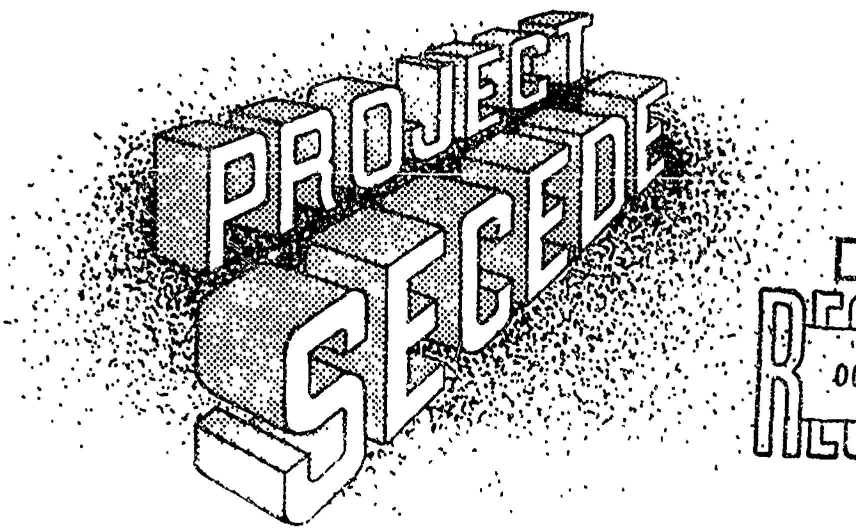
RADC-TR-71-195
Technical Report
20 May 1971

Prepared By
Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York 13440



TRACKING BARIUM RELEASES USING THE TV-TRACK SYSTEM

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 1057

Contractor: University of Alaska
Contract Number: F30602-70-C-0179
Effective Date of Contract: 15 December 1969
Contract Expiration Date: March 1972
Amount of Contract: $221,204.00
Program Code Number: OE20

Approved for public release; distribution unlimited.

Principal Investigator: Dr. T. Neil Davis
Phone: 907-479-7393

Contract Engineer: Robert A. Mather
Phone: 315-330-3451

Project Engineer: Vincent Coyne
Phone: 315-330-3107

112

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

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

1. ORIGINATING ACTIVITY (Corporate author)

Geophysical Institute
University of Alaska
College, Alaska 99701

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

N/A

3. REPORT TITLE

Tracking Barium Releases Using the TV Track System

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

Technical-Interim Report 16 Dec 1970 - 30 May 1971

5. AUTHOR(S) (First name, middle initial, last name)

S.P. Geller
T.N. Davis

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
20 May 1971	35	

8a. CONTRACT OR GRANT NO.

F30602-70-C-0179

b. PROJECT NO.

ARPA Order 1057

c.

d. Program Code No. - OE20

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

RADC-TR-71-195

10. DISTRIBUTION STATEMENT

Approval for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

Monitored by: RADC/OCSE
Robert A. Mather
Griffiss AFB NY 13440

12. SPONSORING MILITARY ACTIVITY

Advance Research Project Agency
1400 Wilson Blvd
Arlington VA 22209

13. ABSTRACT

Described herein is a TV tracking system capable of real-time visual object tracking. The total system consists of low-light TV cameras and communications allowing for data to be sent from remote sites to a small centrally located computer. The position of the object that the three cameras are observing is calculated by the computer and transmitted to other sites for the purpose of "pointing" other equipment. Solutions are available once per second.

This report describes the actual use of this system during the SECEDE II test series and some problems encountered. It also contains enough detailed information to allow duplication of the system software or to extract certain portions of it that may be useful to other applications.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related government procurement operation, the government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded, by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Do not return this copy. Retain or destroy.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Barium Releases						
TV-tracking system						

TABLE OF CONTENTS

TRACKING BARIUM RELEASES USING THE TV-TRACK SYSTEM

S. P. Geller
T. N. Davis

University of Alaska
Geophysical Institute

**Approved for public release;
distribution unlimited.**

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by Robert A. Mather RADC (OCSE), GAFB, NY 13440 under Contract No. F30602-70-C-0179.

FOREWARD

This is Technical Report No. 2 covering the period December 16, 1970 to May 30, 1971 on Contract No. F-30602-70-C-0179.

This technical report has been reviewed and is approved.

RADC Project Engineer

RADC Contract Engineer

SUMMARY

This report describes the use of TV TRACK, a tracking system using low-light TV cameras, during SECEDE II at Eglin AFB, Florida, during January 1971. The purpose of this system was to record the appearance of barium clouds with television cameras located at three sites along the Gulf Coast and provide real-time position data to experimenters who were attempting to aim probe rockets and instruments at the cloud. A previous technical report "TV TRACK: A Real-Time Output System for Object Tracking", RADC-TR-70-273, described the preliminary specifications of this system. The present report describes the actual use and modifications made to the system during the SECEDE operation. Some problems encountered during tracking are also discussed. This report contains enough detailed information to allow duplication of the system software or to extract those portions of it that may be useful for other applications. Additional system information is contained in another report being prepared by Sandia Corporation, Albuquerque, New Mexico.

INTRODUCTION

This is a report of an actual operation with TV TRACK, a system for real-time visual object tracking. The system consists of low-light TV cameras and a communications system which allows data to be sent from remote TV sites to a portable small computer. The computer, an INTERDATA model 4, calculates the position of the object that the cameras are observing and transmits this position to other remote sites for use in orienting other equipment. A position solution is available once a second. A previous technical report "TV TRACK: A Real-Time Output System for Object Tracking", RADC-TR-70-273, described the preliminary specifications of the system, which may be deployed anywhere that telephone lines or other suitable means of communication are available.

The computer software is easily modified to allow outputs of the solution in a variety of forms. The basic system handles up to 4 observing stations. In addition to receiving input look angles from the observing TV sites, the computer also calculated look angles to the position solution appropriate to each site and transmits this data back to each site for display on NIXIE tubes. This provides a means of feedback control for the TV mount operators and may serve to re-orient a site which may have dropped tracking for a while.

This report describes the actual use of TV TRACK to track barium releases during SECEDE II at Eglin AFB, Florida, during January 1971.

Mission and Responsibilities

The TV TRACK system was set up at three sites: Barin NAS, Alabama; Eglin AFB, Site C-6, near Portland, Florida; Tyndall AFB, Florida. (The station coordinates used by the University of Alaska for these operations are given in Appendix 1.) The computer for the position solutions was located at site C-6. Look angle data were transmitted to the computer via phone lines and a position solution was generated each second. "Feedback" look angles were sent back to each site, giving directions to the position solution.

The University of Alaska was responsible for three outputs to external users:

1. Position solutions were sent to the CDC 6600 Computer at Building 380

at Eglin Main. The 6600 used these positions, sent every 5 sec, to compute aim points for the LASL aircraft so that it would be positioned along the same field line and below the barium cloud. The 6600 also used the real-time position data to calculate a predicted position of the cloud for the use of the rocket launching crew, who were to launch probes and other rockets at the cloud.

