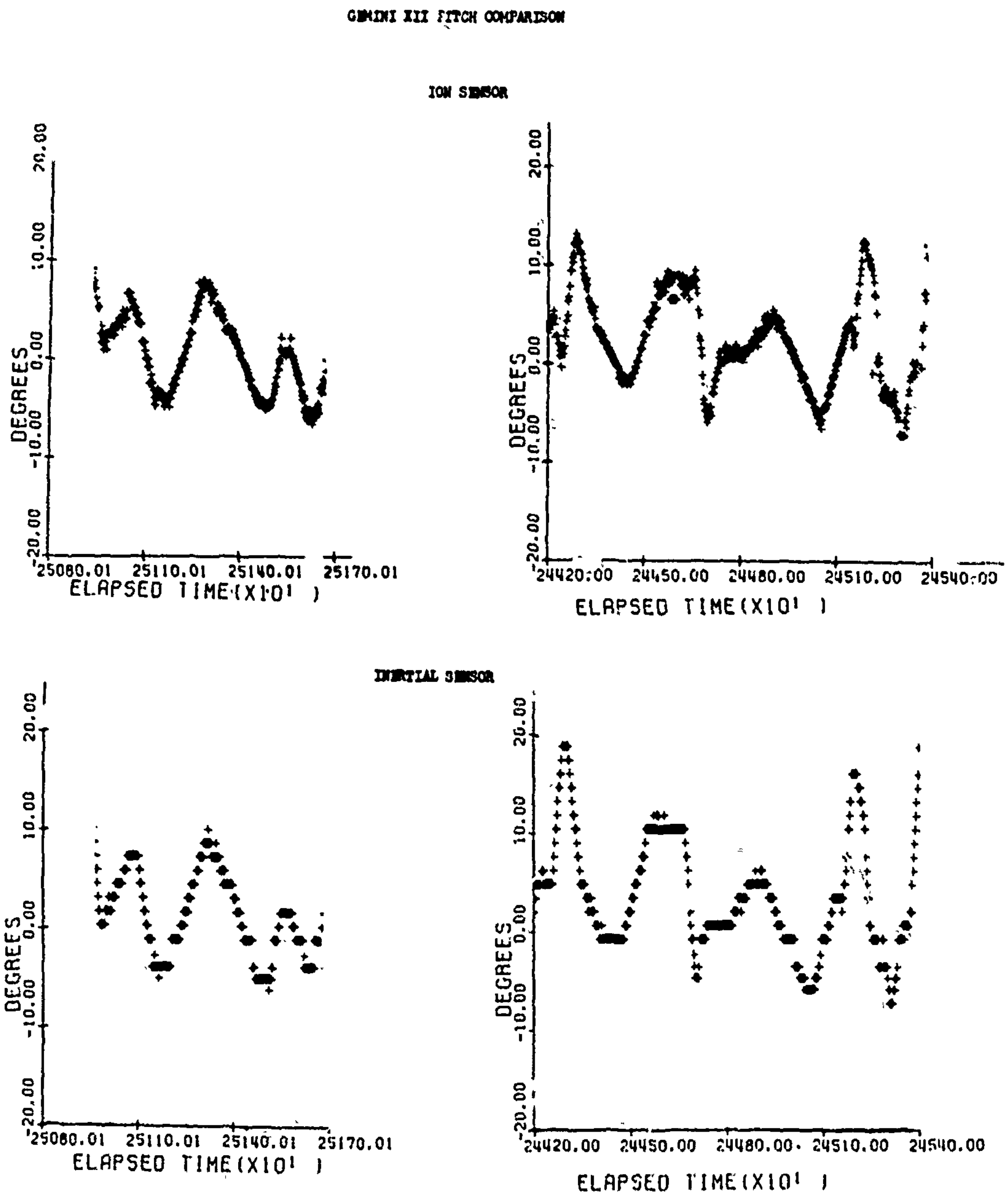

Figure 25. Comparison of Simultaneous Pitch Angular Measurements by Means of The Ion Sensor and the Inertial Guidance System vs Time From Launch (sec)- Gemini-12

Another Gemini X flight result that was confirmed by the Gemini XII flight is the fact that variations in spacecraft roll position do not affect the yaw or pitch measurements. The Gemini flights also demonstrated, as illustrated in Figure 26, that the experiment functions in the reverse direction as well as in the forward direction. We believe this unexpected result was due to the fact that the sensors were mounted away from the spacecraft on a boom. The ratio of the velocity of the spacecraft to the mean ion thermal velocity was therefore greater than the theoretically operable limit for the system. This is a potentially important result because pitch or yaw attitude measurements may be obtained throughout a 360 deg range with a single sensor. This characteristic would be of importance in preparation for re-entry, for example.

