INTRODUCTION
OF
S-BAND TELEMETRY TRACKING SYSTEMS
AT THE
CHURCHILL RESEARCH RANGE (CRR) DURING 1983/84

Brian F. Dawson
Operations Section
Canada Centre for Space Science
Ottawa, Canada

ABSTRACT

S-Band Auto-track systems were introduced at CRR in January 1983 and each consists of a 3.0 metre reflector, pedestal, servo drive, antenna controller with dual RF channels, double ended feed, low noise amplifier and downconverters to P-Band frequencies. The S-Band requirements and restrictions at CRR will be discussed, and the factors restricting launch acquisition explained. Angle data (AZ/EL) is transferred in real-time to an HP 9845 processor for quick-look and later trajectory analysis purposes plus comparison with Interferometer/Tone Ranging and Command Systems (TRACS) data.

This presentation is intended to provide a basic familiarity with S-Band facilities and capabilities now available to Range Users at CRR.

INTRODUCTION

Most sounding rocket launches in Canada take place at Churchill, Manitoba on the west shore of Hudson Bay. The Churchill facilities consist of three launch pads capable of handling rockets up to 20 metres in length and weighing 5000 kilograms, along with installations where rockets and payloads can be assembled and tested before launching. During launches, S-Band telemetry and data transmission equipment is used to acquire and track the rockets, and to receive and record signal emissions from these payloads.

Before 1983, all scientific and diagnostic flight data at CRR was transmitted to the ground facilities via telemetry and tracking equipment operating in P-Band (215-315 MHz range). General crowding of P-Band by military and aeronautical users made the P-Band telemetry equipment susceptible to radio interference which affected the data quality from rocket transmissions. The shift to S-Band avoided problems existing at P-Band and accommodated the higher data rates that are required for today's more advanced and complex payloads. the rocket operational requirements that needed to be satisfied were:-

(1) Minimal size and weight, easily transportable;
(2) Auto-track capability at high slew rates, 15°/sec;
(3) Rugged and capable of operating in severe temperature extremes as low as -50°C;
(4) High gain system to track vehicles to altitudes of 1000 km or greater. The upcoming MARIE operation in December 1984 requires a Black Brant X rocket vehicle and an apogee of 1100 km;
(5) In-service date of one year after capital funding approval.

The S-Band telemetry antennas at CRR are located adjacent to the Operations Building at the Rangehead approximately 400 metres from the launch pads. This choice of site was determined by operations manning considerations and was not a preferred location following typical rocket trajectory analysis. This restriction on siting prevented tracking of vehicles directly from the launch pads due to excessive angular rates that occur early in flight. The acquisition strategy in use at CRR is designed to intercept and track targets from about T+15 seconds into the flight.

SYSTEM DESCRIPTION

The antenna consists of a 3.0 metre reflector, pedestal, servo drive, antenna control unit, S-Band feed, low noise amplifier, downconverter and interconnecting cables. The system was built by Scientific Atlanta, Inc.

To aid in the initial acquisition of high velocity vehicles, the tracking antenna has a double ended feed system which consists of an acquisition antenna mounted coaxially in front of the main antenna feed. As a further aid in initial acquisition at launch, the antenna system is designed to "lock-out" any downward servo drive signals preventing the auto-track system from attempting to lock onto the below-the-horizon signal image. The antenna system has the capability of simultaneous reception of Right Hand Circular Polarized and Left Hand Circular Polarized signals with automatic tracking over the full 2.26 to 2.36 GHz receive bandwidth. The downconverter is a dual channel unit - one for each of the two polarizations - with the capability of converting the S-Band signals to P-Band 215-315 MHz frequencies. The antenna system performance characteristics are:

Antenna Type	Parabolic, Focal Point Feed
Antenna Mount	EL over AZ
Aperture Size	3 Meters
G/T (Main Antenna Feed)	10 dB/°K

G/T (Acquisition Feed)	-11.5 dB/°K
Polarization	Simultaneous LHC and RHC
Polarization Discrimination	20 dB
Beamwidth (Main Antenna Feed)	3.1°
Beamwidth (Acquisition Array)	36°
Sidelobe Levels	-18 dB
Operating Modes	Manual, slew, standby, slave, stow, scan, autotrack
Autotracking Accuracy	.03 degree
AZ/EL Pointing Resolution	.01 degree
Antenna Velocity	15°/Sec max.
Antenna Acceleration	15°/Sec2 max.
Antenna Travel	±370° Azimuth -5°/+185° Elevation

The modes of operation of the S-Band Autotrack Antenna system are:

STANDYBY
SLEW
MANUAL POSITION
SLAVE
STOW
SCAN
AUTOTRACK ACQUISTION

These functions are achieved through the Scientific Atlanta, Model 3842, Autotrack Controller which is a solid state microprocessor-based system that produces the necessary servo error signals to drive the power amplifiers located in the pedestal. The controller can be interfaced with other computers for data transfer and control.