2. Positions were sent to the Sandia launch site at A-15A, to be typed out on a local teletype. These were used by the Sandia aeroballistics staff to estimate the cloud's drift, and to prevent firings of probes that would go off the reserved area of the rocket range.

3. The SRI investigators at the FPS-85 radar required the cloud height for some of their experiments. This was sent as a difference from the anticipated release height.

Each external output is described in detail under Real-Time TV TRACK Program below.

An additional external output was devised on the spot for the benefit of the AVCO experimenters, who required the range to the cloud from their site. Since they were located physically close to the U of A Tyndall site, the feedback look angle display at Tyndall was used to indicate the range, from that site, on request to the computer operator. The mount operator at Tyndall then relayed the information to AVCO.

Computer Hardware and Communications

The small computer used in the tracking system was an INTERDATA Model 4. This is a 1-microsec. 16-bit machine that is equipped with 8K bytes (4K words) of memory and floating-point registers. Microprogrammed instructions for Sine, Cosine, ArcTangent and Square Root are built in. Input/Output gear attached to the computer are:

1. Two teletype modules, which transmit serial ASCII code to a teletype

or into a data modem.

2. A manual data entry module, consisting of 16 thumbnail switches to allow entry of decimal digits. An ENTER key signals the computer to read the 16 digits.

3. A real-time clock, which provides interrupts at a fixed rate of 10 per second.

4. A "halfword" module enabling 16-bit words to be entered from an external source. This is used in conjunction with special interface equipment to transmit and receive data over the communications lines.

5. A high-speed 60 char/sec paper tape punch. This is used to record the log data on half-inch paper tape.

6. A high-speed optical paper tape reader. This runs at 300 char/sec and is used to enter the programs and the setup data.

All of the above devices have interrupt capability. No direct memory access channel is available on this computer.

Real-Time TV TRACK Program

TV TRACK is an INTERDATA-4 computer program which produces position solutions every second. Data are gathered from remote observing stations in the form of azimuth and elevation angles and the position solution computed. A setup program SETUP-TRACK is used to define the station positions, the position of anticipated object acquisition and a central location from which XYZ coordinates may be computed. SETUP-TRACK produces a "parameter tape" containing all the tables and constants needed for operation of TV TRACK. Such a tape may be prepared for each mission.

TV TRACK begins operation by loading the parameter tape, then starting the real-time clock. The real-time clock gives interrupts continuously every tenth of a second, at which times the computer will read whatever is o s communications lines from remote stations and store this data as received. The start-up sequence finishes by enabling interrupts from the teletypes and the manual entry module, the computer is then placed into "wait" state at the beginning of the main executive routine TASK. When the real-time clock has counted off a complete second, the wait state is reset, and the program begins executing TASK. TASK is a sequence of subroutine calls, some external, some internal to itself. The subroutines check input for validity and store it in floating-point form, compute the position solution and drive the outputs. At the end of TASK execution, the computer is again placed in wait state until the next second, when TASK starts again. The teletypes and real-time clock may interrupt TASK and the wait state when service is required.

The solution and certain common values are maintained in a storage area called COMVEC, which may be accessed by any system component.

Subroutines of TASK

UPTIME Update time by one second. Universal time is stored in COMVEC in BCD as hours, minutes and seconds. Time is set by manual entry interrupt. (See Setting Time in TV TRACK.) After 24 hours, the time goes back to 00:00:00. No accounting is made for days.

MDE Process data from the manual data entry (MDE) module. When the enter key on the MDE is pressed, an interrupt is generated, to which the program responds with a read, and stores the data until it can be processed. Data from up to two stations may be entered in this manner. The data are converted to floating-point and stored in the appropriate station table(s) with an indication of data origin.

INPANG The 8 digits of each module are assigned as follows:

1 - Station ID (0,1,2), 2-5 - azimuth XXX.X, 6-8 - elevation XX.X

This routine examines the data sent in over the communications lines. The data are checked for validity and stored as floating-point in the station tables, overriding any data stored there from the MDE. The console switches are read at this point to enable the operator to inhibit input from selected stations. As part of the validity check, input look angles are rejected if they differ by more than about 5 degrees from their values on the previous second. The rejection of azimuth implies rejection of elevation and vice-versa. Once rejected, input must stay within 5 degrees of previous for four consecutive seconds before it is again accepted. This is to forestall use of wild data that happens to be legal BCD.

STDHGT If a switch on the console is set, this routine will move the location of the anticipated initial object acquisition into the solution area. This is useful in order to aim the tracking stations before object acquisition (See FEDBAK).

SELECT This routine produced the position solution on the basis of the data stored in the station tables. The best solution of all possible two-station solutions is selected on the basis of minimum miss-error (See Two-Station Algorithm). A one-station solution is computed when no two-station solutions are available. The solution quality is set in this routine. More details on SELECT are given in The SELECT Algorithm.

FEDBAK To keep mount operators informed about where they should look to be pointed at the position solution, the look angles from each station to the solution generated in SELECT are computed here and sent out over the communications lines. No examination of solution quality is made - whatever is stored as the solution is used. This may be the last solution obtained, or that stored by STDHGT. FEDBAK always sends data, even if a station is disabled for input by the operator.

LOGPCH This drives the log punch. If a console switch is pressed, the paper tape punch is started and the LOG routine called. The log output consists of the time, solution quality, input look angles and stations used for the solution. The punch is turned off when the switch is released.

DSPLY This drives the console display lights at the computer. All communications input and output may be displayed by switch selection. Time and solution quality may also be displayed.

EXT1 This drives the first "external" output of the system. For SECEDE II this was the output of the position solution to Eglin's CDC 6600 as a difference from the location of the launcher. EXT1 starts the teletype module associated with it and calls the SECEDE II routine EGLIN.

EXT2 This drives the output to the ASR-33 teletype in the B-27 trailer site at A-15A, in much the same manner as EXT1. The SECEDE II routine is LAUNCH.

EXT3 This drives the output of delta-height to the SRI personnel at the FPS-85 building. This was over a communication line rather than a teletype module. The SECEDE II routine is SRI. The external routines may easily be varied with the tracking application. A discussion of each external routine follows.

External Output to EGLIN

Routine EGLIN drives a teletype module which is connected to a data set for transmission down the phone lines to the CDC 6600 at Building 380 on Eglin Main. A 24-character message is sent every 5 seconds, on the UT second, according to computer time. The message begins with a carriage-return and a line-feed to enable listing on a teletype. The last character is all ones, except for parity, which is zero, for end-of-line. Preceding the EOL character is a checksum, which is an exclusive-OR of all data characters including CR and LF with the EOL. The position solution is given in displacement form, as a difference from the position of the central location (launch site). Note that all data characters have the 8th bit (parity) always zero.

Position	Contents
1-2	Carriage Return (CR) and Line Feed (LF)
3	Character 'E' for Eglin
4	Solution Quality Code: 5 = 2-station solution, reliable, error under 2 km. 4 = 2-station solution, reliable, error over 2 km. 3 = 2-station solution, unreliable 2 = 1-station solution with assumed height 1 = solution from manually entered data. 0 = no solution
5-9	Latitude Displacement, signed minutes of arc, SXXX(.)X
10-14	Longitude Displacement as latitude
15-18	Height above sea level, kilometers, XXX(.)X

Position	Contents
19-22	Minutes and Seconds of Universal Time, MMSS
23	Checksum
24	EOL, All ones except parity, X'7F'

All characters have parity bit zero.