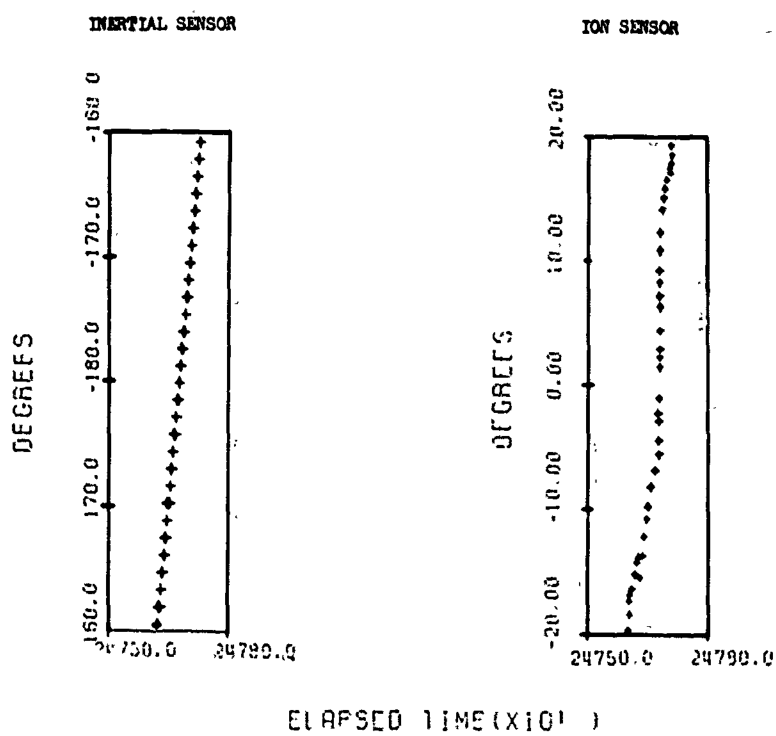

Figure 26. Simultaneous Measurements of Pitch Angle by Means of the Inertial and Ion Sensors in the Vehicle Wake Region

It was noted earlier that on the Gemini XII mission, a real-time station for the D-10 experiment was set up at the Manned Space Flight Center. An unexpected opportunity for the in-flight application of the ion sensor occurred during the Gemini XII flight. Shortly after experiment turn-on, the on-board inertial computer was turned on in the angular measurement mode.

During the real-time comparison of the two systems, their outputs for both pitch and yaw agreed within a fraction of a degree. This verified accuracy of the ion sensor system proved useful later in the flight when fuel cell degradation occurred and the inertial system had to be turned off to conserve fuel. The D-10 experiment was then utilized by mission control as a check on the spacecraft attitude and for updating the mission flight plan.

It was also demonstrated on Gemini XII that the firing of various spacecraft thrusters, those directed toward the sensors and other operational thrusters, did not influence the operation of the D-10 experiment. The rapid response time of the D-10 experiment shows that it could be particularly valuable for docking, for special operations such as photography, or in any flight maneuvers where fine control of the spacecraft attitude is desirable.

An example of the variation of positive ion density obtained during a complete orbital period is illustrated in Figure 27. The large variations in charge density from 10^3 to 10^6 per cm^3 on a given orbit are due largely to changes in production on the night and day side of the earth. This result demonstrates that the D-10 type experiment could be a valuable tool for determining the variations in the world-wide distributions of positive ions during a period of rising solar activity.

Consistent with the Gemini X results discussed earlier, the calculations of the charged densities from the simultaneous outputs of the four electrometers of the Gemini XII D-10 experiment, using either the inertial or ion attitude angles, are in very good agreement. This result is illustrated in Figures 28 A through H.

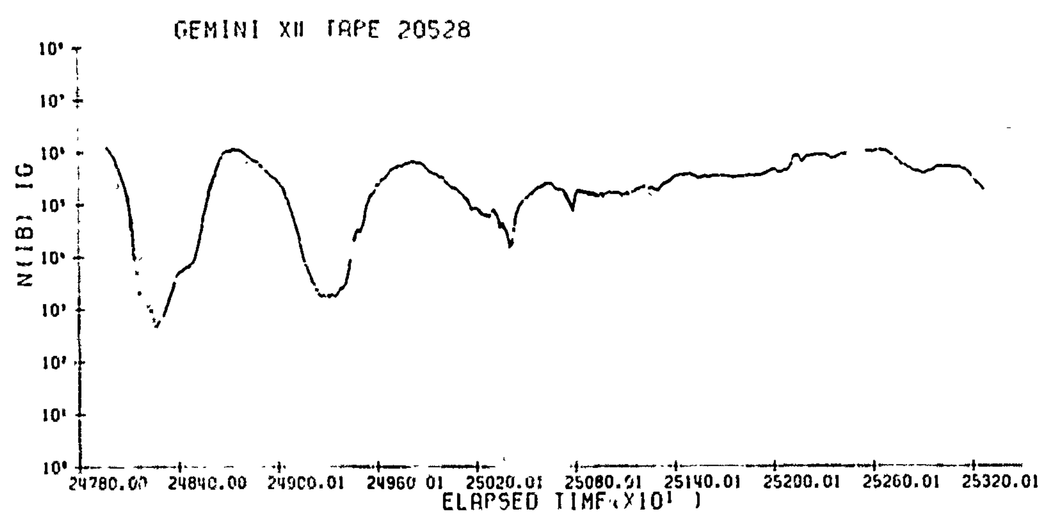

Figure 27 A. Ion Density (no/cm^3) vs Time From Launch (sec), One Orbit of Gemini-12

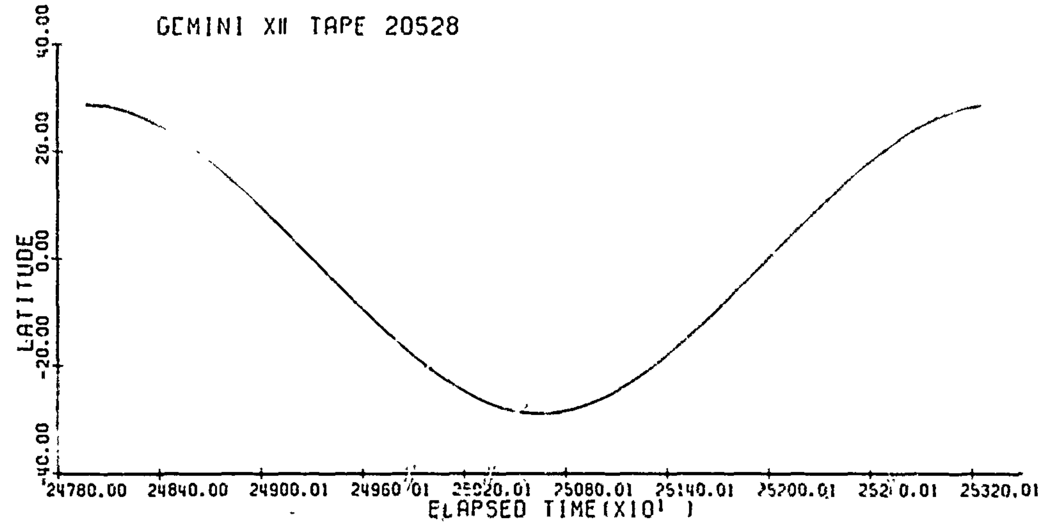

Figure 27 B. Geographic Latitude vs Time From Launch (sec), on One Orbit of Gemini-12

