NASA Technical Memorandum 100749

Shuttle Laser Technology Experiment Facility (LTEF)-to-Airplane Lasercom Experiment--Airplane Considerations

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Shuttle Laser Technology Experiment Facility (LTEF)-to-Airplane Lasercom Experiment--Airplane Considerations

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SUMMARY

This report was originally intended as a trip report regarding the use of airplanes for a Shuttle LTEF-to-airplane lasercom experiment; however, because of the wide range and relative completeness of the pertinent technical material that was covered, it is prepared as a technical report. It includes relevant technical details about–

The pros and cons of the Wallops Flight Facility airplanes, and some information about the Ames Research Center airplanes.

Orbital mechanics of tracking/viewing a Shuttle Orbiter from an airplane (including slant range, azimuth, elevation and time, magnitudes and time rates) and their effects on aircraft maneuvers, selection of a viewing port, and viewing blockage.

The pros and cons of a side port with a bubble window vs. a top port with a dome.

The mechanics of why the elevation angular rate increases with elevation angle and the corresponding coverage time; i.e., time in view decreases (drastically–about one order of magnitude) during increments of higher elevation angles of a given pass.

The optimum aircraft latitude location (a few degrees less than the Shuttle's orbital inclination) for maximum coverage of consecutive Shuttle Orbiter passes.

The mechanics of why the total coverage/available viewing time of an orbital pass is practically the same for an airplane as for a ground station.

The total coverage per day by an optimally located airplane, which could be six consecutive passes of approximately 8.5 minutes average/pass or approximately 50 minutes per day, assuming that the airplane can stay up for 9 hours, because the passes are 1.5 hours apart.

Also included is a set of computer run outputs and various Shuttle Orbiter ground traces with an airplane coverage circle. The Wallops airplanes can operate out of either Cape Canaveral, Holmstead AFB, or San Marco, all of which are suitably located for maximum coverage of a Shuttle Orbiter and for continuous RF communications to provide operational command and control from the POCC with planned NASCOM support. Wallops has in the offing, a Gulfstream, G-4 airplane which this experiment might use in the early 1990s. This airplane seems ideal for the purposes of this experiment.

1.0 Introduction

Originally, a series of lasercom experiments was planned between a lasercom terminal onboard the geosynchronous (GEO) Advanced Communication Technology Satellite (ACTS), and a Laser Technology Experiment Facility (LTEF) onboard a low-earth orbiter (LEO), namely the Hitchhiker-G (HH-G), a payload-of-opportunity carrier on the Shuttle Orbiter. The lasercom terminal onboard ACTS was a joint effort between the Massachusetts Institute of Technology-Lincoln Laboratories (MIT-LL), with Department of Defense (DOD) support, and the Goddard Space Flight Center (GSFC). The DOD has withdrawn its support, while there is still NASA support. However, the NASA support is not adequate for the GEO terminal as originally planned, but there is apparently adequate support for the LEO-LTEF terminal. Therefore, a working group was established at the GSFC within the Engineering Directorate under the leadership of Mike Fitzmaurice, the Head of the Instrument Electro-Optics Branch/Code 723. The author was assigned to the working group (WG) and was given the task of evaluating the NASA aircraft for use as carriers of a lasercom terminal for performing lasercom experiments between the LEO-LTEF terminal and the aircraft terminal.

NASA has aircraft at the GSFC, Wallops Flight Facility (WFF), and at the Ames Research Center (ARC).

The purpose and scope of this report is to present a preliminary assessment of which of the NASA aircraft could be used cost effectively as a host carrier of a lasercom terminal for performing lasercom experiments with the LTEF that would be onboard a Shuttle Orbiter.

2.0 Orbital Mechanics Considerations

The total available contact time per Shuttle Orbiter pass as seen by an aircraft tracking station is

- 6.3 minutes for $\epsilon_{max} = 5.2°$
- 8.6 minutes for $\epsilon_{max} = 20°$
- 9.0 minutes for $\epsilon_{max} = 40°$
- 9.2 minutes for $\epsilon_{max} = 90°$.

This is diagrammatically depicted in Figure 1, where ϵ_{max} is the maximum elevation angle of the slant range (SR) vector from the aircraft to the Shuttle Orbiter for a given Shuttle pass that is covered by the aircraft's coverage circle; i.e., the circle whose radius is the maximum slant range at 0° elevation (see also Figure 1). In this case, the maximum slant range (SR_{max}) is:

- $SR_{max} \cong 1980$ km = 1,070 nm = 1230 statute miles or just plain miles

for

- $h_s = 300$ km, altitude of Shuttle Orbiter
- $h_a \cong 30{,}000 \text{ ft.} \times 0.305 \times 10^{-3}$ km/ft

  $\cong 9$ km, altitude of aircraft.

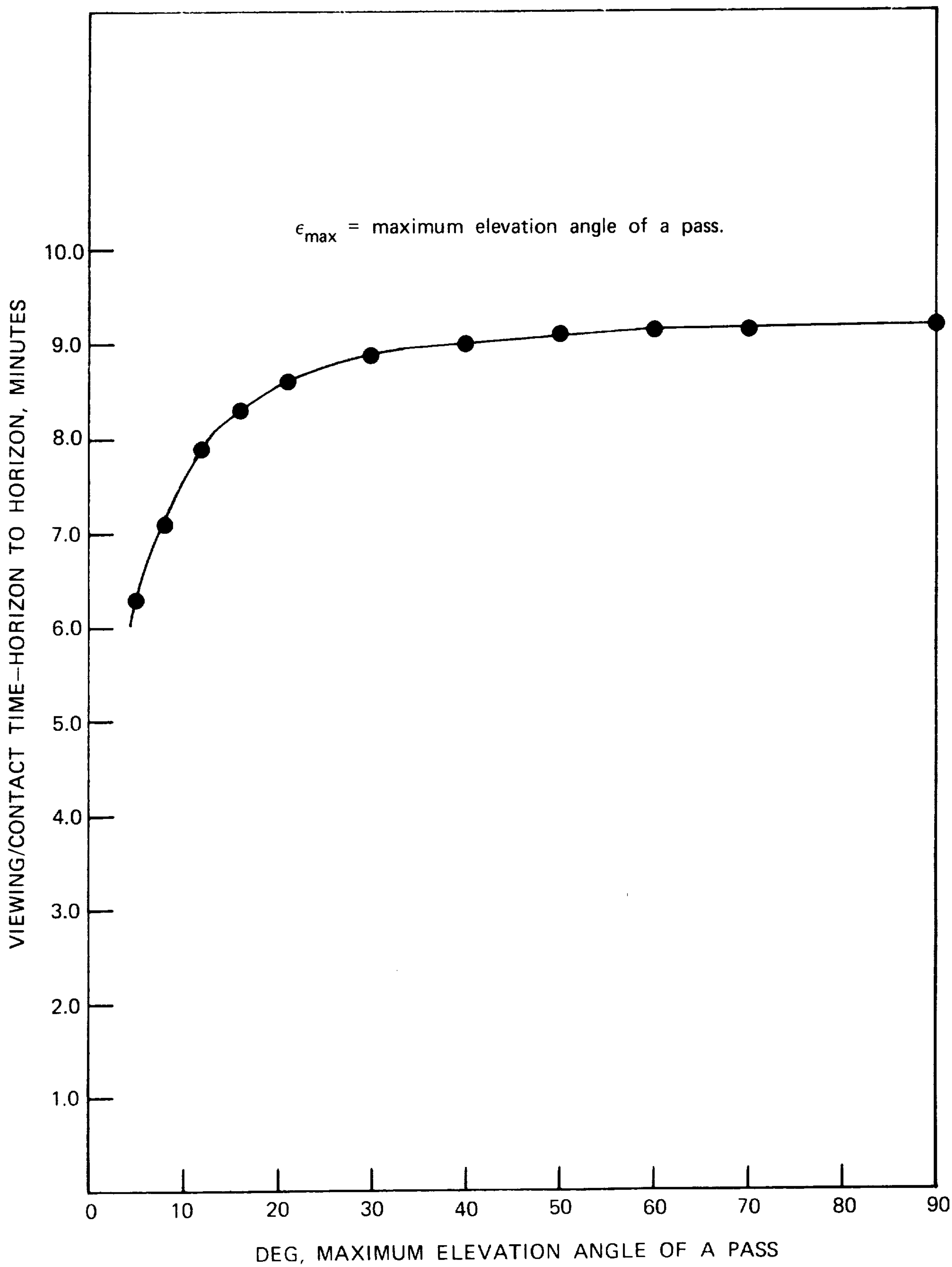

Figure 1. Maximum Available Viewing Time vs. Maximum Elevation Angle of the Pass.

The maximum slant range for a ground station is only 30 km more than for the aircraft, and hence, the viewing time for a ground station is only less than or approximate to 9 seconds more than for an aircraft for the worst case of $\epsilon_{max} = 90°$, and significantly is less for lower ϵ_{max}. Note that the Shuttle Orbiter is traveling at a linear speed of ~ 7 km/sec.

Shown in Figure 2 are the elevation angle, ϵ, versus time for several ϵ_{max}. It can be seen that the elevation angular rate, $d\epsilon/dt$, increases rapidly above $\epsilon \cong 30°$ and peaks at ϵ_{max}. This can be shown mathematically by considering the extreme cases, $d\epsilon/dt$ at $\epsilon = 0°$ and at ϵ_{max}. Referring to Figure 3 for an overhead pass with $\epsilon_{max} = 90°$,

- At $\epsilon = \epsilon_{max}$
- $d\theta/dt = v/(R+h)$ (1)

  $d\epsilon/dt_{overhead} = v/h.$ (2)

  $\therefore\ d\epsilon/dt = [(R+h)/h]\ d\theta/dt$, overhead (3)

- At $\epsilon = 0°$, i.e. at horizon

  - from triangle ABC

    $\phi = 90° - \theta.$ (4)

  from straight line AC

    $\alpha + 90 + \phi = 180°$

    $\therefore\ \alpha = 90 - \phi = \theta.$ (5)

The component of v normal to SR is $v \sin \theta$, and at horizon

$$d\epsilon/dt = (v \sin \theta)/(SR) \quad (6)$$

but $\sin \theta = (SR)/(R+h)$, from Δ ABC (7)

$$\therefore\ d\epsilon/dt_{horizon} = v/(R+h) << d\epsilon/dt_{overhead} = v/h. \quad (8)$$

This helps explain why, for example, the total time in view is 8 minutes for an Orbiter pass that has a maximum elevation angle of 14° versus 9.2 minutes for an Orbiter pass that has a maximum elevation angle of 90°. This highlights the need for the tracker on the aircraft to be capable of viewing the Orbiter at the lower elevation angles. Also, it highlights the disadvantage of those aircraft telescopes that can only view at elevation angles of 35° to 70°, as in the case of the NASA Kuiper A/C, C-141 KAO at Ames Research Center. The maximum total contact time available during this increment of elevation angle (35° to 70°) is only about 1.8 minutes. For this and other reasons, the following discussions will concentrate on the Wallops aircraft, while the Ames aircraft are covered in Appendix E.

3.0 Optimum Airplane Location

The best aircraft location for providing maximum coverage of several consecutive Orbiter passes, and

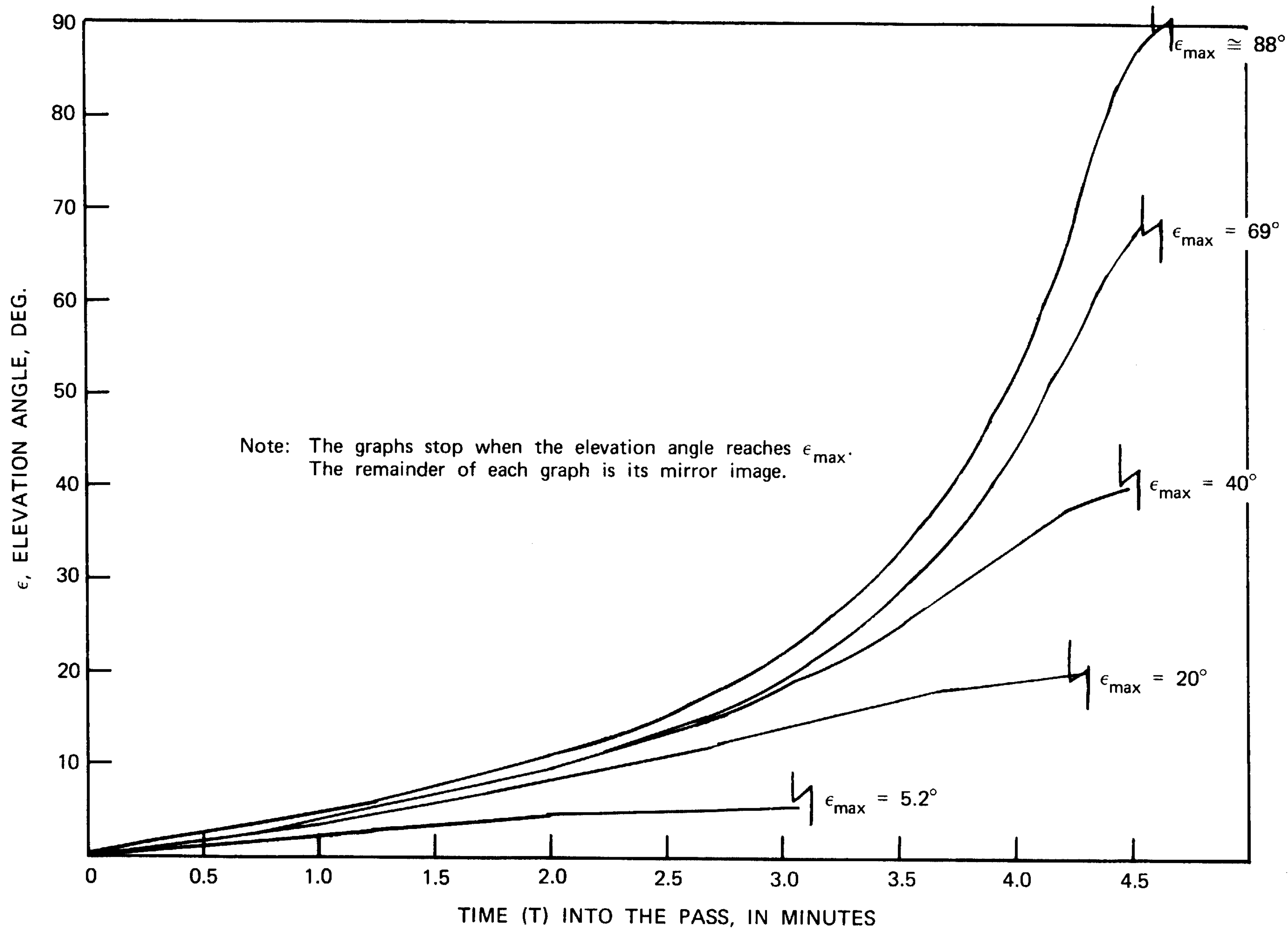

Figure 2. Elevation Angle vs. Time for Several ϵ_{max}.

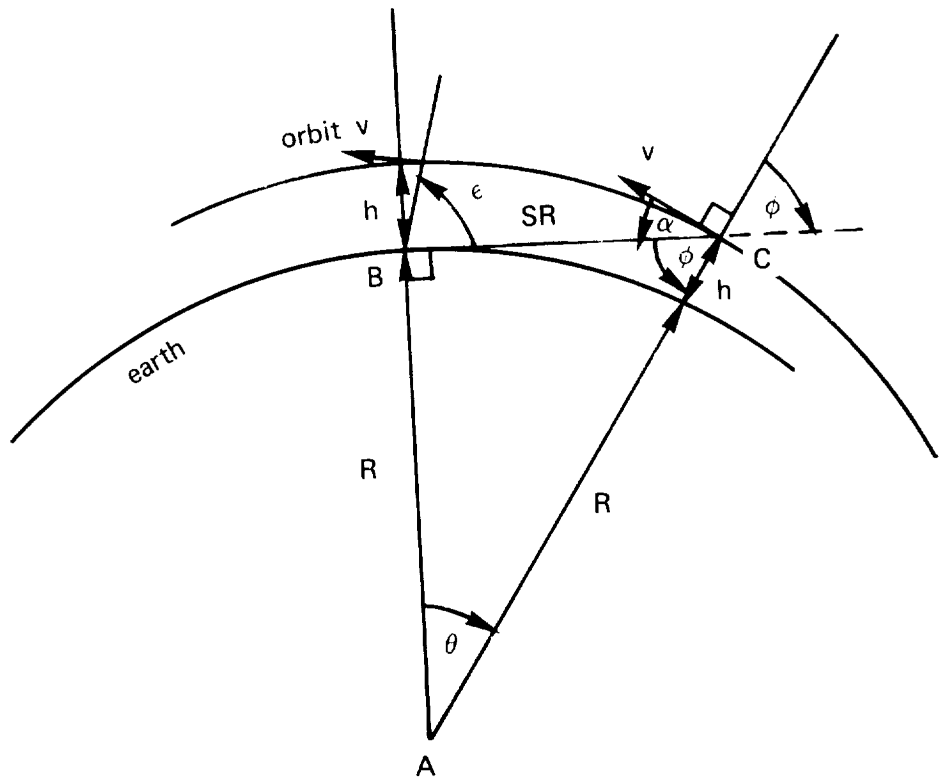

Figure 3. Simplified Tracking Geometry.

hence maximum viewing time, is at latitudes between about 19° and 28° for an orbital inclination of 28.5°. For instance, observe the Shuttle Orbiter ground traces in Figure 4 from reference 1. Assume that the airplane is operating out of Holmstead AFB at a latitude of about 25°. The maximum slant range seen by the aircraft while operating/flying "on-station" is about 1,000 nmi, which corresponds to a viewing distance of 17° in latitude (i.e., there are 60 nmi per one degree of latitude). Now draw a coverage circle (actually it will appear as an ellipse as will now be explained) with the center near Holmstead AFB and the radius of 17° in latitude and 17°/cos 25° = 19° in longitude, because the number of nmi per degree longitude is 60 nmi X cos (latitude); i.e., the longitude lines approach each other as the latitude increases until they meet at the pole. Such a coverage circle is shown in Figure 4. From that coverage circle, it can be seen that up to seven consecutive passes can be seen by the aircraft.

These series of consecutive passes as seen by an airplane tracking station at a given latitude and given longitude (within the useful flight range of the aircraft) come in bunches of five to seven consecutive passes covered once per day at aircraft latitudes ~ 20° to 28°, and bunches of two to three consecutive passes every 12 hours at aircraft latitudes of ~ 0° (i.e., at the Equator); see reference 1 for details. In both cases, the average time per covered pass is 8 to 8.5 minutes. Thus, an airplane operating at ~ 25° latitude can provide up to an average contact time of 40 to 50 minutes per day, which corresponds to 4.5 to 6 hours per 7-day Shuttle Orbiter mission. This could be a favorable trade-off consideration when comparing an aircraft-to-Shuttle lasercom experiment versus a Spartan-to-Shuttle lasercom experiment, because although a Spartan could provide ~ 40 hours of operation time per present design and battery power limitations, the Spartan would need to get a manifest on the Shuttle, which could be difficult and probably relatively expensive. The Wallops

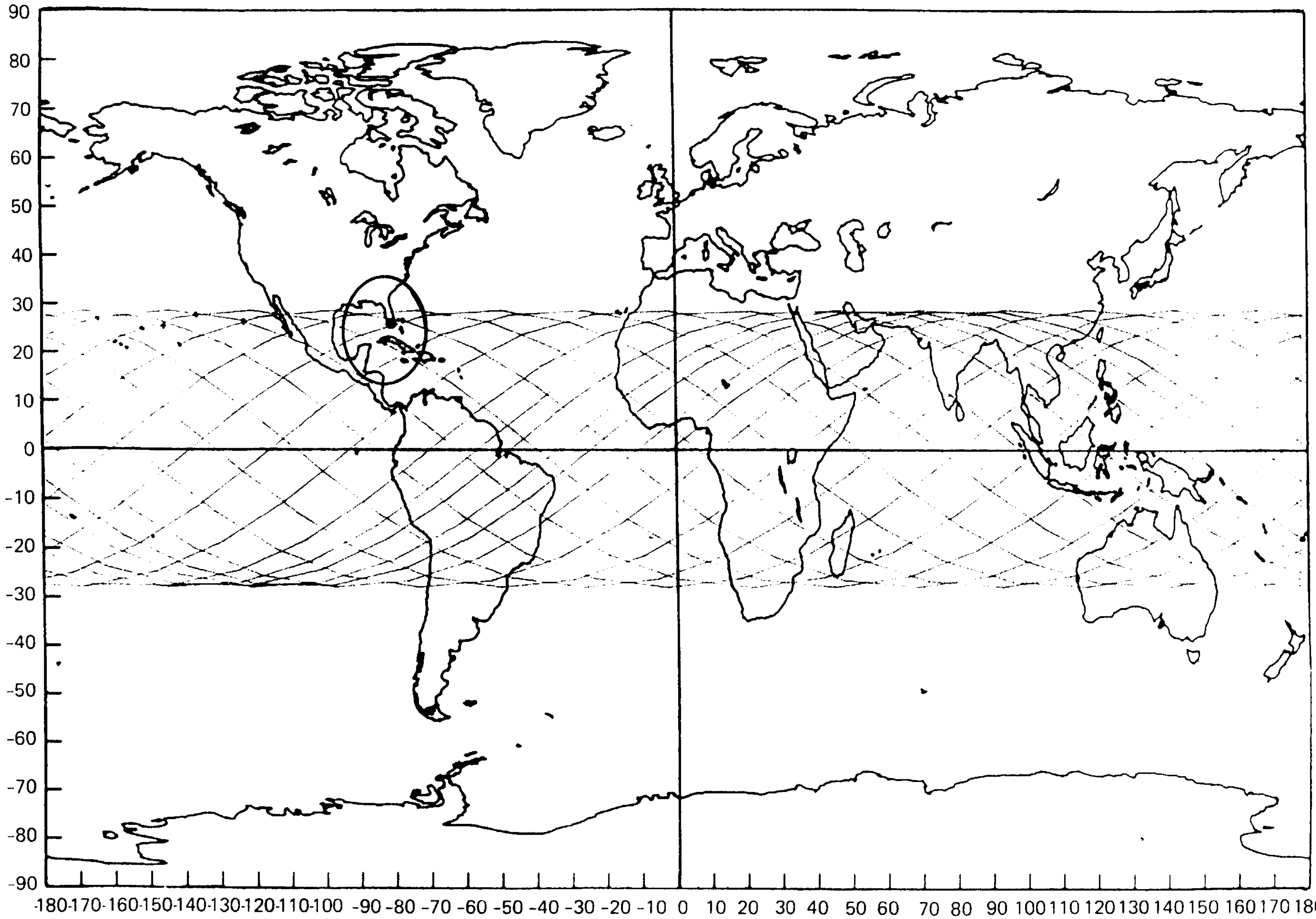

Figure 4. Shuttle Orbiter ground traces and airplane coverage circle for 300-km Orbital Altitude and 28.5° Orbital Inclination.

personnel were astute enough to point this out. It is clear that they are enthusiastic about this experiment and would like very much to participate in it.

There are 1-1/2 hours between passes. Thus, to cover four consecutive passes, an airplane tracker would need to remain aloft for 6 hours or more, a factor that may affect the choice of which airplane to use. Some airplanes can stay airborne longer and at higher altitudes than others.

Regarding the places that the Wallops airplanes can operate out of in order to provide the maximum coverage discussed above, the Wallops Flight Facility has contacts at Patrick AFB/Cape Canaveral, Holmstead AFB, and San Marco. The Wallops airplanes can operate out of any of those places.

4.0 Wallops Airplanes

Figure 5 shows the existing Wallops aircraft. Appendix E provides information about the Ames airplanes and why they were dropped from further consideration at this time. The Wallops aircraft of interest to us for use as a lasercom terminal and their pertinent characteristics are as follows (see also Table 1).

4.1 Saberliner, T-39 has the following features: one 16-inch-diameter hole presently being installed in the top, which could be used for a dome; 39,000-foot maximum flying altitude; very small side ports which are not useful for lasercom; greater than or approximately equal to 3 hours flying time; and $1,050-per-hour cost for flying. When the costs for travel to Holmstead AFB, contractor support, per diem, and other project-unique costs are considered, the total operational cost to the Project is about $44K to $65K for use of this airplane for lasercom experiments for a 7-day Shuttle Orbiter mission.

Because of its 3-hour flight limitation, this T-39 would cover two passes, land and refuel, and ascend during the 1-1/2 hours between passes to cover two more passes for a total coverage of four passes per day. These passes would average about 8.5 minutes per pass, which corresponds to ~ 34.0 minutes total available lasercom experimentation time.

The cost for installing and integrating a dome is essentially nil. The 16-inch-diameter hole in the top of the T-39 is ordinarily covered with a plate. To install a dome, the plate would be removed, and the dome inserted and bolted into place. We would provide the dome with a flange that has the proper dimensions and holes for bolting into place. An O-ring could be used to provide the proper pressure seal. See Figure 6, which shows a dome for use on aircraft (reference 2). The first flange from the top is the flange for bolting to the aircraft frame.

The Chief Pilot, Mr. Riley, asked about the aerodynamic effects/hazards of such a dome on the T-39. Mr. Doug Young, the aeronautical engineer, said that he could install a "makeshift" or cylindrical dome on the T-39 when the hole is finished in the next few months, and fly the T-39 to assess the effects of the dome.

Regarding information about the vibration spectra for the three airplanes of interest, Doug, the aeronautical engineer, has a spectrum analyzer, which he can use. He could install some accelerometers and obtain some vibration spectra for the LTEF Working Group (WG). Also, he could send the WG appropriate airplane MIL specifications that are to be used for designing instruments/experiments for use on the airplanes. Those specifications may also have some useful vibration data and/or spectra.

An airplane that can fly above the clouds most or all of the time is advantageous. Thus, the T-39 would be more advantageous than the Electra or the Orion from that viewpoint, because it flies at

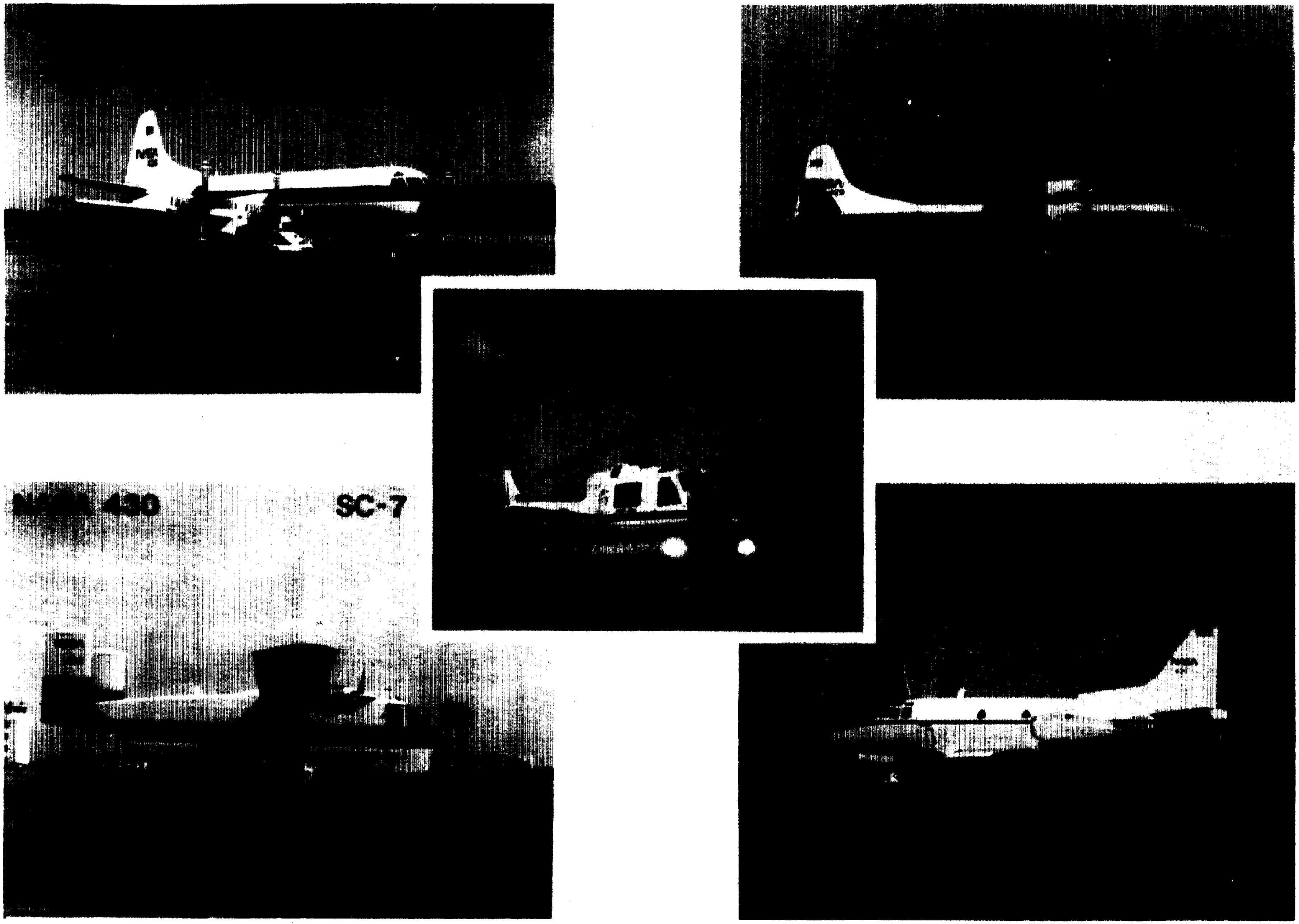

Figure 5a. GSFC/Wallops Flight Facility Remote Sensing Aircraft.

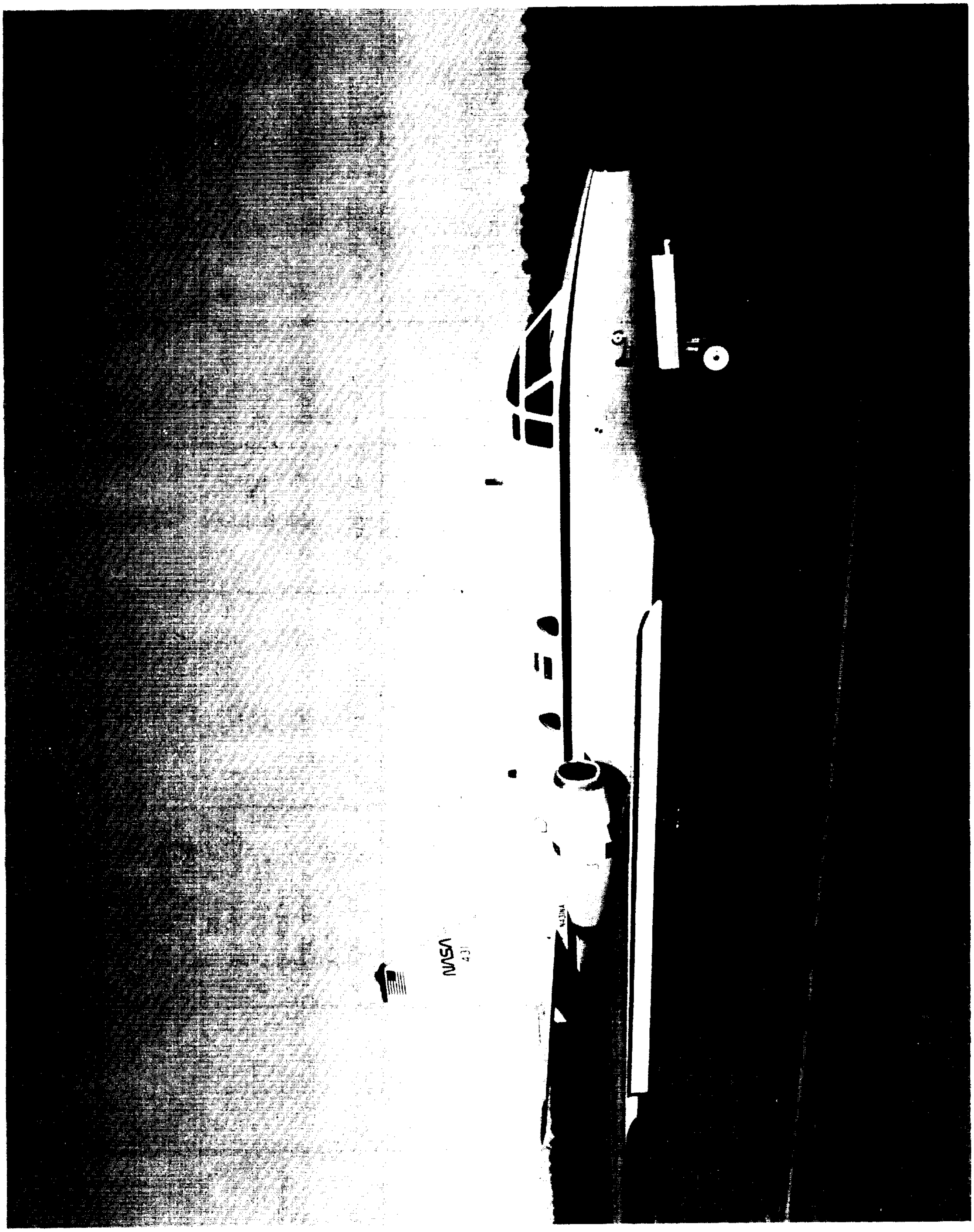

Figure 5b. Saberliner T-39, NASA 431.