External output to LAUNCH

Routine LAUNCH drives a teletype module which is connected to a data set for phone line transmission to an ASP-33 Teletype machine at site A-15A. The message sent gives the Universal Time and the location of the object, every 5 seconds. The location is expressed as X, Y and Height above sea level. The X and Y are computed with respect to the control location, X is east; Y is north. The control location was the launch pad at A-15A (See Table 1). The height is taken directly from the solution. Look angles and range to the object from the launch site are computed using subroutine LOOK and we calculate:

$$X = RANGE * COS(EL) * SIN(AZ) \tag{1}$$

$$Y = RANGE * COS(EL) * COS(AZ) \tag{2}$$

All values are in kilometers. The message is formatted for readability, in ASCII characters with parity always set to zero. When there is no solution available, the words "NO SOLUTION" replace the X, Y and Height.

External Output to SRI

Routine SRI drives a communication line to the FPS-85 building. The line is one of the same kind as are used to send feedback look angles to the tracking sites. Information is sent every second and consists only of incremental height, defined as:

$$\Delta h = (\text{Object Height} - \text{Predicted Acquisition Height}) \div 3 \tag{3}$$

The information is sent out regardless of whether a solution was indicated, using the last height stored. The data are sent in both binary and BCD formats in a single 32-bit frame. For the format, see the program listing for SRI.

Operator Control of TV TRACK

The console switches on the INTERDATA may be interrogated by the program. There are 16 of these switches; many of them are used to modify the system's operation in real time. The following functions are under operator control:

1. Tracking status of each station: One switch is assigned to each station. If the switch is on, input from that station may be used in the solution, otherwise it is not used, regardless of its value.

2. Aim at release point: If no solution is obtained for a given second, this switch causes the predicted location of the release to be stored as the solution. This causes feedback look angles to be sent to each station appropriate for aiming the stations at the anticipated release point.

3. Starting and stopping the punching of the log tape: The log tape was started at the launch of the barium carrier rocket.

4. Each external output is controlled by a switch. This is used to start and stop transmissions to each external user. No control is provided for feedback look angles, which are considered as "internal" outputs. Feedback look angles are sent every second regardless.

In addition to the console switch functions, a dual rotary switch on the console is read under program control to select displays in the lights on the console. The basic display is minutes and seconds of time, solution quality code and which stations are being used to compute the solution. The operator is able to select a display of input or output that is currently on each of the four communications lines. The two teletype-code outputs (to Eglin Main and to A-15A) were repeated on local teletypes. It was thus possible to check out all data transmissions at any time.

Setting Time in TV TRACK

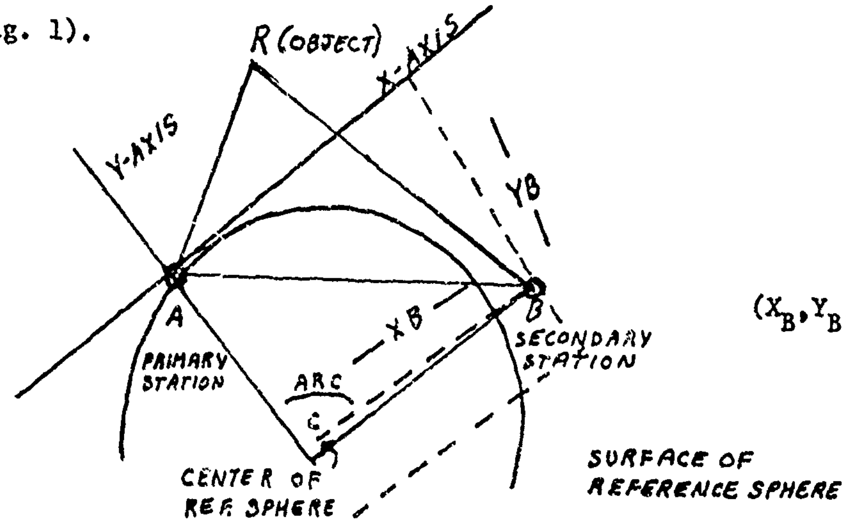
The computer runs on its own real-time clock. This gives interrupts every tenth of a second. After 10 interrupts, a new second is recognized. The value of time is kept in BCD as hours, minutes, seconds and updated every second. The initial value is set in from the manual data entry module.

The hours, minutes and seconds of an approaching UT time on WWV are set in the manual switches and station "9" is indicated. When the enter switch is pressed by the operator synchronous with the mark on WWV, an interrupt is generated which causes the program to reset the time. The time value set on the MDE is read and stored as the time and the tenth-of-a second counter reset to zero. The program then proceeds as before it was interrupted. Time can be set at any moment in this manner, good to at least 0.3 second. During an hour, there is less drift than 0.5 second in the computer time.

Two-Station Solution

The position of the object is computed as the closest approach of the two range vectors. The orientation of the range vectors is determined from the given look angles. The positions of the two stations are given on a reference sphere.

The solution is done using a cartesian system with origin at one of the stations (A) and with X-axis in the plane containing the two stations and the center of the reference sphere. The X-axis is tangent to the reference sphere at A, and is positive toward the other station (B). The Y-axis is vertical at A; the Z-axis is chosen to complete a "right-handed" coordinate system (see Fig. 1).



$(X_B, Y_B, 0)$

FIGURE 1

$$X_B = \overline{CB}\ \mathrm{Sin}\ (\mathrm{Arc}) \tag{4}$$

$$Y_B = \overline{CB}\ \mathrm{Cos}\ (\mathrm{Arc}) \tag{5}$$

(Y_B in general will be negative)

The azimuth bearings of B from A and of A from B are necessary to adjust observed azimuths for orientation to the XYZ system. They may be computed using the spherical law of sines.

$$\text{Az of B from A} = \mathrm{Sin}^{-1}\left(\frac{\mathrm{Cos}\ (\mathrm{Lat}\ (B))\ \mathrm{Sin}\ (\Delta\ \mathrm{long})}{\mathrm{Sin}\ (\overline{AB})}\right) \tag{6}$$

$$\text{Az of A from B} = \mathrm{Sin}^{-1}\left(\frac{\mathrm{Cos}\ (\mathrm{Lat}\ (A))\ \mathrm{Sin}\ (\Delta\ \mathrm{long})}{\mathrm{Sin}\ (\overline{AB})}\right) \tag{7}$$

where $\overline{AB}$ is the great circle from A to B and Δ long = long (A) - long (B) Note that these azimuths must be adjusted for quadrant. Station pairs for

TV TRACK are selected so that A is always west of B (See Fig. 2).