Automatic antenna selection of the acquisition array (widebeam) or the main antenna (narrowbeam) is provided by the AUTOTRACK ACQUISITION Mode. When AUTOTRACK ACQUISITION is activated, the widebeam antenna is selected and held until after the maximum tracking dynamics have occurred early in the flight; this prevents premature selection of the narrowbeam antenna. During the acquisition phase the control processor monitors the selected receiver AGC level and tracking errors. If the widebeam antenna is selected and the AGC level falls below a preset value, the control processor checks the tracking error voltage. If the tracking error is within preset limits, then the narrowbeam antenna is selected. Widebeam tracking continues until these conditions are satisfied. If loss of acquisition occurs, the widebeam antenna may be manually selected.

Manual selection of either antenna may be accomplished at any time. Transfer between the widebeam and the narrowbeam antennas is accomplished without significant dropouts or data losses that may occur due to switching transients. The switching time is typically 10 msec.

SYSTEM EVALUATION

Trajectory data was obtained during the flight of the SABRE rocket vehicle (Black Brant VIIIB) in May 1983. The S-Band systems were complemented by a P-Band TRACS system, built by Physical Science Laboratories (PSL) of New Mexico State University. The PSL system has been used for many years for trajectory measurement at CRR. Slant range measurements were made with TRACS using a 210 kHz tone modulating an RF Ground transmitter at 550 MHz linked to a QUANTA type rocketborne receiver and on-board telemetry downlink. Comparative analysis of the two systems relied on joint use of the tone range for slant measurements. The evaluations objectives were to:

(1) investigate the tracking accuracy of the S-Band pedestals; and
(2) identify technical problem areas in the operation of S-Band system

A tracking error budget summary was supplied by the S-Band pedestal manufacturer, Scientifc Atlanta, and is included at Table 1 (Ref. 1). From the table, the total error per axis at 60 degrees elevation is:

Elevation	0.024°
Azimuth	0.012°

The error budget for the interferometer and ranging system (TRACS) is listed in Tables 2 and 3 respectively (Ref. 2). From the tables, the elevation and azimuth errors are:

Elevation	0.05°	
Azimuth	0.06 to 0.19°	over elevation range of 60-80 degrees at AZ 135 degrees (SABRE).

The S-Band and TRACS data were each compared to a trajectory software program called TRJMK2. The following assumptions were made:

a) Fitting of tracking data to an ellipse is sound;

b) Errors generated by the software would be similar for both sets of data; and

c) Magnitude of errors is not known.

SUMMARY OF RESULTS

An initial direct comparison of S-Band and TRACS data taken every 10 sees., produced the following results:

	AZ°	EL°
Mean Difference	-0.047°	-0.012°
Standard Deviation	-0.103°	-0.054°

SABRE RESULTS

				Standard Deviation	
System	No. of Pts.	Apogee	Apogee Time	AZ°	EL°
S-Band	248	351.1 km	304.1 sees.	0.08° (cf:0.012°est)	0.04° (cf:0.024°est)
TRACS	308	351.1 km	304.1 sees.	0.06° (cf:06°to0.19° est.)	0.02° (cf: 0.05°)

Figures 1 and 2, showing plots of observed azimuth, elevation data versus time over the SABRE flight are included for the S-Band system; together with Figures 3 and 4, showing the deviations between the observed and computed values of azimuth and elevation data using the TRJMK2 program. Preliminary S-Band and TRACS data (Figures 5 - 8) are also included from the most recent launch in March 1984 at CRR for ARIES ‘A’ (TD8302).

DISCUSSION

The above results indicate that the trajectory measurement capability of the S-Band system compares favourably with the model and agrees very well with the results of the TRACS system. Tracking performance is outside the estimated values, especially in azimuth. These results may raise doubts about the estimates shown in Table 1. Errors which are difficult to measure at the Range are:

a) RF/Mechanical axes boresight calibration is practical in azimuth but difficult in elevation;

b) backlash in all gear trains;

c) position digitizer versus elevation and azimuth; and

d) boresight scope/RF alignment at different azimuths and elevations.