Table 1. Summary of Characteristics of Wallops Aircraft Suitable for Lasercom Experiment with Shuttle.

Airplane		Useful Holes/Port	Operations Costs to User (1)	Altitude	Flight Time	Accommodations/ Comments
Name	Designation					
Saberliner	T-39	• One 16" dia.-hole in top. Can accommodate a dome. • Two ~ 9" triangular ports on each side (too small for Lasercom)	$1,050.00/hr.	39,000 ft.	3 hrs. or more	• Two Std, 19" W X 24" D X 40" H racks for electronics & two operators plus "payload." • No toilet. • Advantage: can fly above clouds most of the time.
Electra	L-188	• Three 16" dia.-holes in top. Can use a dome(s). • Several 18" dia. side ports on each side. Can use Bubble to increase "dynamic FOV" (2).	$2,700.00/hr.	25,000 ft.	6 hrs. or more	• Large A/C. Can accommodate several racks of equipment. • Very adequate accommodations. • Toilet. • Disadvantage: cloud cover may be an issue.
Orion	P-3	• Two 16" dia.-holes in top. Can use a dome(s). • Several 18" dia. side ports on each side. Can use Bubble to increase "dynamic FOV" (2).	$2,700.00/hr.	25,000 ft.	6 hrs. or more	• Similar to Electra.

(1) Plus other project-unique costs.
(2) Dynamic FOV means Azimuth and Elevation Look angles.

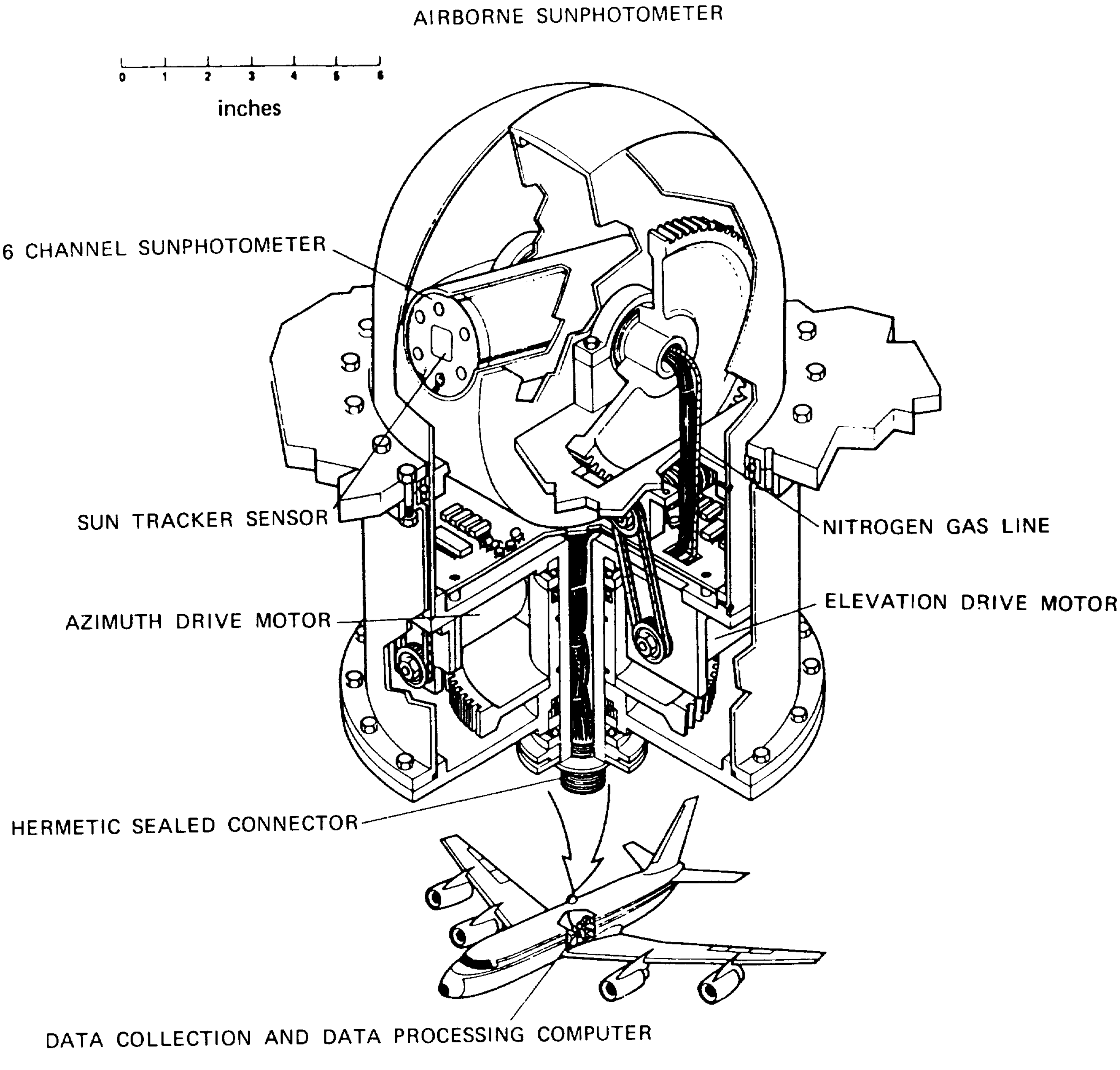

Figure 6. Dome for Airborne Sunphotometer (ref. 2).

39,000 feet, whereas the Electra and Orion fly at ~ 25,000 feet. Clouds are essentially opaque to our laser wavelength of ~ 870 nanometers. This is one of the primary reasons to use an airplane instead of a ground station, a question that was brought up by Doug Young. Also, a ground station can see the Shuttle Orbiter little more (less than or approximately equal to 9 sec/pass) than an airplane can. In addition, as is generally well known, the atmosphere, moisture, and particulates in the atmosphere, as well as atmospheric turbulence play havoc with a laser beam.

4.2 Orion, P-3 has two 16-inch-diameter holes in the top, which can be used for a dome(s). Its base operational cost is $2,700 per hour, it flies at ~ 25,000 foot altitude, and it can stay up in excess of 6 hours. Thus, it could cover four consecutive passes per flight. It is a relatively large airplane and can provide more-than-adequate accommodations, including a toilet.

Figure 7 shows the Orion P-3 and some of its capabilities, while Figure 8 shows the Electra, which is similar (reference 3).

The Orion has two or more side ports of 18-inch-diameter on each side. A bubble of good optical quality can be used in lieu of the plastic ones presently in place. The bubble extends out a few inches past the fuselage surface, and thus can provide increased azimuth and elevation viewing angles for a two-axis gimballed telescope or a rotating flat one. For instance, it appeared that the range of elevation angles from a side port with a bubble could be from $\leqslant 0°$ to about 40°, which would cover most of the available viewing time as pointed out earlier, see also reference 1.

When viewing out of a side port, the aircraft must maintain its heading such that the Shuttle Orbiter remains in view. This is diagrammatically depicted in Figure 9 for the case when the port being used is on the left-hand side (LHS) of the airplane, and the airplane location is north of the Shuttle ground trace, as the Orbiter is heading east and southeast. In this case, if the airplane is south of the Shuttle ground trace, then it would need to bank and turn to the right. Again, with the airplane north of the Shuttle ground trace as shown in Figure 9 and a viewing port on the right-hand side (RHS) being used, then the original airplane heading at time (1) would have been southerly, and the airplane would have to bank and turn towards its left, and so on for other cases.

If the lasercom aperture can be gimballed in azimuth, then the aircraft can be relieved of flying a perfect (or nearly perfect) heading. The amount of azimuth that must be accommodated depends on the length of the pass being covered, which in turn, depends on the ϵ_{max} of the pass. Figure 10 shows how the azimuth depends on ϵ_{max}.

Another important factor to be considered is the rate at which the viewing azimuth varies with time, because this will affect the design of the aperture azimuth drive/speed and/or will dictate how steep and fast the airplane must bank and turn, respectively. Figure 11 shows how the dAz/dt varies with time for two of the worst cases of ϵ_{max}; i.e., ϵ_{max} = 69° and 81°. Other cases are shown in Appendix C. The dAz/dt is worst for the larger ϵ_{max}.

Many airplanes can turn at 180°/minute without difficulty. Whenever dAz/dt exceeds either the 180°/minute guideline or whatever the airplane's turn capability is, then the Az drive of the telescope/aperture can take up the slack in the case of a side port installation. In the case of a dome, the dome's Az drive can do the entire job of keeping the telescope/aperture properly aligned, regardless of the airplane heading. However, for a direct overhead pass where ϵ_{max} = 90°, the dAz/dt can become infinitely large at ϵ = 90°. Therefore, it would be desirable to plan the aircraft location ahead so as to avoid direct overhead passes.

When the airplane is banked, the elevation viewing angle relative to the airplane's wings is affected.

Orion/P3 Capabilities

• Electrical Power:	16 kw - 60 cycle 115V single phase 15 kw - 400 cycle 115V three phase 80 amps - 28 VDC
• Flight Endurance:	7.5 hours at 300 knots
• Max. Operating Altitude:	25,000 feet
• Cruising Altitude:	18,000 - 25,000 feet
• Range:	1,800 mi. (end-to-end)
• Add on Instrumentation Payload Weight:	300 to $\geqslant$ 1000 pounds depending on location
• Base:	Wallops Flight Facility
• Ports:	Two 16-inch diameter, Zenith viewing (pressurized)

Figure 7. Lockheed Orion NP-3A (NASA N428NA).

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Electra Capabilities

- Electrical Power: 24 kw - 60 cycle 115V single phase
  15 kw - 400 cycle 115V three phase
  80 amps - 28 VDC
- Flight Endurance: 7.5 hours at 300 knots
- Max. Operating Altitude: 25,000 feet
- Cruising Altitude: 18,000 - 25,000 feet
- Range: 1,800 mi. (end-to-end)
- Add on Instrumentation Payload Weight: 300 to $\geqslant$ 1000 pounds, depending on location
- Base: Wallops Flight Facility
- Ports: Two 16-inch diameter, Zenith viewing (pressurized)

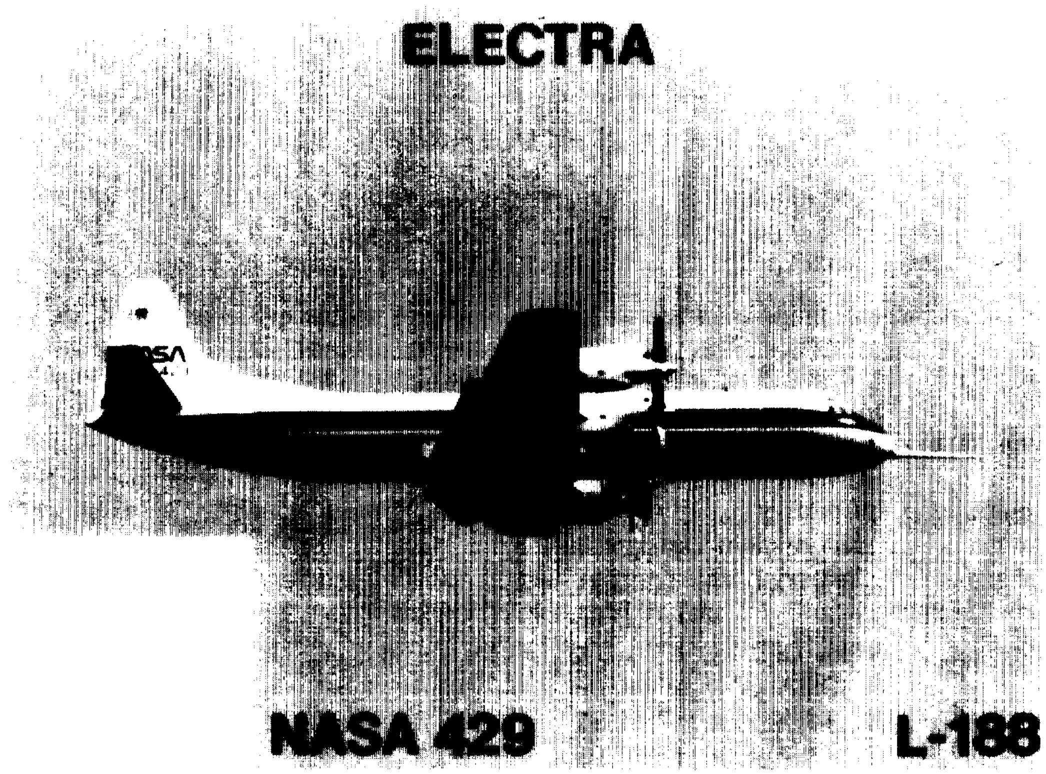

Figure 8. Lockheed Electra L-188 (NASA N429NA).

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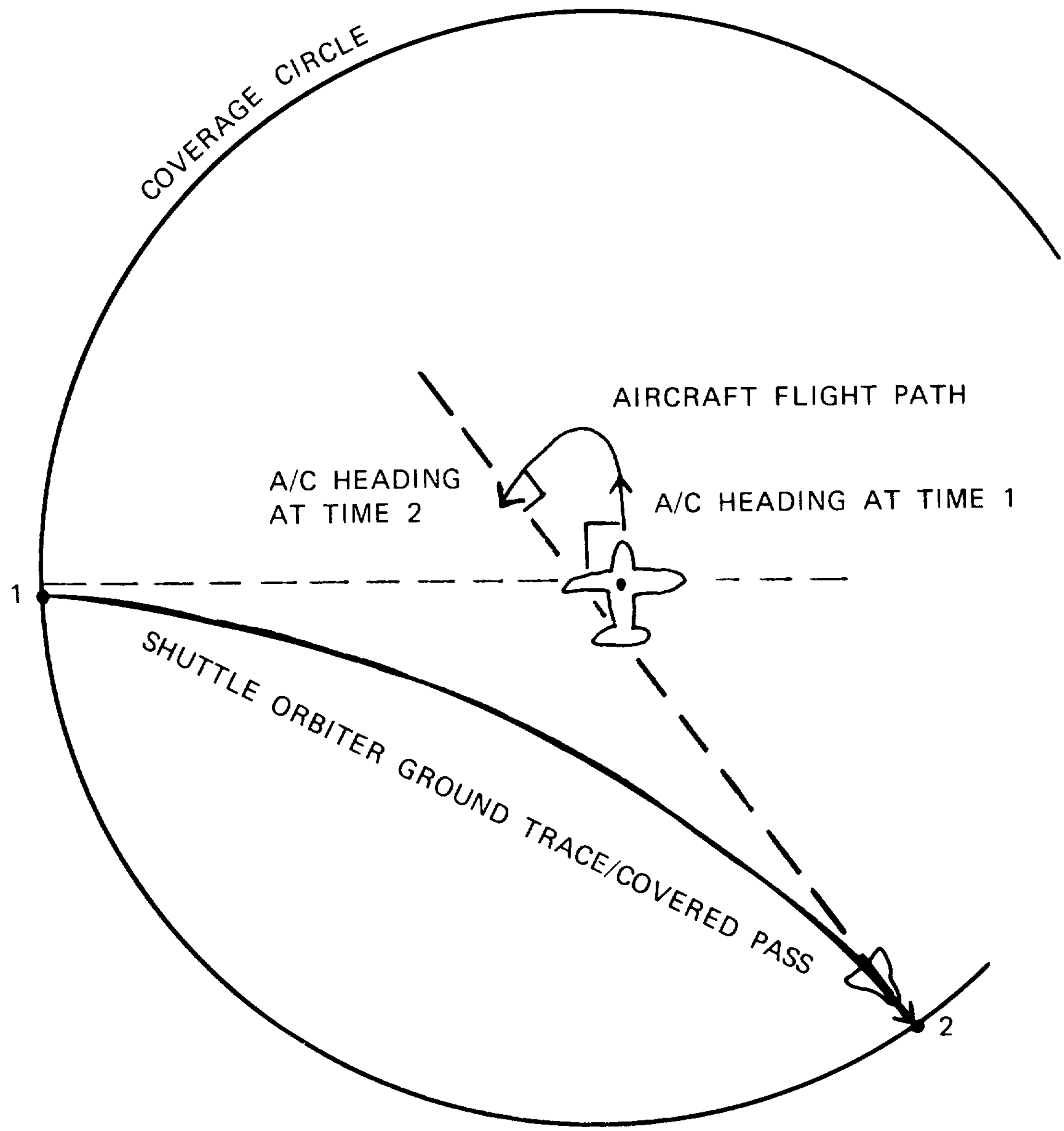

Figure 9. Aircraft Heading and Flight Path Vs. Shuttle Heading and Flight Path for a Viewing Port on the Left-Hand Side.

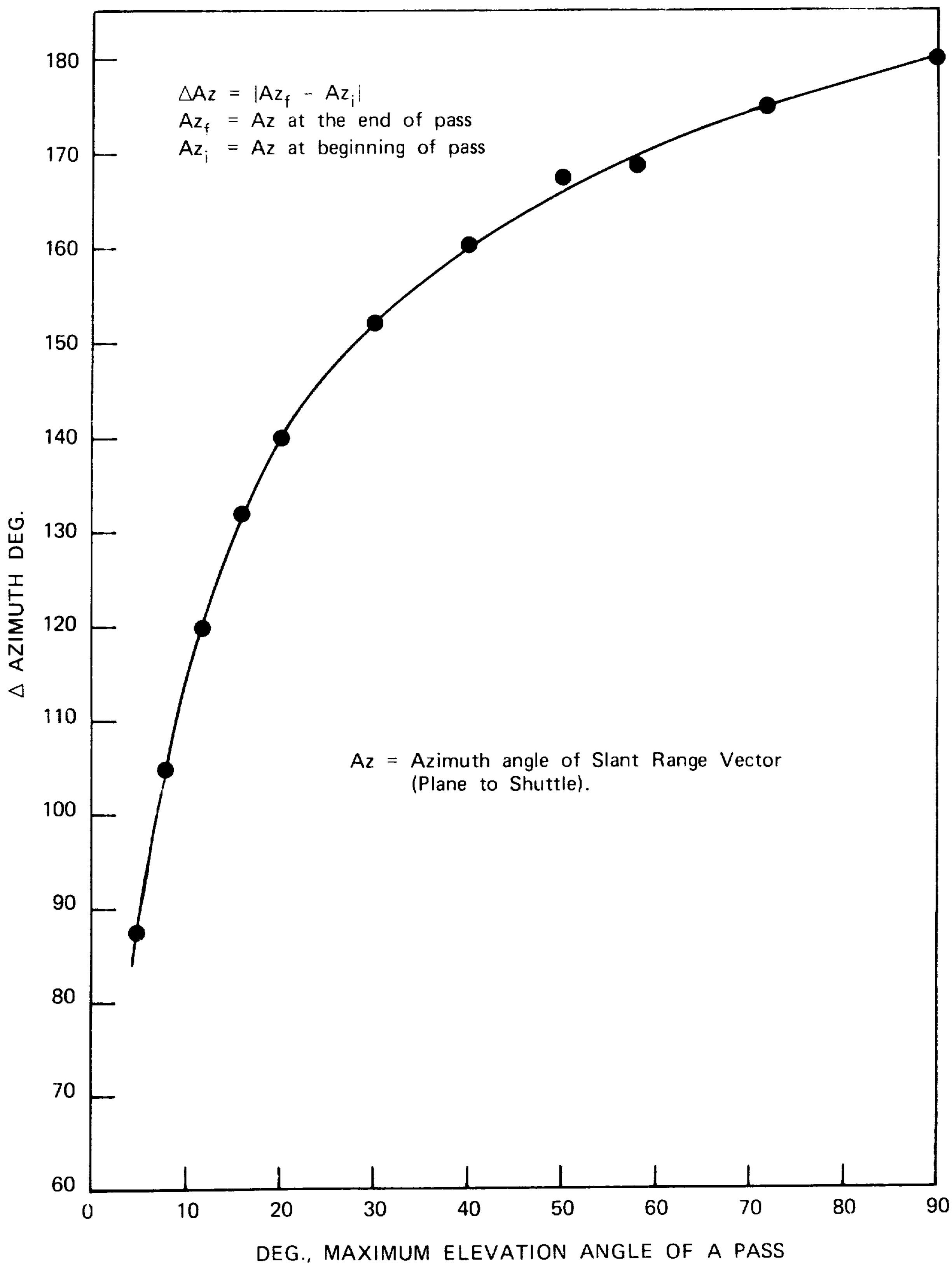

Figure 10. ΔAz vs. ϵ_{max}.

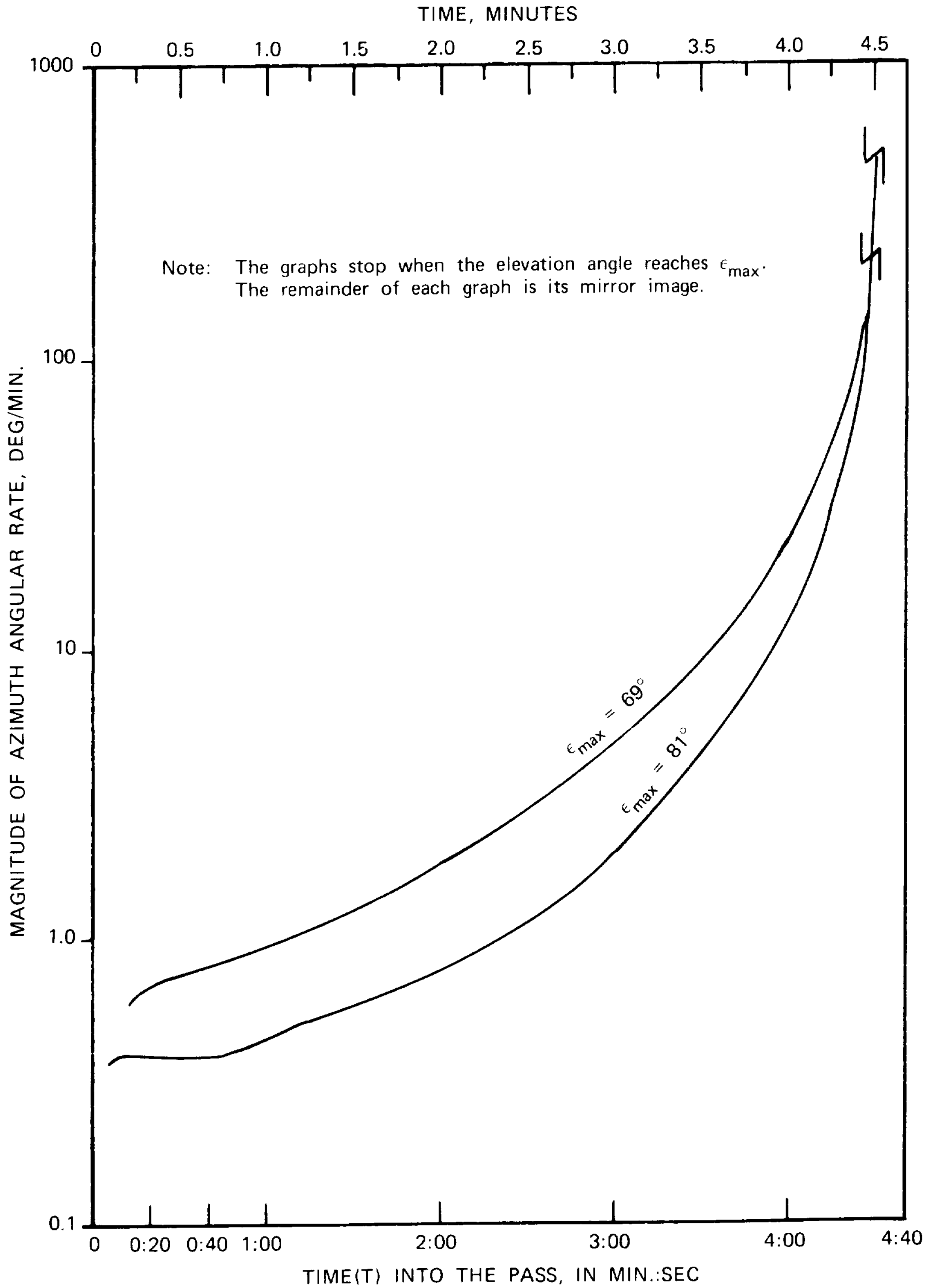

Figure 11. $\dot{A}z$ vs. Time.

For instance, in the case shown in Figure 9, the airplane must bank and turn to its left, so the maximum elevation that is available for viewing is reduced by the amount of the bank angle. Keep in mind that the maximum elevation angle that is available for viewing depends on the blockage caused by the upper lip/edge of the viewing port. Mathematically,

let ϵ_{AMH} = the Available Maximum viewing elevation angle allowed by the port blockage relative to the local horizontal, and i.e., relative to the earth's Horizontal; and

let ϵ_{AMW} = the Available Maximum viewing elevation angle allowed by the port blockage relative to the airplane Wings.

$$\text{Then } \epsilon_{AMH} = \epsilon_{AMW} \pm |BA| \qquad (9)$$

$|BA|$ = absolute value of the bank angle.

Use the negative sign for a bank to the left, the positive sign when the bank is to the right, and the viewing port is on the LHS; and vice-versa when the viewing port is on the RHS.

Based on these complicating factors, one can begin to see the merits of a dome that has azimuth and elevation drives that give a 360° range in azimuth and a 180° range in elevation as allowed by the dome of Figure 6, reference 2, shown earlier. Furthermore, the azimuth and elevation drive motors of this dome can drive the azimuth and elevation angles at rates of

360° in 4 sec for Az,

180° in 20 sec for ϵ,

or

$$dAz/dt \text{ (maximum drive rate)} = 90°/\text{sec},$$

$$d\epsilon/dt \text{ (maximum drive rate)} = 9°/\text{sec},$$

which appear adequate to handle the dAz/dt and $d\epsilon/dt$ for the passes computed in the figures and attachments. For instance, the maximum angular rates that would be experienced, if we restrict ourselves to passes that have maximum elevation angles of 80° or less, are

$$\left.\begin{array}{l} d\epsilon/dt < \text{or} \sim 1°/\text{sec} \\ dAz/dt < \text{or} \sim 8°/\text{sec} \end{array}\right\} \text{for } \epsilon_{max} \leqslant 81°. \qquad (10)$$

One advantage to a side viewing port is that the Shuttle can usually be seen from the aircraft at night due to reflected sunlight, a phenomenon that can be used advantageously during signal acquisition. The Wallops people have experienced this phenomenon. The Shuttle appears as a very bright, moving star which can be seen as it comes up over the horizon. In such a case, the acquisition scenario for Lasercom can be modified to take advantage of this visual acquisition. For instance, the Lasercom telescope could have an aligned "gun-sight" mounted on it. The operator could put the Shuttle on the cross hairs of the eyepiece and notify the POCC via the radio links. Per the Wallops people, the aircraft would be in continuous RF contact with the ground, and with proper planning of the ground links (NASCOM support), the airplane could be in continuous contact with the POCC. The POCC could then command the LTEF onboard the Shuttle HH-G to turn on its beacon and to point it in a specified direction, based on the positions of the Shuttle and the airplane. By keeping the Shuttle in his "gun-sight," the operator could switch the acquisition to automatic, or he could assist the acquisition until the Shuttle-based LTEF beacon is detected and then hand over the acquisition to the electronics. It is a bit too complicated to adequately discuss/ explain this apparent advantage, but perhaps it merits some consideration in the trade-offs used in deciding on a side port with a bubble versus an overhead port with a dome.

4.3 Gulfstream G4 airplane is in the offing at Wallops in the time-frame of interest for this experiment; i.e., early 1990s. This airplane flies at 50,000 to 60,000 feet, well above any cloud cover or "dense" atmosphere. It can fly for 10 to 12 hours and could cover six consecutive Shuttle passes. This appears to be a very suitable airplane for our purpose. For additional information, see Appendix F—"Gulfstream SRA-4 Aircraft" and reference 5.

5.0 Atmospheric Effects

The atmospheric effects were analyzed and reported herein as Appendix G by Harvey Safren, Code 723, for Shuttle LTEF-to-aircraft-based lasercom terminal experiments. In summary, on the downlink from the Shuttle Orbiter to the aircraft, there is no severe atmospheric absorption at altitudes above 25,000 feet, even at low elevations, provided the downlink wavelength is selected to be away from the water vapor absorption lines (see Appendix 7 for details). Regarding absorption, the above is also true for the uplink. Regarding turbulence caused by the air flow past the optical window, there is no significant effect on the downlink, but on the uplink there may be some significant beam steering caused by the atmospheric turbulence. This beam steering effect can be compensated for by using a wider beamwidth and transmitting more power to compensate for the increased spreading/space loss. On the uplink, it is expected that adequate transmitter power can be provided. In any event, this issue will be analyzed more thoroughly in an ongoing analysis.

Regarding atmospheric turbulence, there may be significant fading a small percentage of the time at the low elevation angles, for both downlink and uplink. This fading would be roughly a maximum of: (a) 3dB a small percentage of the time at 25,000 feet, and (b) 1.5dB a small percentage of the time at 39,000 feet.

6.0 Conclusions

Wallops has three airplanes, each with advantages and disadvantages as summarized in Table 1 presented earlier, and a fourth airplane in the offing that apparently has all of the advantages, but none of the disadvantages. This fourth airplane is a Gulfstream G-4, that can fly at altitudes of 50,000 to 60,000 feet with a 10- to 12-hour flight duration, that has a toilet, and has good accommodations for payload, electronics, and people. It may be available in the time frame—early 1990s—of interest for this experiment. It is worth looking into further.

A side port with a bubble-type window is more advantageous than a flat plate window, because the ports are limited in size. A bubble window would allow coverage of a significantly wider range in the viewing elevation and azimuth angles without blockage.

At night, the Shuttle Orbiter is visible as a bright star. In that case, a side port lends itself more readily than a top port for manual and visual assistance during acquisition.

A top port with a dome, similar to the one described in reference 2, is, in my opinion, the most advantageous choice for a Shuttle LTEF-to-airplane lasercom experiment. A dome can provide complete elevation and azimuth coverage, and the one detailed in reference 2 can meet all the angular rates except for direct overhead passes where dAz/dt approaches infinity. The costs to integrate the dome in an available top port are essentially nil (per the Wallops Flight Facility personnel). The cost to make a dome such as the one in reference 2 is very modest (per the Ames Research Center personnel). Although a preliminary cost estimate is ballparked at $80K (per the Ames Research Center personnel), for an in-house build, this attractive number needs to be thoroughly researched and verified.

It should be mentioned that the airplanes of the Ames Research Center have been looked into (see Appendix E) and the references given therein. This effort, as well as the overall effort of evaluating the NASA aircraft for Shuttle LTEF-to-Airplane Lasercom Experimentation, will continue.