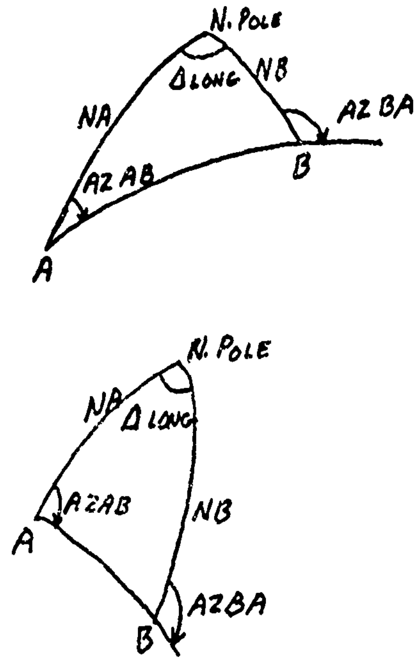


FIGURE 2

Orientations of Azimuths

$$\frac{\text{Sin (Az AB)}}{\text{Sin (NB)}} = \frac{\text{Sin }(\Delta\text{ long})}{\text{Sin }(\overline{\text{AB}})} = \frac{\text{Sin (Az BA)}}{\text{Sin (NA)}} \qquad (8)$$

The Z-coordinate of station B in this system is identically zero.

The arc distance (great circle angle) from A to B is obtained from the spherical law of cosines:

$$\text{Cos (Arc)} = \text{Sin (lat (A) Sin (lat (B))} + \text{Cos (lat (A)) Cos (lat (B))} \\ \text{Cos (long (A) - long (B))} \qquad (9)$$

The geocentric distances to A and B are computed by adding the model radius to their heights.

$$R_A = H_A + R \; ; \; R_B = H_B + R \tag{10}$$

From this, the X and Y coordinates of B may be computed:

$$X_B = R_B \text{ Sin (Arc)} \tag{11}$$

$$Y_B = R_B \text{ Cos (Arc)} - R_A \tag{12}$$

Calculation of a Two-Station Solution

An initial assumption is made that the range vectors do intersect. This allows determination of the two ranges D_A and D_B.

We have: $$\vec{AB} = \vec{AR} - \vec{BR} \tag{13}$$

Dot Product (13) with AR, giving:

$$\vec{AR} \cdot \vec{AB} = D_A^2 - \vec{AR} \cdot \vec{BR}$$

or (14)

$$= D_A^2 - D_A D_B \text{ Cos } \theta$$

where θ is the angle between $\vec{AR}$ and $\vec{BR}$

Dot product of (13) with BR similarly gives:

$$\vec{BR} \cdot \vec{AB} = D_A D_B \text{ Cos } \theta - D_B^2 \tag{15}$$

Now let

$$M = \frac{\vec{AR} \cdot \vec{AB}}{D_A} \quad N = \frac{\vec{BR} \cdot \vec{AB}}{D_B}$$

and

$$P = \text{Cos } \theta \tag{16}$$

Equations (14) and (15) now become

$$\begin{aligned} D_A - D_B P &= M \\ PD_A - D_B &= N \end{aligned} \tag{17}$$

The slant ranges are now obtained from simultaneous solution of the system (17).

$$D_A = \frac{M - PN}{1 - P^2} \quad D_B = \frac{PM - N}{1 - P^2} \tag{18}$$

If the look angles from A and B to R are used to compute direction cosines within the XYZ coordinate system: (A_X, A_Y, A_Z) w/r/t A and (B_X, B_Y, B_Z) w/r/t B, M and N are:

$$\begin{aligned} M &= A_X X_B + A_Y Y_B + A_Z Z_B \\ N &= B_X X_B + B_Y Y_B + B_Z Z_B \end{aligned} \tag{19}$$

Note that the coordinates of B in the XYZ system are (X_B, Y_B, 0)

The value c` P - Cos θ is the dot produce of the unit vectors (direction cosines):

$$P = A_X B_X + A_Y B_Y + A_Z B_Z \tag{20}$$

Now that the values of the two slant ranges D_A and D_B are available, the original direction cosines are used to compute the XYZ coordinates of the object first w/r/t A, then w/r/t B.

From A: $(A_X D_A, A_Y D_A, A_Z D_A) = \overline{R}_A$

(21)

From B: $(X_B + B_X D_B, Y_B + B_Y D_B, B_Z D_B) = \overline{R}_B$

The result position is taken to be the mean:

$$\frac{\overline{R}_A + \overline{R}_B}{2} \tag{22}$$

Two additional solution parameters are available (See Fig. 3):

Reliability - Taken to be P = Cos θ

Precision - The distance between the points R_A and R_B

$$E = \left(R_A - R_B\right)^2$$

The XYZ position of the object is now converted to latitude, longitude, and height, using the given coordinates of A on the reference sphere.

Height of Object

(See Fig. 4) The radius distance RC is computed by solving triangle RCD. The radius of the reference sphere is subtracted from RC to give the