The S-Band systems met all specification requirements during in-plant testing under laboratory conditions, but it is apparent that performance is degraded under field conditions unless particular care is taken in setting-up, routine checks and calibration. A field Standard Operating Procedure (SOP 07-31) has been developed for the three S-Band systems and includes functional testing, levelling, RF alignment, analog error and AGC calibrations, computer interface checks and bit error rate testing. The error analysis does not address sources of instability due to non-orthogonality of RF and mechanical axis as a function of frequency and polarization. Tracking errors are more pronounced at high elevation angles for both S-Band and TRACS. Azimuth errors are accentuated by the secant corrector gain as a function of the elevation angle in the servo-control circuitry, and the trajectory plots confirm this condition consistently. The azimuth deviations appear to have a periodic modulation of approximately 100 seconds. The period is likely related to the coning period of the payload; and the AGC ground receiver record appears to confirm this condition. This data sample appears to indicate that the tracking detection network is sensitive to signal strength.

CONCLUSION

The results of this evaluation demonstrate a good agreement in the trajectory measurement from S-Band and TRACS systems. The importance of consistent set-up and check-out procedures is recongnized, and close monitoring of the servo error analog signals and AGC levels is necessary. Sufficient data exists to instill confidence in the use of S-Band systems in support of future rocket operations at CRR, and that S-Band tracking performance will soon approach the high order of science telemetry data quality already achieved on the SABRE and ARIES projects.

ACKNOWLEDGMENTS

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REFERENCES

1. Scientific Atlanta Proposal 62-2-058 dated November 1981.
2. Hendry, R.D. TRACS/S-Band “Preliminary Evaluation” dated 27 October 1983.

Table 1

Tracking Error Budget Summary

	Elevation Axis (Degrees) 0		20		60	
	El	Az	El	Az	El	Az
Bias (Fixed) Errors[1] Null Axis Alignment	.030	.030	.030	.028	.030	.015
Servo Amplifier Drift and Offset	.013	.013	.013	.012	.013	.007
$\varepsilon_{bias}\ (RMS) = 1/3\left[\Sigma\ \varepsilon\ (peak)\right]$	.014	.014	.014	.013	.014	.007
Random Errors[2] A. Static — Gear Backlash	.008	.008	.008	.008	.008	.004
Wind Torque (Gust)[3]	0	.012	.006	.011	.012	.006
Servo Noise Jitter	.006	.006	.006	.006	.006	.003
$\varepsilon_{RS}\ (RSS) = \left[\Sigma\ \varepsilon_i^2\ (RMS)\right]^{1/2}$	.010	.016	.012	.016	.016	.008
Static Tracking Error $\varepsilon_{static}\ (RSS) = \left[\varepsilon_{bias}^2 + \varepsilon_{RS}^2\right]^{1/2}$	.017	.021	.018	.021	.022	.011
B. Dynamics (Target-Relate) — Velocity Lag[4]	.006	.006	.006	.006	.006	.003
Acceleration Lag[5]	.007	.007	.007	.007	.007	.004
$\varepsilon_{dynamic}\ (RSS) = \left[\Sigma\ \varepsilon_i^2\ (RMS)\right]^{1/2}$	.009	.009	.009	.009	.009	.005
Total Error Per Axis (RSS): $\varepsilon_{axis}\ (RSS) = \left[\varepsilon_{static}^2 + \varepsilon_{dynamic}^2\right]^{1/2}$	.019	.023	.020	.023	.024	.012
Total System Error (RSS): $\varepsilon_{sys} = \left[\varepsilon_{Az}^2 + \varepsilon_{El}^2\right]^{1/2}$	.030		.030		.027	

[1]All bias errors are peak errors. Th RMS bias error contribution for the worst case is calculated adding the peak errors algebraically.

[2]Random errors assume a normal distribution. Therefore, the RMS error is equal to one-third the peak error.

[3]Wind torque error computed for 50 Km/hour, wind gusting to 75 Km/hour.

[4]Velocity lag computed for 1.0 deg/sec velocity.

[5]Accerleration lag computed for 0.2 deg/sec^2 acceleration.