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2. T. Matsumoto, P. Russell, C. Mina, W. Van Ark, and V. Banta (ARC/NASA/CA), "Airborne Tracking Sunphotometer," Journal of Atmospheric and Oceanic Technology, Vol. 4, No. 2, June 1987, pp 336-339.
3. Instrumentation Handbook, Vol. VII, Aircraft Instrumentation Systems, January 1981, Wallops Flight Facility, Contact: Roger L. Navarro, Project Support Section, Aeronautical Programs Branch.
4. Telecon with Dwaine Allen/ARC/8–464–5812, 3–18–88, 3:30p.m. EST.
5. "Gulfstream IV Detail Specification," Revision D, January 4, 1988, Gulfstream Aerospace Corporation, P.O. Box 2206, Savannah International Airport, Savannah, Georgia 31402-2206. Contact: Edward J. Kane, U.S. Government Requirements, Gulfstream Aerospace Corporation, 1000 Wilson Blvd., Suite 2701, Arlington, Virginia 22209, Telephone: 703-276-9500.

Appendix A

February 24, 1988

TO: 723/Instrument Electro-Optics Branch/Dr. Kalil

FROM: 531.1/RF Interface & Mission Analysis Section

SUBJECT: Aircraft Coverage of a Shuttle Orbit

An analysis was done to determine the maximum amount of coverage possible from a flying aircraft communicating with a typical Space Shuttle orbit.

The following are the assumptions used in the analysis:

a. Shuttle orbit of 300 km.

b. A 28.5° inclination.

c. A possible flight range of 600 miles between orbits for the aircraft.

d. An elevation angle from the aircraft of 0° to 90°.

The results of the analysis are as follows:

a. The maximum possible pass time is 9.2 minutes.

b. For an equatorial location, there is approximately 43 minutes of possible coverage per day.

c. For a location at 26.5° there is approximately 60 minutes of possible coverage per day.

d. By moving the aircraft 8° east for the first two passes, then to the central longitude (crossing point of two nonconsecutive orbits) for the next three, then 8° west for the last two or three passes, there is approximately 57 minutes of coverage per day. (See the table for mobile position around 26.5° latitude.)

e. For a location at 19.5°, there is approximately 50 minutes of possible coverage per day.

f. For a central position of 19.5° latitude located at the crossing point of two orbits that are separated by three orbital periods, and moving the aircraft according to the following instructions, approximately 80 minutes of coverage per day could be expected. Movement of the aircraft is as follows:

1. For pass 1, aircraft is located 10^{o} east and 10^{o} south of central position.

2. For pass 2, aircraft is located 5^{o} east and 5^{o} south of central position.

3. For pass 3, aircraft is located at central position.

4. For pass 4 through 6, aircraft is located 7^{o} north of central position.

5. For pass 7, aircraft is located at central position.

6. For pass 8, aircraft is located 5^{o} west and 5^{o} south of central position.

7. For pass 9, aircraft is located 10^{o} west and 10^{o} south of central location.

It appears that any location between 19^{o} and 28^{o} latitude will allow 50 minutes of coverage a day, with additional coverage available by moving the aircraft between the orbits. It should be noted that in order to obtain this coverage, over 10 hours of flight time is required while on location, excluding flight time to and from the support position.

Attached are the tables and the acquisition of signal (AOS) and loss of signal (LOS) times for various positions indicated above, and a world map with a ground track of a 300 km Shuttle orbit.

If you have any questions or need further analysis, contact me at 286-8692.

Ronald Vento

Ronald Vento

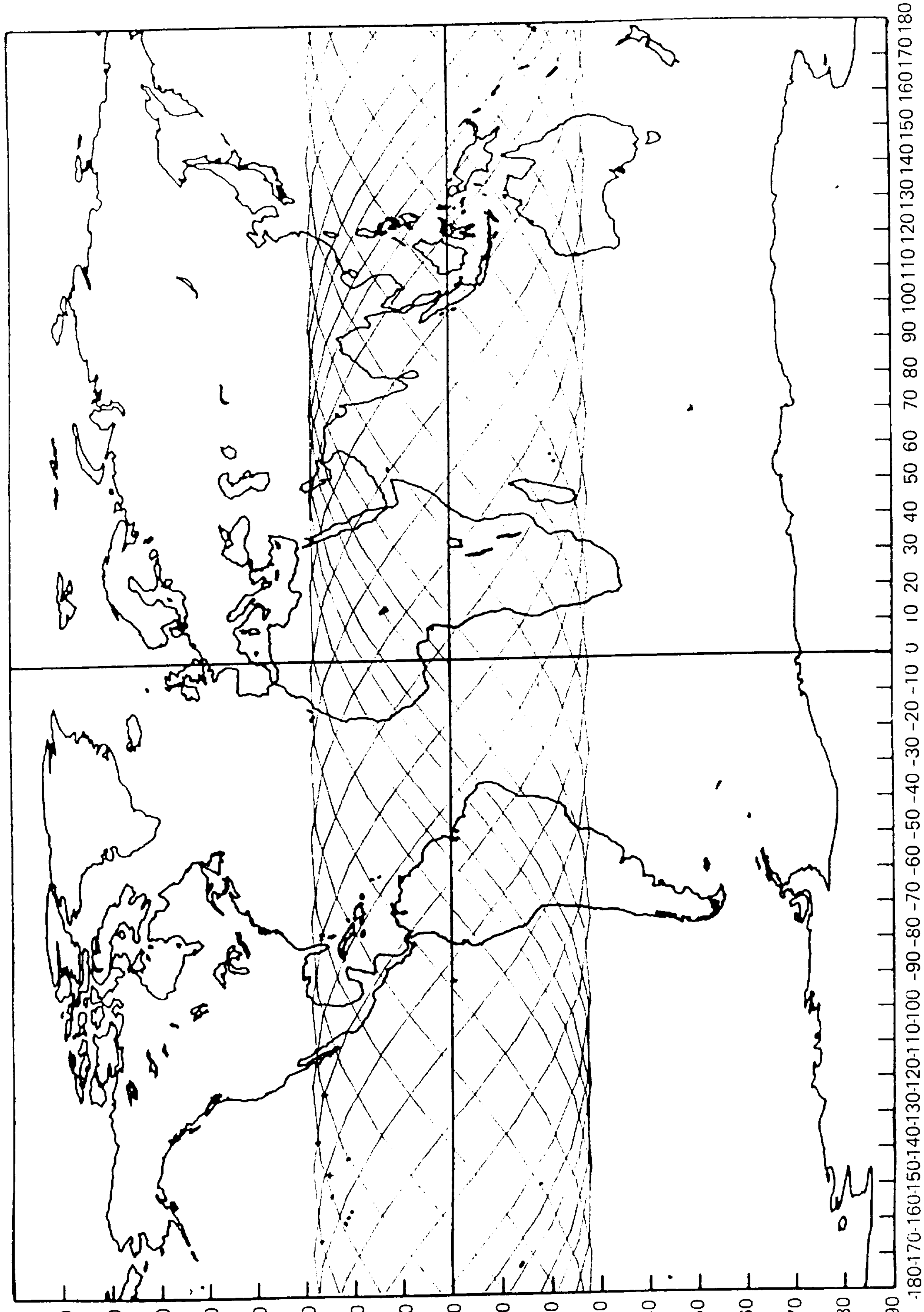
Attachments

cc: Mr. Stocklin/531.1
Mr. Scherer/531.1

			EQUATORIAL STATION			FIXED STATION LAT. 26.5°			MOBILE STATION MOVING AROUND NOMINAL LATITUDE OF 26.5°		
				TOTAL TIME	MAX EL	PASS (H:M:S)	CONTACT TIME (MIN)	MAX EL OF PASS (°)	PASS (H:M:S)	CONTACT TIME (MIN)	MAX EL OF PASS (°)
DAY 1	HH:MM:SS	AOS	01:25:24	9.2	90°	10:36:28	3.3	2°	10:36:39	6.3	5°
		LOS	01:35:35			10:39:44			10:42:56		
		AOS	03:02:00	7.1	8°	12:09:03	8.4	18°	12:10:35	8.9	30°
		LOS	03:09:10			12:17:29			12:19:30		
		AOS	11:07:13	4.2	2°	13:44:06	9.2	90°	13:44:06	9.2	90°
		LOS	11:11:24			13:53:15			13:53:15		
		AOS	12:40:40	8.7	31°	15:19:48	9.1	50°	15:19:48	9.1	50°
		LOS	12:49:20			15:28:52			15:28:52		
		AOS	14:16:32	8.0	14°	16:55:28	9.1	90°	16:55:28	9.1	90°
		LOS	14:24:30			17:04:32			17:04:32		
		AOS				18:31:14	8.4	21°	18:29:15	8.8	36°
		LOS				18:39:41			18:38:06		
		AOS				20:08:31	4.2	2°	20:05:38	6.6	7°
		LOS				20:12:45			20:12:14		
DAY 2	HH:MM:SS	AOS	23:55:00*	8.3	16°	10:40:09	6.6	6°	10:41:13	7.9	12°
		LOS	00:04:08			10:46:44			10:49:06		
		AOS	01:31:04	8.9	30°	12:14:13	9.0	33°	12:15:56	9.1	58°
		LOS	01:39:57			12:23:10			12:25:05		
		AOS	03:09:03	4.4	2°	13:49:38	9.2	65°	13:49:38	9.2	65°
		LOS	03:13:24			13:58:48			13:55:38		
		AOS	11:11:27	7.0	8°	15:25:23	9.1	54°	15:25:23	9.1	54°
		LOS	11:18:26			15:34:28			15:34:28		
		AOS	12:46:03	8.9	72°	17:01:01	8.9	54°	16:59:08	9.1	54°
		LOS	12:54:58			17:01:02			17:08:14		
		AOS	14:22:59	6.3	6°	18:37:04	7.6	11°	18:34:55	8.4	19°
		LOS	14:29:14			18:44:39			18:43:19		
		AOS							20:12:28	3.6	2°
		LOS							20:16:06		

*PREVIOUS DAY

DAY 1	MOBILE STATION MOVING AROUND 19.5° LATITUDE			FIXED STATION AT 19.5° LAT		
	HH:MM:SS	CONTACT TIME, MIN	MAX EL (DEG) OF PASS	HH:MM:SS	CONTACT TIME, MIN	MAX EL OF PASS (DEG)
AOS	08:58:43	8.3	16°	10:33:33	7.6	11°
LOS	09:07:02			10:41:41		
AOS	10:33:19	9.0	40°	12:08:10	9.2	90°
LOS	10:42:22			12:17:21		
AOS	12:08:10	9.2	90°	13:44:14	8.5	18°
LOS	12:17:21			13:52:46		
AOS	13:44:06	9.2	90°	15:20:39	7.8	12°
LOS	13:53:15			15:28:28		
AOS	15:19:48	9.1	50°	16:56:27	8.4	17°
LOS	15:28:52			17:04:48		
AOS	16:55:28	9.1	90°	18:31:53	9.0	90°
LOS	17:04:22			18:40:52		
AOS	18:31:53	9.0	90°	20:08:03	7.5	11°
LOS	18:40:52			20:15:31		
AOS	20:06:53	8.8	42°			
LOS	20:15:43					
AOS	21:42:12	8.1	16°			
LOS	21:50:19					


90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-180 -170 -160 -150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180

Appendix B

Reprinted from JOURNAL OF ATMOSPHERIC AND OCEANIC TECHNOLOGY, Vol. 4, No. 2, June 1987
American Meteorological Society

Airborne Tracking Sunphotometer

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VICTOR BANTA

Trans-Bay Electronics, Redwood City, CA 94035

21 March 1986, and 26 September 1986

ABSTRACT

An airborne tracking sunphotometer, mounted on the outside top surface of an aircraft has been developed to provide unrestricted viewing of the Sun. This instrument will substantially increase the data that scientists can gather for atmospheric studies. The instrument has six wavelength channels and an automatic data gathering system. The instrument's optical features, tracking capability, mechanical features, and data gathering system are described.

1. Introduction

An airborne tracking sunphotometer has been developed at NASA Ames Research Center for the purpose of obtaining accurate multispectral atmospheric extinction measurements at different altitudes. The limitations of ground based sunphotometers are discussed in Pitts (1977). This new instrument is designed to be mounted on the top of an aircraft and outside the cabin in a configuration allowing an unobstructed view of the sun. Previous measurements were made by observing the sun through an aircraft window; this configuration severely restricted the viewing angle to the sun. Moreover, an additional calibration of the window had to be done to account for attenuation and angular effects.

2. Instrument

The instrument consists of a solar-tracking system, detector module, temperature-control system, nitrogen-purge system, mechanical drive chain, and data-collection system. A block diagram is shown in Fig. 1.

The two-axis solar-tracking system can be seen in Fig. 2. The solar-tracking system was designed to achieve two objectives: first, to be able to acquire the sun starting from a position several degrees away; and second, to track the sun with an accuracy of ±0.1° in the presence of aircraft movements. A large field of view (FOV) is required because the initial pointing is manually controlled until solar acquisition occurs. The large FOV simplifies the initial pointing and, in addition, enables the system to reacquire the sun if tracking is lost because of abrupt movements by the aircraft. To accomplish the two objectives under normal circumstances is not too difficult, but in this case the sensor was restricted in size and location. It was designed to fit into the detector module surrounded by the science detectors; the sensor design is shown in Fig. 3. The sensors used are Clairex photoresistors that have been matched to track each other over the operational range of sun intensities. The sensing technique uses a shadow mask that bisects each detector when the system is in balance. This design allows for very accurate tracking, yet at the same time provides a FOV of ±25°. This unique design resulted in a sensor with a wide FOV and accurate tracking in a very compact package. The dome rotation is referred to as azimuth motion. The central section of the dome is free to rotate within the dome, perpendicular to the azimuth, and is referred to as elevation motion. The control system is designed to compensate for the flight characteristics of the Convair 990 aircraft and acceleration/vibration limits have not been determined. The flight conditions are benign, except during a turn. During cruise, the typical roll rate is ±40 arc min in 30 sec, typical yaw is ±10 arc min in 30 sec, and typical pitch is ±6 arc min in 30 sec. The worst-case conditions occur during a turn; the time required to turn 360° at 400 kt is 8.2 min for an azimuth rate of 0.73 deg sec^{-1}. The system is designed to move in elevation or azimuth at 8 deg sec^{-1}. The acceleration that may occur during a turn is estimated to be 1.0 rad s^{-2}. If the instrument should lose lock the reacquisition occurs very rapidly as long as the sun is in the FOV of the instrument. The tracking system responds quickly because it uses a single rate of 8 deg sec^{-1} for tracking.

The detector module, shown in Fig. 4, is a cylindrical unit that plugs into the main unit through a connector.

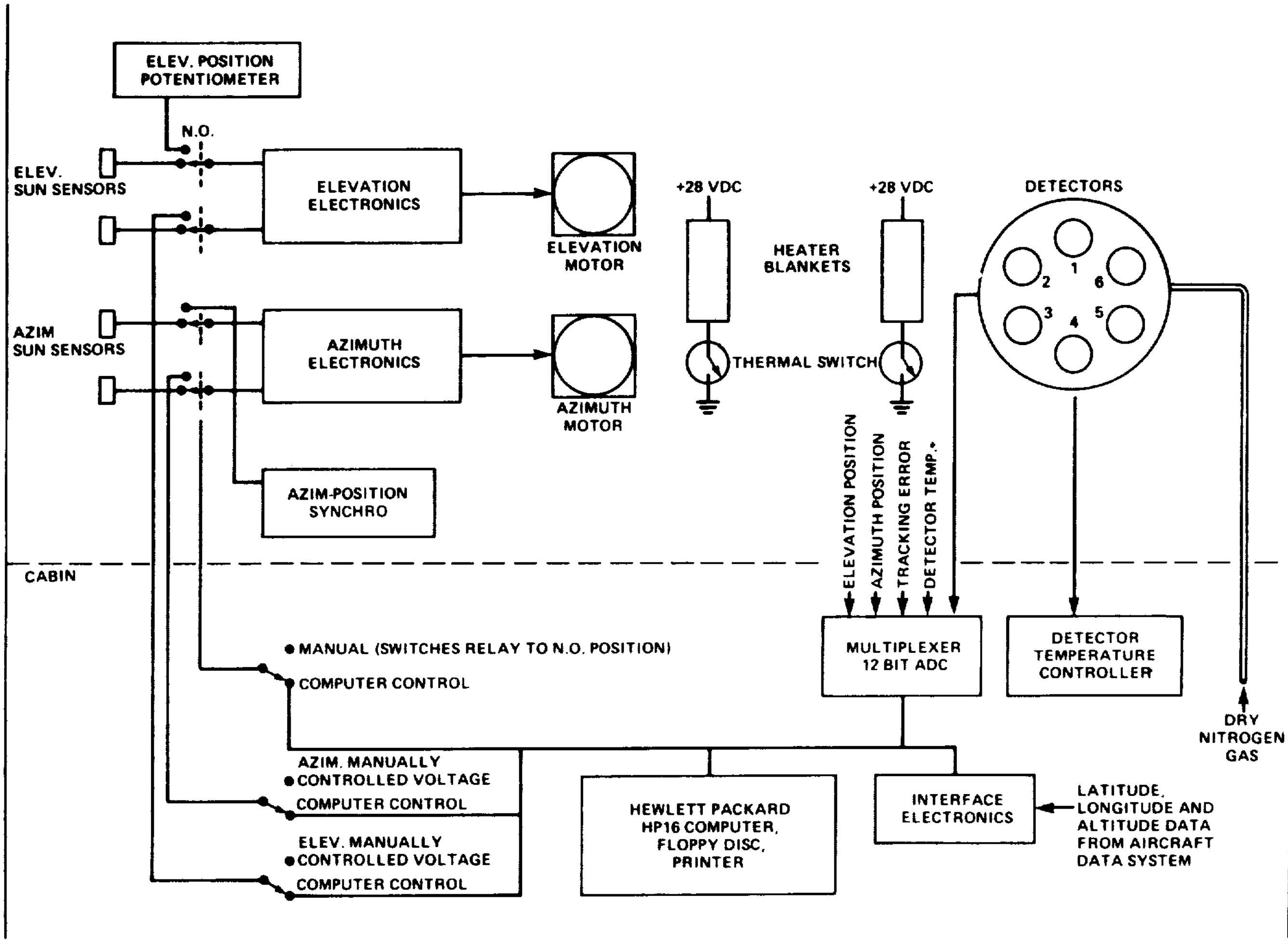

FIG. 1. Airborne sunphotometer block diagram.

The module is easily removable for maintenance and repair. It contains six separate silicon photodetectors, each with its own optical filter, which are replaceable; a sun sensor for sun-tracking purposes; and a temperature sensor and heater to control the temperature inside the module. The filters range from 380 to 1020 nm with a nominal bandwidth of 10 nm. The detectors used are Silicon Detector Corporation devices that combine a detector and preamplifier inside a TO-5 style can. The FOV of each detector is set by the entrance aperture to 2°, the inside surfaces of the aperture assembly are anodized a dull black to reduce internal reflections, and a baffle is included to further reduce reflections. The 2° FOV was selected to allow for ±1° of tracking error without affecting the solar-radiation signal. The entrance aperture is protected from the airstream with a fused quartz window; no lenses are used in the system. Much of this design borrows from earlier work done by Tomasi (1978) and Russell (1978).

The temperature-control system uses a combination of accurate electronic feedback control and simple bimetallic thermostat controls. The reasoning behind this approach is that parts of the system require heating, but not absolute temperature control. The six detectors located inside the detector module require absolute temperature control and are temperature controlled to 45° ±1°C by an analog temperature control system located inside the aircraft cabin. The position control electronics can withstand −55°C, but the stepper motors cannot operate below −10°C. The heating requirements here are easily served by heater blankets controlled by bimetallic switches. To reduce heat loss the dome shell and the detector module are constructed of fiberglass. The system was tested in an environmental chamber at −55°C; the detector temperature dropped to 44.5°C and the stepper motor temperature dropped to 26°C.

To prevent condensation from forming on the window, a dry-nitrogen purge system is included. A small flexible tube is used to route the nitrogen into the detector module, as can be seen in Fig. 2. The nitrogen is continuously on during each flight from takeoff to landing.

The mechanical drive train was designed to provide a mechanical torque multiplication of 80 for the stepper motors and to prevent external forces from driving the

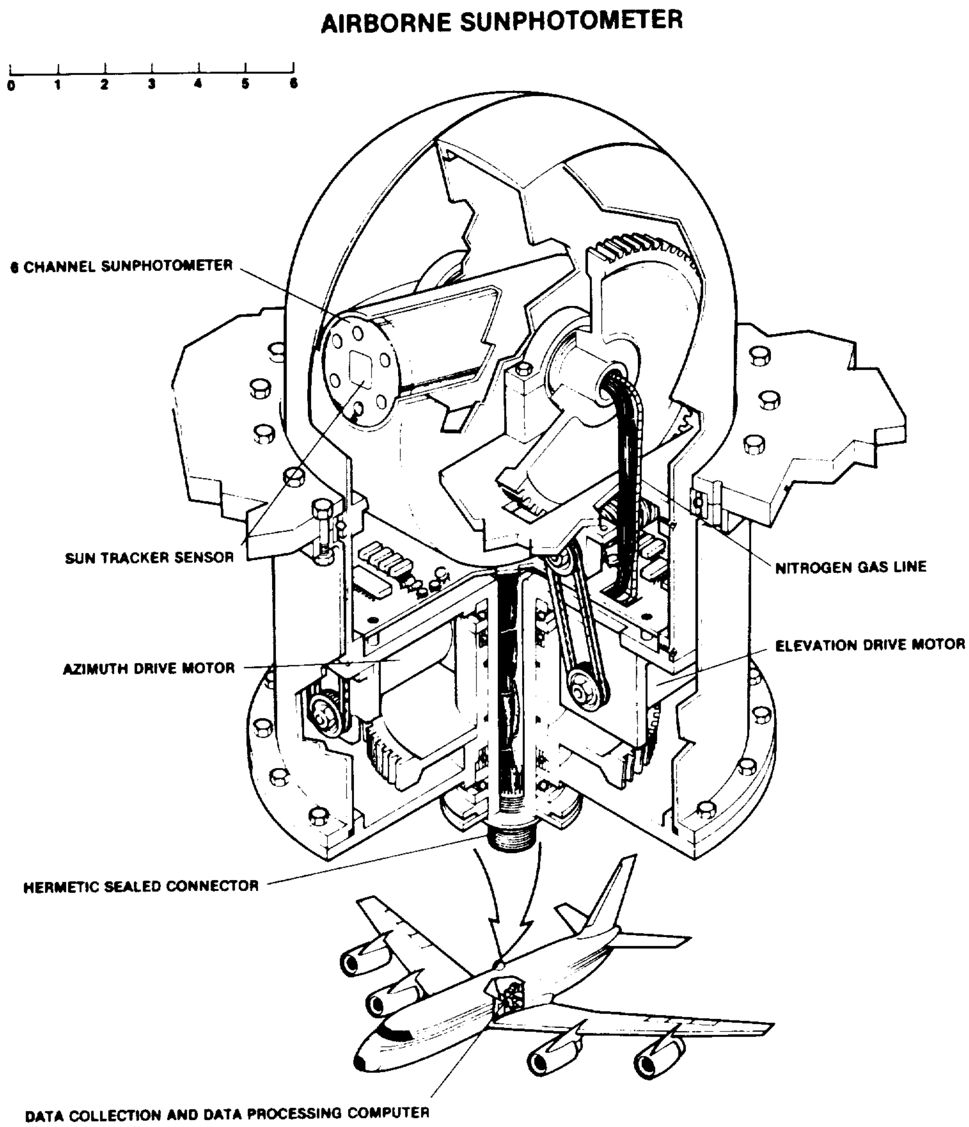

FIG. 2. Airborne sunphotometer.

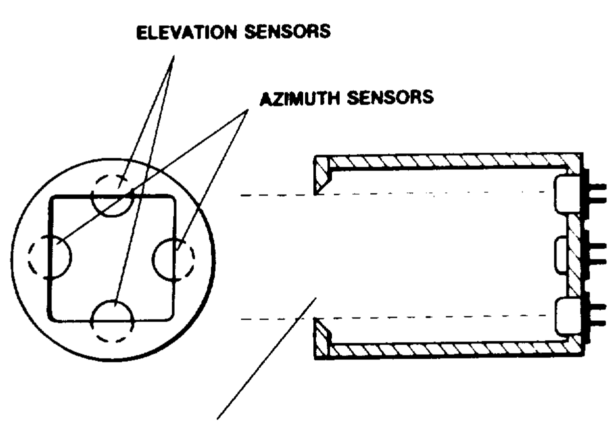

FIG. 3. Solar tracker sun sensor.

gear train backward. The torque multiplication was needed because the size of the stepper motors was limited by the size of the overall dome, which was purposely kept small to minimize aerodynamic drag. Stepper motors were chosen for the drive power because of their inherent reliability and adaptability to digital-control systems. Their reliability is due in large part to the fact that they do not contain brushes, a common source of mechanical failure, and their adaptability to digital control systems because they are digital devices that move in discrete steps. The gear train includes a nonslip drive belt that connects the stepper motors to a worm which in turn drives a worm gear. A characteristic of worm/worm gear combinations is that they cannot be driven backward by external forces. This desirable characteristic was specifically

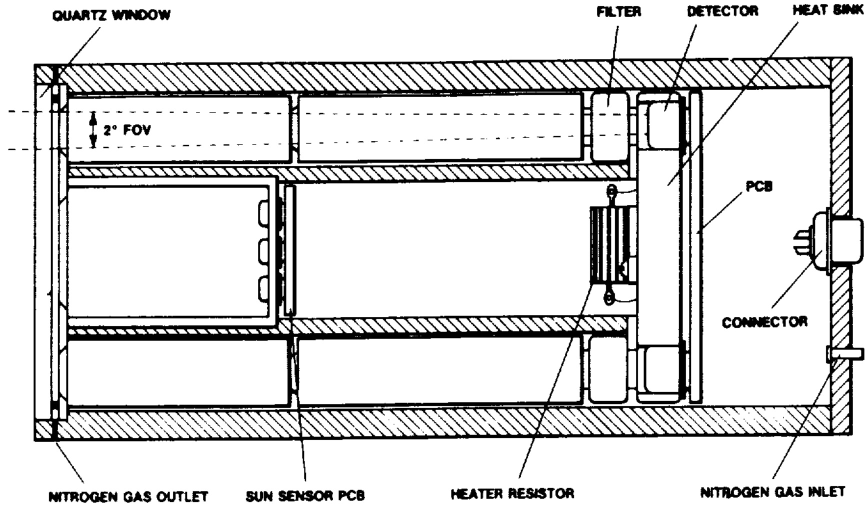

FIG. 4. Detector module.

chosen to prevent aerodynamic forces from setting up mechanical oscillation. Backlash is present in the gear train, but is small enough to be ignored.

3. Data collection

The data-collection system is based on a Hewlett-Packard HP9816 computer with floppy disc and printer. A data-collection, data-processing, and printing program, which is interactive and easy to use, was written for the HP9816. Besides the computer, the data-collection system includes a multiplexer, a 12-bit analog-to-digital converter, and electronics to process the aircraft inertial navigation data. The data are sampled approximately every 2 sec and are synchronized with the aircraft data system which provides the altitude, longitude, and latitude data. The science dataset includes the six detector signals, detector temperature, tracking error, sun tracker azimuth angle, sun tracker elevation angle, and UTC time. The computer stores the data on 3.5 in. floppy disks, each of which can hold 270 kilobytes of data. The data are also printed out for real-time check and backup. Besides the data-collection program, additional programs are being written to process the data and display Langley and optical-depth plots. Future plans are to integrate some of the processing and plotting programs to operate in near real time to provide graphical display of atmospheric conditions during a flight.

4. Calibration and flight tests

The system was test-flown in December 1984, and in April 1985 it was flown in a validation mission for the SAGE 2 satellite. The 1985 mission was based in Brazil, and results were presented at the SAGE 2 Science Team Meeting at Ames Research Center in May 1985. Preparations were made to operate the sunphotometer in a second SAGE 2 validation mission in August 1985. However, the mission was canceled by the loss of the CV990 aircraft. In place of the lost mission, the system was taken to Mauna Loa Observatory to obtain calibration data simultaneously with the University of Arizona calibrated sunphotometer. The instrument is designed to retain its calibration. The detectors are temperature controlled and the amplifier gains are set with precision resistors. The resolution of the detector signals is limited by the 12 bit analog—digital converter that can resolve 1 part out of 2048 of the 0 to +10v detector signals. The instrument is designed to operate in clear skies and it is also assumed that over the period of a flight profile there are no solar fluctuations. There is evidence in the literature that in the wavelength region of interest solar fluctuations would account for less than a 1% variation of the data. On the matter of clear skies, it is possible that the instrument could be used to look through patchy cirrus clouds by controlling the pointing with the data collection computer (assuming that the computer is fast enough to gather data and control the instrument) by utilizing the attitude, longitude, and time of day data. Several future missions are planned for this instrument.

Acknowledgments. We should like to thank William Dyer of SRI International for his help in the formative stages of this project. We are also grateful to the Ames Research Center model shop under Terence Medeiros and the Ames Research Center machine shop under John Anderholm for the excellent work that contributed significantly to the success of this project.

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Russell, P. B., E. J. Scribner and E. E. Uthe, June 1978: An automated multiwavelength sunphotometer to characterize transient aerosol and water vapor events. *Third Conf. Atmospheric Radiation*, Davis, Amer. Meteor. Soc.

Tomasi, C., F. Prodi, M. Sentimenti and G. Cesari, 1983: Multiwavelength sun-photometer for accurate measurements of atmospheric extinction in the visible and near IR spectral range. *Appl. Opt.*, **22**(15), 622–630.

Appendix C
Some Orbital Mechanics/Tracking Considerations

The following figures show:

1. The maximum time that the Shuttle Orbiter is in view of an airplane as a function of the maximum elevation angle (ϵ_{max}) as the Shuttle Orbiter passes by (sometimes referred to as a pass). This type information tells the contact time that would be available for performing communications (lasercom) experiments with the Shuttle.

2. How the elevation angle varies with time for various ϵ_{max}. This type information is useful in evaluating the desired elevation angle coverage by the airplane lasercom terminal.

3. The elevation angular rate ($\dot{\epsilon}$) as a function of time for various ϵ_{max}. This information is needed for determining the slow rate requirements of the airplane lasercom aperture elevation angle drive system.

4. The total change in azimuth (ΔAz) over a Shuttle Orbiter pass as a function of ϵ_{max} for the pass. This information is useful for trading off airplane turning requirements versus the airplane lasercom aperture azimuth drive requirements.

5. The azimuth angle (Az) of the slant range vector from the airplane to the Shuttle Orbiter (i.e., azimuth of the viewing line-of-sight) versus time into the pass for various ϵ_{max}. The azimuth and time are "normalized" or set equal to zero at the start of the pass. This information is useful in trading off the airplane turn requirements versus the airplane lasercom aperture azimuth drive requirements.

6. The magnitude of the azimuth angular rate as a function of time into the pass for various ϵ_{max}. As above, this information is useful in trading off airplane turn requirements versus the airplane lasercom aperture azimuth drive requirements.