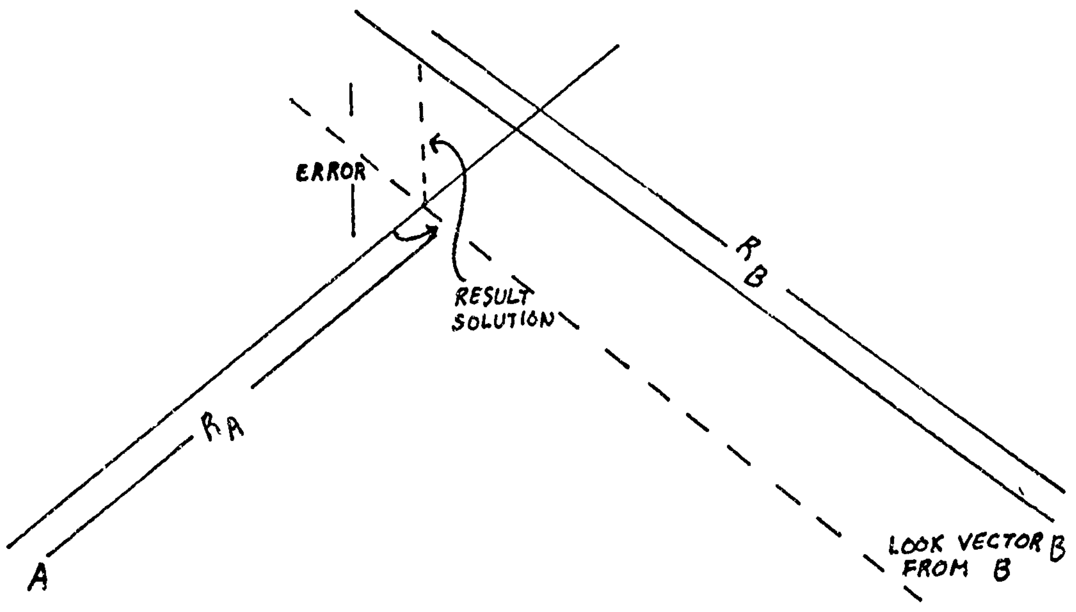


FIGURE 3

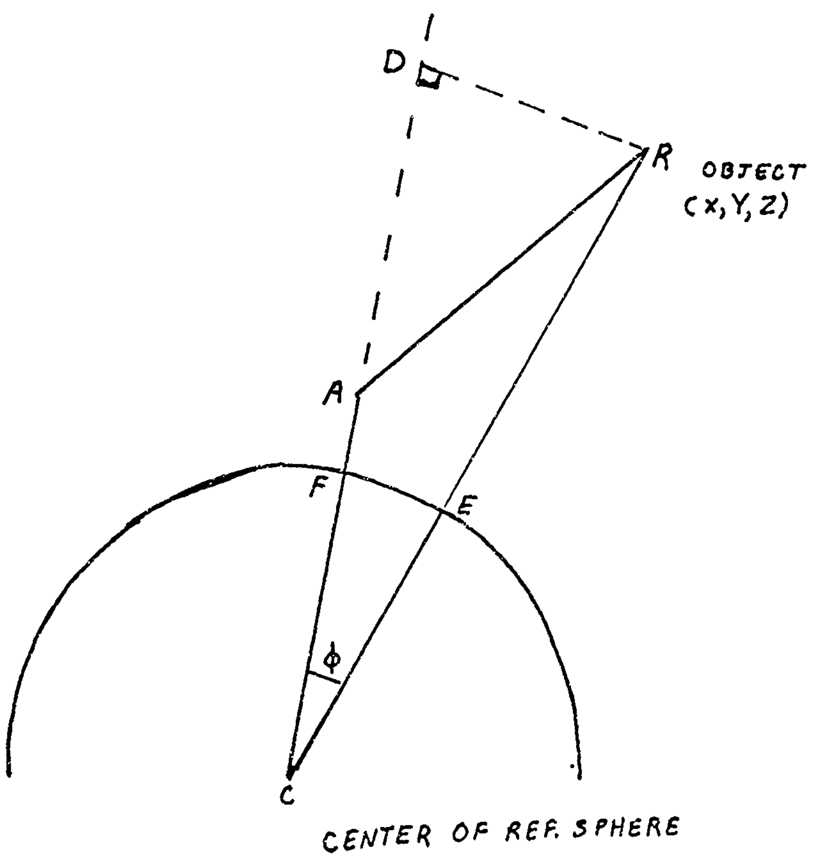


FIGURE 4

object height. If the object position is (X,Y,Z):

$$\overline{DR} = X^2 + Z^2 \quad (23)$$

CF = Radius of Reference Sphere

FA = Known Height of A

AD = Y-Coordinate of R

$$CD = CF + FA + AD \quad (24)$$

$$\overline{RC}^2 = \overline{DR}^2 + \overline{CD}^2 \quad (25)$$

$$Height = RC - CF \quad (26)$$

The great-circle angle (Ø) from A to R may now be computed (See Fig. 5).

$$\emptyset = Tan^{-1}\left(\frac{\overline{DR}}{\overline{CD}}\right) \quad (27)$$

The latitude of R is derived from the spherical law of cosines:

$$Sin\ (lat) = Sin\ (lat\ (A))\ Cos\ \emptyset + Cos\ (lat\ (A))\ Sin\ \emptyset\ Cos\ (Azm) \quad (28)$$

where Azm is the given azimuth angle from A to R.

The longitude of R is derived from the spherical law of sines, as a difference from the longitude of A.

$$Sin\ (\Delta\ long) = Sin\ \emptyset\ Sin\ (Azm)/Cos\ (lat) \quad (29)$$

$$\text{Longitude} = \text{long (A)} - \Delta \text{ long} \quad (30)$$

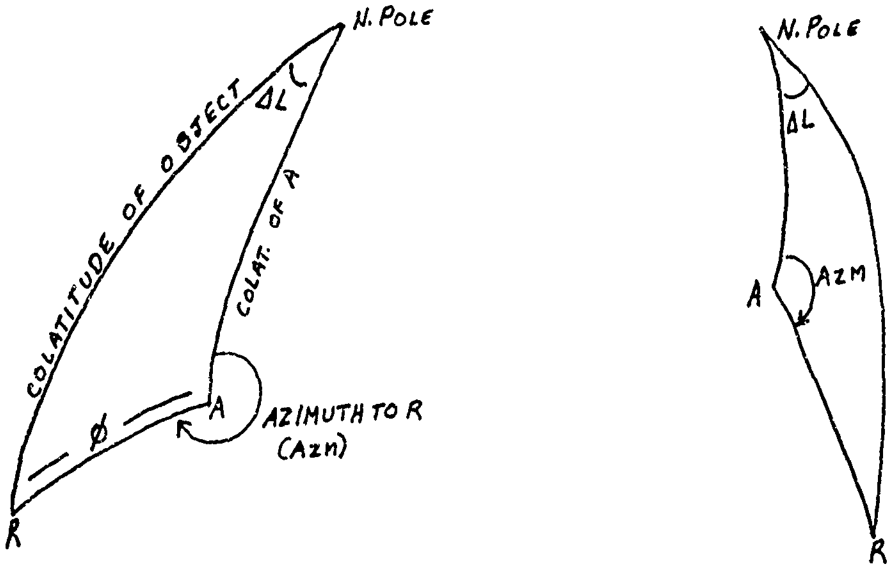


FIGURE 5

$$\text{Cos (NR)} = \text{Cos (NA) Cos } \emptyset + \text{Sin (NA) Sin } \emptyset \text{ Cos (Azm)} \quad (31)$$

$$\text{Latitude of Object} = \text{Sin}^{-1} \text{ (Cos (NR))} \quad (32)$$

$$\text{Sin } \Delta L = \frac{\text{Sin } \emptyset \text{ Sin (Azm)}}{\text{Sin (NR)}} \quad (33)$$

<u>One-Station Solution</u>

Look angles from one observer (A) to object (R) are known. The height of the object (H) is assumed.

(See Fig. 6): The great circle distance $\overline{AR}$ is found by

$$AR = \text{Cos}^{-1} (R_A \text{ Cos (El)}/R_R) - \text{El} \quad (34)$$

where R_A and R_R are the geocentric radii and El is the given elevation angle.

The range is available as:

$$\text{Range} = R_R \text{ Sin (AR)/Cos (El)} \tag{35}$$

The latitude and longitude are computed as with the two-station method, using $\overline{AR}$.