TABLE 2

INTERFEROMETER ERROR BUDGET SUMMARY

<u>Bias/Fixed errors</u>	Each Axis (DEG)
- Survey error	.02
- Electrical null	.0006 (PSL)
drift and offset	.02
ε bias (RMS)=1/3[Σ E peak]	= .0135
<u>Random errors</u>	
Gear backlash	.008 (EST)
Phase noise $\frac{3^\circ}{360}$ el of 4° geom.	.03
$\varepsilon_R = [\Sigma \varepsilon i^2 \text{ RMS}]^{1/2}$	.031
<u>Dynamic</u>	
Velocity and Acceleration lag	.00
Total error per axis	
$= [\varepsilon^2 + \varepsilon_R^2]^{1/2}$	.034°
Probable error 60° -80° elev. Az 45°	
EL .05°	
AZ .06° to .19°	

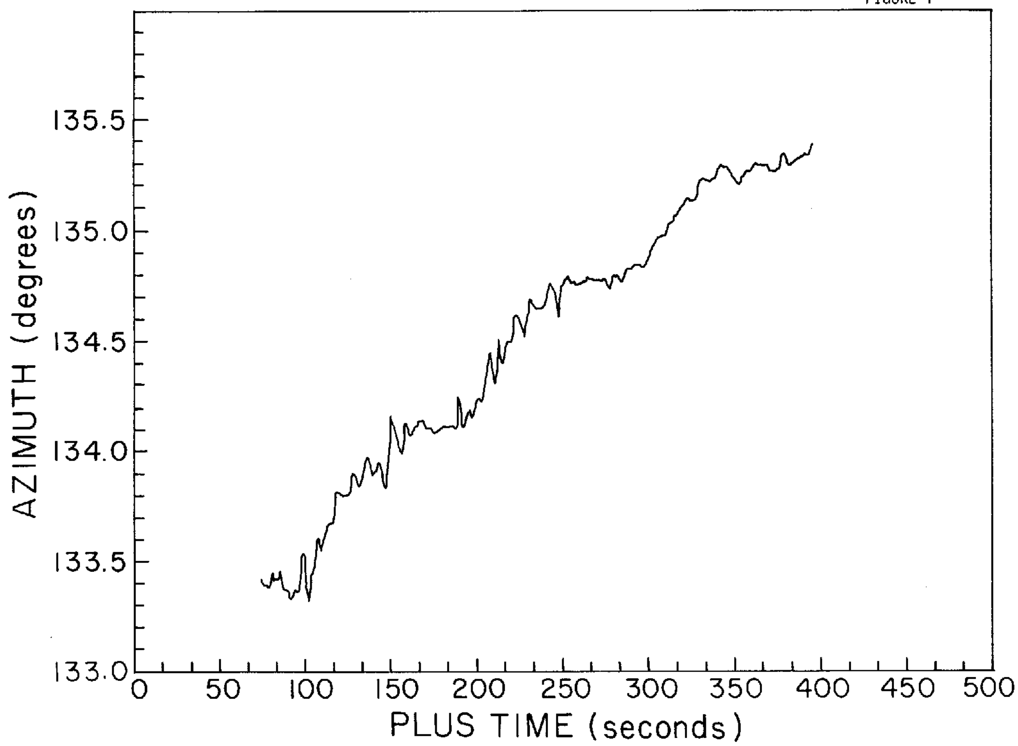
TABLE 3

TONE RANGING ERROR BUDGET SUMMARY

BIAS fixed errors		
Zero Adjustment 1%	7.5 m	
Drift 100 ns (-50-90 dbm)	30 m	
Drift Tm Rx	Not available	
Temp. drift (unknown)	Not available	
ε bias RMS=1/3[$\Sigma\varepsilon$ peak]	12.5 m	
Random errors		
Gear backlash	7.5 m	EST
Servo noise filter	15 m	EST
ε_{RS}	16.8 m	
Dynamic (servo related)		
Velocity lag & V = ε_D	May be large $\frac{1}{10}\lambda$ = -75 m (estimate)	
(Can be corrected)		
Total error $\left[\varepsilon^2 + \varepsilon^2_{RS}\right]^{1/2} \mp \varepsilon_D$	-75 m max ± 20.9 m	