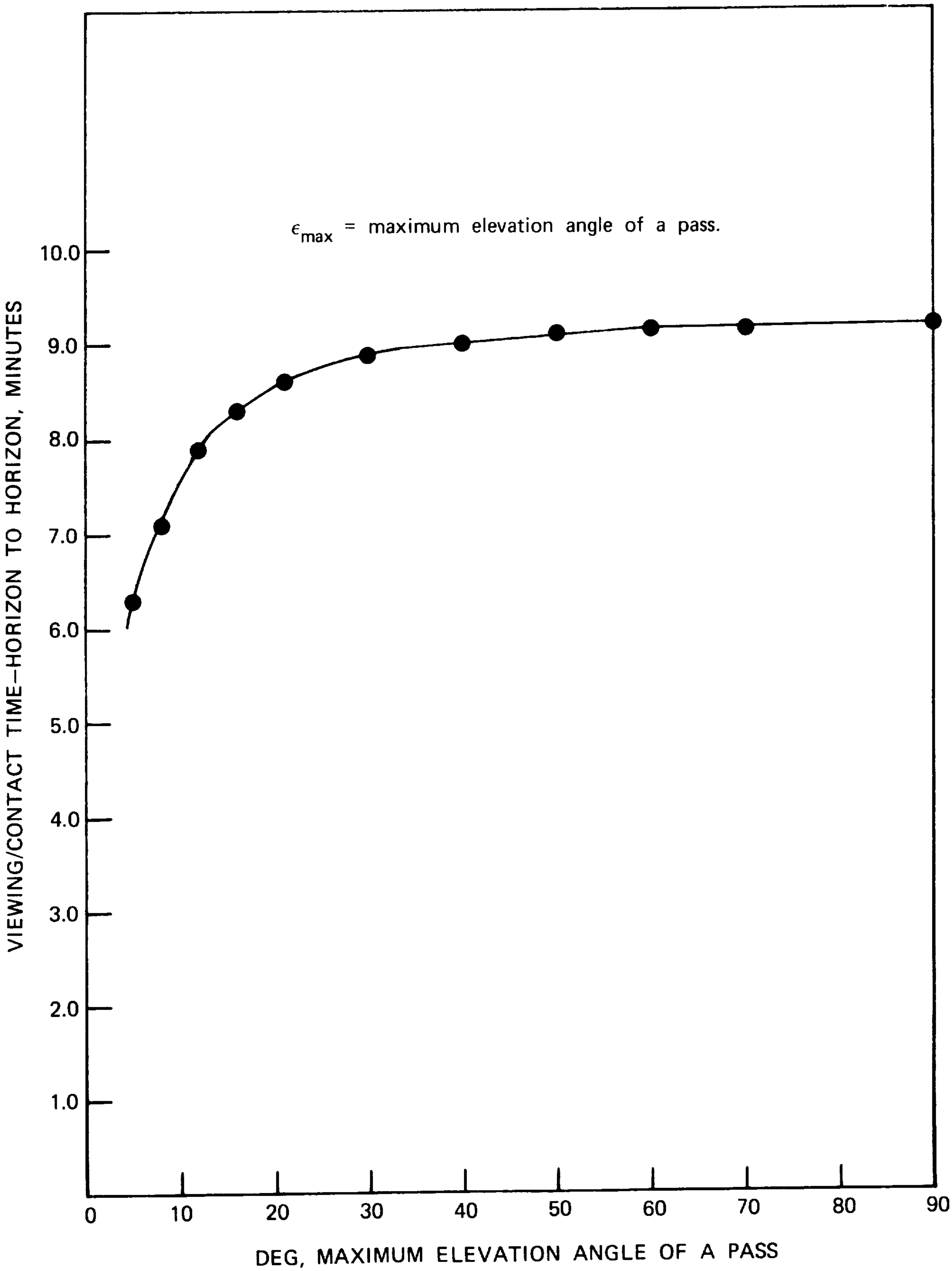


Figure C1. Maximum Viewing Time Vs. ϵ_{max}.

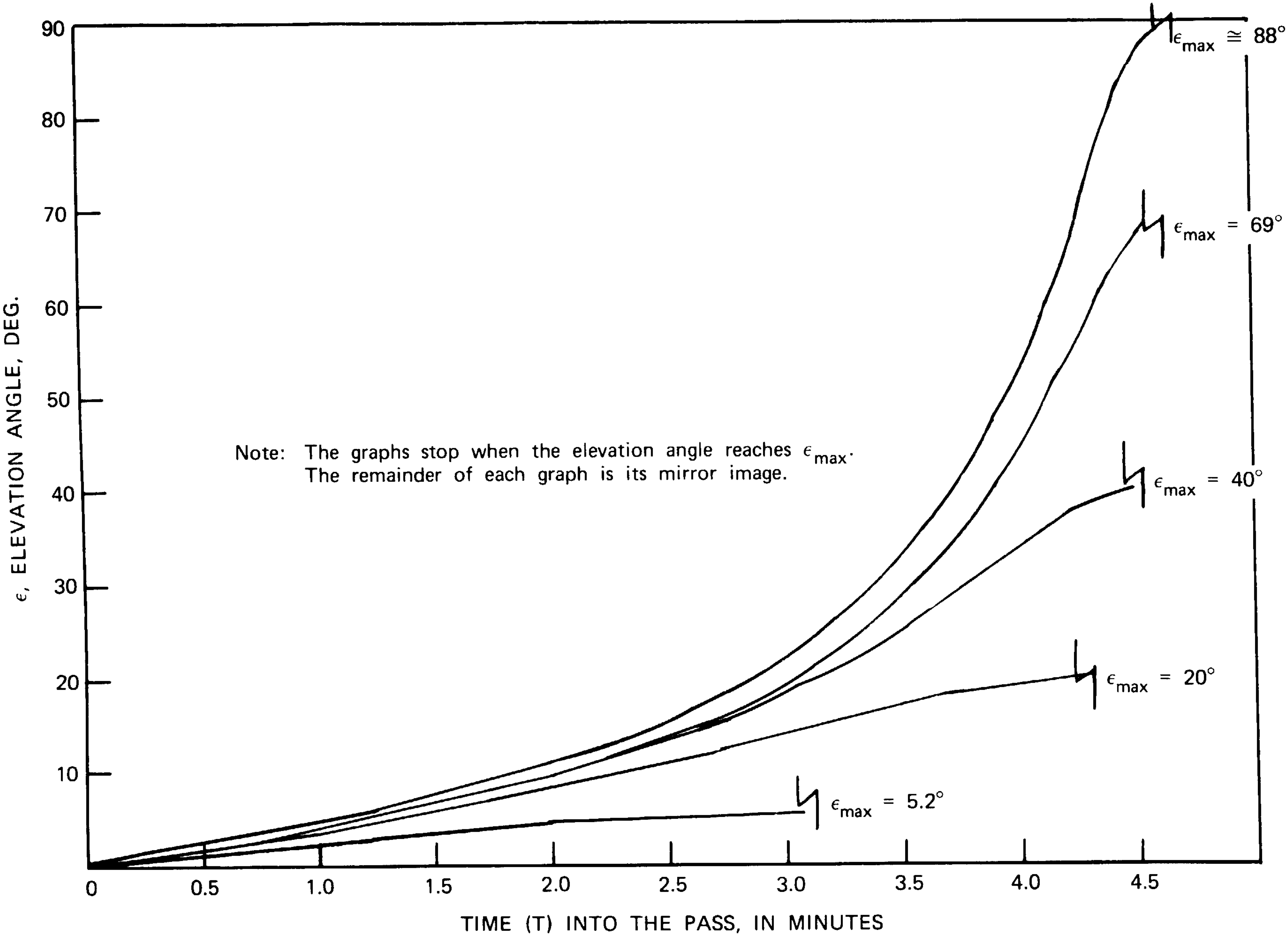


Figure C2a. ϵ Vs. T for several ϵ_{max}; ϵ = Elevation Angle and T = Time into the Pass.

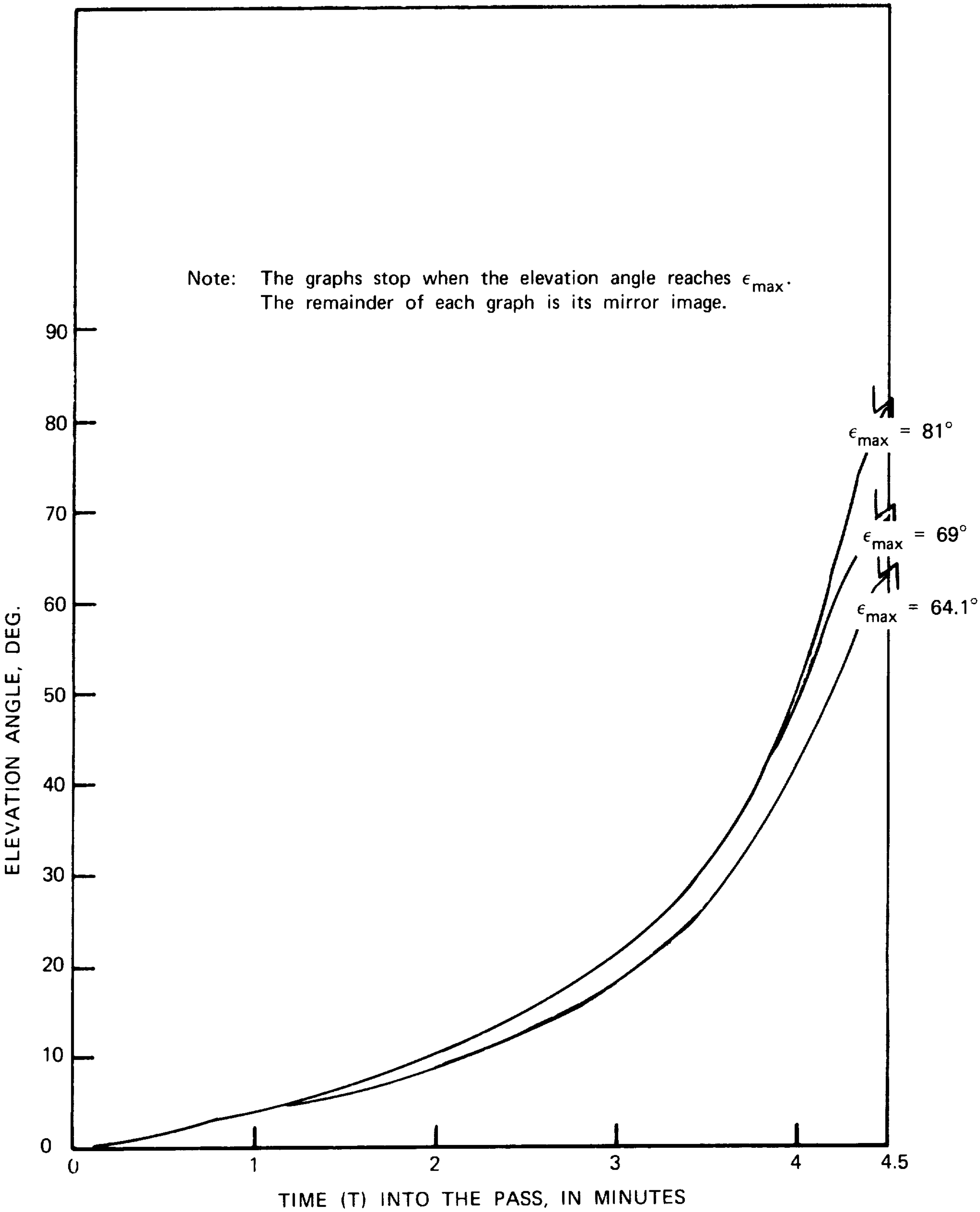


Figure C2b. Elevation Angle (ϵ) Vs. Time (T).

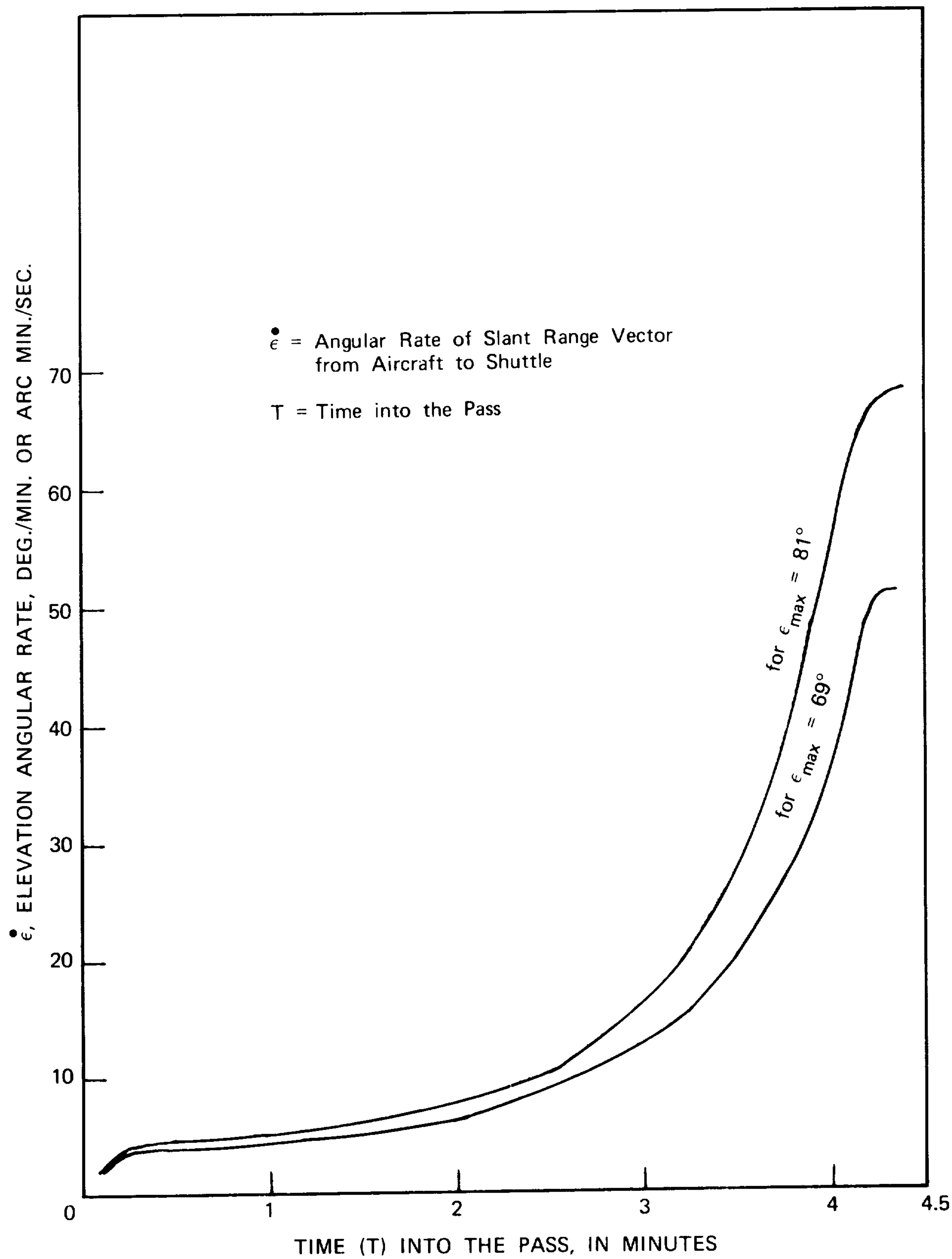


Figure C3. $\dot{\epsilon}$ Vs. T; Elevation Angular Rate $\dot{\epsilon}$ Vs. Time.

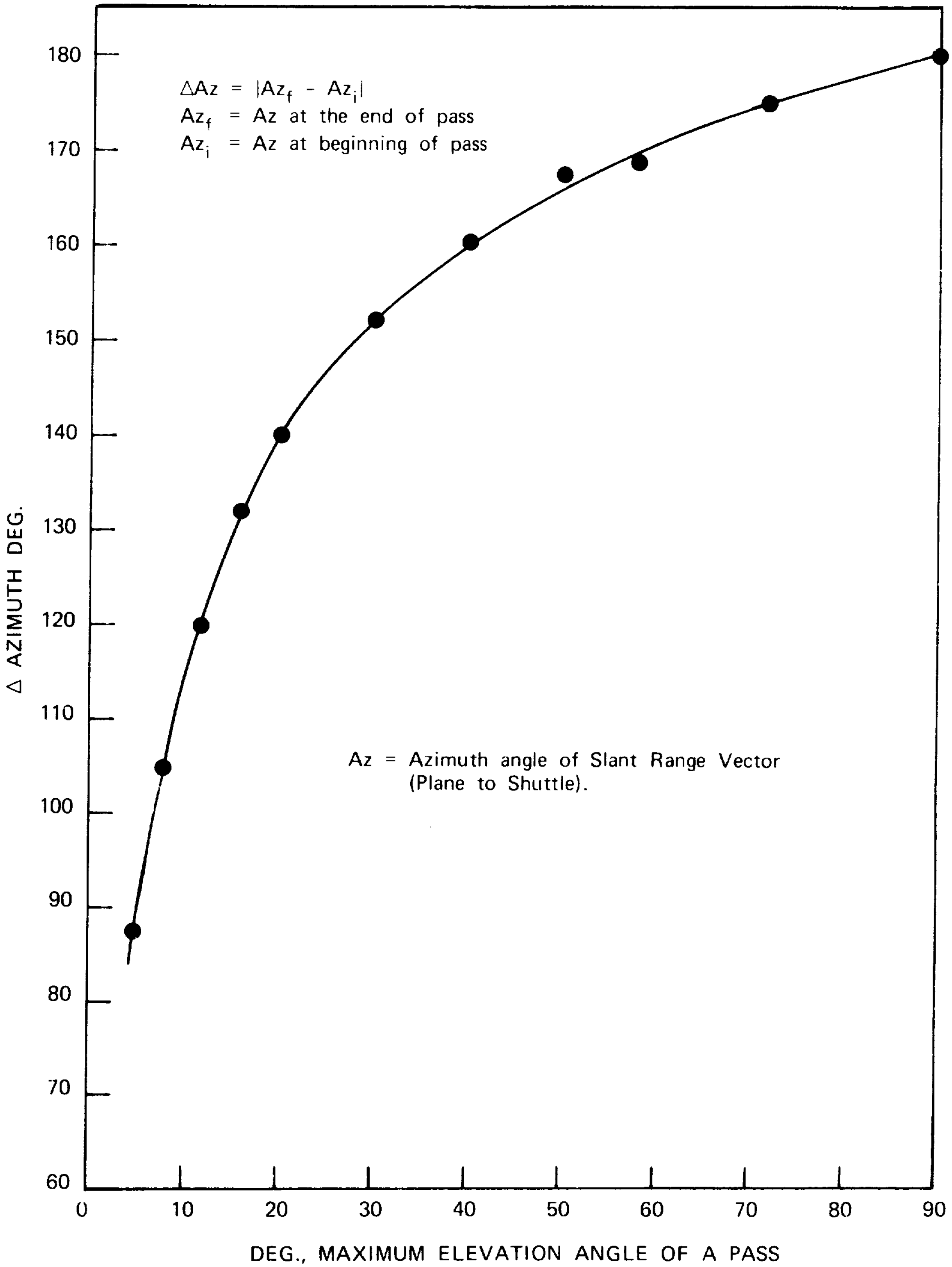


Figure C4. ΔAz vs. ϵ_{max}.

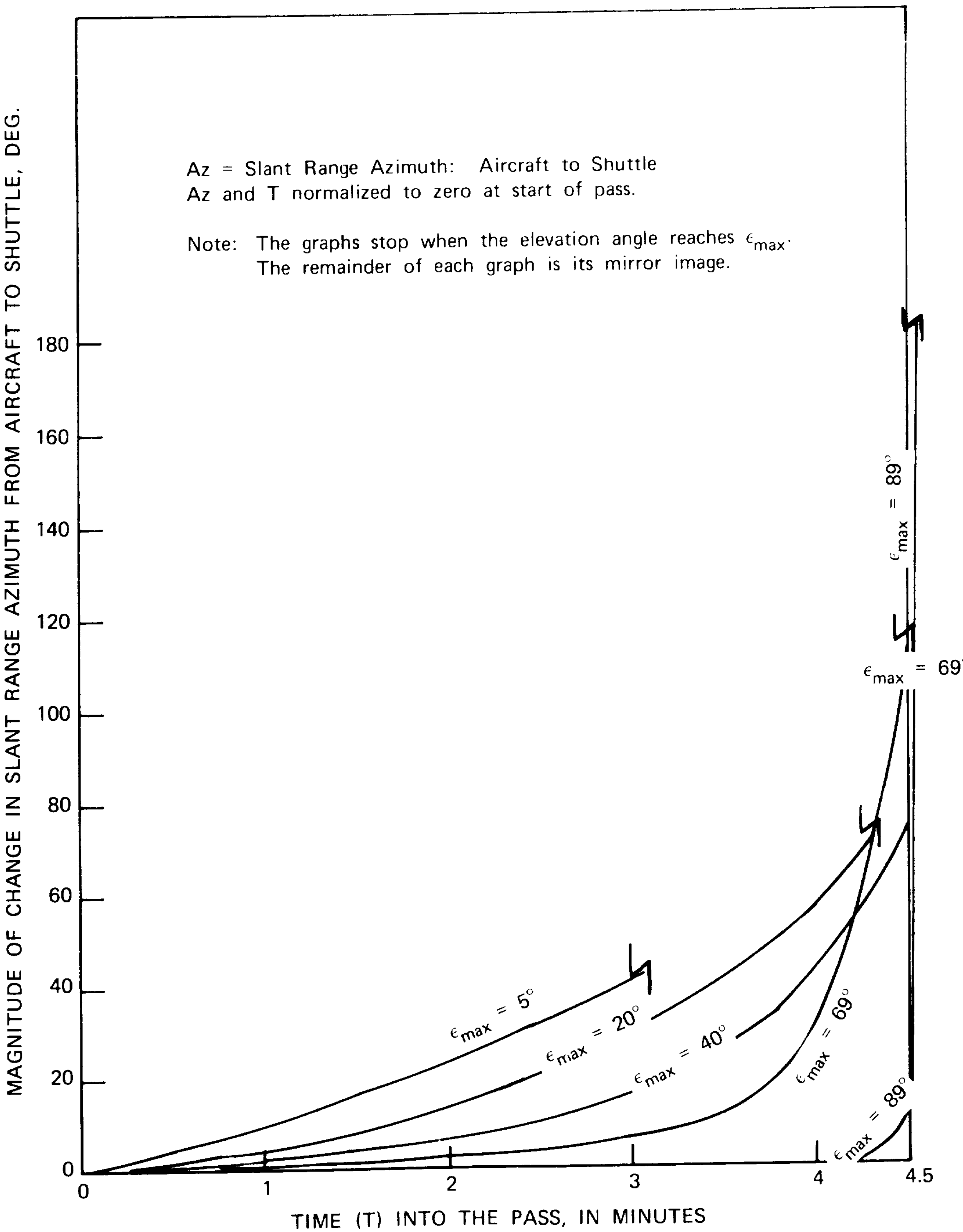


Figure C5. "Normalized" Az Vs. Time (T).

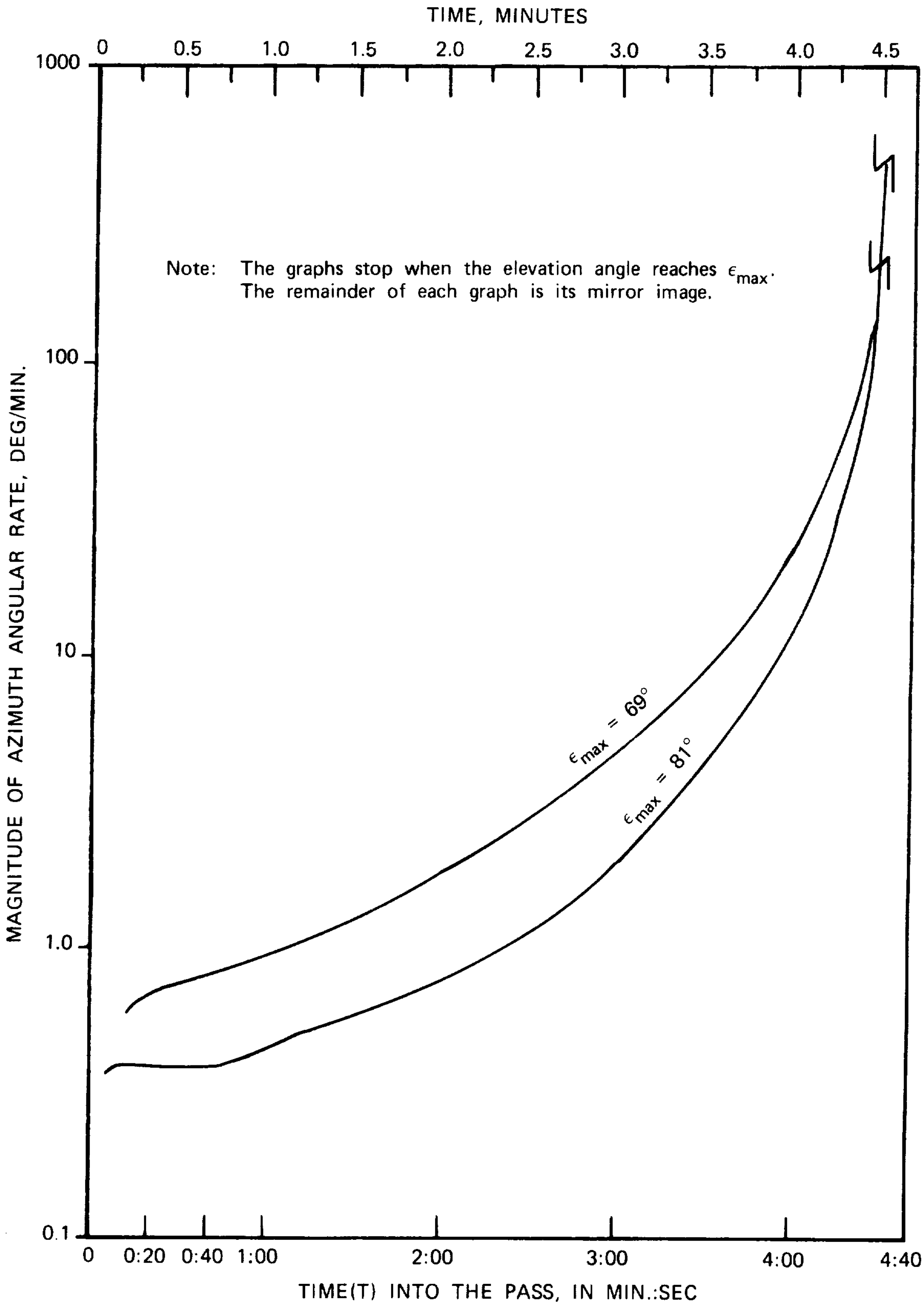


Figure C6a. $\dot{Az}$ Vs. Time (T).

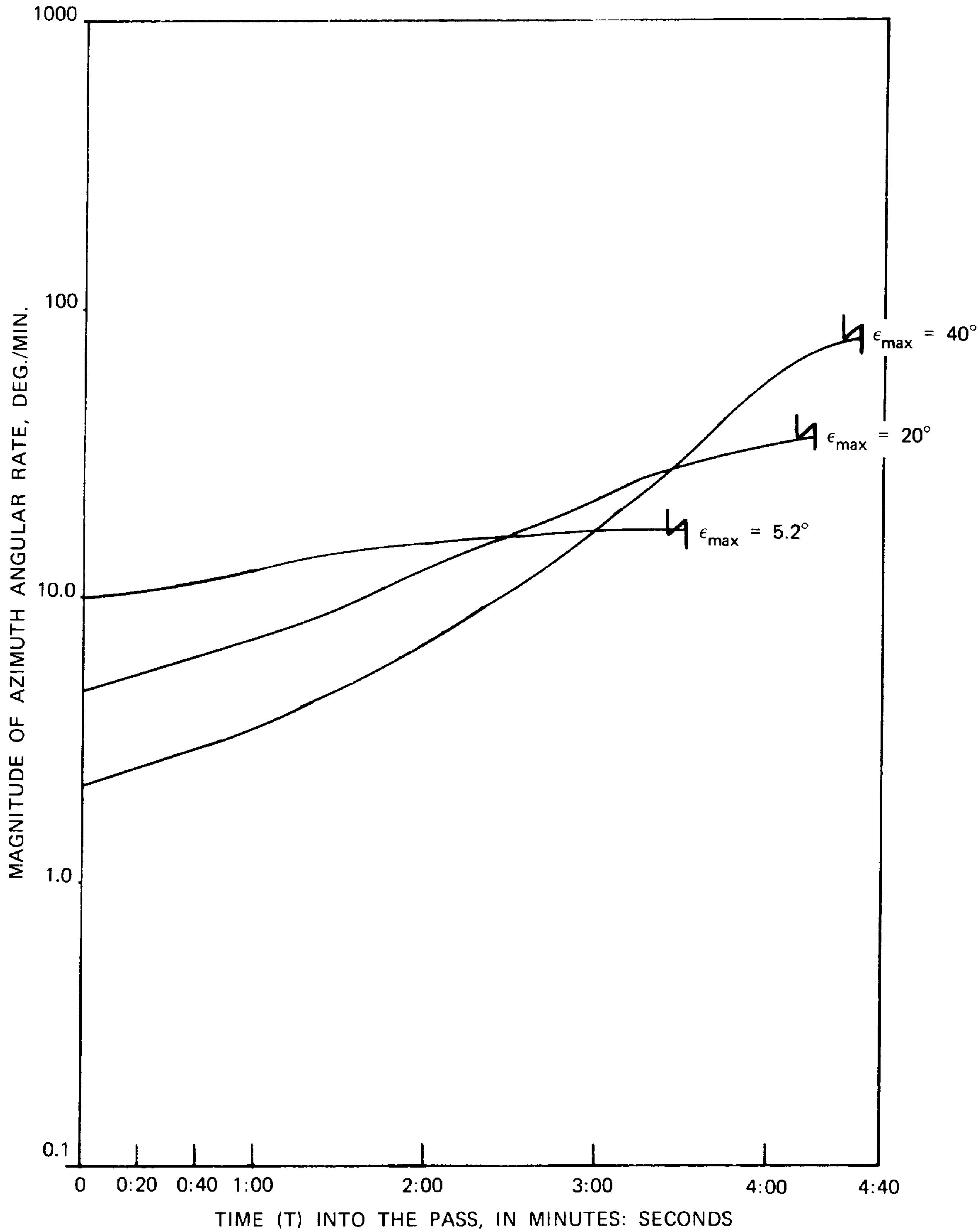


Figure C6b. $\dot{Az}$ Vs. Time.

Appendix D
Tables: Coverage Analysis

In these tables—

- The first 5 columns give the time in units of year, month, day, hour, minutes, and seconds, when the Shuttle Orbiter would be in view of a tracking aircraft station.
- Shuttle position in units of latitude (degrees), longitude (degrees), and altitude (kilometers) are presented in columns 6 through 8.
- Columns 9–11 indicate azimuth (Az in degrees), elevation (EL in degrees) and range (slant range, km) from aircraft to Shuttle, when the Shuttle Orbiter is in view of the tracking aircraft station.