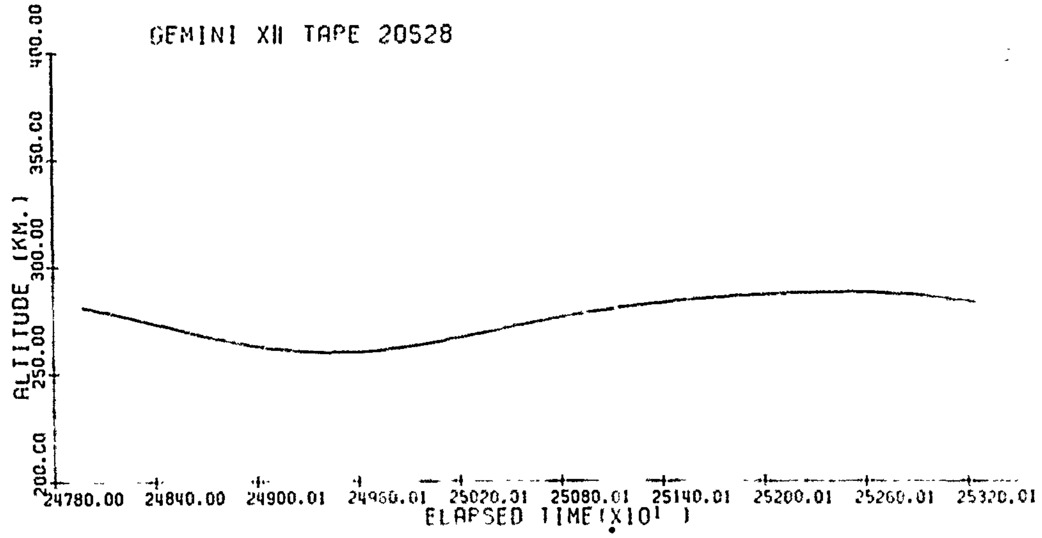

Figure 27 C. Altitude (km) vs Time From Launch (sec) on One Orbit of Gemini-12

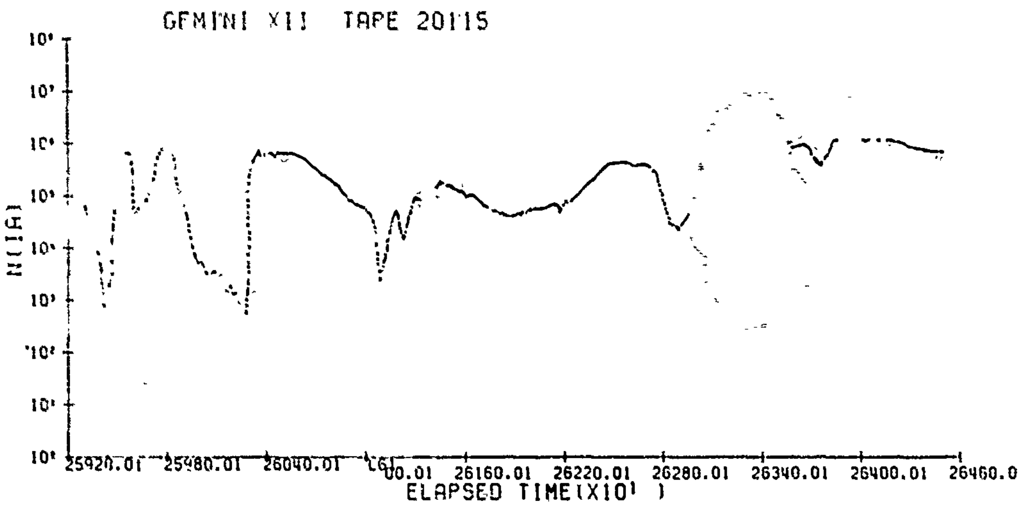

Figure 28 A. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Electrometer IA and Ion Sensor Yaw Angles

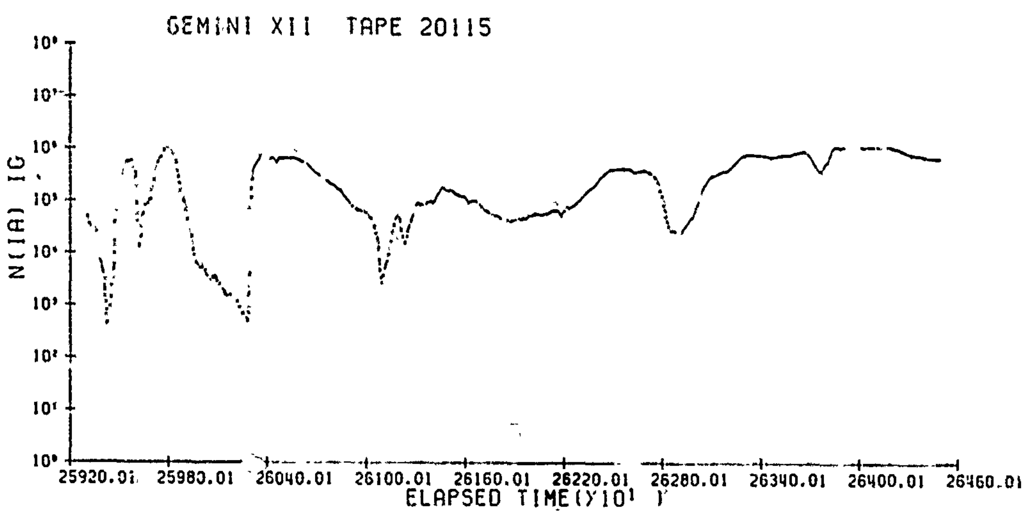

Figure 28 B. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Ion Sensor Electrometer IA and Inertial Yaw Angles IG