$$\text{Sin (lat)} = \text{Sin (lat (A)) Cos (AR) + Cos (lat (A)) Sin (AR) Cos (Az)} \tag{36}$$

$$\text{Sin } (\Delta L) = \text{Sin (AR) Sin (Az)/Cos (lat)} \tag{37}$$

$$\text{long} = \text{long (A)} - \Delta L \tag{38}$$

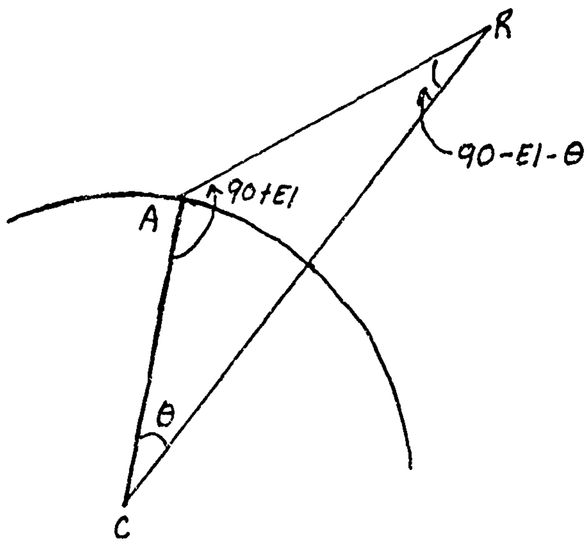


FIGURE 6

$$\frac{\text{Sin } (90 + \text{El})}{\text{CR}} = \frac{\text{Sin } \theta}{\text{AR}} = \frac{\text{Sin } (90 - \text{El} - \theta)}{\text{CA}} \tag{39}$$

$$\frac{\text{Cos (El)}}{\text{CR}} = \frac{\text{Sin } \theta}{\text{AR}} = \frac{\text{Cos (El} + \theta)}{\text{CA}} \tag{40}$$

$$\text{Cos}\ (\text{El} + \theta) = \frac{\text{CA}}{\text{CR}}\ \text{Cos}\ (\text{El}) \tag{41}$$

$$\text{El} + \theta = \text{Cos}^{-1}\left(\frac{R_A}{R_R}\ \text{Cos}\ (\text{El})\right) \tag{42}$$

$$\theta = \text{Cos}^{-1}\left(\frac{R_A}{R_R}\ \text{Cos}\ (\text{El})\right) - \text{El} \tag{43}$$

$$\overline{\text{AR}} = \frac{\text{CR Sin}\ \theta}{\text{Cos}\ (\text{El})} = \frac{R_R\ \text{Sin}\ \theta}{\text{Cos}\ (\text{El})} \tag{44}$$

(R_A, R_R both known)

Look Angles and Range

The coordinates of an observing station (A) and an object (R) are known on a model sphere.

The great-circle angle θ between A and R is available from the law of cosines on a sphere.

$$\text{Cos}\ \theta = \text{Sin (lat (A)) Sin (lat (R)) + Cos (lat (A)) Cos (lat (R)) Cos}\ (\Delta\ \text{long}) \tag{45}$$

where Δ long = long (A) - long (R)

The range may be computed by solving the plane triangle formed by A, R and the model center

$$\text{Range}^2 = (\text{Radius to A})^2 + (\text{Radius to R})^2 - 2\ (\text{Rad (A) Rad (R)) Cos}\ \theta \tag{46}$$

we have:

Radius to A = known height of A + model radius - and similarly for R.

The Elevation Angle is derived by forming a triangle with right angle joining R with the extended radius to A.

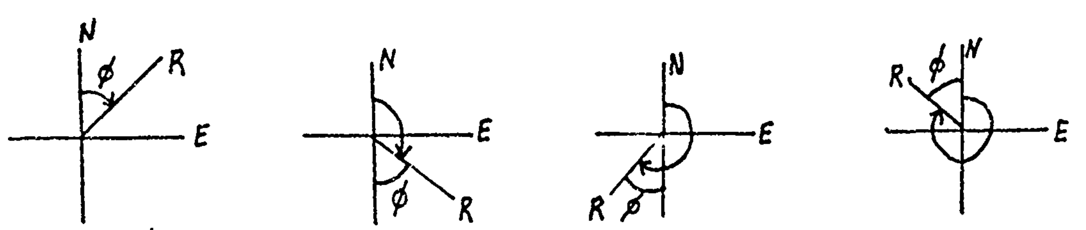
$$\text{Elev} = \text{Tan}^{-1}\left(\frac{R_R \text{ Cos } \theta - R_A}{R_R \text{ Sin } \theta}\right) \tag{47}$$

The Azimuth Angle is first computed from the spherical law of sines, using the great-circle angle $\overline{AR}$ just derived.

$$\text{Sin (Az)} = \frac{\text{Cos (Lat (R)) Sin } (\Delta \text{ long})}{\text{Sin } \theta} \tag{48}$$

$$\Delta \text{ long} = \text{long (A)} - \text{long (R)} \;;\; \theta = \overline{AR}$$

This Azimuth must be adjusted for quadrant. Let $\phi = |Az|$, (See Fig. 7).



$Lat_A < Lat_R$	$Lat_A > Lat_R$	$Lat_A > Lat_R$	$Lat_A < Lat_R$
$Long_A < Long_R$	$Long_A > Long_R$	$Long_A < Long_R$	$Long_A < Long_R$
$Az = \phi$	$Az = 180 - \phi$	$Az = 180 + \phi$	$Az = 360 - \phi$

FIGURE 7

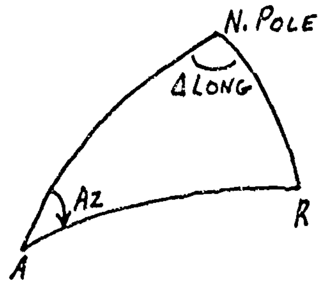


FIGURE 8

$$\text{Cos (AR)} = \text{Cos (NA) Cos (NR)} + \text{Sin (NA) Sin (NR) Cos } (\Delta \text{ long}) \tag{49}$$

$$\frac{\text{Sin (Az)}}{\text{Sin (NR)}} = \frac{\text{Sin } (\Delta \text{ long})}{\text{Sin (AR)}} \tag{50}$$

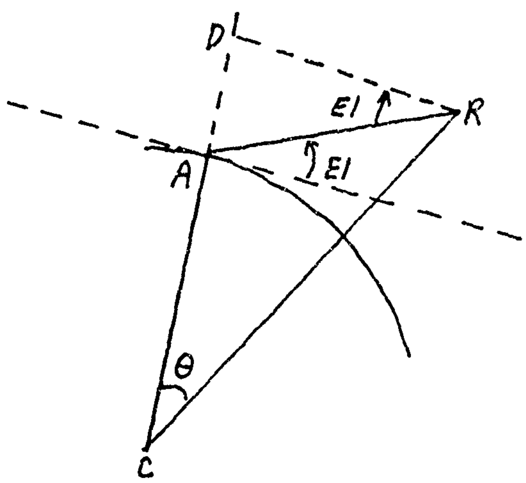


FIGURE 9

$$\overline{AR}^2 = \overline{CA}^2 + \overline{CR}^2 - 2 \cdot \overline{CA} \cdot \overline{CR} \cdot \text{Cos } \theta \tag{51}$$

$$\theta = \overline{AR}$$

$$\text{El} = \text{Tan}^{-1} \left(\overline{AD} / \overline{DR} \right) \tag{52}$$

$$\overline{AD} = \overline{CR} \cdot \text{Cos } \theta - \overline{CA} \tag{53}$$

$$\overline{DR} = \overline{CR} \cdot \text{Sin } \theta \tag{54}$$

$$\overline{CR} = \text{Radius to R} \tag{55}$$

$$\overline{CA} = \text{Radius to A} \tag{56}$$

The SELECT Algorithm

This is the method of determining which solution method is required by the input data, or whether a solution is, in fact, possible. By the time subroutine SELECT is called by the executive TASK, data have been stored from input sources in floating point form. A code in the station tables indicates the presence of data for that station. The procedure is as follows:

1. Run a two-station solution for all station pairs which have data for both stations. If there are no such pairs, go to step 4.