The Shuttle Orbiter passes that are tabulated are for the cases when the maximum elevation (ϵ_{max}) for a particular pass reaches:

(a) 88.4°
(b) 80.8°
(c) 71.6°
(d) 68.6°
(e) 64.1°
(f) 40.2°
(g) 20.0°
(h) 10.5°
(i) 5.2°

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA1   LAT= 19.50   LON=213.00   ALT= 30,000 ft. EL_{max} = 88.4°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 921	12	7	15.0000	10.433	193.626	300.7	247.06	-3.21	2370.0
84 921	12	7	30.0000	10.881	194.468	300.7	247.08	-2.40	2265.6
84 921	12	7	45.0000	11.327	195.312	300.7	247.10	-1.55	2161.1
84 921	12	8	0.0	11.769	196.159	300.7	247.11	-0.67	2056.5
84 921	12	8	15.0000	12.209	197.010	300.7	247.13	0.26	1952.0
84 921	12	8	30.0000	12.645	197.863	300.8	247.15	1.24	1847.4
84 921	12	8	45.0000	13.079	198.719	300.8	247.17	2.29	1742.9
84 921	12	9	0.0	13.509	199.578	300.8	247.19	3.40	1638.4
84 921	12	9	15.0000	13.935	200.441	300.8	247.21	4.61	1534.1
84 921	12	9	30.0000	14.359	201.307	300.8	247.24	5.92	1430.0
84 921	12	9	45.0000	14.778	202.177	300.8	247.26	7.36	1326.1
84 921	12	10	0.0	15.194	203.050	300.8	247.28	8.97	1222.6
84 921	12	10	15.0000	15.606	203.927	300.8	247.31	10.79	1119.6
84 921	12	10	30.0000	16.014	204.807	300.8	247.34	12.88	1017.2
84 921	12	10	45.0000	16.417	205.692	300.8	247.37	15.33	915.8
84 921	12	11	0.0	16.817	206.580	300.8	247.40	18.27	815.6
84 921	12	11	15.0000	17.212	207.472	300.8	247.44	21.89	717.4
84 921	12	11	30.0000	17.602	208.368	300.8	247.49	26.50	622.0
84 921	12	11	45.0000	17.988	209.269	300.8	247.56	32.57	530.9
84 921	12	12	0.0	18.369	210.173	300.7	247.65	40.83	446.8
84 921	12	12	15.0000	18.745	211.082	300.7	247.81	52.39	374.7
84 921	12	12	30.0000	19.116	211.995	300.7	248.22	68.31	322.5
84 921	12	12	45.0000	19.481	212.913	300.7	257.40	88.12	300.9
84 921	12	13	0.0	19.842	213.834	300.7	66.46	71.59	316.1
84 921	12	13	15.0000	20.197	214.761	300.7	67.00	54.86	363.7
84 921	12	13	30.0000	20.546	215.691	300.7	67.18	42.60	433.0
84 921	12	13	45.0000	20.890	216.627	300.6	67.28	33.83	515.3
84 921	12	14	0.0	21.228	217.566	300.6	67.35	27.44	605.4
84 921	12	14	15.0000	21.560	218.510	300.6	67.40	22.61	700.2
84 921	12	14	30.0000	21.886	219.459	300.5	67.44	18.84	798.0
84 921	12	14	45.0000	22.205	220.413	300.5	67.48	15.79	897.9
84 921	12	15	0.0	22.519	221.371	300.5	67.52	13.27	999.1
84 921	12	15	15.0000	22.825	222.333	300.4	67.55	11.12	1101.3
84 921	12	15	30.0000	23.125	223.300	300.4	67.59	9.26	1204.2
84 921	12	15	45.0000	23.419	224.272	300.4	67.62	7.62	1307.7
84 921	12	16	0.0	23.705	225.248	300.3	67.65	6.15	1411.5
84 921	12	16	15.0000	23.985	226.229	300.3	67.68	4.82	1515.6
84 921	12	16	30.0000	24.257	227.214	300.2	67.71	3.59	1619.9
84 921	12	16	45.0000	24.523	228.204	300.2	67.73	2.46	1724.3
84 921	12	17	0.0	24.780	229.197	300.1	67.76	1.41	1828.8
84 921	12	17	15.0000	25.031	230.196	300.1	67.79	0.42	1933.4
84 921	12	17	30.0000	25.274	231.198	300.0	67.82	-0.52	2038.0
84 921	12	17	45.0000	25.509	232.205	300.0	67.86	-1.42	2142.6
84 921	12	18	0.0	25.736	233.216	299.9	67.88	-2.27	2247.1
84 921	12	18	15.0000	25.955	234.231	299.8	67.91	-3.09	2351.5
84 921	12	18	30.0000	26.167	235.250	299.8	67.93	-3.88	2455.9

STATION=STA1   LAT= 19.50   LON=213.00   ALT= 30,000 ft.

	MASK TIME YRMODA	HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 921	12	8	10.8	247.1	-0.0	1981.4	
LOS=	84 921	12	17	21.6	67.8	-0.0	1979.2	9.2
MAX=	84 921	12	12	47.0	271.7	88.4	300.7	
MAXRG=	84 921	12	8	10.8			1981.4	
MINRG=	84 921	12	12	46.0			300.7	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA1 LAT= 19.50 LON=213.00 ALT= 30,000 ft. EL_{max} = 80.8°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 921	18	31	0.0	26.056	192.039	293.8	292.54	-3.05	2326.3
84 921	18	31	15.0000	25.840	193.058	293.6	292.61	-2.23	2221.6
84 921	18	31	30.0000	25.617	194.073	293.4	292.68	-1.39	2116.8
84 921	18	31	45.0000	25.385	195.083	293.2	292.76	-0.50	2012.0
84 921	18	32	0.0	25.145	196.090	293.1	292.84	0.44	1907.1
84 921	18	32	15.0000	24.898	197.093	292.9	292.92	1.43	1802.3
84 921	18	32	30.0000	24.643	198.091	292.7	293.02	2.48	1697.5
84 921	18	32	45.0000	24.381	199.085	292.5	293.12	3.61	1592.7
84 921	18	33	0.0	24.111	200.075	292.3	293.24	4.83	1488.2
84 921	18	33	15.0000	23.834	201.060	292.1	293.36	6.17	1383.8
84 921	18	33	30.0000	23.550	202.041	291.9	293.51	7.64	1279.6
84 921	18	33	45.0000	23.259	203.017	291.8	293.68	9.30	1175.9
84 921	18	34	0.0	22.961	203.989	291.6	293.87	11.18	1072.7
84 921	18	34	15.0000	22.657	204.957	291.4	294.11	13.36	970.2
84 921	18	34	30.0000	22.345	205.920	291.2	294.40	15.94	868.7
84 921	18	34	45.0000	22.028	206.878	291.0	294.77	19.08	768.7
84 921	18	35	0.0	21.704	207.832	290.8	295.26	23.00	670.8
84 921	18	35	15.0000	21.374	208.781	290.6	295.96	28.08	576.2
84 921	18	35	30.0000	21.037	209.726	290.5	297.02	34.90	486.8
84 921	18	35	45.0000	20.695	210.666	290.3	298.86	44.38	406.0
84 921	18	36	0.0	20.347	211.602	290.1	302.89	57.71	340.2
84 921	18	36	15.0000	19.993	212.533	289.9	318.23	75.16	299.5
84 921	18	36	30.0000	19.634	213.460	289.7	72.81	79.67	294.3
84 921	18	36	45.0000	19.269	214.382	289.6	99.74	61.83	326.4
84 921	18	37	0.0	18.899	215.301	289.4	104.99	47.30	386.7
84 921	18	37	15.0000	18.524	216.215	289.2	107.17	36.92	464.3
84 921	18	37	30.0000	18.144	217.124	289.0	108.38	29.50	551.8
84 921	18	37	45.0000	17.759	218.030	288.9	109.14	24.03	645.3
84 921	18	38	0.0	17.369	218.931	288.7	109.68	19.84	742.5
84 921	18	38	15.0000	16.974	219.829	288.5	110.07	16.52	842.1
84 921	18	38	30.0000	16.575	220.722	288.4	110.37	13.81	943.3
84 921	18	38	45.0000	16.172	221.611	288.2	110.62	11.53	1045.6
84 921	18	39	0.0	15.764	222.497	288.0	110.82	9.57	1148.7
84 921	18	39	15.0000	15.352	223.379	287.9	110.99	7.86	1252.4
84 921	18	39	30.0000	14.937	224.257	287.7	111.13	6.34	1356.5
84 921	18	39	45.0000	14.517	225.132	287.6	111.26	4.97	1460.9
84 921	18	40	0.0	14.093	226.003	287.4	111.37	3.72	1565.6
84 921	18	40	15.0000	13.666	226.871	287.3	111.46	2.57	1670.4
84 921	18	40	30.0000	13.236	227.735	287.1	111.55	1.50	1775.3
84 921	18	40	45.0000	12.802	228.596	287.0	111.63	0.49	1880.2
84 921	18	41	0.0	12.365	229.454	286.9	111.71	-0.46	1985.2
84 921	18	41	15.0000	11.924	230.309	286.7	111.77	-1.36	2090.1
84 921	18	41	30.0000	11.481	231.161	286.6	111.84	-2.22	2195.1
84 921	18	41	45.0000	11.035	232.011	286.5	111.89	-3.04	2299.9
84 921	18	42	0.0	10.586	232.857	286.4	111.95	-3.84	2404.8

STATION=STA1 LAT= 19.50 LON=213.00 ALT= 30,000 ft.

	MASK TIME YRMODA	HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 921	18	31	53.0	292.8	-0.0	1956.3	
LOS=	84 921	18	40	52.7	111.7	-0.0	1934.3	9.0
MAX=	84 921	18	36	26.0	43.5	80.8	291.9	
MAXRG=	84 921	18	31	53.0			1956.3	
MINRG=	84 921	18	36	25.0			291.7	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA3 LAT= 14.50 LON=208.00 ALT= 30,000 ft. EL_{max} = 71.6°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 923	10	41	0.0	5.356	188.896	298.7	246.13	-3.37	2383.5
84 923	10	41	15.0000	5.826	189.715	298.7	246.25	-2.56	2279.1
84 923	10	41	30.0000	6.294	190.537	298.8	246.39	-1.72	2174.7
84 923	10	41	45.0000	6.761	191.359	298.9	246.54	-0.84	2070.2
84 923	10	42	0.0	7.226	192.184	299.0	246.70	0.08	1965.8
84 923	10	42	15.0000	7.690	193.010	299.0	246.88	1.05	1861.3
84 923	10	42	30.0000	8.152	193.839	299.1	247.09	2.08	1756.9
84 923	10	42	45.0000	8.612	194.669	299.2	247.31	3.19	1652.6
84 923	10	43	0.0	9.069	195.501	299.2	247.57	4.38	1548.5
84 923	10	43	15.0000	9.525	196.336	299.3	247.87	5.67	1444.5
84 923	10	43	30.0000	9.978	197.173	299.4	248.21	7.08	1340.9
84 923	10	43	45.0000	10.429	198.012	299.5	248.60	8.66	1237.6
84 923	10	44	0.0	10.877	198.854	299.5	249.07	10.44	1134.8
84 923	10	44	15.0000	11.322	199.699	299.6	249.64	12.47	1032.8
84 923	10	44	30.0000	11.765	200.546	299.7	250.34	14.84	931.7
84 923	10	44	45.0000	12.205	201.397	299.7	251.23	17.67	832.0
84 923	10	45	0.0	12.641	202.250	299.8	252.40	21.12	734.3
84 923	10	45	15.0000	13.075	203.107	299.9	254.00	25.46	639.4
84 923	10	45	30.0000	13.505	203.966	300.0	256.31	31.08	549.0
84 923	10	45	45.0000	13.932	204.829	300.0	259.98	38.54	465.6
84 923	10	46	0.0	14.355	205.695	300.1	266.60	48.54	393.7
84 923	10	46	15.0000	14.775	206.565	300.2	281.32	61.05	340.7
84 923	10	46	30.0000	15.191	207.438	300.2	321.75	71.18	316.3
84 923	10	46	45.0000	15.603	208.315	300.3	15.49	66.08	327.1
84 923	10	47	0.0	16.011	209.196	300.4	37.39	53.35	369.8
84 923	10	47	15.0000	16.414	210.081	300.4	46.23	42.25	435.2
84 923	10	47	30.0000	16.814	210.969	300.5	50.79	33.85	514.7
84 923	10	47	45.0000	17.209	211.861	300.5	53.54	27.58	602.8
84 923	10	48	0.0	17.599	212.757	300.6	55.39	22.79	696.1
84 923	10	48	15.0000	17.985	213.658	300.7	56.70	19.02	792.8
84 923	10	48	30.0000	18.366	214.562	300.7	57.70	15.97	891.8
84 923	10	48	45.0000	18.742	215.471	300.8	58.47	13.44	992.3
84 923	10	49	0.0	19.113	216.384	300.8	59.09	11.28	1094.0
84 923	10	49	15.0000	19.479	217.302	300.9	59.61	9.41	1196.4
84 923	10	49	30.0000	19.839	218.223	300.9	60.04	7.76	1299.5
84 923	10	49	45.0000	20.194	219.149	301.0	60.41	6.29	1402.9
84 923	10	50	0.0	20.544	220.080	301.0	60.73	4.95	1506.7
84 923	10	50	15.0000	20.887	221.015	301.1	61.01	3.72	1610.8
84 923	10	50	30.0000	21.225	221.955	301.1	61.25	2.59	1715.0
84 923	10	50	45.0000	21.557	222.899	301.1	61.48	1.53	1819.3
84 923	10	51	0.0	21.883	223.847	301.2	61.68	0.53	1923.6
84 923	10	51	15.0000	22.203	224.800	301.2	61.86	-0.41	2028.0
84 923	10	51	30.0000	22.516	225.758	301.2	62.03	-1.30	2132.4
84 923	10	51	45.0000	22.823	226.720	301.3	62.18	-2.16	2236.8
84 923	10	52	0.0	23.123	227.687	301.3	62.32	-2.98	2341.1
84 923	10	52	15.0000	23.416	228.658	301.3	62.46	-3.77	2445.4

STATION=STA3 LAT= 14.50 LON=208.00 ALT= 30,000 ft.

	MASK TIME YRMODA	HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 923	10	41	58.6	246.7	-0.0	1975.6	
LOS=	84 923	10	51	8.4	61.8	-0.0	1982.4	9.2
MAX=	84 923	10	46	33.0	332.6	71.6	315.6	
MAXRG=	84 923	10	51	8.4			1982.4	
MINRG=	84 923	10	46	33.0			315.6	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA2 LAT= 14.50 LON=218.00 ALT= 30,000 ft. EL_{max} = 68.6°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 922	18	38	15.0000	21.853	198.048	292.9	294.02	-3.01	2317.4
84 922	18	38	30.0000	21.526	198.999	292.7	293.91	-2.19	2212.7
84 922	18	38	45.0000	21.192	199.945	292.5	293.78	-1.34	2108.0
84 922	18	39	0.0	20.853	200.887	292.4	293.64	-0.45	2003.2
84 922	18	39	15.0000	20.508	201.824	292.2	293.48	0.49	1898.4
84 922	18	39	30.0000	20.157	202.757	292.0	293.29	1.48	1793.6
84 922	18	39	45.0000	19.801	203.685	291.8	293.08	2.54	1689.0
84 922	18	40	0.0	19.439	204.609	291.6	292.84	3.67	1584.4
84 922	18	40	15.0000	19.071	205.529	291.4	292.56	4.90	1480.0
84 922	18	40	30.0000	18.699	206.444	291.3	292.24	6.24	1375.8
84 922	18	40	45.0000	18.321	207.355	291.1	291.85	7.72	1272.0
84 922	18	41	0.0	17.938	208.262	290.9	291.40	9.38	1168.6
84 922	18	41	15.0000	17.551	209.165	290.7	290.84	11.27	1065.8
84 922	18	41	30.0000	17.159	210.063	290.6	290.15	13.46	963.9
84 922	18	41	45.0000	16.762	210.958	290.4	289.27	16.05	863.1
84 922	18	42	0.0	16.361	211.849	290.2	288.13	19.18	764.0
84 922	18	42	15.0000	15.955	212.736	290.0	286.58	23.09	667.3
84 922	18	42	30.0000	15.546	213.619	289.9	284.36	28.10	574.4
84 922	18	42	45.0000	15.132	214.498	289.7	280.95	34.73	487.4
84 922	18	43	0.0	14.714	215.374	289.5	275.12	43.64	410.0
84 922	18	43	15.0000	14.293	216.246	289.4	263.30	55.19	348.8
84 922	18	43	30.0000	13.867	217.115	289.2	233.88	66.75	313.5
84 922	18	43	45.0000	13.439	217.980	289.1	181.03	66.91	313.0
84 922	18	44	0.0	13.007	218.843	288.9	151.03	55.41	347.4
84 922	18	44	15.0000	12.571	219.702	288.8	139.00	43.77	408.0
84 922	18	44	30.0000	12.133	220.558	288.6	133.09	34.78	485.0
84 922	18	44	45.0000	11.691	221.410	288.5	129.65	28.10	571.9
84 922	18	45	0.0	11.246	222.261	288.3	127.41	23.04	664.7
84 922	18	45	15.0000	10.799	223.108	288.2	125.85	19.11	761.3
84 922	18	45	30.0000	10.349	223.953	288.1	124.69	15.95	860.3
84 922	18	45	45.0000	9.896	224.795	287.9	123.81	13.35	961.1
84 922	18	46	0.0	9.441	225.634	287.8	123.11	11.15	1063.1
84 922	18	46	15.0000	8.983	226.472	287.7	122.54	9.25	1165.9
84 922	18	46	30.0000	8.524	227.307	287.6	122.07	7.58	1269.3
84 922	18	46	45.0000	8.062	228.140	287.4	121.68	6.10	1373.2
84 922	18	47	0.0	7.598	228.971	287.3	121.35	4.75	1477.4
84 922	18	47	15.0000	7.133	229.800	287.2	121.06	3.52	1581.8
84 922	18	47	30.0000	6.665	230.627	287.1	120.81	2.39	1686.5
84 922	18	47	45.0000	6.197	231.453	287.0	120.59	1.33	1791.2
84 922	18	48	0.0	5.726	232.277	286.9	120.39	0.34	1896.1
84 922	18	48	15.0000	5.254	233.100	286.8	120.22	-0.60	2000.9
84 922	18	48	30.0000	4.781	233.921	286.7	120.06	-1.50	2105.8
84 922	18	48	45.0000	4.307	234.741	286.6	119.92	-2.35	2210.6
84 922	18	49	0.0	3.832	235.560	286.5	119.79	-3.17	2315.4
84 922	18	49	15.0000	3.356	236.378	286.5	119.67	-3.96	2420.1

STATION=STA2 LAT= 14.50 LON=218.00 ALT= 30,000 ft.

	MASK TIME YRMODA	HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 922	18	39	7.3	293.6	-0.0	1952.4	
LOS=	84 922	18	48	5.2	120.3	0.0	1932.1	9.0
MAX=	84 922	18	43	38.0	205.7	68.6	308.7	
MAXRG=	84 922	18	39	7.3			1952.4	
MINRG=	84 922	18	43	38.0			308.7	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA4 LAT= 9.50 LON=223.00 ALT= 30,000 ft. EL_{max} = 64.1°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 922	18	40	0.0	19.439	204.609	291.6	301.10	-3.08	2321.7
84 922	18	40	15.0000	19.071	205.529	291.4	301.29	-2.27	2217.1
84 922	18	40	30.0000	18.699	206.444	291.3	301.49	-1.42	2112.5
84 922	18	40	45.0000	18.321	207.355	291.1	301.72	-0.54	2007.8
84 922	18	41	0.0	17.938	208.262	290.9	301.96	0.40	1903.2
84 922	18	41	15.0000	17.551	209.165	290.7	302.23	1.38	1798.5
84 922	18	41	30.0000	17.159	210.063	290.6	302.53	2.43	1694.0
84 922	18	41	45.0000	16.762	210.958	290.4	302.87	3.56	1589.6
84 922	18	42	0.0	16.361	211.849	290.2	303.26	4.77	1485.4
84 922	18	42	15.0000	15.955	212.736	290.0	303.70	6.10	1381.4
84 922	18	42	30.0000	15.546	213.619	289.9	304.22	7.57	1277.8
84 922	18	42	45.0000	15.132	214.498	289.7	304.82	9.21	1174.6
84 922	18	43	0.0	14.714	215.374	289.5	305.55	11.07	1072.1
84 922	18	43	15.0000	14.293	216.246	289.4	306.44	13.22	970.4
84 922	18	43	30.0000	13.867	217.115	289.2	307.55	15.76	870.0
84 922	18	43	45.0000	13.439	217.980	289.1	308.99	18.82	771.3
84 922	18	44	0.0	13.007	218.843	288.9	310.91	22.62	675.2
84 922	18	44	15.0000	12.571	219.702	288.8	313.62	27.44	582.8
84 922	18	44	30.0000	12.133	220.558	288.6	317.70	33.75	496.4
84 922	18	44	45.0000	11.691	221.410	288.5	324.48	42.05	419.8
84 922	18	45	0.0	11.246	222.261	288.3	337.33	52.44	359.2
84 922	18	45	15.0000	10.799	223.108	288.2	4.70	62.25	323.7
84 922	18	45	30.0000	10.349	223.953	288.1	47.97	62.87	321.9
84 922	18	45	45.0000	9.896	224.795	287.9	77.31	53.47	354.2
84 922	18	46	0.0	9.441	225.634	287.8	91.08	42.90	412.7
84 922	18	46	15.0000	8.983	226.472	287.7	98.24	34.36	488.1
84 922	18	46	30.0000	8.524	227.307	287.6	102.50	27.88	573.7
84 922	18	46	45.0000	8.062	228.140	287.4	105.31	22.92	665.6
84 922	18	47	0.0	7.598	228.971	287.3	107.29	19.03	761.4
84 922	18	47	15.0000	7.133	229.800	287.2	108.76	15.91	859.9
84 922	18	47	30.0000	6.665	230.627	287.1	109.89	13.32	960.3
84 922	18	47	45.0000	6.197	231.453	287.0	110.79	11.13	1061.9
84 922	18	48	0.0	5.726	232.277	286.9	111.52	9.24	1164.4
84 922	18	48	15.0000	5.254	233.100	286.8	112.13	7.58	1267.5
84 922	18	48	30.0000	4.781	233.921	286.7	112.65	6.10	1371.2
84 922	18	48	45.0000	4.307	234.741	286.6	113.09	4.76	1475.2
84 922	18	49	0.0	3.832	235.560	286.5	113.47	3.53	1579.5
84 922	18	49	15.0000	3.356	236.378	286.5	113.80	2.39	1684.0
84 922	18	49	30.0000	2.879	237.196	286.4	114.10	1.34	1788.7
84 922	18	49	45.0000	2.401	238.012	286.3	114.36	0.35	1893.4
84 922	18	50	0.0	1.923	238.828	286.3	114.60	-0.59	1998.1
84 922	18	50	15.0000	1.444	239.644	286.2	114.81	-1.48	2102.9
84 922	18	50	30.0000	0.965	240.459	286.1	115.00	-2.34	2207.7
84 922	18	50	45.0000	0.485	241.274	286.1	115.17	-3.15	2312.4
84 922	18	51	0.0	0.006	242.089	286.0	115.33	-3.94	2417.0

STATION=STA4 LAT= 9.50 LON=223.00 ALT= 30,000 ft.

	YRMODA	MASK TIME HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 922	18	40	53.7	301.9	-0.0	1947.3	
LOS=	84 922	18	49	50.4	114.4	0.0	1931.0	8.9
MAX=	84 922	18	45	23.0	27.7	64.1	318.3	
MAXRG=	84 922	18	40	53.7			1947.3	
MINRG=	84 922	18	45	23.0			318.3	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA2 LAT= 14.50 LON=218.00 ALT= 30,000 ft. EL_{max} = 40.2°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 921	10	32	30.0000	1.972	201.764	300.6	233.65	-2.85	2319.9
84 921	10	32	45.0000	2.448	202.576	300.6	233.24	-2.03	2216.6
84 921	10	33	0.0	2.923	203.389	300.6	232.78	-1.17	2113.3
84 921	10	33	15.0000	3.398	204.203	300.6	232.28	-0.28	2010.2
84 921	10	33	30.0000	3.872	205.018	300.6	231.72	0.66	1907.2
84 921	10	33	45.0000	4.346	205.833	300.6	231.09	1.65	1804.5
84 921	10	34	0.0	4.818	206.650	300.6	230.39	2.70	1702.0
84 921	10	34	15.0000	5.289	207.467	300.7	229.60	3.82	1599.8
84 921	10	34	30.0000	5.759	208.286	300.7	228.70	5.03	1498.2
84 921	10	34	45.0000	6.227	209.107	300.7	227.66	6.34	1397.1
84 921	10	35	0.0	6.694	209.929	300.7	226.46	7.78	1296.8
84 921	10	35	15.0000	7.159	210.753	300.7	225.04	9.37	1197.5
84 921	10	35	30.0000	7.623	211.579	300.7	223.34	11.16	1099.5
84 921	10	35	45.0000	8.085	212.406	300.7	221.29	13.18	1003.2
84 921	10	36	0.0	8.545	213.236	300.7	218.77	15.49	909.1
84 921	10	36	15.0000	9.002	214.067	300.7	215.59	18.17	818.2
84 921	10	36	30.0000	9.458	214.901	300.8	211.51	21.30	731.5
84 921	10	36	45.0000	9.911	215.737	300.8	206.12	24.95	650.8
84 921	10	37	0.0	10.362	216.576	300.8	198.84	29.11	578.7
84 921	10	37	15.0000	10.811	217.417	300.8	188.88	33.55	518.7
84 921	10	37	30.0000	11.256	218.261	300.8	175.45	37.59	475.6
84 921	10	37	45.0000	11.699	219.108	300.8	158.68	39.97	454.0
84 921	10	38	0.0	12.139	219.958	300.8	140.70	39.61	457.2
84 921	10	38	15.0000	12.576	220.810	300.8	124.65	36.68	484.5
84 921	10	38	30.0000	13.010	221.666	300.8	112.14	32.45	532.4
84 921	10	38	45.0000	13.441	222.525	300.8	102.93	28.04	595.8
84 921	10	39	0.0	13.868	223.387	300.8	96.19	24.00	670.4
84 921	10	39	15.0000	14.292	224.253	300.8	91.18	20.49	752.8
84 921	10	39	30.0000	14.712	225.122	300.8	87.35	17.48	840.7
84 921	10	39	45.0000	15.128	225.994	300.8	84.36	14.90	932.6
84 921	10	40	0.0	15.541	226.871	300.8	81.98	12.66	1027.3
84 921	10	40	15.0000	15.949	227.750	300.8	80.03	10.71	1124.1
84 921	10	40	30.0000	16.353	228.634	300.8	78.42	8.98	1222.5
84 921	10	40	45.0000	16.753	229.522	300.8	77.07	7.42	1322.1
84 921	10	41	0.0	17.149	230.413	300.8	75.92	6.02	1422.7
84 921	10	41	15.0000	17.540	231.309	300.8	74.92	4.73	1523.9
84 921	10	41	30.0000	17.927	232.209	300.8	74.06	3.55	1625.8
84 921	10	41	45.0000	18.308	233.113	300.8	73.30	2.44	1728.1
84 921	10	42	0.0	18.685	234.021	300.7	72.63	1.41	1830.7
84 921	10	42	15.0000	19.057	234.933	300.7	72.04	0.43	1933.6
84 921	10	42	30.0000	19.424	235.850	300.7	71.51	-0.49	2036.7
84 921	10	42	45.0000	19.785	236.771	300.7	71.03	-1.37	2139.9
84 921	10	43	0.0	20.141	237.697	300.7	70.59	-2.22	2243.2
84 921	10	43	15.0000	20.491	238.627	300.7	70.20	-3.03	2346.6
84 921	10	43	30.0000	20.836	239.561	300.6	69.84	-3.81	2450.0

STATION=STA2 LAT= 14.50 LON=218.00 ALT= 30,000 ft.

	MASK TIME YRMODA	HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 921	10	33	19.7	232.1	0.0	1978.0	
LOS=	84 921	10	42	22.0	71.8	-0.0	1981.9	9.0
MAX=	84 921	10	37	51.0	151.5	40.2	452.2	
MAXRG=	84 921	10	42	22.0			1981.9	
MINRG=	84 921	10	37	51.0			452.2	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA3 LAT= 14.50 LON=208.00 ALT= 30,000 ft. EL_{max} = 20°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 922	12	11	30.0000	12.022	187.305	300.4	265.51	-2.82	2318.6
84 922	12	11	45.0000	12.460	188.157	300.4	266.40	-2.03	2219.7
84 922	12	12	0.0	12.895	189.012	300.4	267.37	-1.22	2121.3
84 922	12	12	15.0000	13.327	189.870	300.5	268.44	-0.38	2023.4
84 922	12	12	30.0000	13.755	190.731	300.5	269.61	0.50	1926.2
84 922	12	12	45.0000	14.180	191.596	300.6	270.90	1.42	1829.8
84 922	12	13	0.0	14.601	192.464	300.6	272.34	2.38	1734.4
84 922	12	13	15.0000	15.018	193.336	300.6	273.95	3.39	1640.1
84 922	12	13	30.0000	15.432	194.211	300.7	275.75	4.45	1547.2
84 922	12	13	45.0000	15.841	195.090	300.7	277.78	5.58	1456.1
84 922	12	14	0.0	16.247	195.973	300.7	280.08	6.78	1367.0
84 922	12	14	15.0000	16.648	196.859	300.8	282.72	8.05	1280.4
84 922	12	14	30.0000	17.045	197.750	300.8	285.74	9.40	1197.0
84 922	12	14	45.0000	17.437	198.645	300.8	289.23	10.83	1117.3
84 922	12	15	0.0	17.825	199.543	300.8	293.28	12.34	1042.4
84 922	12	15	15.0000	18.208	200.446	300.9	297.98	13.89	973.2
84 922	12	15	30.0000	18.586	201.353	300.9	303.43	15.45	911.3
84 922	12	15	45.0000	18.959	202.264	300.9	309.70	16.95	858.1
84 922	12	16	0.0	19.327	203.180	300.9	316.81	18.28	815.3
84 922	12	16	15.0000	19.690	204.100	301.0	324.70	19.32	784.8
84 922	12	16	30.0000	20.047	205.024	301.0	333.16	19.92	767.9
84 922	12	16	45.0000	20.399	205.952	301.0	341.88	20.01	765.5
84 922	12	17	0.0	20.745	206.886	301.0	350.46	19.56	777.9
84 922	12	17	15.0000	21.085	207.823	301.0	358.55	18.65	804.2
84 922	12	17	30.0000	21.420	208.766	301.0	5.93	17.39	843.3
84 922	12	17	45.0000	21.748	209.712	301.0	12.47	15.93	893.4
84 922	12	18	0.0	22.070	210.664	301.0	18.17	14.38	952.7
84 922	12	18	15.0000	22.386	211.619	301.0	23.10	12.82	1019.7
84 922	12	18	30.0000	22.696	212.580	301.0	27.34	11.30	1092.8
84 922	12	18	45.0000	22.999	213.545	301.0	31.01	9.84	1171.1
84 922	12	19	0.0	23.295	214.514	301.0	34.17	8.47	1253.4
84 922	12	19	15.0000	23.584	215.488	301.0	36.93	7.17	1338.9
84 922	12	19	30.0000	23.867	216.467	301.0	39.34	5.95	1427.2
84 922	12	19	45.0000	24.142	217.450	301.0	41.46	4.80	1517.7
84 922	12	20	0.0	24.410	218.437	301.0	43.33	3.71	1610.0
84 922	12	20	15.0000	24.671	219.429	300.9	45.00	2.69	1703.7
84 922	12	20	30.0000	24.925	220.426	300.9	46.49	1.71	1798.7
84 922	12	20	45.0000	25.171	221.426	300.9	47.84	0.78	1894.7
84 922	12	21	0.0	25.409	222.431	300.9	49.06	-0.10	1991.6
84 922	12	21	15.0000	25.640	223.440	300.8	50.16	-0.96	2089.1
84 922	12	21	30.0000	25.863	224.453	300.8	51.17	-1.78	2187.3
84 922	12	21	45.0000	26.077	225.469	300.7	52.10	-2.57	2285.9
84 922	12	22	0.0	26.284	226.490	300.7	52.96	-3.34	2384.9