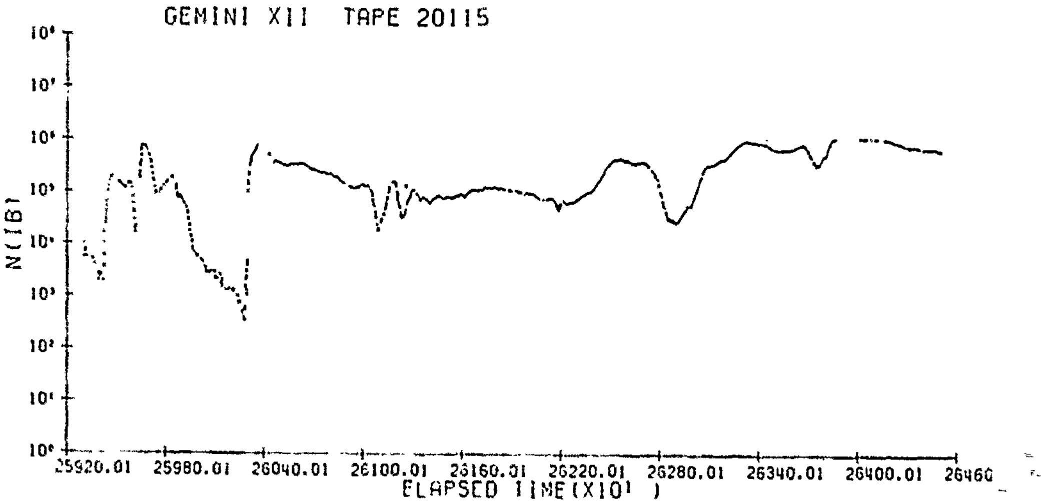

Figure 28 C. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Electrometer IB and Ion Sensor Yaw Angles

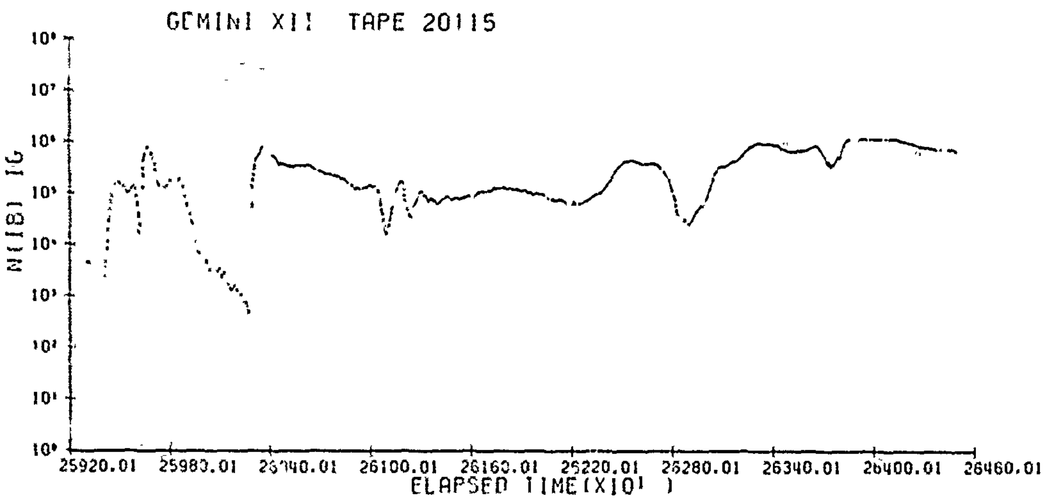

Figure 28 D. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Yaw Ion Sensor Electrometer IB and Inertial Yaw Angles IG

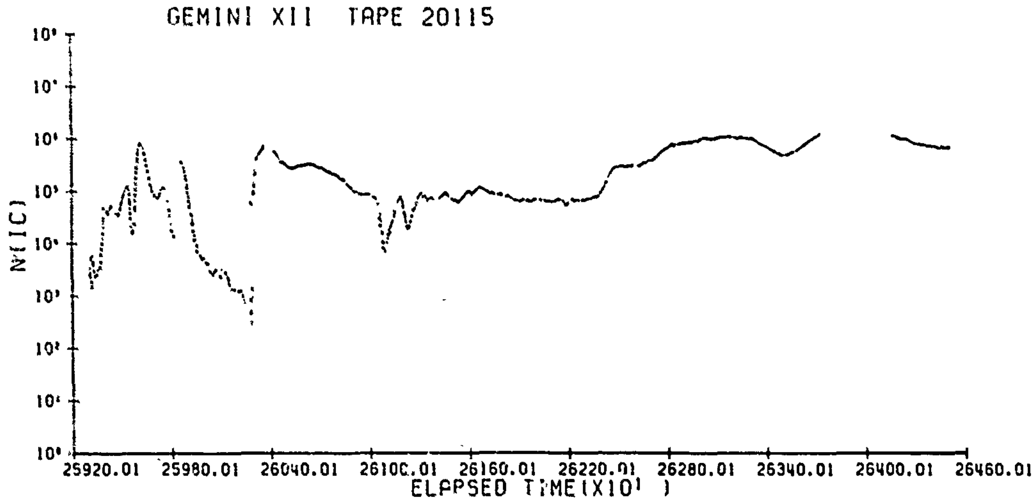

Figure 28 E. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Electrometer IC and Ion Sensor Pitch Angles