2. Eliminate all "unreliable" two-station solutions. There are two-station solutions for which the angle between the look vectors is less than 15 degrees. If all two-station solutions are unreliable, choose the one with the largest angle between look vectors as the output solution, set quality code 3.

3. Of all reliable two-station solutions, choose the one with the smallest miss-distance between the look vectors (see Two-Station Algorithm). If the resultant miss-distance is under 2 km, set quality code 5, otherwise set quality code 4.

4. If there were no two-station solutions possible, examine all stations for input, scanning west to east. If there is no input for any stations, then no solution is possible; set quality code 0. Choose the first station encountered in the scan for a one-station solution with height assumed the same as the previous second's solution, set quality code 2.

If any of the above solutions were calculated from manually entered data, set quality code 1 in all cases.

Note that a two-station solution is always rejected if the miss-distance is over 100 km or if the solution height is negative. Negative heights are calculated when the look vectors are divergent.

Validation of Input Data

Erroneous data values can be received by the tracking system due to faults with the telephone lines, the communications interface, or at the tracking sites. Since the input data is in the form of BCD look angle values, some software checks are possible.

First, look angles which are not legal BCD in all positions are rejected. Rejection occurs even when only one pair of the angles, such as azimuth, is bad. No value may be over 360 degrees; negative angles are not represented by the hardware. Elevation angles of greater than 90 degrees are rejected.

It is possible for input angles to be legal BCD and legal values but still be incorrect due to hardware malfunction affecting but one digit. For example, the hundreds digit of azimuth from one station may change by one every so often. An "excessive swing" check was implemented to ensure that successive input angles do not differ more than 5 degrees. If this 5 degree limit per second is ever exceeded, the program stores the new range of values without accepting them. After four successive values in the new range are stored, that does not break the 5 deg/sec limit, the program begins accepting values again.

It is possible for the computer operator to reject a station regardless of its input values by releasing a console switch. See Operator Control of TV TRACK.

Tracking a Barium Cloud

An object as large and amorphous as a barium cloud presents special problems in tracking. In SECEDE II, the three tracking locations were set up essentially along a parallel of latitude, north of the cloud for all events. The predicted release location for each event was available and stored in the computer, enabling look angles to the release point from each site to be sent out to the feedback displays (see FEDBAK routine). When the cloud initially formed, it appeared as a small dish to all stations, and it was easy to lock onto the center of the cloud. After this very early time, the cloud began to spread out from a relatively stationary leading edge and form into a billowing sheet along the magnetic field lines. This sheet gave a very different appearance from the eastern station (Barin) than from the western station (Tyndall). During event REDWOOD, the tracking system was run with all three stations engaged and the solution selected from the resulting three pairs on the basis of least miss-error (see Two-Station Solution). The TV mount operators were attempting to stay on the apparent cloud center, but this point appeared to be quite different as seen from Barin than from Tyndall. The central station (C-6) was looking up the field lines into the sheet structure and the "best" solution oscillated between Barin-C-6 and Tyndall-C-6. The effect of this was to produce the track of a "jumping" cloud whose position, particularly the height, changed frequently and abruptly. When one pair was governing the solution, the feedback look angles to the unused wing station indicated that the operator should look at the edge of the cloud or even away from it. Under these conditions the operators refused to steer their cameras to such an obviously incorrect orientation and tracked the cloud center as they saw it. The program on the CDC 6600 at Eglin Main for cloud position prediction gave very poor extrapolations of these TV TRACK positions and caused some consternation when the results were sent to the launch site to guide probe rocket launches.

After examining the video tape playbacks from the wing stations and having consultations with the operators, it was determined that only two stations at a time should be used in tracking. This was easily arranged at the computer (see Operator Control of TV TRACK) and event PLUM was tracked largely with the station pair C-6-Tyndall, with complaints from Barin that the solution was often not in the cloud as they saw it. This did not solve the problem completely, although it did eliminate some of the jumping. A mount operator still tended to move from his current orientation to a part of the cloud that appeared to be more central. This activity caused the solution to jump. Attempts were made to mitigate this effect by not allowing a mount operator to move until he was given central direction. This [illegible] e the desirable compromise of keeping the solution in some part of the cloud, if not always the same part, but not causing it to jump about and cause difficulties at the 6600 in extrapolating.

An interesting piece of information about TV TRACK's position accuracy came from the opportunity to track a "certification" firing of a probe rocket one evening when the barium event had been cancelled. The "release" point was set at the launch site and feedback look angles directed the three mount operators to look there. Some brief difficulty was experienced in initial acquisition, but starting at just before apogee and essentially all the way to splashdown the tracking was excellent. A plot of the results after the event showed a fine parabolic trajectory on the down leg. The probe rocket had a flashing light, and provided a good, unambiguous point source to track. This and similar experiments conducted previously with high-flying aircraft made it clear that TV TRACK was accurate on any small object.

Permanent Digital Records

The data from four events (OLIVE, PLUM, REDWOOD, SPRUCE) was recorded on a paper tape log during tracking. This log data is in the form of time, solution quality, participating stations in the solution and the input look angles. All four logs have been converted to magnetic tape and the solutions added using the University of Alaska's IBM 360/40. A single 2400 foot tape with all four events has been filed at SRI for general use. Due to malfunction of the INTERDATA computer at the time, there is no log for event NUTMEG. (See Appendix I)

Television Image Records

The input devices to the TV TRACK system were image orthicon television sub-systems located at Site C-6, Barin and Tyndall. Shaft encoders on the television mounts provided the digital data transmitted to the INTERDATA computer. Each TV was equipped with a lens allowing a 12° by 16° field of view. During the early part of each release observation, interference filters placed over the lenses restricted the incoming light to that of a barium ion line. The TV systems operated at the rate of 60 field/sec (30 frames/sec). All image fields were recorded on magnetic tape and every other field was recorded on 16 mm film. Peripheral data recorded with the image orthicon output were 1) elevation and azimuth readings from the shaft encoders, time, date and station locations.

At Site C-6 a second TV was operated on the instrument mount. This TV was equipped with an unfiltered lens allowing a field of view of 16° by 20°. Hence, both the neutral and ion clouds were recorded as long as both remained in the field of view.

Post-Event Analysis

A "quick look" at the data was obtained from the tracking and TV recordings in the few hours following each release. A plot of the cloud track was obtained after each event from the teletype repeats of the information sent to Eglin and Sandia. The output to Sandia at A-15A was in the form of X, Y and cloud height, which was simple to plot. The video tape from at least one of the wing stations was brought to the central station (at Site C-6) for comparison with the tape recorded at the central station. The location of the neutral cloud was scaled off the TV monitors and the INTERDATA used to calculate several points along its track by employing an off-center correction to the displayed look angles for the frame under examination. The same operation was also carried out on other interesting portions of the cloud, such as the leading edge, which was thus determined to be nearly stationary with respect to the rest of the ion cloud. A log of the tracking data is now available (See Permanent Records).