	MASK TIME YRMODA	HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 922	12	12	21.6	268.9	0.0	1980.8	
LOS=	84 922	12	20	58.1	48.9	0.0	1979.4	8.6
MAX=	84 922	12	16	40.0	339.0	20.0	764.7	
MAXRG=	84 922	12	12	21.6			1980.8	
MINRG=	84 922	12	16	40.0			764.7	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA1 LAT= 19.50 LON=213.00 ALT= 30,000 ft. EL_{max} = 10.5°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 921	10	32	45.0000	2.448	202.576	300.6	212.30	-2.41	2261.6
84 921	10	33	0.0	2.923	203.389	300.6	210.87	-1.68	2171.2
84 921	10	33	15.0000	3.398	204.203	300.6	209.32	-0.93	2082.1
84 921	10	33	30.0000	3.872	205.018	300.6	207.64	-0.16	1994.6
84 921	10	33	45.0000	4.346	205.833	300.6	205.81	0.62	1908.7
84 921	10	34	0.0	4.818	206.650	300.6	203.80	1.43	1824.8
84 921	10	34	15.0000	5.289	207.467	300.7	201.60	2.25	1743.2
84 921	10	34	30.0000	5.759	208.286	300.7	199.18	3.08	1664.3
84 921	10	34	45.0000	6.227	209.107	300.7	196.53	3.93	1588.5
84 921	10	35	0.0	6.694	209.929	300.7	193.60	4.79	1516.2
84 921	10	35	15.0000	7.159	210.753	300.7	190.39	5.65	1448.0
84 921	10	35	30.0000	7.623	211.579	300.7	186.86	6.50	1384.6
84 921	10	35	45.0000	8.085	212.406	300.7	182.99	7.32	1326.7
84 921	10	36	0.0	8.545	213.236	300.7	178.77	8.10	1274.9
84 921	10	36	15.0000	9.002	214.067	300.7	174.20	8.82	1230.2
84 921	10	36	30.0000	9.458	214.901	300.8	169.30	9.44	1193.3
84 921	10	36	45.0000	9.911	215.737	300.8	164.11	9.93	1164.9
84 921	10	37	0.0	10.362	216.576	300.8	158.68	10.28	1145.8
84 921	10	37	15.0000	10.811	217.417	300.8	153.12	10.45	1136.4
84 921	10	37	30.0000	11.256	218.261	300.8	147.50	10.45	1136.9
84 921	10	37	45.0000	11.699	219.108	300.8	141.94	10.26	1147.4
84 921	10	38	0.0	12.139	219.958	300.8	136.54	9.90	1167.5
84 921	10	38	15.0000	12.576	220.810	300.8	131.37	9.40	1196.7
84 921	10	38	30.0000	13.010	221.666	300.8	126.51	8.77	1234.5
84 921	10	38	45.0000	13.441	222.525	300.8	121.97	8.05	1280.0
84 921	10	39	0.0	13.868	223.387	300.8	117.79	7.27	1332.5
84 921	10	39	15.0000	14.292	224.253	300.8	113.96	6.44	1391.1
84 921	10	39	30.0000	14.712	225.122	300.8	110.46	5.59	1455.1
84 921	10	39	45.0000	15.128	225.994	300.8	107.28	4.74	1523.8
84 921	10	40	0.0	15.541	226.871	300.8	104.39	3.88	1596.6
84 921	10	40	15.0000	15.949	227.750	300.8	101.77	3.03	1672.9
84 921	10	40	30.0000	16.353	228.634	300.8	99.38	2.20	1752.3
84 921	10	40	45.0000	16.753	229.522	300.8	97.21	1.38	1834.3
84 921	10	41	0.0	17.149	230.413	300.8	95.23	0.58	1918.5
84 921	10	41	15.0000	17.540	231.309	300.8	93.42	-0.20	2004.8
84 921	10	41	30.0000	17.927	232.209	300.8	91.76	-0.97	2092.7
84 921	10	41	45.0000	18.308	233.113	300.8	90.24	-1.71	2182.1
84 921	10	42	0.0	18.685	234.021	300.7	88.84	-2.44	2272.8
84 921	10	42	15.0000	19.057	234.933	300.7	87.54	-3.16	2364.6

	MASK TIME YRMODA	HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 921	10	33	33.3	207.3	0.0	1975.6	
LOS=	84 921	10	41	11.3	93.9	-0.0	1983.0	7.6
MAX=	84 921	10	37	22.0	150.5	10.5	1135.4	
MAXRG=	84 921	10	41	11.3			1983.0	
MINRG=	84 921	10	37	22.0			1135.4	

Shuttle: Altitude = 30 km
Inclination = 28.5°

STATION=STA4 LAT= 9.50 LON=223.00 ALT= 30,000 ft. EL_{max} = 5.2°

Time				Spacecraft Position			Tracking Station (Aircraft) boresight angles and range		
YRMODA	HR	MN	SE.COND	LATITUDE (DEG)	LONGITUDE (DEG)	HEIGHT (KM)	AZ (DEG)	EL (DEG)	RANGE (KM)
84 921	12	10	15.0000	15.606	203.927	300.8	289.98	-2.18	2238.9
84 921	12	10	30.0000	16.014	204.807	300.8	291.91	-1.56	2161.6
84 921	12	10	45.0000	16.417	205.692	300.8	293.97	-0.93	2086.7
84 921	12	11	0.0	16.817	206.580	300.8	296.18	-0.30	2014.4
84 921	12	11	15.0000	17.212	207.472	300.8	298.55	0.32	1944.9
84 921	12	11	30.0000	17.602	208.368	300.8	301.09	0.94	1878.6
84 921	12	11	45.0000	17.988	209.269	300.8	303.81	1.54	1815.9
84 921	12	12	0.0	18.369	210.173	300.7	306.72	2.13	1757.2
84 921	12	12	15.0000	18.745	211.082	300.7	309.82	2.69	1702.9
84 921	12	12	30.0000	19.116	211.995	300.7	313.12	3.22	1653.5
84 921	12	12	45.0000	19.481	212.913	300.7	316.61	3.71	1609.3
84 921	12	13	0.0	19.842	213.834	300.7	320.29	4.15	1571.0
84 921	12	13	15.0000	20.197	214.761	300.7	324.14	4.53	1538.8
84 921	12	13	30.0000	20.546	215.691	300.7	328.14	4.83	1513.3
84 921	12	13	45.0000	20.890	216.627	300.6	332.26	5.06	1494.7
84 921	12	14	0.0	21.228	217.566	300.6	336.47	5.20	1483.4
84 921	12	14	15.0000	21.560	218.510	300.6	340.72	5.24	1479.4
84 921	12	14	30.0000	21.886	219.459	300.5	344.97	5.20	1483.0
84 921	12	14	45.0000	22.205	220.413	300.5	349.18	5.06	1493.9
84 921	12	15	0.0	22.519	221.371	300.5	353.31	4.83	1512.0
84 921	12	15	15.0000	22.825	222.333	300.4	357.32	4.52	1537.2
84 921	12	15	30.0000	23.125	223.300	300.4	1.18	4.14	1568.9
84 921	12	15	45.0000	23.419	224.272	300.4	4.87	3.70	1606.9
84 921	12	16	0.0	23.705	225.248	300.3	8.37	3.21	1650.7
84 921	12	16	15.0000	23.985	226.229	300.3	11.68	2.68	1699.8
84 921	12	16	30.0000	24.257	227.214	300.2	14.80	2.12	1753.8
84 921	12	16	45.0000	24.523	228.204	300.2	17.72	1.53	1812.2
84 921	12	17	0.0	24.780	229.197	300.1	20.45	0.93	1874.6
84 921	12	17	15.0000	25.031	230.196	300.1	23.01	0.31	1940.5
84 921	12	17	30.0000	25.274	231.198	300.0	25.39	-0.32	2009.7
84 921	12	17	45.0000	25.509	232.205	300.0	27.61	-0.94	2081.8
84 921	12	18	0.0	25.736	233.216	299.9	29.69	-1.57	2156.4
84 921	12	18	15.0000	25.955	234.231	299.8	31.62	-2.20	2233.4
84 921	12	18	30.0000	26.167	235.250	299.8	33.43	-2.83	2312.3

	YRMODA	MASK TIME HR	MN	SE.C	AZ	EL	RG(KM)	TIME IN CONTACT (MINUTE)
AOS=	84 921	12	11	7.0	297.3	-0.0	1981.4	
LOS=	84 921	12	17	22.5	24.2	-0.0	1974.7	6.3
MAX=	84 921	12	14	15.0	340.7	5.2	1479.4	
MAXRG=	84 921	12	11	7.0			1981.4	
MINRG=	84 921	12	14	15.0			1479.4	

Appendix E
Shuttle/Aircraft Lasercom Study

F. Kalil

Summary to Date (3/7/88)

1. General

Strong consideration was given to using the NASA Kuiper A/C (reference 1, 2), C-141 KAO, which operates out of the Ames Research Center (ARC), because it has its own telescope (36-inch/91.5-cm aperture) with a tracking and pointing system (reference 2). Per reference 2, it can track a 10.5th magnitude star with an accuracy of a few arc seconds. It can take payloads of up to 350 pounds. Under normal conditions, it can maintain roll, pitch, and yaw to about ±0.5° or less under autopilot control. The autopilot can limit roll in light turbulence to ±2°; however, the telescope is isolated from these fluctuations in attitude.

It appears that we cannot use their acquisition system because of the way it is designed and implemented for their use, namely as an Astronomy Observatory. For instance, to acquire, they use pre-prepared masks of star maps for their acquisition camera, which apparently has a video-type display. When the star "background" in the sky matches their pre-prepared mask, the operator initiates completion of acquisition, and switches to the tracking mode. Here again, it appears that we cannot use their tracking system, because the tracking mode of interest to us (it seems to me) would be what they call PEAK. They use PEAK for automatically centering on the position of maximum signal from the experiment detector (reference 2). At first glance, this would appear to be applicable to automatically centering on our laser signal from Shuttle; however, my concern is based on the following quotes: "Field rotation occurs at rates which may be as high as 70° per hour"..."The drive rates are approximately one arc-minute per second." It appears that their drive rates are designed to match the field rotation rates that they experience in their astronomy experiments/observations. These drive rates are much too slow for tracking a Shuttle Orbiter. It is my opinion that the ARC would not permit us to modify/speed up their drive system.

Two other important factors which lead me to feel that the C-141 KAO is not attractive as a candidate aircraft for a lasercom experiment with the Shuttle are the following:

1. The limitations of the 36-inch telescope in elevation and azimuth angles, and;

2. The high demand by astronomers for the C-141 KAO (references 3, 4), which leads me to believe that our proposal for use of the C-141 KAO would receive a low priority.

The C-141 KAO telescope looks out of a port on the LHS of the aircraft in front of the left wing. Its angular excursions are limited to 35° to 70° elevation and ±2° in azimuth (reference 2). This severely limits the viewing time of a Shuttle Orbiter. Computer runs, giving elevation angle, azimuth angle and slant range of the Shuttle to a judiciously located aircraft, have been made (reference 5). These runs show that, precluding elevation angle or azimuth angle limitations, the judiciously located A/C can cover five consecutive Shuttle Orbiter passes, each averaging about 8 minutes, with little or no aircraft change in its prescribed "on station" location.

Later on, the elevation and azimuth angles and slant ranges will be plotted versus time to show the effect of viewing angle limitations due to telescope/viewing port configurations. Then, various NASA aircraft, viewing ports, domes, telescope, and/or rotating flat (mirror), and judiciously prescribed aircraft maneuvers will be studied to cost-effectively optimize the viewing time.

For instance, assuming that a dome with a rotating flat is cost-effective (this will be looked into further), then maximum coverage/viewing time can be realized. On the other hand, aircraft maneuvers can be used to some extent to overcome elevation/azimuth angle limitations. For instance, the larger NASA aircraft can fly straight with a bank angle of 5° without significant loss in altitude and dangerous side slip (reference 6). Also, to cover a 5- to 6-minute Shuttle pass, the aircraft could fly a semi-circular pattern in 5 to 6 minutes with a 5° bank angle. Most aircraft can complete a 180° turn in 1 minute, if necessary, so that from the LHS side of the aircraft, one could view the Shuttle Orbiter as it comes up over the horizon. Then the aircraft could make its 180° turn in 1 minute to let us view the Shuttle Orbiter as it descends over the horizon.

It is interesting to note that a viewing port on the RHS of the aircraft is more optimum than a port on the LHS of the aircraft, because the Shuttle Orbiter flies from west to east, and viewing times are prolonged while the orbiting "target" spacecraft appears at the lower elevation angles (ϵ) where its angular rate ($d\epsilon/dt$) relative to the tracking aircraft is lowest, i.e., $d\epsilon/dt$ increases with ϵ. Thus, the necessary aircraft bank angle during a semicircular flight pattern would enhance the viewing time from the RHS when there are limitations on the telescope's lower elevation angles.

Acquisition

Regarding the acquisition scenario, it would be advantageous to let the Shuttle Orbiter provide the acquisition beacon. Then the aircraft laser terminal that is seeking the beacon would be looking skyward at a dark, cold sky with relatively low background noise. On the other hand, if the aircraft was to be the source of the acquisition beacon, then the laser terminal on-board the Shuttle would be looking earthward at a warm earth and bright clouds with relatively high background noise.

Radio Communication

Per reference 6, the Wallops aircraft have HF, VHF, and UHF radio. Wallops has access to bases in Florida near the most advantageous latitudes, for coverage of 28.5° inclination Shuttle orbits. At these bases, the aircraft could be in continuous RF communication with the ground base. By proper planning and NASCOM support, the Lasercom POCC could be in continuous RF contact with the aircraft via the ground base, as well as in contact with the Shuttle LTEF via TDRSS. Thus, with proper planning, we can have continual RF contact/communications with both the Shuttle LTEF and the Aircraft Lasercom Link, for telemetry, voice, command and control.

Aircraft Position Error

Per reference 7, the Wallops aircraft use the Litton LTN51 Inertial Navigation System (INS), which is about 10 years old. In addition to other error sources, this INS has a position error due to drift of 1 nmi/hr. For flight/on-station times of 6 hours, this corresponds to a position error of 6 nmi. This is intolerable for our lasercom experiment. However, Wallops has recently purchased some GPS systems for use in their aircraft. They are presently in the process of installing and checking the GPS performance.

The GPS has two modes/levels of accuracy. The course mode provides the aircraft user position to within ±30 meters CEP. In the "fine" mode, the GPS can provide the aircraft user position to under ±10 cm CEP.

The Wallops aircraft and the Shuttle will be equipped with GPS in our time frame of interest (i.e., 1990 and beyond).

Aircraft Altitude

Per reference 7, the Wallops aircraft use the Litton LTN51 INS, which provides continuous attitude knowledge directly to the aircraft experimenter and his experiment. Reference 7 could give me no information on INS drift or bias errors, but the INS provides roll and pitch to ~0.1 deg. (rms) out of the S to D loop at 500 Hz. The ~0.1 deg. is due to the least significant bit.

The yaw error is also ~0.1 deg. rms. The yaw information comes out of the INS computer at 4 readouts per second.

Time (reference 7)

The time of day is needed for synchronizing the lasercom experiment activities on the Shuttle with those on the aircraft. The GPS system, which will be on both the Shuttle and Wallops aircraft, provides time-of-day to an accuracy in the microsecond range.

The GPS system will have an essentially complete constellation of satellites in 1990–91.

Dome Costs (reference 8)

A quartz dome of good optical quality that could withstand the pressure differential (aircraft interior to high-altitude exterior) was prohibitively expensive for Ames. They (ARC) designed, built, and are using a relatively inexpensive dome. The dome characteristics are the following:

- Observatory-type dome (9-inch diameter) with a moveable slot.
- The whole dome rotates in azimuth.
- The slot is a 3-inch square hole covered with plate glass of proper optical quality.
- The slot moves up and down.
- The dome has two motors, one for azimuth and one for elevation.
- The dome was "hogged out" of a solid piece of fiberglass.
- The dome was made in-house at a total cost of less than $10,000.

Mr. Tak Matsumoto (8-464-6525) "built" it and followed through on it. He would know more about the costs and might be able to provide estimates for larger domes. I will call him when I have a better idea about how large a dome(s) I want to consider.

Dwaine Allen, a technician (ext. 5812), goes/flies all over with it and has drawings for it. Dwaine works for Rudy (ext. 5254), an experimenter who uses the dome.

I will contact Dwaine Allen/Ames/ext. 5812 to get drawings of this above-mentioned dome.

I will contact Tak Matsumoto/Ames/ext. 6525 to get estimates of dome costs.

Meanwhile, Phil Russell/Ames/ext. 5404 will send me a User's Manual for this dome.

Per Roger Navarro (reference 6), Wallops has a T-39 small jet aircraft, with a 16-inch-diameter hole in the top, capable of accommodating a dome. This small jet aircraft can carry 1500 pounds, including people, at altitudes of 38,000-39,000 feet for 3 hours and 15 minutes. Because of its short flight time capability of 3 hours and 15 minutes, it could cover only two (possibly three) consecutive Shuttle passes. Even so, I will look into it further.

Continuing Activities

- Call Dwaine Allen/Ames 8-464-5812 for drawings of their fiberglass, observatory-type dome.
- Call Tak Matsumoto/Ames 8-464-6525 for estimates of dome costs.
- Plot azimuth, elevation and slant range vs. time for assessing the impact of limited viewing angles from aircraft ports.
- Assess the impact of limited viewing angles (elevation = 35-70°, and azimuth = ±2°) of the C-141 KAO aircraft for viewing a Shuttle Orbiter. (I am not ruling out the C-141 KAO as yet.)
- Sketch some configurations of telescopes/viewing ports/domes and rotating flats/viewing ports/domes, to optimize cost effective viewing time capabilities.

References

. Mike Fitzmaurice and Jim Abshire, private conversations with F. Kalil.

. "Gerard P. Kuiper Airborne Observatory-Investigator's Handbook," Ames Research Center, undated latest revision received January 1988.

Lou Haughney, Project Manager of C-141 KAO, FTS 8-464-6484 or 415-694-6484, Ames Research Center, private telecons with F. Kalil, January 1988.

Memorandum for the Record, by F. Kalil/723, GSFC, "Telecons with Ames Research Center Regarding their Research Airplanes," February 2, 1988.

Ron Vento, Computer Printouts and Memorandum; TO: 723/Instrument Electro-Optics Branch/ Dr. Kalil; From: 531.1/RF Interface and Mission Analysis Section; Subject: "Aircraft Coverage of a Shuttle Orbit," February 24, 1988.

Roger Navarro, Wallops Flight Facility/831.1, Telephone: 7-1448, private telecons and consultation with Wallops Pilots, January, February, and March 1988.

Bill Krabill, Wallops Flight Facility/672, Telephone: 7-1717, private telecons, March 2, 1988.

Phil Russell, Ames Research Center, Telephone: 8-464-5404 or 415-694-5404, private telecons, March 3, 1988.

Appendix F

Gulfstream SRA-4 Airplane

by

Gulfstream Aerospace, A Chrysler Company

1

Single, versatile aircraft type minimizes costs of performing several specialized missions

Unique capabilities result in higher utilization

For any government, large or small, the Gulfstream SRA-4 can reduce aircraft acquisition and operating costs by providing new dimensions in utilization.

This single aircraft can perform any specialized support mission requiring a combination of long endurance and high cruise speeds, large cabin size, and maximum operating flexibility under the broadest range of conditions:

- Electronic and/or optical surveillance and reconnaissance
- Maritime patrol
- Medical evacuation
- Priority cargo
- Administrative transport

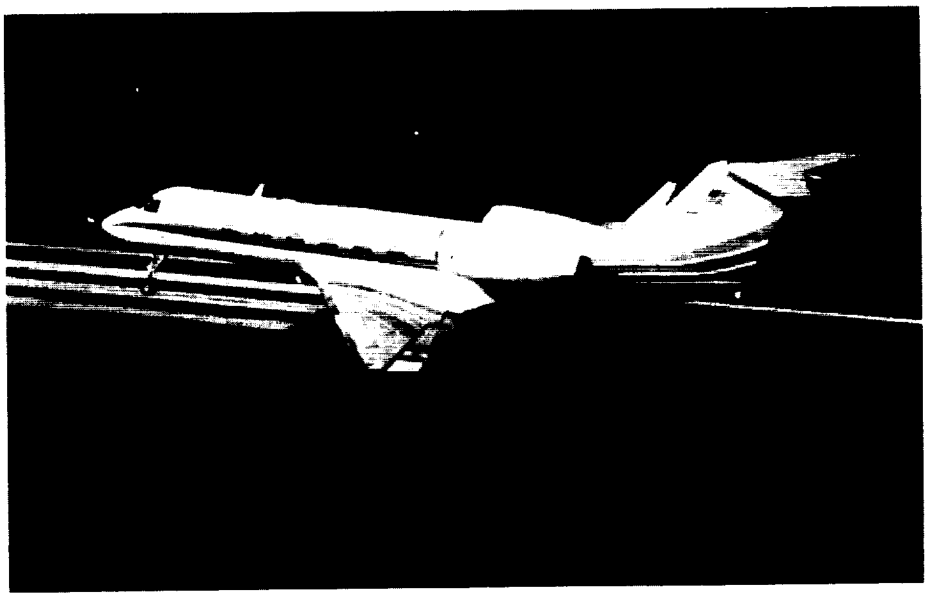
Interiors can be engineered for rapid reconfiguration for different missions; frequently, the Gulfstream SRA-4 can perform two or more of these missions simultaneously, such as administrative transport and priority cargo.

A proven airframe with superior performance

This unique versatility is possible because the Gulfstream SRA-4 is a derivative of the highly advanced Gulfstream IV executive jet transport now entering service with many of the world's major corporations and governments.

With its computerized flight management systems, new Rolls-Royce engines and other advanced systems, the Gulfstream IV achieves levels of performance and productivity unequalled by any other aircraft in its category.

The Gulfstream SRA-4 has these same superior features.



Gulfstream jet aircraft are used by military and governmental agencies world-wide for such diverse missions as maritime patrol and fisheries inspection; advanced systems research, evaluation and training; airways navigation checks; medical evacuation; priority cargo; and search-and-rescue.

- *Long range:* IFR range of 4,300 n.m. (7967 km) provides airborne endurance in excess of 9 hours at long range cruise speeds of Mach .80 (851 km/hr).
- *High operating altitudes:* Maximum operating altitude of 51,000 feet (15545 m) permits unrestricted operations.
- *Airport performance:* Excellent takeoff and landing distances on hot days and higher elevation airports maximize long range mission capabilities.
- *Engine reliability:* Rolls-Royce Tay engines combine low maintenance requirements, 7,000 hours TBO, excellent fuel efficiency to contribute to low operating costs.
- *Cabin size and environment:* Usable cabin volume is approximately 1,700 cubic feet (47.6 m^3), with a flat floor and stand-up headroom throughout. A superior pressurization system maintains a comfortable cabin environment at all altitudes to enhance crew efficiency on long missions.

The Gulfstream SRA-4, with its unique capabilities, low acquisition and life-cycle costs, offers any nation maximum return on the investment it must make in support missions aircraft.

We have developed a comprehensive presentation that details the specialized missions of the Gulfstream SRA 4, including appropriate systems and equipment, interior configurations and performance data. To arrange a briefing, contact: Gulfstream Aerospace Corporation, Military Requirements, 1000 Wilson Blvd., Suite 2701, Arlington, Virginia 22209 U.S.A. Telephone (703) 276 9500

Gulfstream Aerospace
A CHRYSLER

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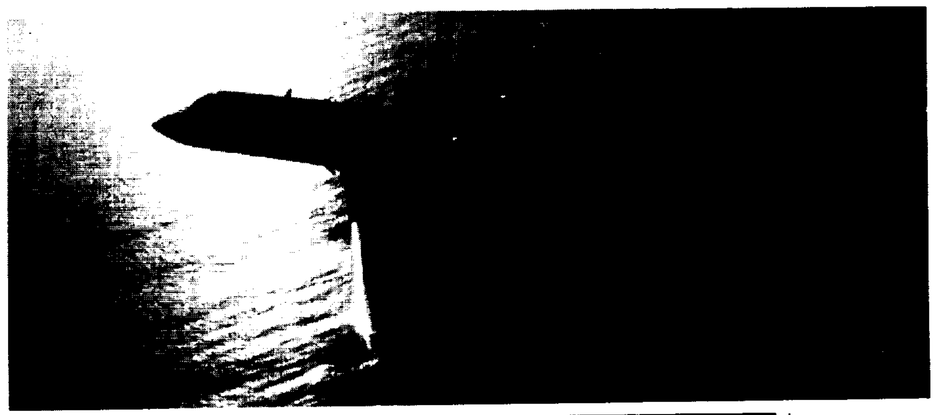
2

Versatile performance, 4,300 n.m. range increase maritime patrol effectiveness

Exclusive Economic Zones require effective patrol

Most maritime nations have adopted the concept of the 200 nautical mile Exclusive Economic Zone (EEZ). Even relatively small island nations face the tasks of surveillance, patrol, resource control and law enforcement involving large ocean areas.

The Gulfstream SRA-4, a derivative of the new and highly advanced Gulfstream IV executive jet transport, is ideally suited by performance, technology and size to perform extremely effective maritime patrol missions.



Systems support, multiple advantages

The Gulfstream SRA-4 has the cabin size and environment, plus ample power to support the equipment and specialists required for maritime surveillance missions lasting several hours.

Features which increase the suitability of the Gulfstream SRA-4 for extended sea surveillance include:

- Rapid transit to and from search areas
- Ability to loiter economically
- Excellent low-speed, low altitude handling characteristics
- Large cabin windows for visual search

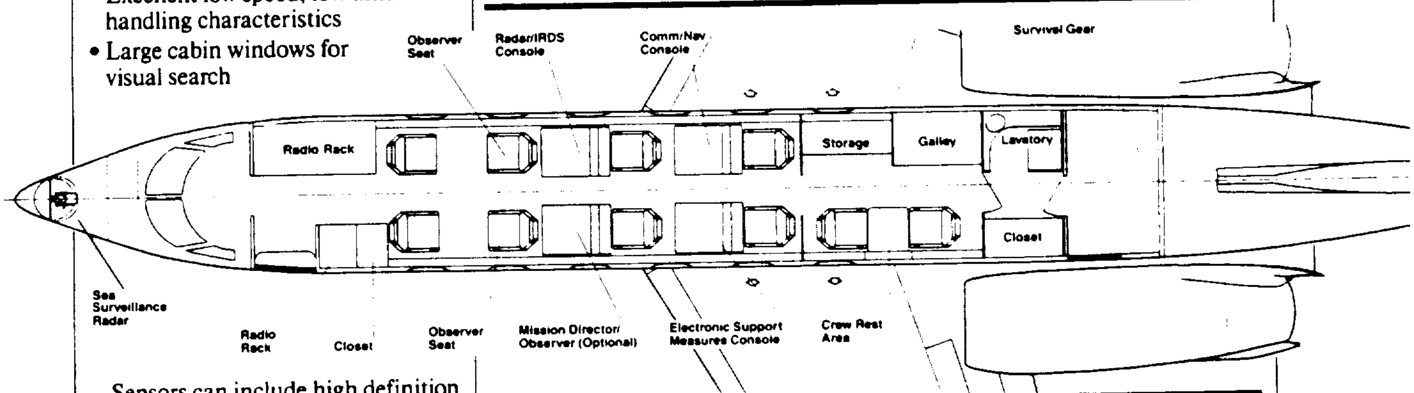
Unique versatility for other missions

In addition to maritime patrol, the Gulfstream SRA-4 can perform other missions requiring long endurance, high speeds, a large cabin and operational flexibility.

With "quick change" interiors, the aircraft can be reconfigured rapidly for any of these missions, and frequently perform two or more simultaneously:

- Electronic and/or optical surveillance and reconnaissance
- Anti-submarine warfare
- Medical evacuation (up to 15 litter patients plus medical staff)
- Administrative transport (up to 18 passengers plus attendant)
- Priority cargo

With new dimensions in performance and utilization, plus low acquisition and life-cycle costs, the Gulfstream SRA-4 can maximize the investment every government must make in aircraft for specialized missions.



Sensors can include high definition sea surface search radar; Forward-Looking Infrared (FLIR) system; and Electronic Support Measures (ESM) for emitter identification, classification and location.

We have developed a comprehensive presentation that details the specialized missions of the Gulfstream SRA-4, including appropriate systems and equipment, interior configurations and performance data. To arrange a briefing, contact: Gulfstream Aerospace Corporation, Military Requirements, 1000 Wilson Blvd., Suite 2701, Arlington, Virginia 22209 U.S.A. Telephone: (703) 276-9500.

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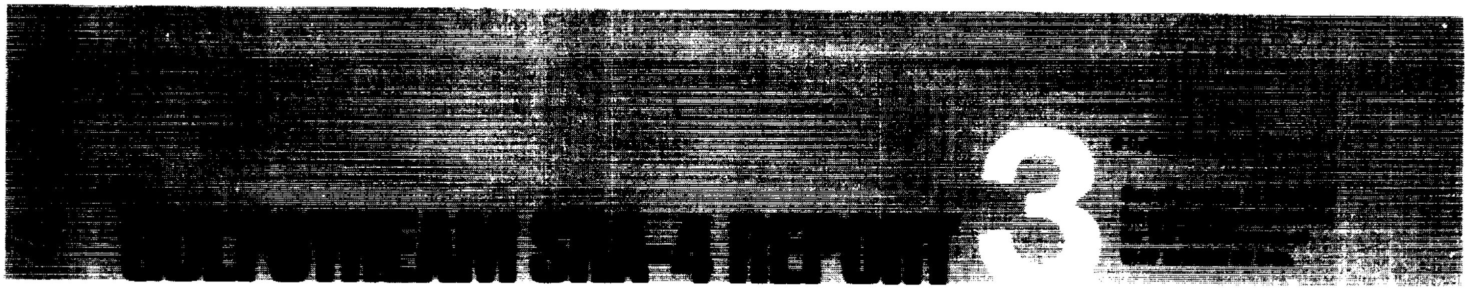
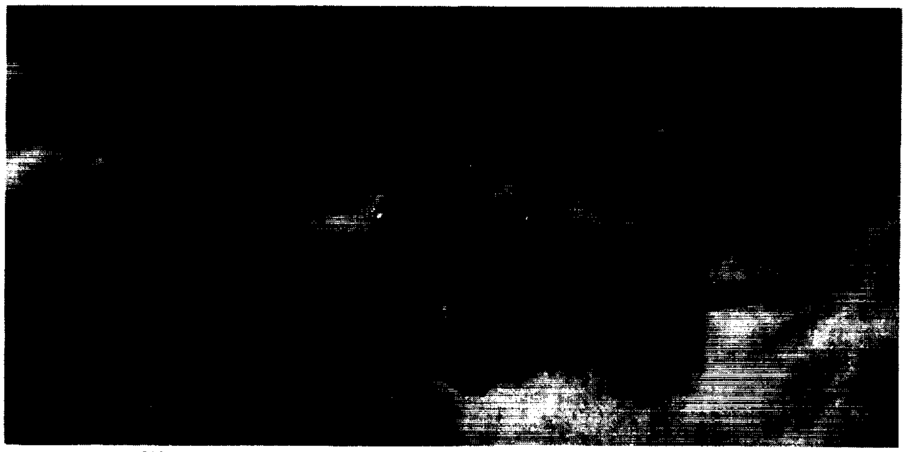


High operating altitudes, long endurance, large cabin size make ideal platform for electronic/optical surveillance



Gathering intelligence data by air is an essential element of planning for a nation's defense. The effectiveness of such missions, of course, requires an aircraft with the optimum combination of long endurance at high altitudes, speed and excellent operating efficiencies.

The Gulfstream SRA-4, a derivative of the new and highly advanced Gulfstream IV long range executive jet transport, is ideally suited to perform these missions from stand-off positions within a nation's own borders.

In addition, the Gulfstream SRA-4 has excellent stability for sensors; in-flight access to many components for corrective maintenance; and a comfortable working environment for flight crew and systems specialists throughout missions lasting as long as 10 hours at high altitudes.

Unique versatility for greater utilization

By taking advantage of a system of "quick change" interiors, the Gulfstream SRA-4 can also be used for other missions. The aircraft is ideally suited by its high performance and size for these additional support missions:

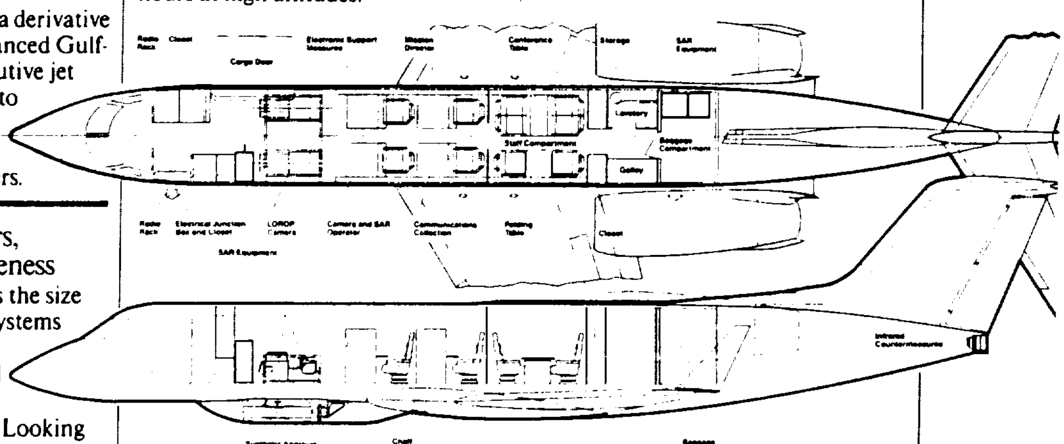
- VIP transportation
- Administrative transport (up to 18 passengers plus attendant)
- Medical evacuation (up to 15 litter patients plus medical staff)
- Priority cargo

The Gulfstream SRA-4, with its unique capabilities, low acquisition and lifecycle costs, plus outstanding operating efficiencies, enables any government to maximize the investment it makes in aircraft to perform special support missions.