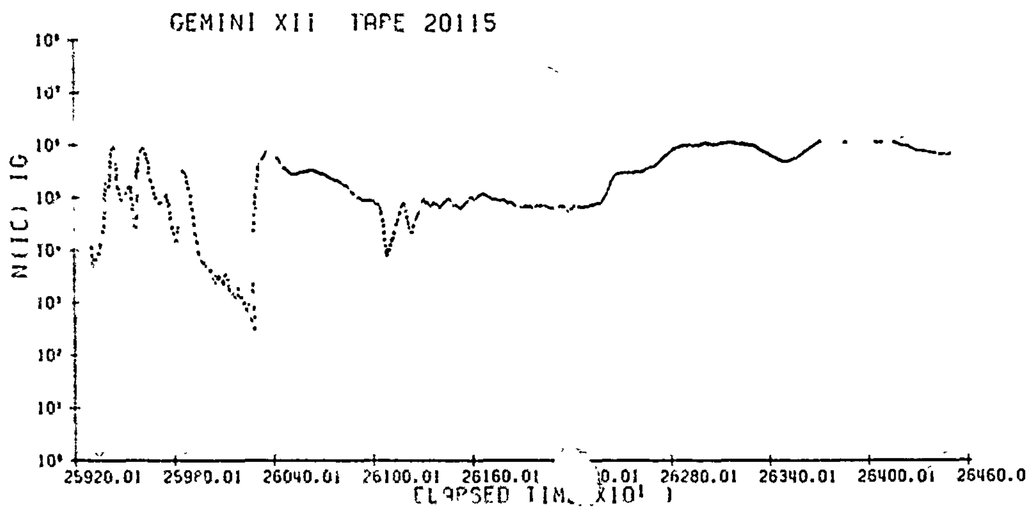

Figure 28 F. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Ion Sensor Electrometer IC and Inertial Pitch Angles IG

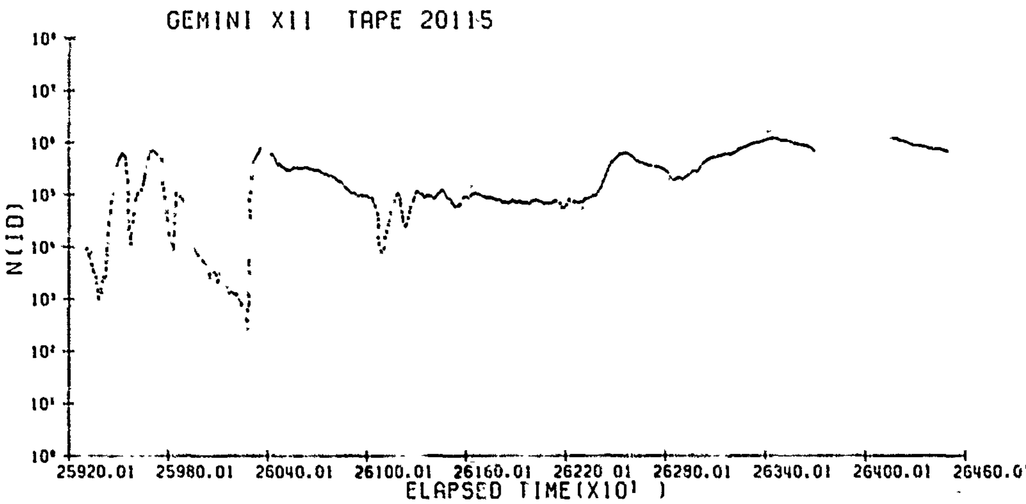

Figure 28 G. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Electrometer ID and Ion Sensor Pitch Angles

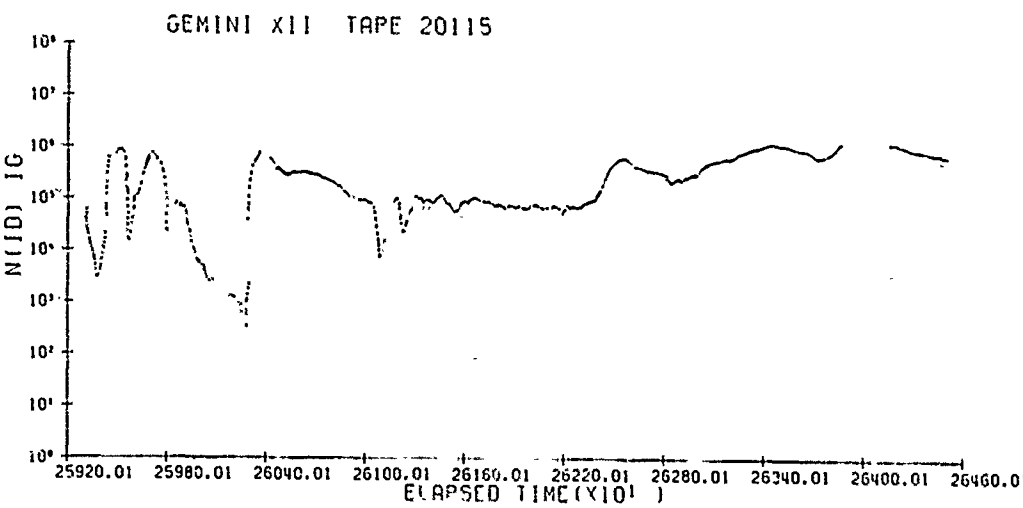

Figure 28 H. Positive Ion Density (no/cm^3) vs Time From Launch (sec) Pitch Ion Sensor Electrometer ID and Inertial Pitch Angles IG

An example of the measurement of the distribution of ionization as a function of position around the spacecraft is given in Figure 29. This figure shows that the charge density decreases by over an order of magnitude in the -180 deg position (the wake region). A separate scientific report will be written on the significance of the distribution of charged particles as a function of position about the spacecraft in the altitude region where free molecular flow exists.