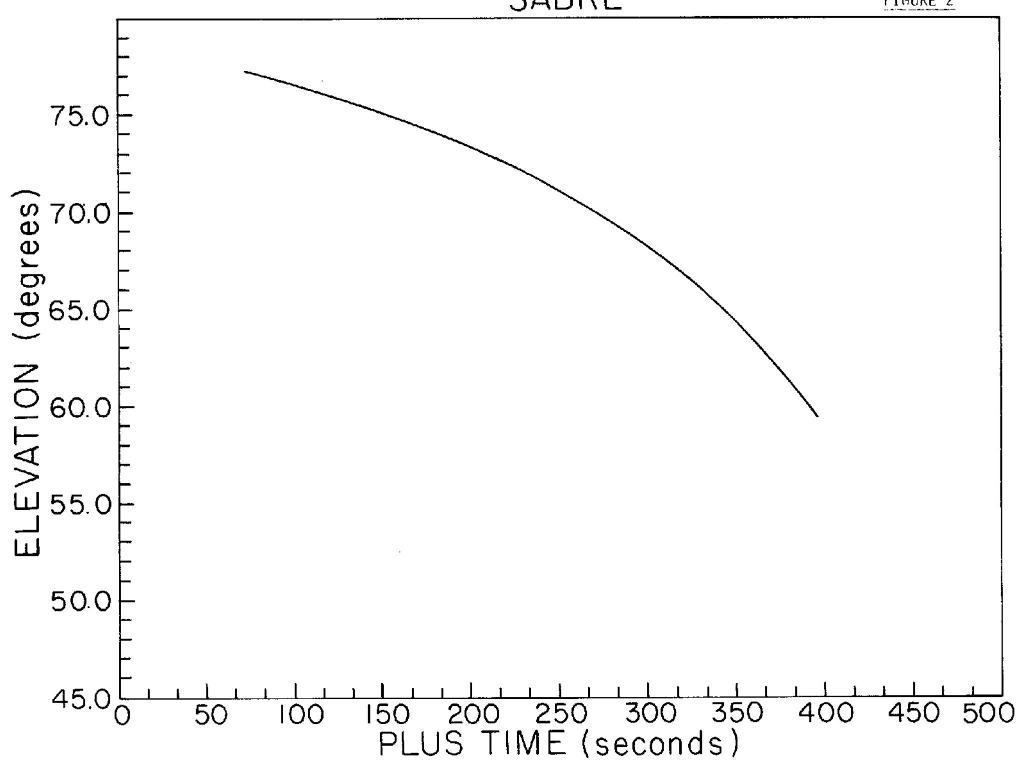
TRAJECTORY OF BBVIII-08 S-BAND
'SABRE'

FIGURE 1



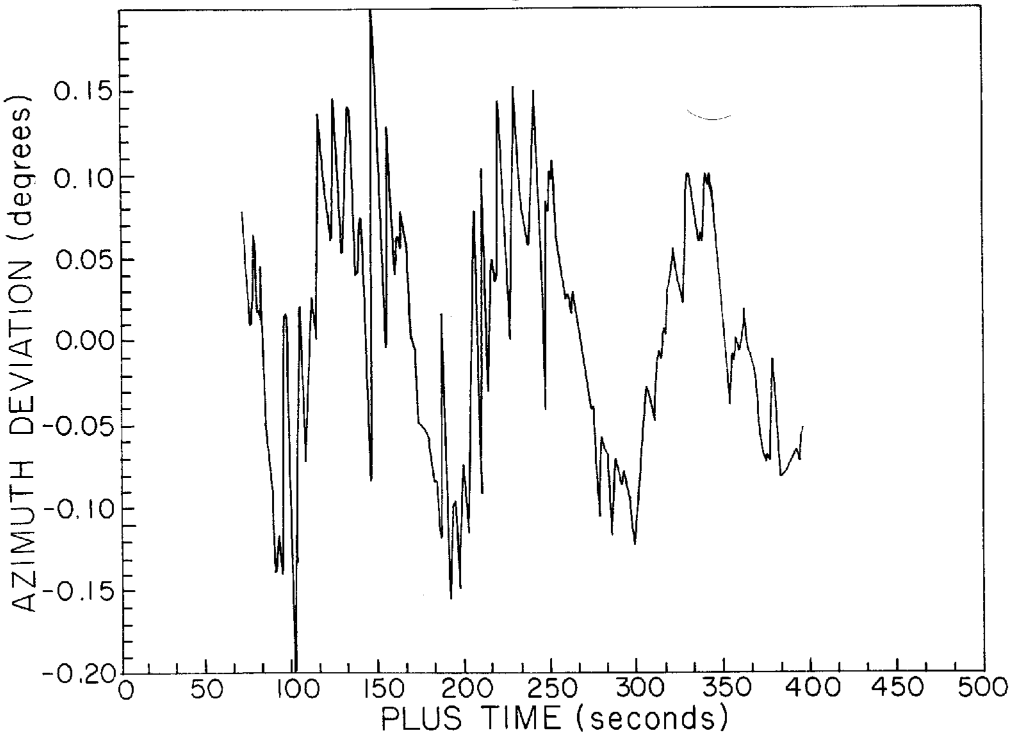
TRAJECTORY OF BBVIII-08 S-BAND
'SABRE'