Multiple sensors, maximum effectiveness

The Gulfstream SRA-4 has the size and power to support the systems and specialists necessary to obtain the most meaningful intelligence data.

Sensors can include Side Looking Synthetic Aperture radar (SLAR); Long range Oblique Photographic (LOROP) camera; Electronic Support Measures (ESM); communications intercept system; and VHF/UHF/HF communications for command control.



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GULFSTREAM SRA-4 MISSION DATA

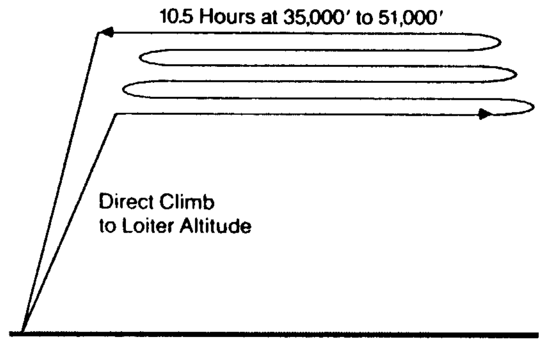
Surveillance/Reconnaissance Configuration

Weight Summary
in pounds

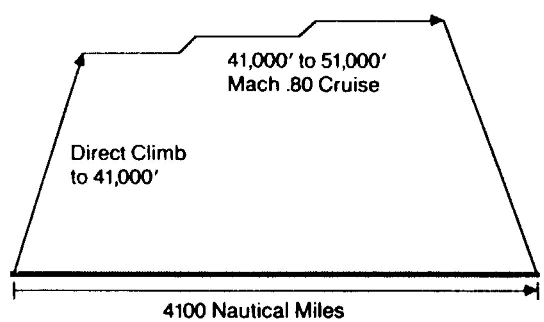
Design Weight Limits

Maximum Ramp Weight		75,000
Maximum Takeoff Weight		74,500
Maximum Zero Fuel Weight		48,000
Fuel Capacity		29,500
Payload/Fuel Capability		
Maximum Mission Payload		7,731
Fuel with Maximum Payload		27,000
Payload with Maximum Fuel		5,231
Loading Summary, Typical Mission		
Basic Empty Weight, Furnished		40,269
Mission Payload		5,231
Mission Equipment	3,182	
Crew (6) and Equipment	1,818	
Additional Payload	231	
Zero Fuel Weight		45,700
Fuel		29,500
Ramp Gross Weight		75,000
Start and Taxi Fuel		-500
Takeoff Gross Weight		74,500

Basic Electronic Surveillance Mission Profile



Basic Long Range Mission Profile



For more information about the Gulfstream SRA-4, please address your inquiry to:
Gulfstream Aerospace Corporation, Military Aircraft Requirements, P.O.Box 2206, Mail Station B-04, Savannah, Georgia 31402 U.S.A.

Gulfstream Aerospace
A CHRYSLER COMPANY

Electronic surveillance and reconnaissance are essential elements of sound strategic and tactical planning for a nation's defense. Using highly advanced methods of gathering information, these activities provide the capability of establishing the military potential of a suspected adversary. Their effective use enables a command to identify, locate, classify and catalog potential threats and monitor them to determine any changes in operational deployment or activity. Using the sensors decribed below those missions may be carried out in the Gulfstream SRA-4 from safe, stand-off positions from within one's own borders.

The Sensors

Sensors which together provide the outputs needed by the national command authorities include the following:

- Side-looking synthetic aperture radar (all-weather, "real time," moving target indication)
- Long Range Oblique Photographic (LOROP) camera (may include electro-optical capability)
- Electronic Support Measures (ESM) for emitter identification, classification and location
- Communications intercept system
- VHF/UHF/HF communications for command control

Gulfstream SRA-4 Suitability

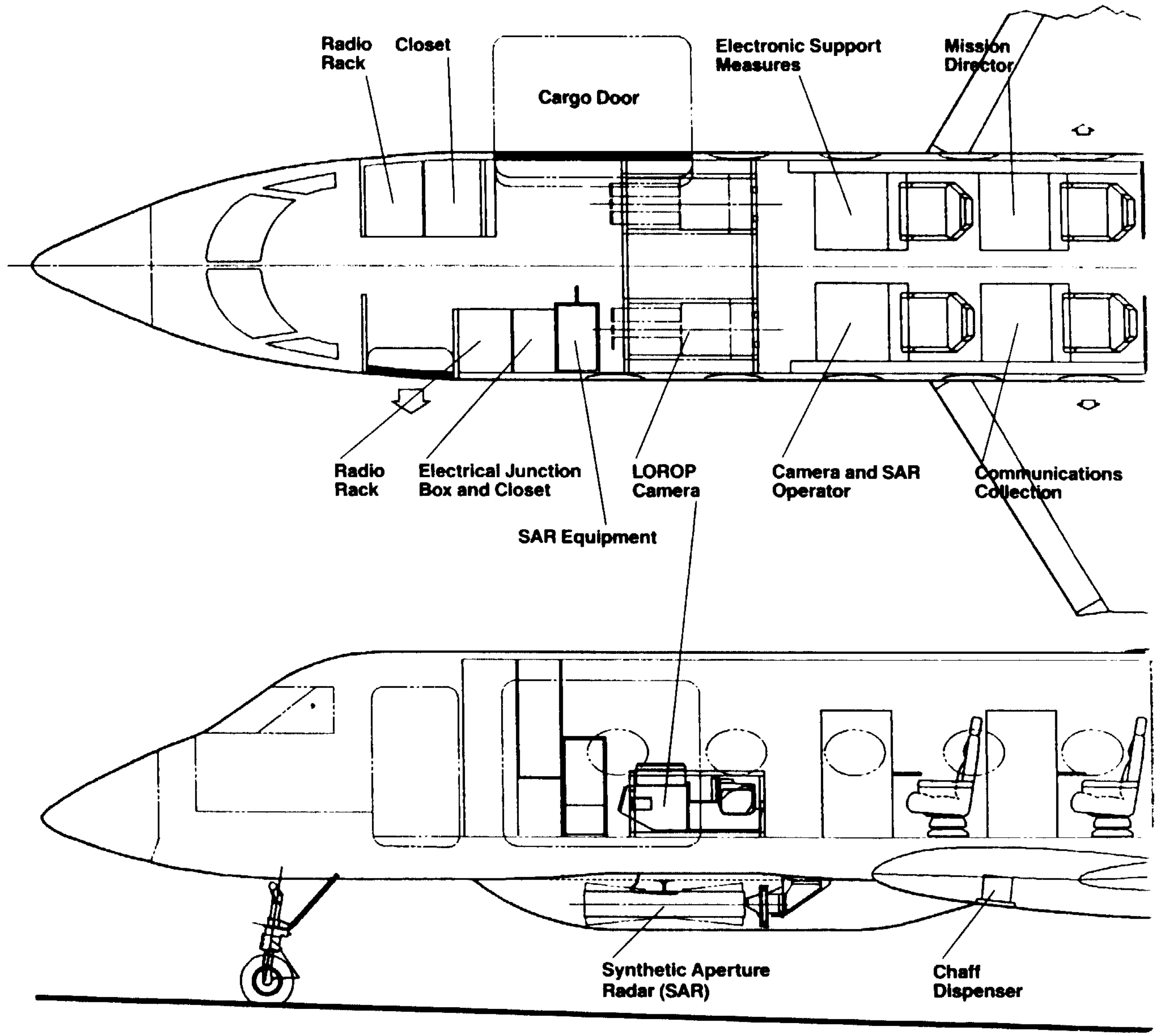
The Gulfstream SRA-4 surveillance/reconnaissance variant offers the following advantages:

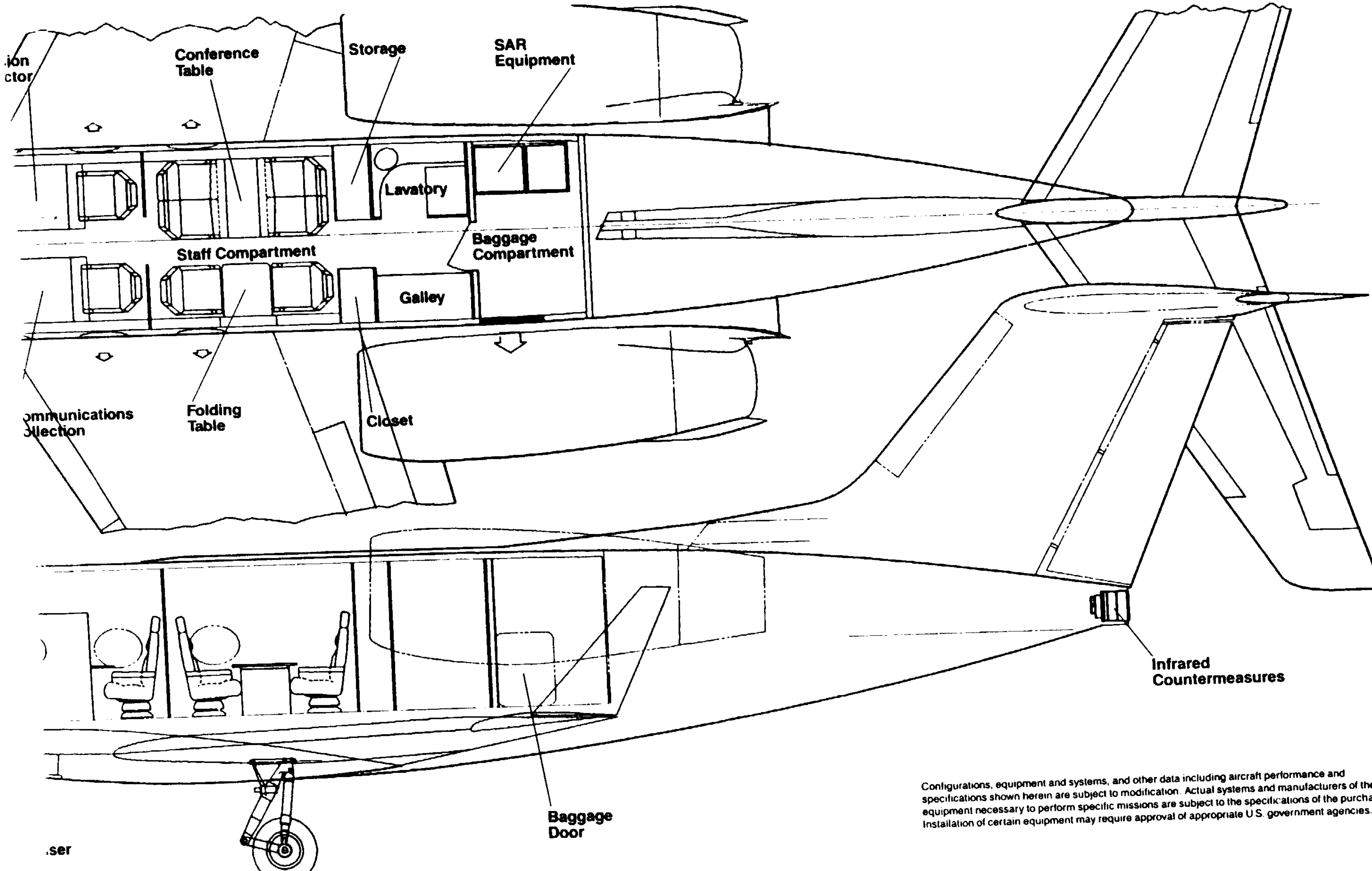
- Multiple sensors for data fusion and correlation
- Excellent stability for sensors
- On-board mission specialist for each sensor
- Real-time analysis and assessment
- In-flight access to many sensor components for corrective maintenance
- Quiet, comfortable working environment
- Additional capacity for specialists, data links, etc.
- Low acquisition and life-cycle costs

Supplementary Missions

As with other specialized configurations of the Gulfstream SRA-4, the surveillance and reconnaissance variant can be reconfigured rapidly for the following missions:

- VIP transportation
- Personnel/administrative transportation (seating for up to 18 passengers plus attendant)
- Medical evacuation (15 litter patients plus medical staff)
- Priority cargo





Configurations, equipment and systems, and other data including aircraft performance and specifications shown herein are subject to modification. Actual systems and manufacturers of the equipment necessary to perform specific missions are subject to the specifications of the purchaser. Installation of certain equipment may require approval of appropriate U.S. government agencies.

Appendix G

ATMOSPHERIC EFFECTS
FOR
LEO/AIRCRAFT LASERCOM

The effects of the earth's atmosphere on the laser beam may be divided into four categories:

1. Atmospheric extinction–i.e., loss of beam intensity due to absorption by atmospheric gases (mainly water vapor in the spectral region around 8700 angstroms), absorption and scattering by aerosols;

2. Refractive bending by the atmosphere;

3. Atmospheric turbulence effects–scintillation, beam wander and beam broadening;

4. Effects due to turbulence near the observation dome of the aircraft (due to the aircraft's motion).

Each of these categories will now be discussed in turn.

Atmospheric Extinction

Calculations of atmospheric extinction were made for paths down through the atmosphere to aircraft at altitudes of 25,000 and 39,000 feet, for elevation angles of 5° and 45°. For each altitude and elevation angle a transmission spectrum was computed, spanning the wavelength range from 8,000 to 8,700 angstroms.

The calculations were done using the computer code described in Reference G1. The code is based on the LASER code published by the Air Force Geophysics Laboratory in 1978 (Reference G2), which was extensively modified to allow execution on a desktop microcomputer and to generate transmission spectra rather than tables of extinction coefficients.

The transmission spectra include the effects of absorption by water vapor (which is effectively the only absorber in the wavelength range considered), Rayleigh (molecular) scattering (which is small in the near infrared) and aerosol absorption and scattering. The atmosphere model used is a variant of the U.S. Standard Atmosphere (1962), which is adjusted to apply to mid-latitudes in the summer, with a rather high concentration of water vapor (3.68 precipitable centimeters). Also, a high concentration of aerosols was assumed, so that the total atmospheric extinction shown in the spectra is on the high side.

The spectra are shown in Figures G1 and G2. It is apparent that the atmosphere is nearly transparent from 8,000 to 8,700 angstroms as seen from an altitude of 39,000 feet, even at an elevation angle of 5°. For an altitude of 25,000 feet, however, the atmosphere is nearly opaque at 5° elevation and shows strong absorption at 45° elevation, for wavelengths from about 8,100 to 8,400 angstroms; outside this range (but within the 8,000–8,700 angstrom range) the absorption becomes quite weak, even at 5° elevation.

From the above results, it is clear that the laser wavelength should be either less than about 8,100 angstroms or greater than about 8,400 angstroms, to ensure small atmospheric extinction at an aircraft altitude of 25,000 feet.

Atmospheric Refractive Bending

From the classical astronomical formulas for the atmospheric bending of visible (or near-visible) light (see, for example, reference G3), it may be concluded that the laser beam can be expected to undergo a refractive bending (in elevation) of about a milliradian or less at low elevation angles, and less at high elevation angles. However, because this effect should vary slowly in time (ignoring beam wander due to turbulence), it should pose no problem for acquisition, tracking or signalling in a laser communication system.

Atmospheric Turbulence Effects

Downlink–For the downlink case, beam wander and broadening are insignificant, because the path through the atmosphere is too short for slight angular deviations of portions of the wavefront (due to turbulence) to result in an appreciable displacement normal to the beam. Thus, only scintillation needs to be considered. To assess the effect of scintillation, which causes signal fading, calculations were made with a computer program (described in Reference G4) which, among other things, computes the probability distribution of the received signal strength of a laser beam which passes through a turbulent atmosphere.

The calculations were done for aircraft altitudes of 25,000 and 39,000 feet, with elevation angles of 5° and 45° at each altitude. The shape of the distribution, and the ratio of the standard deviation to the mean, depend only on the altitude integral of the index of refraction structure constant (which in turn, depends on the aircraft altitude), the elevation angle and the receiving aperture area. (The aperture area was taken to be 0.9 square meter, which is larger than the actual receiving aperture would be and thus smooths the signal fluctuations more than the actual aperture would; thus the degree of fading may be expected to be slightly greater than the values computed here.) The computed ratios of the standard deviation to the mean of the signal for the cases computed are shown in Table G1.

Table G1. Ratio of Standard Deviation to Mean of Signal.

		Elevation Angle (degrees)	
		5	45
Aircraft Altitude (feet)	25,000	0.37	0.016
	39,000	0.18	0.0079

From Table G1, it appears that fading will be slight at high elevation angles, but may be very deep at low elevation angles. A better intuitive grasp of the signal distribution, and the corresponding degree of fading, may be acquired by looking at a plot of the signal distribution; Figure G3 shows the distributions for an aircraft altitude of 25,000 feet, for elevation angles of 5° and 45°. From these plots the likelihood of a given degree of fading is at least roughly apparent. Figure G4 shows the same distributions plotted on a magnified vertical scale to more clearly show the shape of the distribution for the 5° elevation angle. (The top of the 45° distribution is cut off.)

Uplink–For the uplink case, slight angular deviations of portions of the wavefront due to turbulence will result in appreciable displacements normal to the beam, because of the long path of the beam after it leaves the atmosphere. Also, if the transmitting aperture is small (a few inches in diameter), the fluctuations in index of refraction across the beam will be correlated, so that the entire beam may tend to be deflected. Thus, for the uplink case, beam wander and broadening may be appreciable and will have to be taken into account, along with scintillation, in calculating the signal fluctuations at the receiver. The beam may be intuitively visualized as wandering erratically in direction, with its width fluctuating slightly, while the intensity across the wavefront scintillates–i.e., fluctuates in subregions of the wavefront. The three effects are correlated, because they all arise from the same index of refraction fluctuations along the beam path. While it is not difficult to estimate some kind of "worst case" fading at the receiver by treating each effect independently, it is not a simple matter to calculate the actual probability of the signal at the receiver. It is interesting that this calculation can be avoided by using a reciprocity theorem (see reference G5, which states the theorem without proof and also contains an extensive bibliography on propagation through turbulent media).

As formulated in Reference G5, the reciprocity theorem states:

> For two optical systems, each consisting of a coherent transmitter and receiver sharing a common antenna aperture through a beamsplitter, the effect of atmospheric turbulence on the signal received by the first unit from the second will be identical instant-by-instant to the effect of atmospheric turbulence on the signal received by the second unit from the first.

As noted in Reference G5, this theorem allows the use of fast adaptive optics to sense instantaneous path distortions and uses that information to introduce a compensating distortion in the outgoing beam. In particular, the measured fluctuations in angle of arrival of the downlink beam may be used to modify the pointing of the uplink beam, which will compensate, in part, for the turbulence-induced wandering of the uplink beam. The effect of this wandering may also be avoided by increasing the width (and also the power) of the uplink beam.

For the purpose of computing the received signal fluctuation for the uplink case in the absence of any adaptive pointing compensation, the reciprocity theorem allows the calculation of the uplink case to be circumvented, because the signal fluctuations will be the same as for the downlink case, which was calculated above by considering only scintillation effects, since beam wander and broadening are negligible, as remarked above. Thus, the conclusions about fading reached for the downlink case apply also to the uplink case, as do the plots of the signal distributions (except for signal magnitude scaling factors).

Dome Turbulence Effects

Downlink–The effect on the signal strength of turbulence around the observation dome caused by the aircraft's motion would appear to be negligible. This seems intuitively clear, because the angular deviations of portions of the wavefront would have to be very large (on the order of 1 milliradian or so) to cause even a few percent reduction of the signal strength, because of the small thickness of the turbulent layer, and it seems unlikely that the turbulence would be strong enough to cause such large angular deviations.

This conclusion may be strengthened by a simple mathematical argument. If is is assumed that the motion-induced turbulence effects depend on the integral of the index-of-refraction structure constant through the turbulent layer, as is true for atmospheric turbulence, then it is easy to show that the total effect due to motion-induced turbulence is orders of magnitude below the effect of atmospheric turbulence, even if the structure constant for motion-induced turbulence is orders of magnitude above the atmospheric structure constant.

The conclusion that the motion-induced turbulence has a negligible effect on the received signal strength was further confirmed by consultation with another member of the Instrument Electro-Optics Branch, who is very knowledgeable about this subject (see reference G6).

It should be noted that these conclusions apply only to the received signal strength; the effect of motion-induced turbulence on the angle of arrival of the signal may not be negligible, but no quantitative information about this effect is presently available to the author.

Uplink–Because the effect of motion-induced turbulence on the received signal strength is apparently negligible for the downlink case, it follows from the reciprocity theorem that the same is true for the uplink case. If adaptive pointing is used, any effect that might be present due to beam wandering would be reduced, since the angle-of-arrival fluctuations caused by the motion-induced turbulence layer would be lumped together with the fluctuations caused by atmospheric turbulence. As mentioned above in the discussion of atmospheric turbulence, the effect of beam wandering may be avoided simply by broadening the beam and correspondingly increasing its power.

References

G1. Safren, H. G., "A Computer Code to Calculate Line by Line Atmospheric Transmission Spectra on a Microcomputer," NASA Technical Memorandum 100686, July 1987.

G2. McClatchey, R. A. and D'Agati, A. P., "Atmospheric Transmission of Laser Radiation: Computer Code Laser," AFGL-TR-78-0029, January 31, 1978.

G3. Smart, W. M., Textbook on Spherical Astronomy," Chapter III, Cambridge University Press, 1956.

G4. Safren, H. G., "Fading in a Space to Ground Laser Communication Link due to Atmospheric Turbulence and Transmitter Pointing Jitter," NASA Technical Memorandum, in publication.

G5. The Infrared Information and Analysis Center of the Environmental Research Institute of Michigan, 1978; Chapter 6, "Propagation Through Atmospheric Turbulence," The Infrared Handbook. W. L. Wolfe and G. J. Zissis, ed.

G6. Consultation with Peter Minott, Instrument Electro-Optics Branch, Goddard Space Flight Center, Greenbelt, Maryland.

Appendix H
Ames Research Center Aircraft

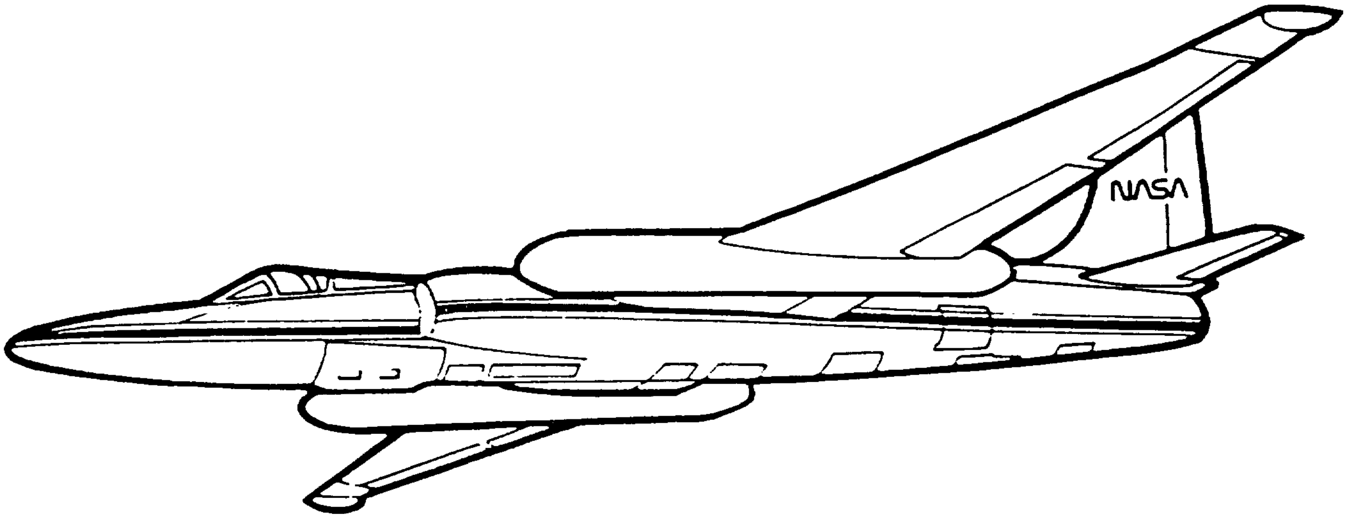
FY 1988

Airborne Science and Applications Program
Facilities

The FY 1988 Airborne Science and Applications Program (ASAP) facilities include aircraft, core sensors, and support facilities and equipment. The ASAP has four aircraft, two high altitude aircraft (an ER-2 and a U-2) and two medium altitude aircraft (a C-130B and a DC-8-72). These facilities are described in Figures H1 through H4.

Figure H5 summarizes the sensor systems available and identifies on which aircraft they are flown. Figure H6 shows the spectral characteristics of major ASAP scanners and radiometers available. The aircraft Thematic Mapper Simulators (TMS), simulates the Landsat-4 and -5 Satellite Thematic Mapper (TM) spectral characteristics. At 70,000 feet altitude, the Daedalus TMS also simulates the TM spatial resolution of 30 meters in the visible and IR bands. In addition, Ames maintains a data facility for photographic and electronic data production (See Figure H7). Further information on these ASAP facilities may be obtained by contacting the respective NASA/ARC Aircraft Manager as follows:

ER-2/U-2 and Data Facility	John C. Arvesen Chief, High Altitude Missions Branch	Commercial FTS	(415) 694-5376 464-5376
C-130B/ DC-8-72	Donald L. Anderson Chief, Medium Altitude Missions Branch	Commercial FTS	(415) 694-5338 464-5338
C-141-KAO (Kuiper)	Lou Haughner Project Manager	Commercial FTS	(415) 694-5339 464-5339



ER-2, Lockheed

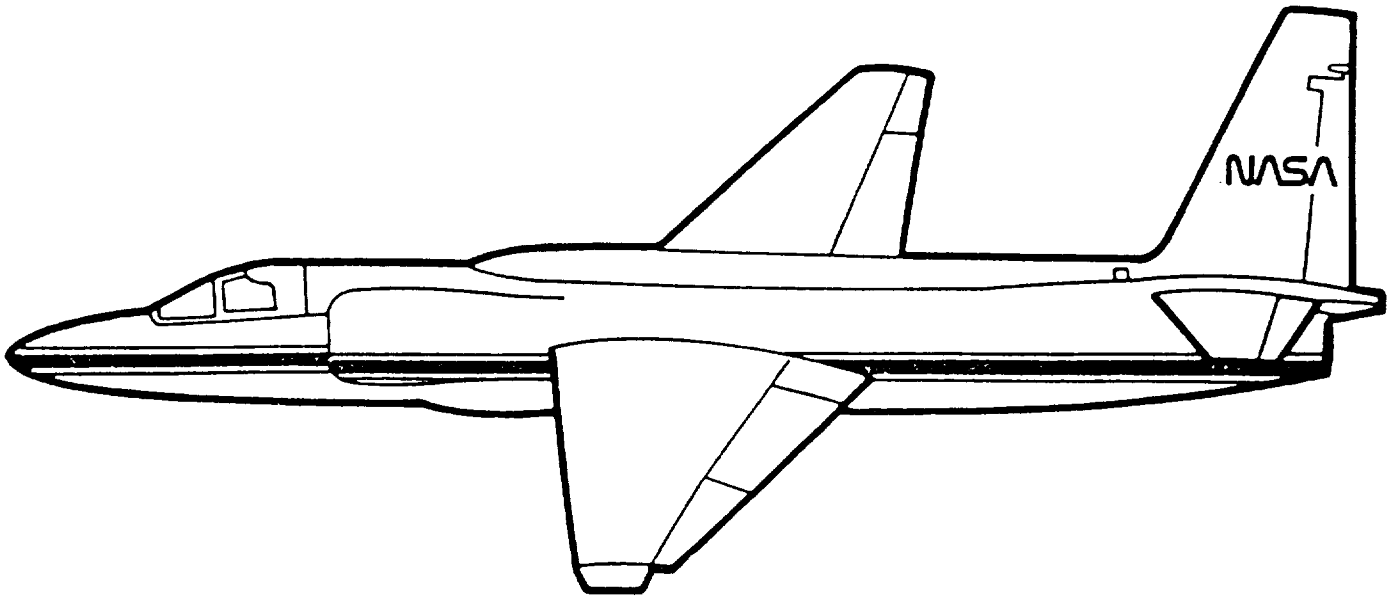
Description:	Crew:	One Pilot
	Length:	62 feet, 1 inch
	Wingspan:	103 feet, 4 inches
	Engine:	One Pratt & Whitney J75-P-13B
	Base:	Ames Research Center, Moffett Field, CA
Performance:	Altitude:	70,000 feet (Cruise)
	Range:	3000 nautical miles
	Duration:	8 hours (Nominal 6.5 hours)
	Speed:	410 knots True Air Speed
	Payload:	600 lb, Nose; 750 lb, Q-bay; 1360 lb, Wing pods

Accommodations:
Q-Bay Instrumentations Area and Payload Pallets (Pressurized)
Wing Mounted Instrumentation Pods (Pressurized)
Nose Cone Instrumentation Area (Pressurized)
Zenith and Nadir Viewing Capability

Support:
Inertial Navigation
GOES Satellite Time Code Receiver

Sensors:
High Altitude Multispectral Scanner
Airborne Coastal Zone Scanner
Airborne Ocean Color Scanner
Linear Array Scanner
Metric Cameras
High-Resolution Panoramic Cameras

Figure H1.



U-2, Lockheed

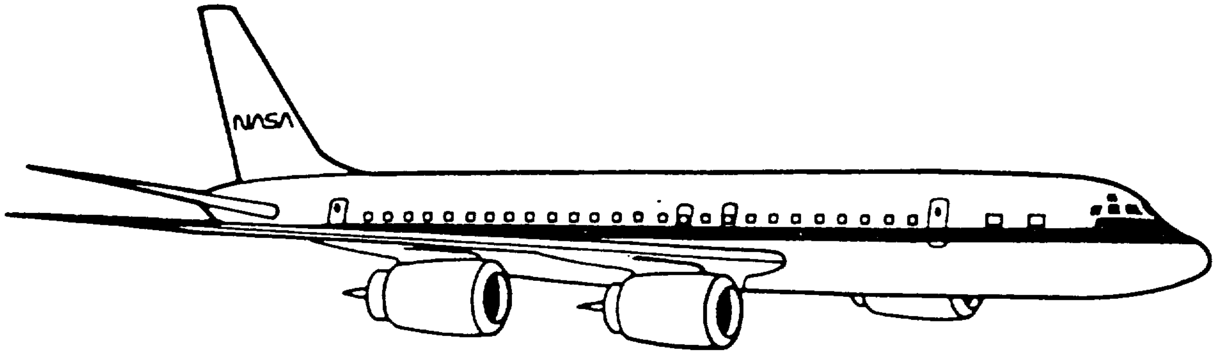
Description:	Crew:	One Pilot
	Length:	49 feet, 9 inches
	Wingspan:	80 feet, 2 inches
	Engine:	One Pratt & Whitney J75-P-13B
	Base:	Ames Research Center, Moffett Field, CA
Performance:	Altitude:	65,000 feet (Cruise), 70,000 feet (Maximum)
	Range:	2500 nautical miles
	Duration:	6.5 hours
	Speed:	400 knots True Air Speed
	Payload:	750 lb, Q-bay; 100 lb, Canoe; 600 lb, Wing pods

Accommodations: Q-Bay Instrumentations Area and Payload Pallets (Pressurized)
Wing Mounted Instrumentation Pods (Unpressurized)
Nose Cone Instrumentation Area (Unpressurized)
Zenith and Nadir Viewing Capability

Support:
Inertial Navigation
GOES Satellite Time Code Receiver

Sensors:
High Altitude Multispectral Scanner
Airborne Coastal Zone Color Scanner
Airborne Ocean Color Scanner
Linear Array Scanner
Metric Cameras
High Resolution Panoramic Cameras

Figure H2.