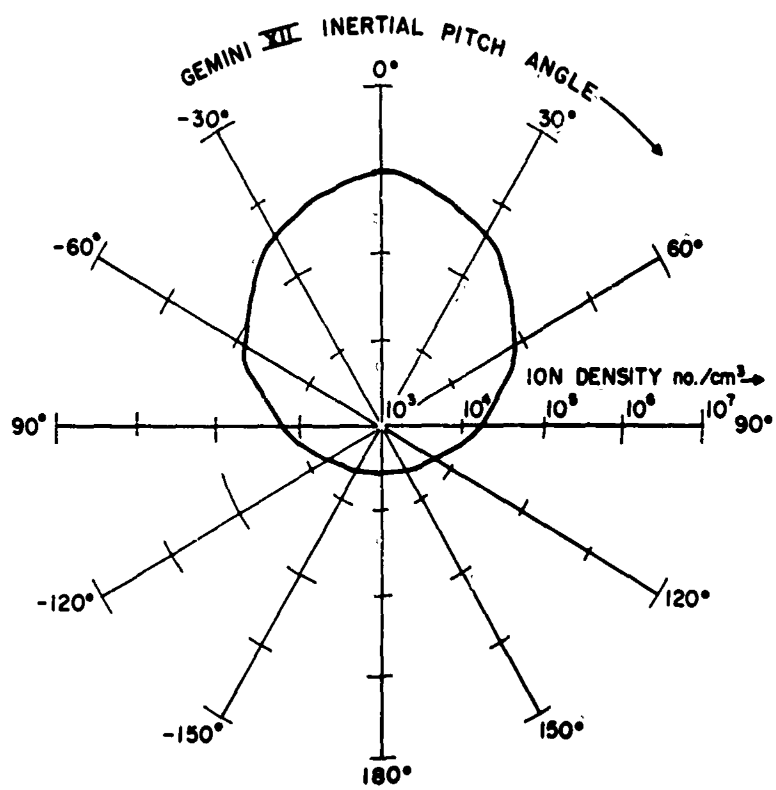

Figure 29. Example of the Measurement of the Distribution of Ionization as a Function of Position Around the Spacecraft - Gemini XII

It was anticipated and noted in the pre-flight mission plan that thruster firings, specifically thrusters 14 and 16, might adversely affect the D-10 operation. These thursters are fired in the direction of either the pitch or yaw sensors. In Figure 30, it is seen that, as expected, the firings did change the attitude of the vehicle. This is confirmed by the inertial results. The firings also changed the charge density for a period of approximately 2 sec. However, the density changes did not affect the angular measuremement and no deterioration of the D-10 sensors was observed.

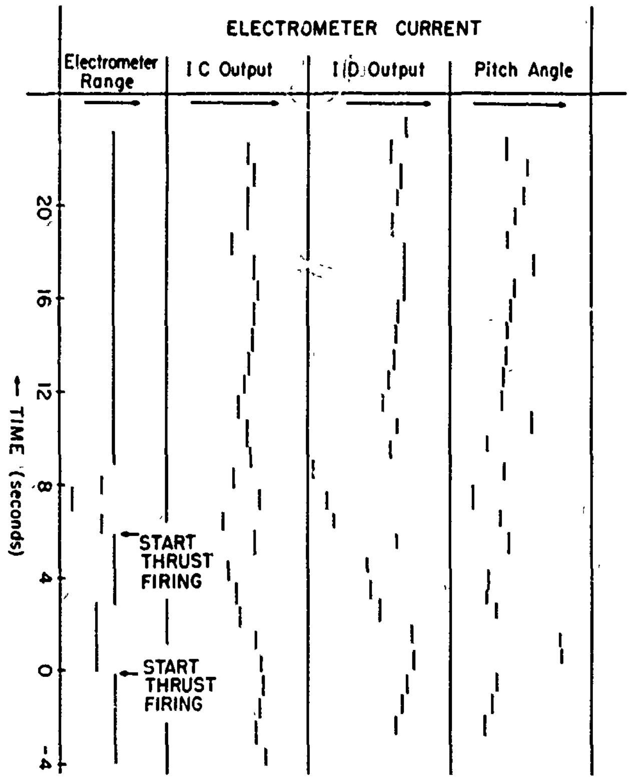

Figure 30. Illustration of the Effect of Thruster Firings on Pitch Angle and on Pitch Electrometer Currents as a Function of Time. Form of data is determined by the real-time telemetry system - Gemini-12

From the post-flight analysis of the experimental results, the dependence of ion angular measurements on latitude could be determined. In the case of Gemini XII, the geographic latitude range was approximately ± 30 deg. Any systematic variation in $\Delta\phi$, the difference between the inertial and ion attitude ion measurements, over this latitude range would indicate variations in the mean ion drift motions in the F-region, along the spacecraft trajectory. Only angular (pitch or yaw) measurements obtained over the range ± 20 deg were selected for the analysis, at 5 deg intervals. The results, as indicated in Figure 31 giving latitude vs $\Delta\phi$, do not show a significant dependence on geographic latitude (± 30 deg). The result implies a negligible influence of ion drift motion on latitude over the geographic region investigated. A detailed discussion of the significance of these results will be given in a separate scientific report.