FIGURE 2



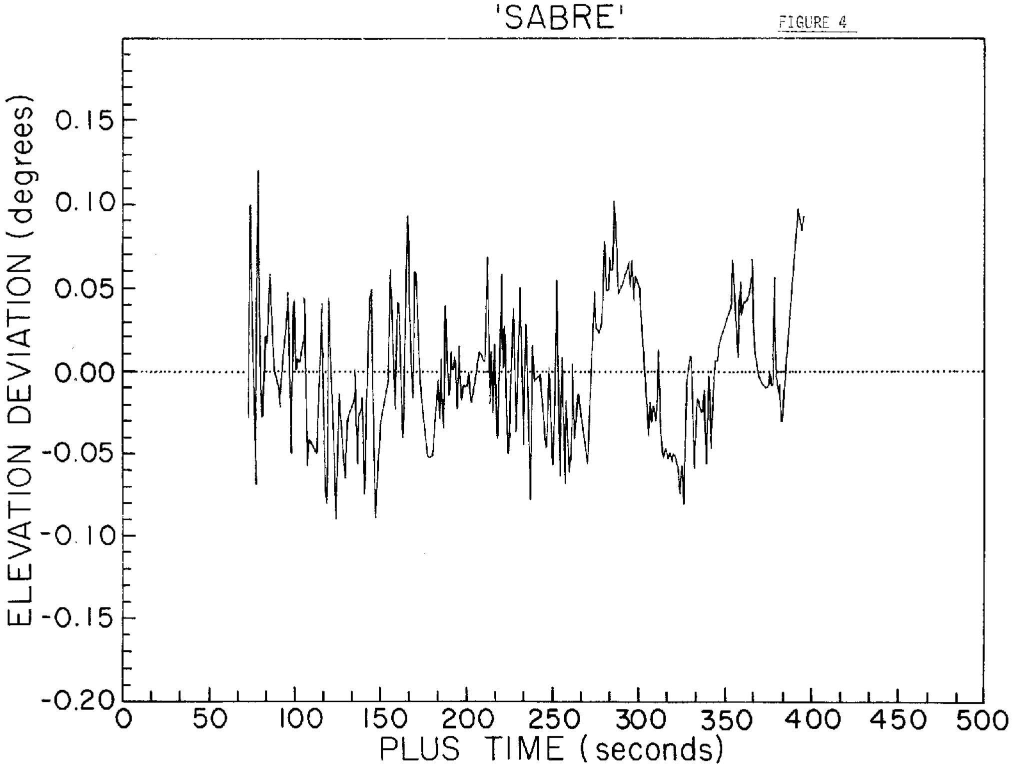
TRAJECTORY OF BB VIII-08 S-BAND
'SABRE'

FIGURE 3



TRAJECTORY OF BB VIII-08 S-BAND
'SABRE'