DC-8-72, McDonnell Douglas

Description:	Crew:	Two Pilots, Flight Engineer, Navigator
	Length:	157 Feet
	Wingspan:	148 Feet
	Engines:	Four CFMI CFM56-2-C1 High Bypass Ratio Engines
	Base:	Ames Research Center, Moffet Field, CA
Performance:	Altitude:	30,000-40,000 feet (Cruise), 42,000 feet (Maximum)
	Range:	5460 nautical miles, 3000 nautical miles (Nominal)
	Duration:	12 hours, 6.0 hours (Nominal)
	Speed:	425-490 knots True Air Speed
	Payload:	30,000 lb

Accommodations: (6/87)

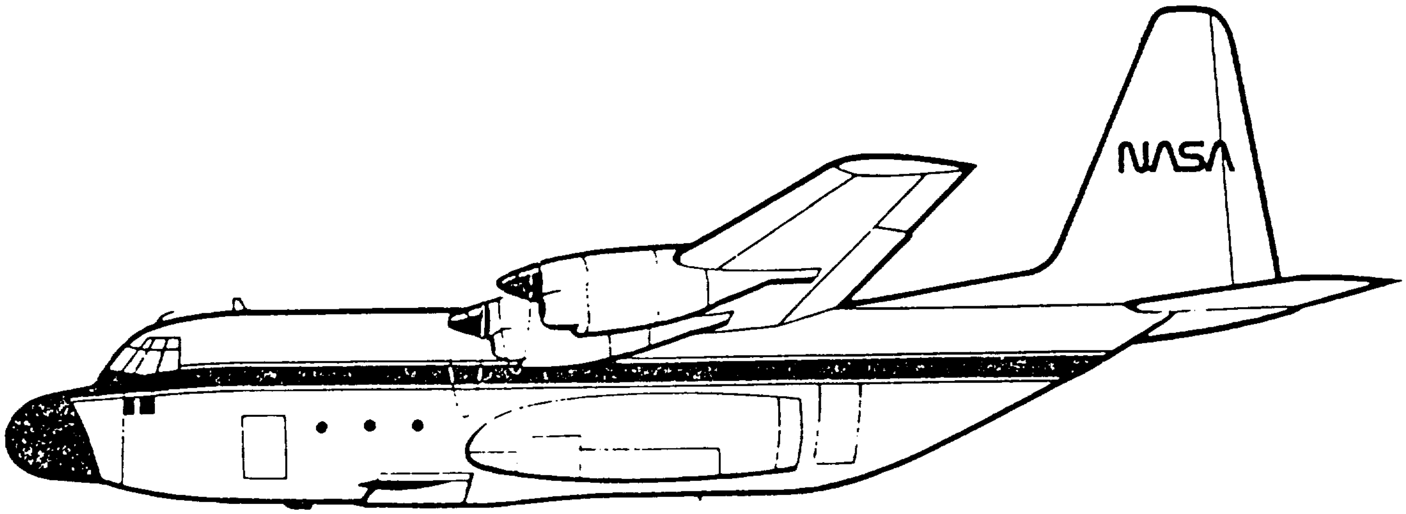
Sensor Viewports at 8° and 62° Elevations
Optical Windows
19-inch Panel Equipment Racks

Systems Support: (6/87)

Dew/Frost Point Hygrometers
Radar Altimeter
Weather Radar
IR Surface Temperature Radiometer
Inertial Navigation
Time Code Generator
Metric and Panoramic Camera
  (Nadir Port Mods Not Accomplished)
Housekeeping Data Distribution System
  (Navigation, Flight, Environment, and TCG)
Walk-on: Ten to Twelve Stations Provided for
  Investigator Supplied and Operated Sensors

Note: Additional Aircraft Modifications and Support Systems Will Be Implemented as Required

Figure H3.



C-130B, Lockheed

Description:

Crew: Two Pilots, Fight Engineer, Navigator
Length: 97 feet, 9 inches
Wingspan: 132 feet, 7 inches
Engine: Four Allison T56-A-7 Turboprop
Base: Ames Research Center, Moffett Field, CA

Performance:

Altitude: 25,000 feet
Range: 2500 nautical miles
Duration: 8 hours at 25,000 feet
Speed: 150-330 knots True Air Speed
Payload: 20,000 lb

Accommodations:

Zenith and Nadir Viewports
External Antenna Attachment Mounts
Optical Windows
19-inch Panel Equipment Racks

Support:

Dew/Frost Point Hygrometer
Radar Altimeter
Weather Radar
Inertial Navigation
Time Code Generator
Closed Circuit Television
Data Acquisition

Sensors:

Metric Cameras
Multispectral Scanner
Microwave Scatterometers
Walk-on: Eight Stations Provided for Investigator Supplied and Operated Sensors

Figure H4.

AIRBORNE SCIENCE AND APPLICATIONS PROGRAM (ASAP)

FY 1988 SENSORS SYSTEMS

SYSTEMS		MAINTAINED & OPERATED	AIRCRAFT
SCANNERS/RADIOMETERS			
NS001-THEMATIC MAPPER SIMULATOR	8 CHANNELS	ARC	C-130B
DAEDALUS-THEMATIC MAPPER SIMULATOR[1]	12 CHANNELS	ARC	ER-2/U-2
DAEDALUS-AIRBORNE OCEAN COLOR IMAGER	9 CHANNELS	ARC	ER-2/U-2
PRT-5 RADIOMETER	1 CHANNEL	ARC	C-130B/DC-8-72
SYNTHETIC APERTURE RADAR	L,C&P BAND	JPL	DC-8-72
AVIRIS	220 CHANNELS	JPL	ER-2/U-2
CAMERAS			
METRIC - 6", 12", 24" FOCAL LENGTH		ARC	ER-2/U-2/ C-130B/DC-8-72[2]
PANORAMIC		ARC	DC-8-72[2]
HIGH RESOLUTION PANORAMIC		ARC	ER-2/U-2
GENERAL SUPPORT		ARC	DC-8-72
GENERAL SUPPORT			
DEW/FROST POINT HYGROMETER		ARC	C-130B/DC-8-72
RADAR ALTIMETER		ARC	C-130B/DC-8-72
WEATHER RADAR		ARC	C-130B/DC-8-72
INERTIAL NAVIGATION		ARC	ALL AIRCRAFT
TIME CODE GENERATOR		ARC	ALL AIRCRAFT
CLOSED CIRCUIT TELEVISION		ARC	C-130B
HOUSEKEEPING DISTRIBUTION SYSTEMS		ARC	C-130B/DC-8-72
DATA FACILITIES		ARC	ER-2/U-2 C-130B/DC-8-72

[1]REAL-TIME DATA LINK CAPABILITY

[2]DC-8 NADIR PORTS NOT INSTALLED

Figure H5.

SPECTRAL CHARACTERISTICS OF MAJOR ASAP SCANNERS/RADIOMETERS — FY 88

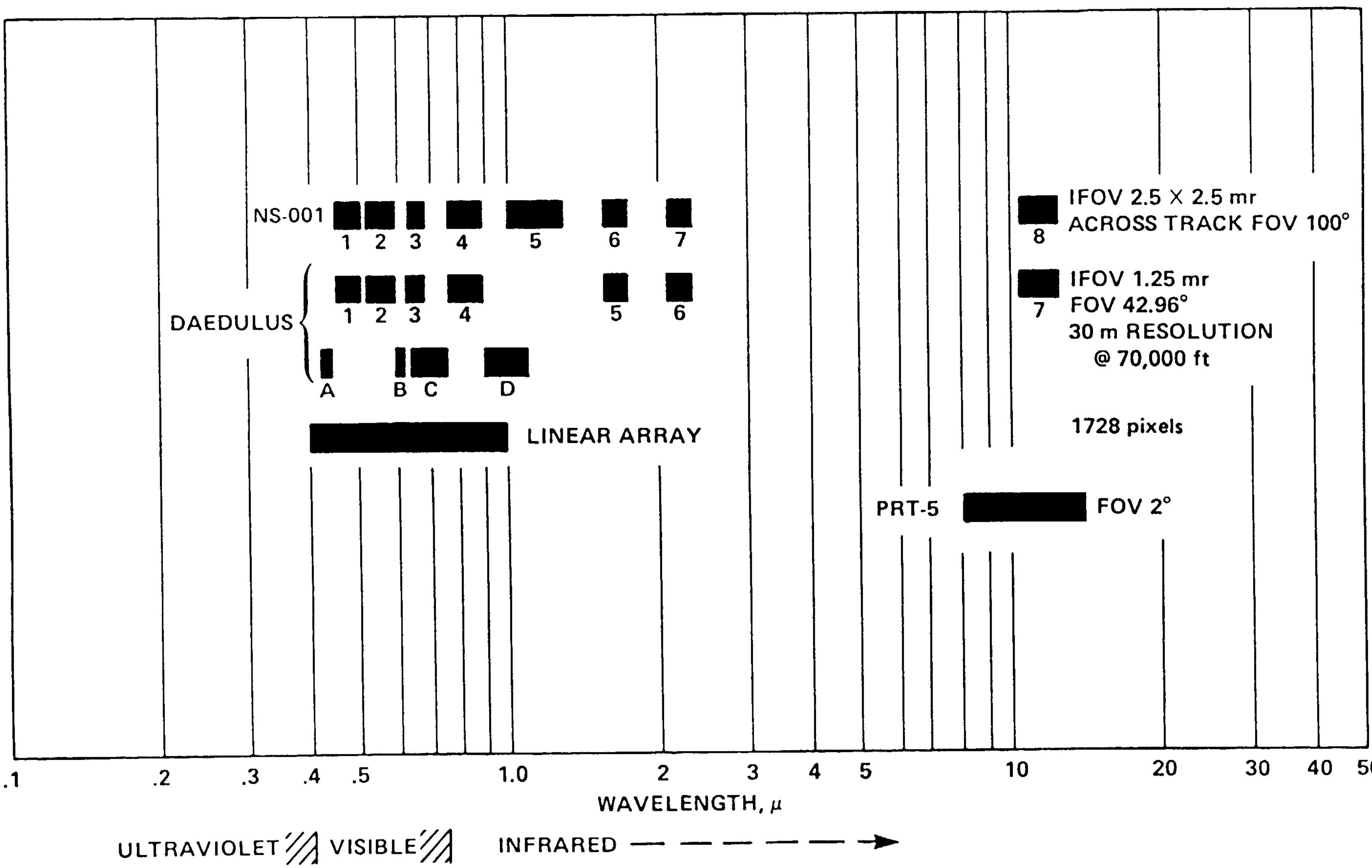
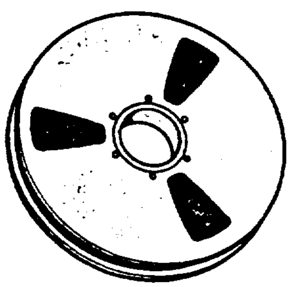


Figure H6.

Image Processing Capabilities

Applications Aircraft Data Management Facility
High Altitude Missions Branch
NASA-Ames Research Center
(415) 965-6252

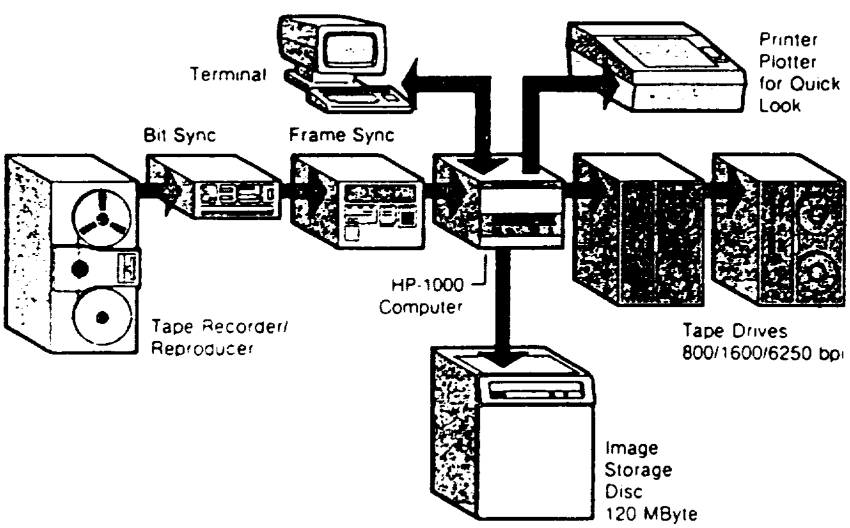
Data Acquisition



Airborne data are recorded in a digital Pulse Code Modulated (PCM) format.

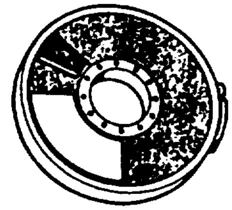
The A.A.D.M.F. Image Processing Facilities are capable of: (1) converting 14-track high density PCM tapes to computer compatible tapes (CCTs), and (2) performing interactive image analysis on these.

Conversion to CCTs



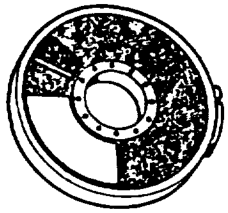
The airborne data tapes are converted to CCTs on an HP-1000 host computer system. The process includes decommutation, storage of each band or scan line on disk, optional correction for geometric distortion, and writing the final tapes in computer compatible format.

CCTs to Experimenter



CCTs are available for an experimenters use at this point. These are written in 8 bit, 9 track form and are available in either 800, 1600 or 6250 bpi.

Image Processing and Enhancement

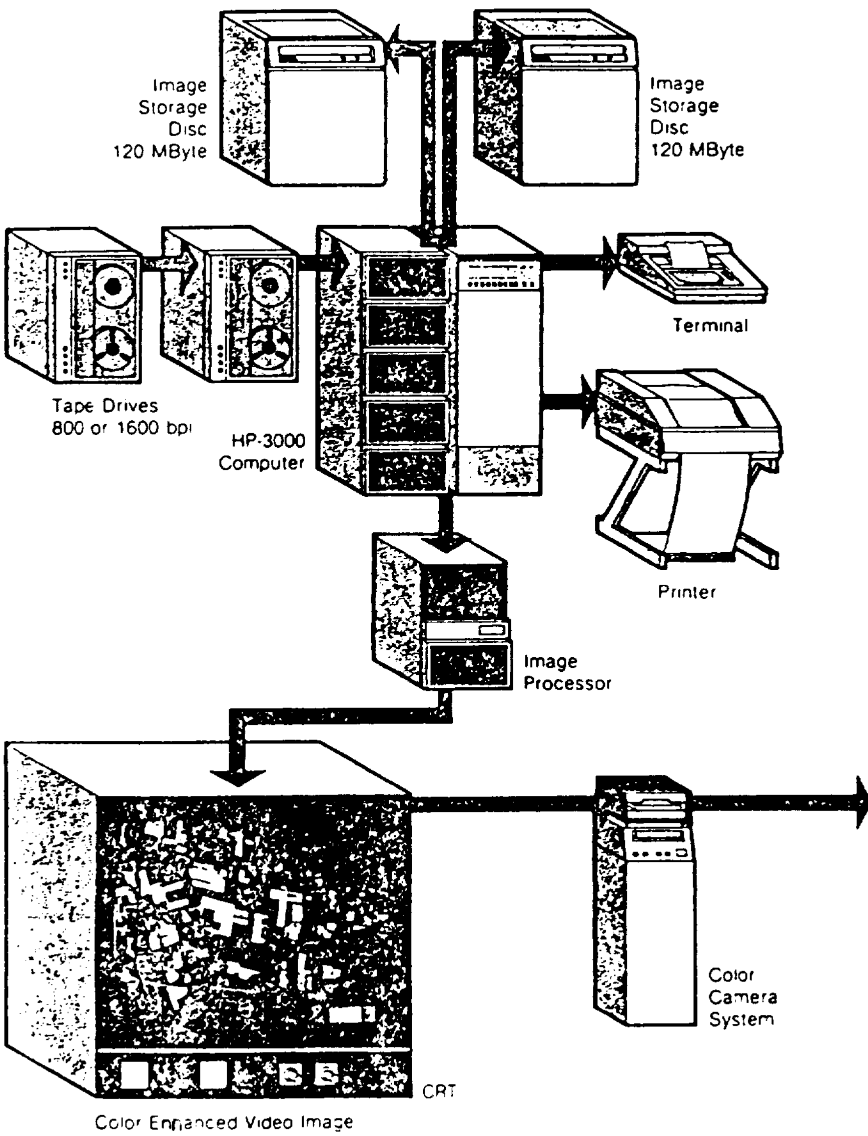


Previously acquired scanner data are available and may be viewed on IDIMS* (Interactive Digital Image Manipulation System)-by appointment.

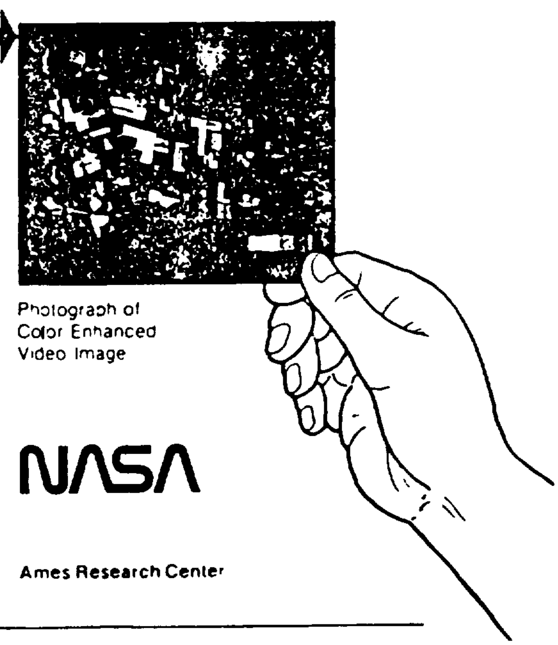
*Product of ESL, Inc.

Interactive Digital Image Manipulation System

Image processing and enhancement are performed on IDIMS. With this system, images may be pseudo-colored; images in various bands can be ratioed and manipulated algebraically; gain changes can be made; overlays with other data can be made; and images can be rotated or translated.



Output products are in the form of computer listings, color enhanced video images, and prints or transparencies of these images. Prints are 8" X 10" with 512 X 512 line resolution. Transparencies are 4" X 5" with 4096 X 4096 line resolution.



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Ames Research Center

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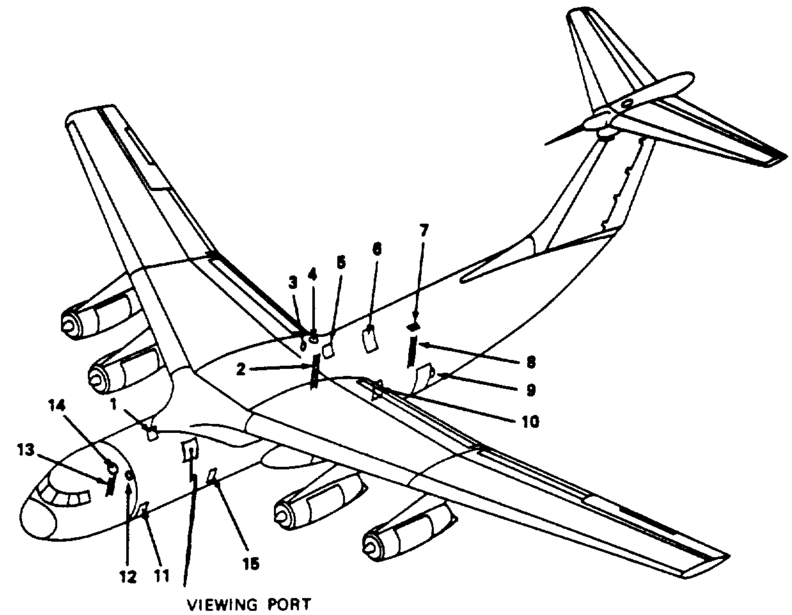
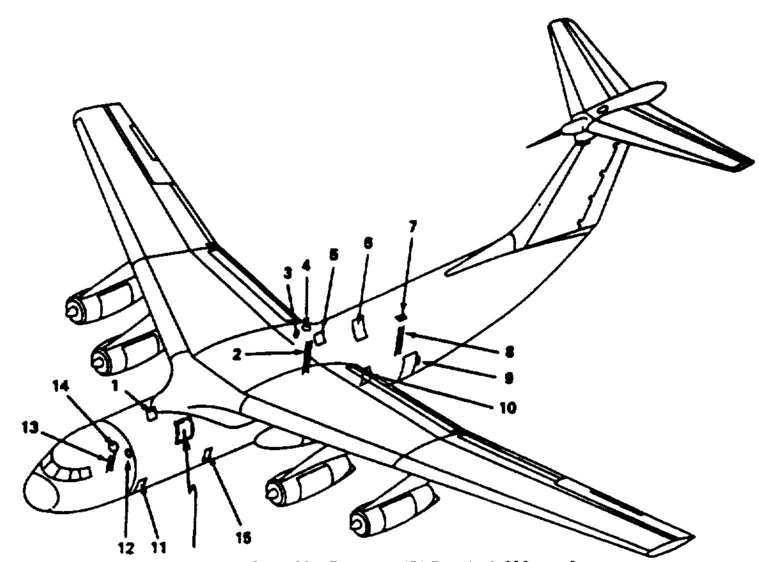
OF POOR QUALITY



1. SIDE EMERGENCY EXIT DOOR (RH FORWARD)
2. EMERGENCY ESCAPE LADDER (RH REAR)
3. ESCAPE ROPE (RH REAR EMERGENCY ESCAPE HATCH)
4. EMERGENCY ESCAPE HATCH (NO. 3 HATCH)
5. SIDE EMERGENCY EXIT DOOR (RH REAR)
6. DOOR (RH REAR)
7. EMERGENCY ESCAPE HATCH (NO. 4 HATCH)
8. EMERGENCY ESCAPE LADDER (LH REAR)
9. DOOR (LH REAR)
10. SIDE EMERGENCY EXIT DOOR (LH REAR)
11. CREW DOOR (LH FORWARD)
12. ESCAPE ROPE (FLIGHT STATION) EMERGENCY ESCAPE HATCH
13. STATIONARY LADDER (FLIGHT STATION EMERGENCY ESCAPE HATCH)
14. FLIGHT STATION EMERGENCY ESCAPE HATCH (NO. 1 HATCH)
15. SIDE EMERGENCY EXIT DOOR (LH FORWARD)

C-141-KAO

Figure H7a. Emergency Exits.



Viewing Port, 36" Telescope (91.5 cm), 1-500 μm Spectrum

- C-141-KAO, Kuiper Airborne Observatory
- Base: Ames RC, Moffet Field, CA
- Altitude: 45,000 Ft (14 km)
- Range: 6000 n.mi. (11,000 km)
- Duration: > 10 hrs.
- Payload/Rack Instrumentation: 600 lbs.
- Viewing Elevation Angle: 35-70° With Existing Telescope
- Viewing Azimuth via Aircraft Heading.

Note: 1-15 Are doors and emergency exits.
- Base: Ames RC

Figure H7b.

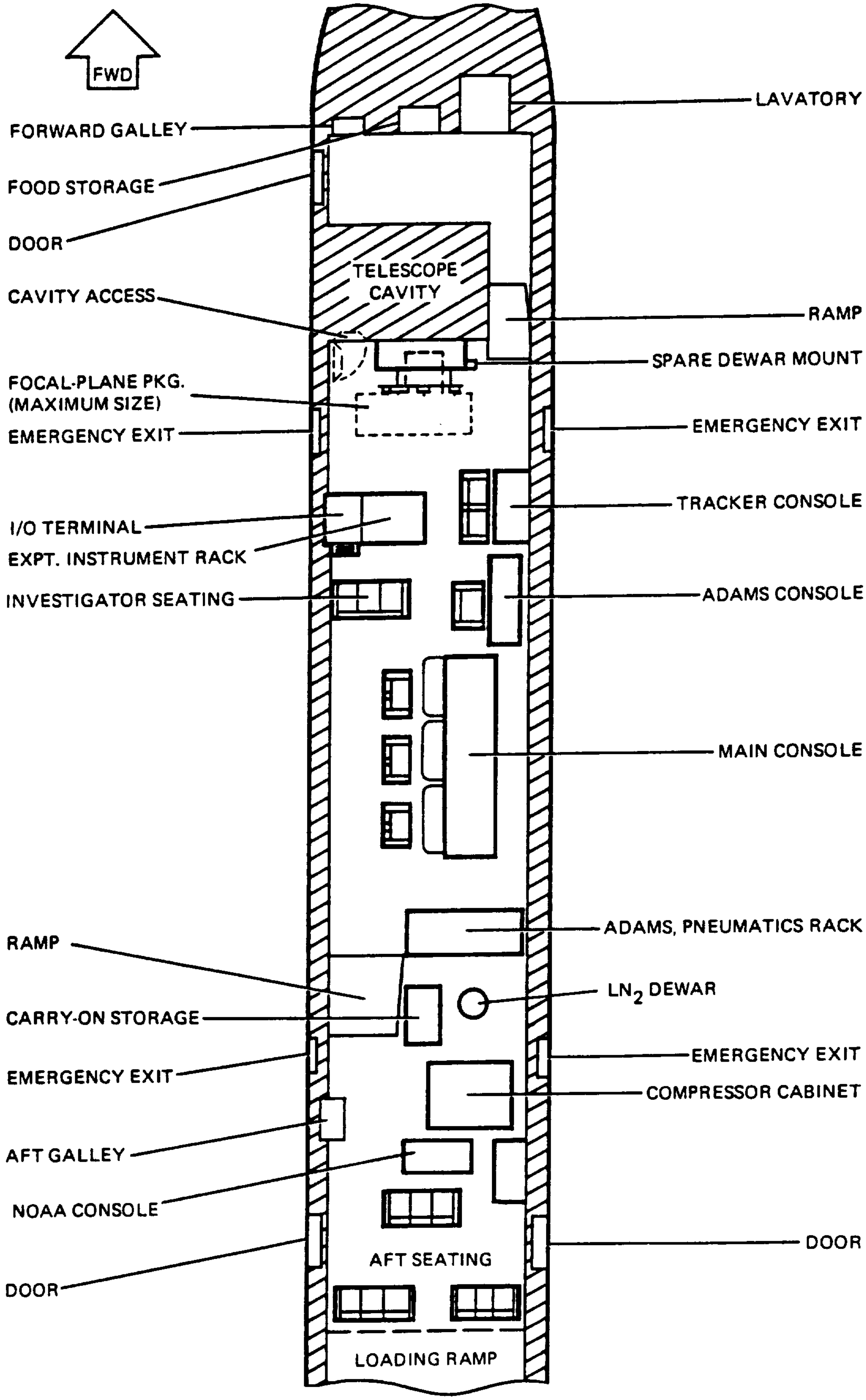


Figure H8. Plan View of KAO Cabin.

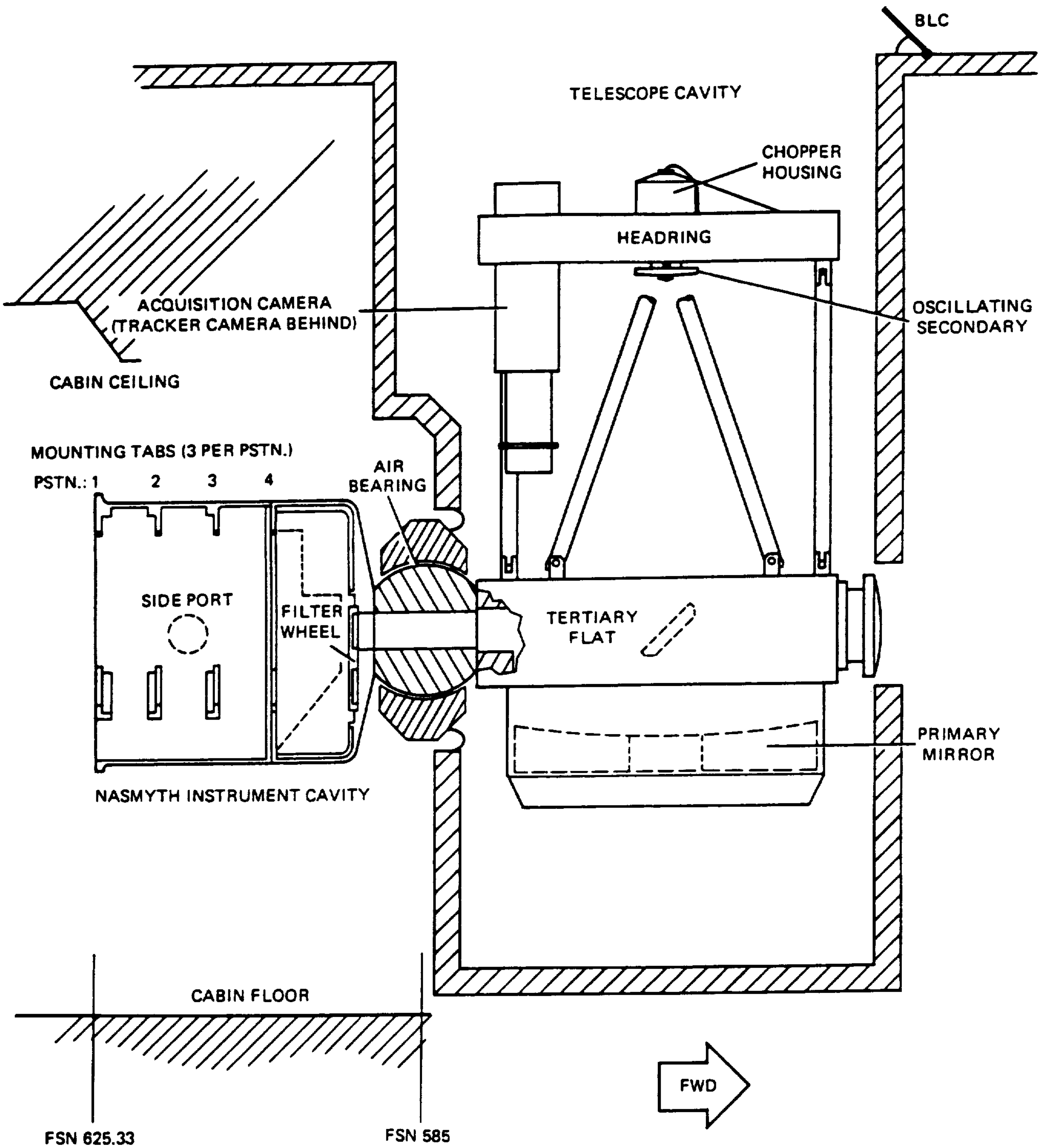


Figure H9. Diagram of Telescope Assembly.
The telescope assembly has been rotated into a vertical plane. Approximate scale 16:1.

Report Documentation Page

National Aeronautics and Space Administration

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4. Title and Subtitle Shuttle Laser Technology Experiment Facility (LTEF)-to-Airplane Lasercom Experiment--Airplane Considerations		5. Report Date January 1990
		6. Performing Organization Code 723.0
7. Author(s) Ford Kalil		8. Performing Organization Report No. 90B00014
		10. Work Unit No.
9. Performing Organization Name and Address Instrument Electro-Optics Branch Goddard Space Flight Center Greenbelt, Maryland 20771		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

NASA is considering the use of various airplanes for a Shuttle LTEF-to-Airplane laser communications experiment. As supporting documentation, this report includes pertinent technical details about the potential use of airplanes located at Ames Research Center and Wallops Flight Facility. The effects and application of orbital mechanics considerations are also presented, including slant range, azimuth, elevation, and time. The pros and cons of an airplane equipped with a side port with a bubble window versus a top port with a dome are discussed.

17. Key Words (Suggested by Author(s)) Laser, Space Communications, Lasercom, Spacecraft to Aircraft, Aircraft Considerations, Orbital Mechanics, Contact/Viewing Time	18. Distribution Statement Unclassified - Unlimited Subject Category 17

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