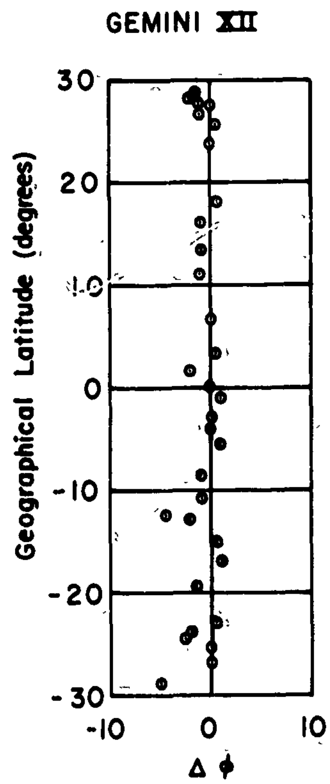

Figure 31. Geographical Latitude (deg) vs Δφ; Δφ = Inertial Minus Ion Pitch Angles

9. CONCLUSIONS

The results of the D-10 experiment flown on Geminis X and XII show that it is possible to measure pitch and yaw angles to within a fraction of a degree utilizing environmental ions. This conclusion is based on the results obtained during 45 hr of operation. During this period specific maneuvers were carried out to determine the effects of photo-emission currents, the effect of pitch and roll on yaw maneuvers, the effect of yaw and roll on pitch maneuvers, etc.

The results also demonstrated the degree to which the Astronauts could control the motion of the spacecraft. They showed that the firing of lateral thrusters directly into the sensors did not affect the operation for more than a fraction of a second. The response time of the ion attitude (D-10) system was found to be much more rapid than the inertial guidance system (milliseconds compared to seconds).

The flight results also showed that the use of the ion attitude sensing system could considerable reduce the time required for special maneuvers such as docking, and for photography, re-entry, etc. On Gemini XII for example the Astronauts reduced the time required to align the inertial platform from 40 to approximately 5 min by using the ion pitch and yaw sensors as a reference. The yaw sensing part of the system is particularly valuable because no other instrument exists that can directly give spacecraft yaw.

One of the Astronauts indicated that he observed a transient in the ion sensor "Flight Director Indicator" for a fraction of a second when certain thrusters were turned on. This could not be detected in the real time transmitted data nor in the tape-recorder play-back. The latter data is played back at the rate of once per second. A transient could be due to current surges or ground loops in the electrical circuits resulting from varying spacecraft potential or to transients in the power ground lines at the time of firing. Ground tests could be designed to determine the exact source of any transients and proper filtering could be introduced in future ion attitude systems.

The Gemini X and XII results indicate that the use of a horizon detector together with pitch and yaw sensors would give a complete description of the spacecraft position and attitude. Furthermore, with the addition of a servo-type system it could be utilized to provide a completely automatic attitude control system. It would be applicable from the lowest satellite altitudes up to at least 10 earth radii.

The results also showed that by transmitting output voltages from the individual electrometers of the system, the charge density along the trajectory of the satellite could be determined. This would be very useful in determining phenomena that occur in manned or in unmanned spaceflight.

If a sweep voltage were periodically applied to the appropriate grids of the sensor, the spacecraft potential with respect to the undisturbed environment could be measured. The value of the spacecraft potential has been of special interest to those interested in manned spaceflight. The measurement of spacecraft potential is always incorporated in our unmanned satellite experiments where the properties of thermal charged particles are studied.

The Gemini X D-10 results also showed that there is no significant systematic change in the ion drift motion with latitude over the range of ± 30 deg (Gemini spacecraft latitude). This demonstrates that for precision attitude determination, one does not need to take into account a mean ion drift motion as a correction to the measurement. We have not completed the analysis of D-10 Gemini XII data; however, this appears to hold true for this flight also. This latter point will be discussed fully in future scientific reports.

10. RECOMMENDATIONS

The ion attitude sensing system developed by AFCRL with the support of OAR, SSC, Research and Technology Directorate, and the Manned Spacecraft Center, and which was flown successfully on Geminis X and XII, can be a very valuable tool for future space flight. A manually controlled attitude system could be devised from the proper combination of pitch and yaw sensors together with either orbital information or a horizon scanner. The system could be made fully automatic by transmitting the output to reaction wheels, a servo system, torquing coils, etc.

As shown in Table 1, it has a very rapid response time, light weight, small power consumption, long lifetime, reduced volume, and lower cost. A comparison of the characteristics of the ion attitude sensing system and the inertial system used on Geminis X and XII is given in Table 1.

Table 1. Comparison of Ion Attitude Sensor and the Inertial System Characteristics, Gemini X and XII

	Inertial System	D-10 System	Improvement Factor
Response Time	1 sec	1 msec	1,000
Weight	750 lb	15 lb	50
Power	150 W	3.0 W	50
Lifetime	≈ 14 days (mechanical)	>1 year	infinite
Volume	3 cu ft	0.2 cu ft	15
Cost	$ 1,500,000	$ 30,000	50

It is recognized that the relative cost, complexity, etc., would vary for either system depending upon the accuracy desired, for example. The D-10 system includes the development cost of a new system. Depending upon the required accuracy, angular range, and quality, its cost could be significantly reduced. The fast response time is a particularly important attribute of the ion sensing system for special in-flight maneuvers. For long-lived spacecraft, the low weight and power consumption of the D-10 type system are very desirable. Its use would also be of particular importance on satellites where reliability and low power and fuel consumption are necessary.

Specific applications of the D-10 experiment alone or with the addition of a horizon scanner and servo system are given in Table 2. It has been noted that crude gravity gradient stabilization and magnetic stabilization systems exist. They tend, however, to be directed toward specific scientific objectives determining the pitch angles of incoming energetic particles. They are not particularly suited to attitude control of manned or unmanned space vehicles.