FIGURE 4



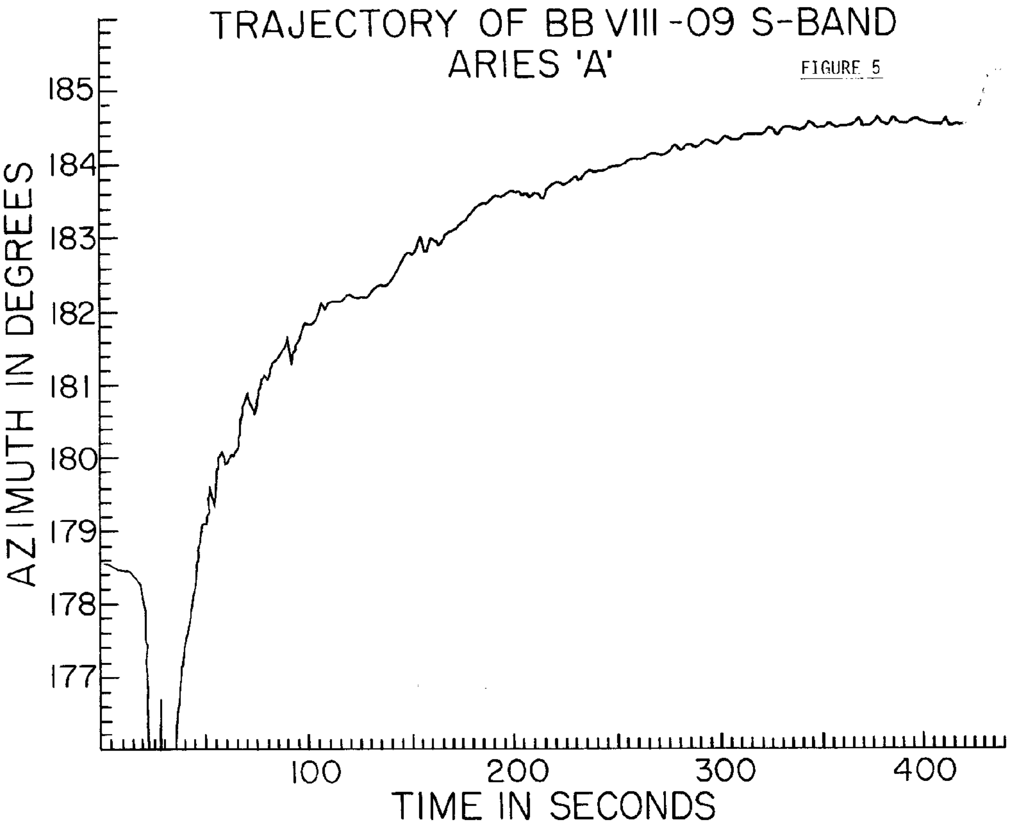


FIGURE 5

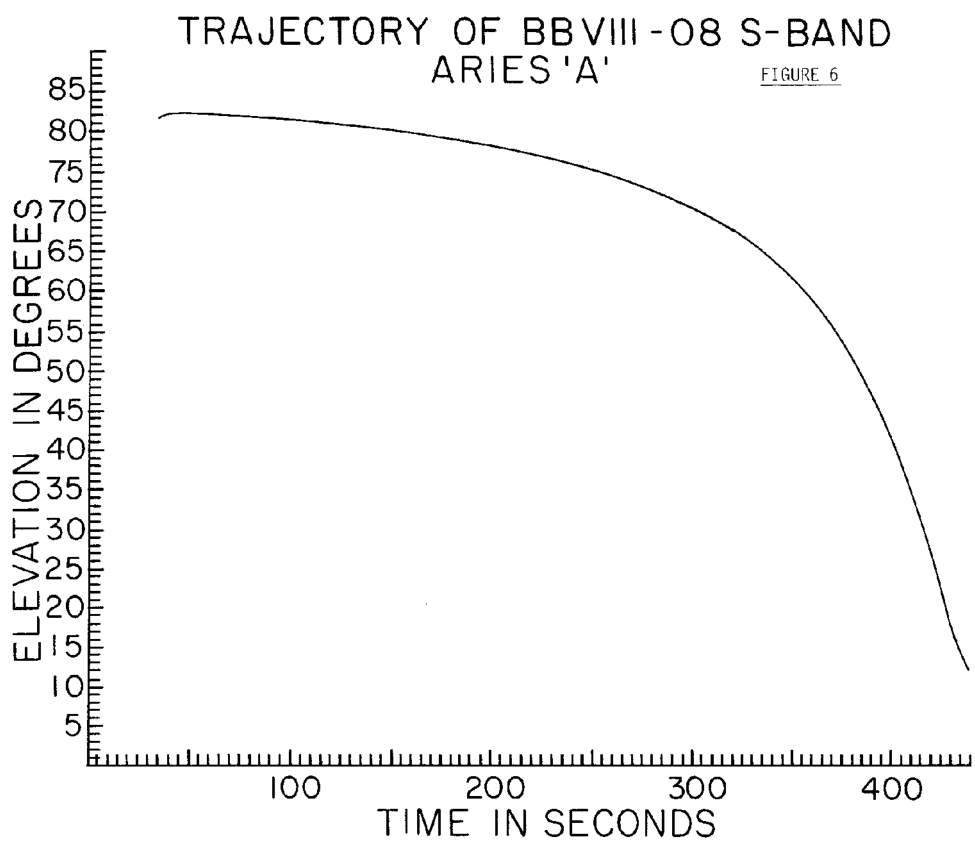