APPENDIX I

SECEDE II Log Data Printout

This is a listing of the data recorded on the SECEDE II Log Data Tape. Everything on the tape appears on the printout. Four events are listed: OLIVE, PLUM, REDWOOD and SPRUCE. The event name appears as part of each page heading. Look angles are as they were recorded during tracking. In the case of unreadable data, the value recorded was converted to 999.9 on the tape. Note that BARIN was not operational during SPRUCE. Latitudes are geodetic.

Under STATIONS USED a 1 signifies that the associated station data was used to compute the solution. The coordinates of the stations appear on the next page. Note that the solutions were not computed on the INTER-DATA. The log data was used to determine which stations participated in the solution during tracking and a solution with those stations was done using FORTRAN versions of the algorithms on the 360/40.

Position Values Used by University of Alaska TV TRACK

Tyndall

Lat N 29° 58' 3.8"

Long W 85° 28' 11.3"

Height 10 feet

Barin

Lat N 30° 23' 28.6"

Long W 87° 38' 12.6"

Height 58.5 feet

Launch Site Central Location (A-15A)

Lat N 30° 23' 14.285"

Long W 86° 48' 10.762"

Height 9.842 feet

Note that the Barin station was not operational during event SPRUCE.

C-6

Lat N 30° 34' 22"

Long W 86° 13' 2"

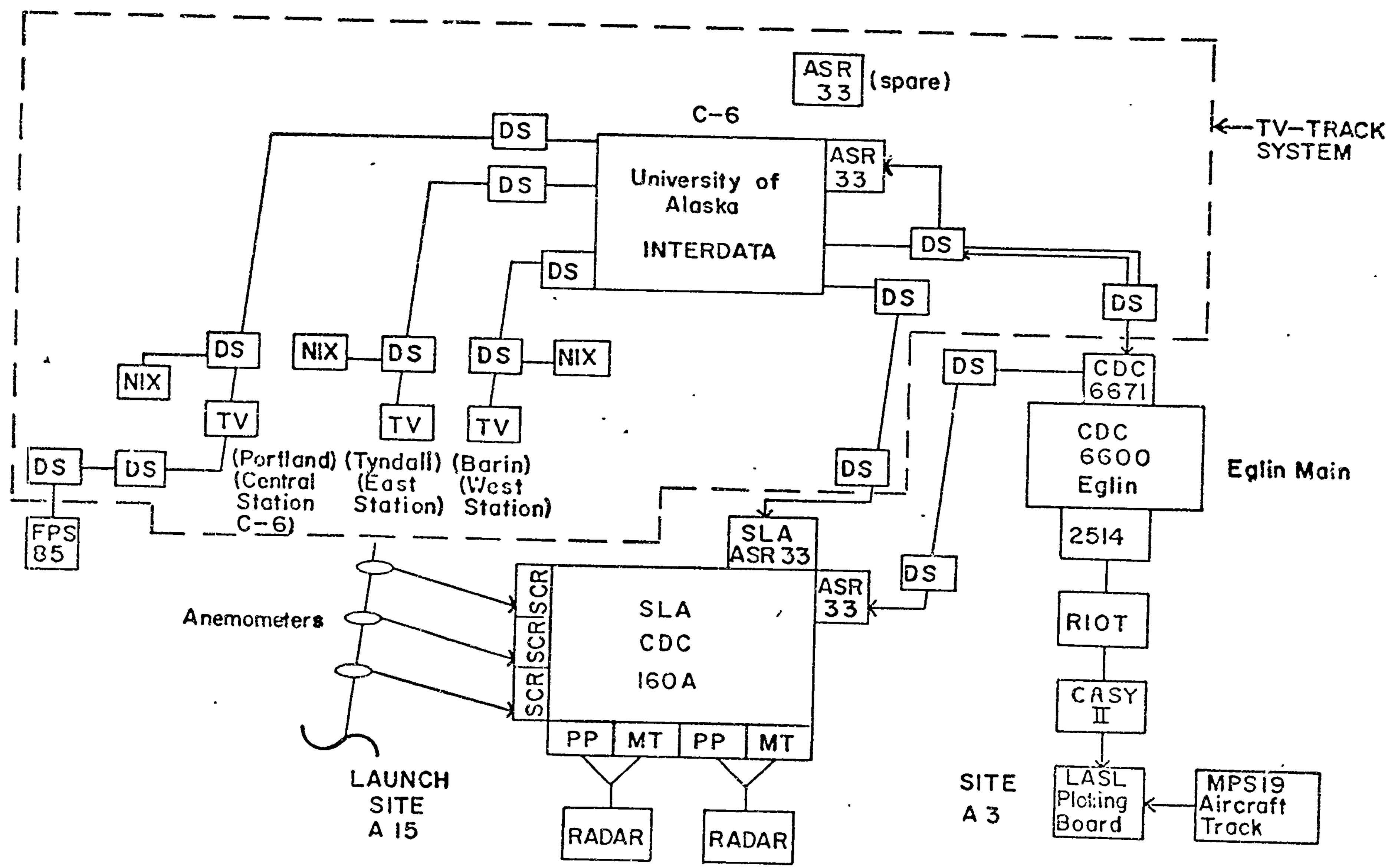
Height 100 feet

APPENDIX II

SAMPLE OUTPUT FROM UNIVERSITY OF ALASKA TV TRACK

TO LAUNCH SITE (A-15A)

Time (U) H M S	X	Y	Height
13:01:35	45.7	-57.9	185.0
13:01:40	45.6	-58.0	185.0
13:01:45	45.6	-58.0	185.0
13:01;50	45.5	-58.0	185.0
13:01:55	45.5	-58.1	185.0
13:02:00	45.4	-58.1	185.0
13:02:05	45.4	-58.2	185.0
13:02:10	45.3	-58.2	185.0
13:02:15	45.3	-58.6	185.0
13:02:20	45.2	-58.6	185.0



DS = Data set
CDC = Control Data Corp
NIX = Nixie Display
SCR = Strip Chart Recorder

PP = Paper Punch
MT = Magnetic Tape
ASR = A Teletype Designation
SLA = Sandia Corp.

LASL = Los Alamos Scientific Labs
RIOT = Real Time Input/Output Terminal System
FPS-85 = A Particular Radar Type

APPENDIX III: DIAGRAM OF EQUIPMENT LAYOUT FROM T. R. #1

APPENDIX IV

ASSIGNMENT OF CONSOLE SWITCHES IN TV TRACK

0	Unused
1	Unused
2	Unused
3	Unused
4	Transmit to Eglin Main
5	Transmit to Sandia at A-15A
6	Transmit to SRU at FPS-85 site
7	Unused
8	Unused
9	Simulate connunications line using manual entry (for testing)
10	Start the Log Punch
11	Set Anticipated Release location as solution
12	Engage Tracking Station 0 (Barin)
13	Engage Tracking Station 1 (C-6)
14	Engage Tracking Station 2 (Tyndall)
15	Unused

REFERENCES

LaPoint, G. C., S. P. Geller and T. N. Davis, "TV TRACK: A Real-Time Output System for Object Tracking", RADC-TR-70-273, Technical Report, Geophysical Institute, University of Alaska, College, Alaska (1970).