Table 2. Potential Applications

1.	Yaw measurements for rockets and satellites (accuracy: fraction of a degree).
2.	Complete attitude system—including pitch, roll, and yaw—with addition of horizon scanner for: manned spacecraft; unmanned spacecraft; manual control; automatic control.
3.	Attitude sensing for supersonic transport vehicles.
4.	Space maneuvering applications: docking, re-entry, photography, etc.

On the basis of our experience with the D-10 experiment on Gemini X and XII spacecrafts, certain recommendations and comments can be made:

(1) The attitude sensing system should be on the main spacecraft, not on the aft section. The aft section must be removed before retrofire, which means that it could not be used in re-entry maneuvers.

(2) The electronics and sensor units were mounted on a complicated boom; this was necessary because of the integration constraints on the aft section. On future vehicles it would be desirable to mount the electronics package in the sprcecraft and place the sensors on simpler booms at appropriate points outside the vehicle. They could be retracted during other extra-vehicle activities if necessary. Booms would not be required on vehicles where sensors could be appropriately positioned. It should be noted that common electronics could be used for pitch and yaw and for both the forward and reverse direction measurements. They would considerably reduce the cost of the total system.

(3) The precise positioning of the sensors is important in the design of the experiment. This depends on each mission objective. For large look-angle requirements (approximately ± 90 deg) the sensors could be mounted forward in the main capsule where the vehicle shadowing is significantly

reduced. The pitch and yaw measurements are independent of roll; however, if the sensors are not mounted properly, a pitch variation will affect the yaw measurement and vice versa. This was demonstrated on the maneuvers conducted on Gemini spacecrafts X and XII.

(4) It has been noted that pre-flight briefings with the Astronauts to discuss the performance, objectives, emergency operations, etc., of the system are very important. More time was spent with the Astronauts before the Gemini XII flight then before the Gemini X mission. This additional briefing time contributed significantly to the increased performance of the Astronauts in carrying out the various maneuvers required to evaluate the ion attitude system. Nevertheless, increased preflight participation of the Astronauts would be desirable. This should include simulation procedures with the experimentor. Post-flight analysis has shown that the specific mission tests were not usually met during inflight maneuvers. In the case of the D-10 experiments, this did not degrade the quality of the results. It did, however, make it much more difficult to analyze, evaluate, and interpret the data. For example, when the Astronauts were carrying out a pitch maneuver, they were usually also varying yaw and roll. Although some of this is inherent in limitations of spacecraft control, angular limits could have been given which could have aided the Astronauts and reduced the time required for data processing and evaluation of results.

Acknowledgments

The authors wish to acknowledge the support of other AFCRL personnel who contributed to the development and evaluation of the positive ion attitude sensing system, including D. DeCourcy, A. Romanelli, and S. Cleaves. The authors are particularly grateful to Astronauts Young, Collins, Lovell, and Aldrin for their cooperation and excellent performance in carrying out the maneuvers required to properly test the system. We also gratefully acknowledge the financial support of the Research and Technology Directorate, SSD-Los Angeles, and the liaison assistance of SSD Detachment 2 personnel at the Manned Space Flight Center, Houston, Texas. The NASA Data Processing Group and the Experiment Support Group at the Manned Space Flight Center, Houston, Texas, were also generous in their support.

References

Dalgarno, A., McElroy, M.B., and Moffett, R.J. (1963) Planetory Space Science 2:463.

Sagalyn, R.C. (1967) Charged Particle Measurements by Means of Electrostatic Probes, COSPAR Technical Manual No. 36.

Sagalyn, R.C. Smiddy, M., and Bhargava, Y.N. (1965) Satellite measurement of the diurnal variation of electron temperatures in the F Region, Space Research V:189-206.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Cambridge Research Laboratories (CRU) L.G. Hanscom Field Bedford, Massachusetts 01730	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
POSITIVE ION SENSING SYSTEM FOR THE MEASUREMENT OF SPACECRAFT PITCH AND YAW, AIR FORCE D-10 EXPERIMENT FLOWN ON GEMINI X AND XII

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific. Interim.

5. AUTHOR(S) (First name, middle initial, last name)
R.C. Sagalyn
M. Smiddy

6. REPORT DATE December 1967	7a. TOTAL NO. OF PAGES 59	7b. NO. OF REFS 3
8a. CONTRACT OR GRANT NO. b. PROJECT, TASK, WORK UNIT NOS. 8617-01-01 c. DOD ELEMENT 6240539F d. DOD SUBELEMENT 681310	9a. ORIGINATOR'S REPORT NUMBER(S) AFCRL-67-0158 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFSG No. 201	

10. DISTRIBUTION STATEMENT
1—Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (CRU) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

An attitude sensing system utilizing the properties of ambient positive ions was developed and successfully flown on Gemini Spacecrafts X and XII. In this device the outputs of two planar electrostatic analyzers mounted symmetrically about the appropriate axis are combined to give directly pitch and yaw angles. Comparison of the flight results with those obtained simultaneously with an on-board inertial guidance system shows that over the angular range for which the ion sensing system was designed, ± 20 deg, the average values are in good agreement. The in-flight results also provided a unique description of the distribution of charged particles around the spacecraft, including the wake region, and new information on the motion of the neutral winds and the mean ion drift motion in the upper atmosphere relative to the earth's rotation.

The system could be readily adapted or modified for automatic control of manned or unmanned rockets, satellites, or supersonic aircraft. Significant reductions in required weight, power, volume, warm-up time, response time, and cost make this a potentially valuable tool for future space flight.

DD FORM 1473 1 NOV 65

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Attitude Sensing System						
Ambient Positive Ions						
Electrostatic Analyzers						
Axis						
Pitch						
Yaw Angles						
Supersonic Aircraft						

Unclassified

Security Classification