FIGURE 6

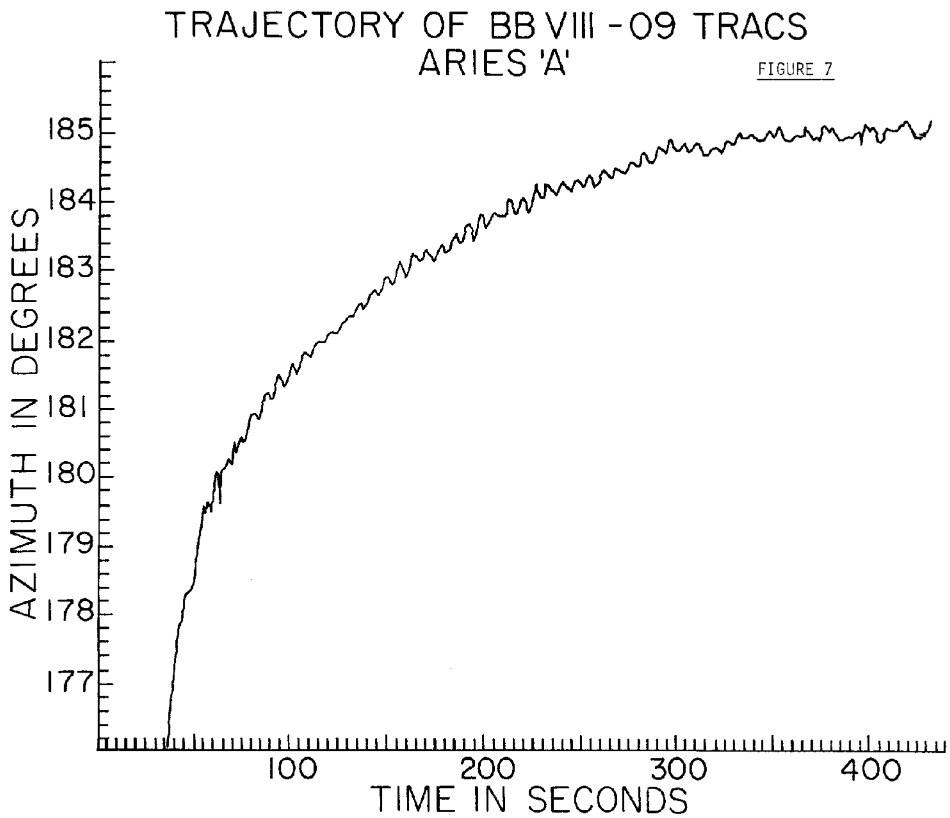


FIGURE 7

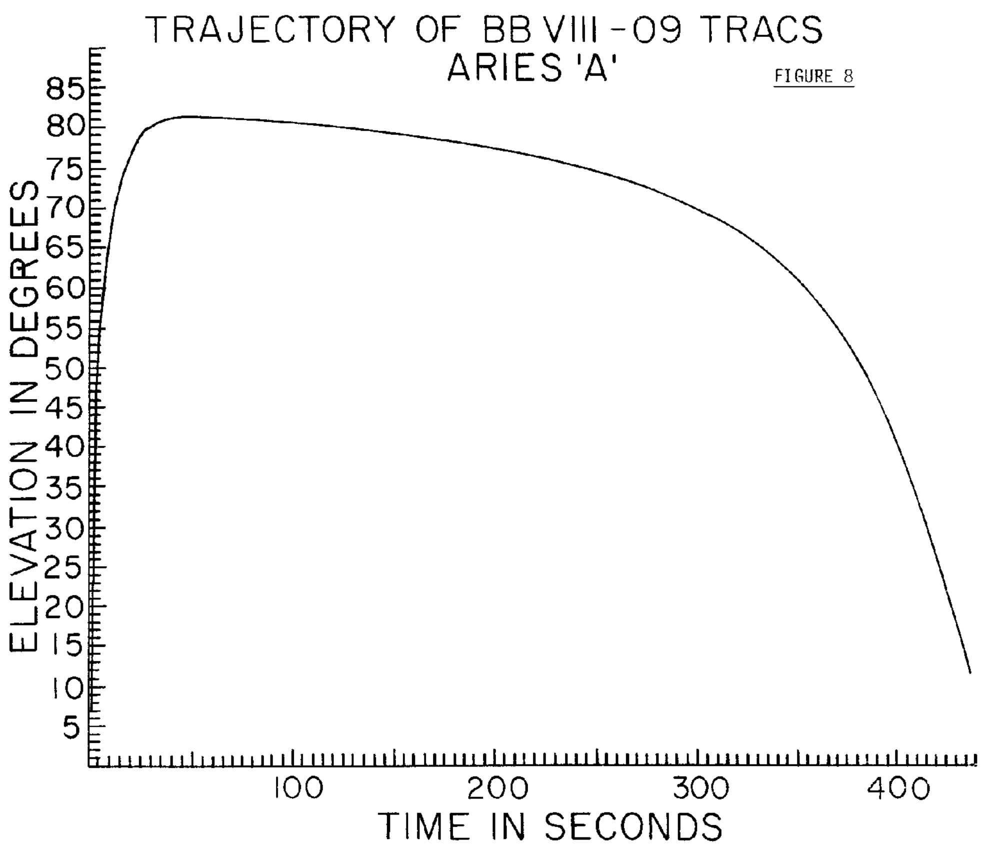


FIGURE 8