DATA HANDLING AT AN AMR TRACKING STATION

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SUMMARY

The downrange tracking station at Ascension Island (AMR Station 12) includes, as part of its instrumentation, a real-time data-handling system. Using digital techniques primarily, this system collects, records, and transmits data describing the trajectory of selected ballistic objects within range of the FPS-16 radar on Ascension Island. Among its functions, the data-handling system performs the following tasks:

- Aids the FPS-16 radar in initial acquisition of the ballistic vehicle, and in reacquisition following any subsequent loss of track.
- Records all raw data collected by the FPS-16.
- Maintains communication with Cape Canaveral (and with other tracking stations when required) prior to, during, and after a flight.
- Provides stations further downrange with real-time acquisition data in the form of updated orbital parameters.
- Provides trajectory data to plotting boards and other instrumentation at Ascension Island.

The UNIVAC 1206 Military Real-Time Computer is used as the central data processor. Associated with the computer are various data buffers, A/D and D/A converters, data recorders, and communication equipment.

Information concerning a planned flight (nominal trajectory parameters and other data) is transmitted from the Cape to Ascension Island prior to lift-off. Shortly after burn-out, actual, measured, parameters are similarly transmitted, along with timing data.

Within the computer, the dynamics of ballistic flight are simulated in real-time in order to predict the coordinates of the vehicle when it comes within range of the Ascension radar. The radar uses these data to acquire the target. After lock-on, the condition is reversed, with the radar supplying track data to the computer, and via the data-handling system to the entire range network. The mathematical treatment of the problem involves editing and smoothing the data (for which a "combination" technique is used), integrating the data to obtain a predicted position of the vehicle, and then extrapolating beyond the integration to obtain a still further look-ahead. The interval of integration and the manner of implementing it have been tailored to fit the particular conditions encountered at Station 12.

The computer program may be considered as comprising two major routines: the initialization routine and the acquisition and track routine. The former routine is executed prior to lift-off and sets the initial conditions prevailing for a specific mission. The latter performs the real-time acquisition and tracking functions during the flight.

INTRODUCTION

The purpose of this paper is to report on the use of a high-speed, general-purpose computer in the data-handling system of a downrange radar tracking station—Ascension Island. The real-time data handling system for Ascension Island consists of equipment, primarily digital, to collect, record, and transmit data describing the trajectory of selected ballistic objects within range of the FPS-16 radar. The primary functions of the system are:

(1) To aid the FPS-16 radar in initial acquisition, and in reacquisition following any loss of track;
(2) To record all raw data collected by the FPS-16 radar;
(3) To enable transmission of FPS-16 data from Ascension Island to Cape Canaveral in real-time and/or post-flight mode;
(4) To provide stations farther downrange with acquisition data in the form of updated orbital parameters;
(5) To provide real-time trajectory data to plotting boards and other local instrumentation.

The equipment consists of three functional groups: namely, the digital computer and associated peripherals, buffers and converters, and the data recovery system. (See Figure 1.) The computer group includes the UNIVAC 1206 computer, a magnetic tape handler and control unit, and an AN/FGC-20 teletypewriter unit. The buffers and converters comprise the necessary analog-to-digital and digital-to-analog converters, impedance matchers, and format control buffers. The data recovery group consists of two subsystems: the first is located on the Island and is made up of a raw data recorder and an output buffer for high-speed RF transmission to the Cape. The second subsystem is at the Cape, and consists of a high-speed RF receiver, followed by an input buffer and

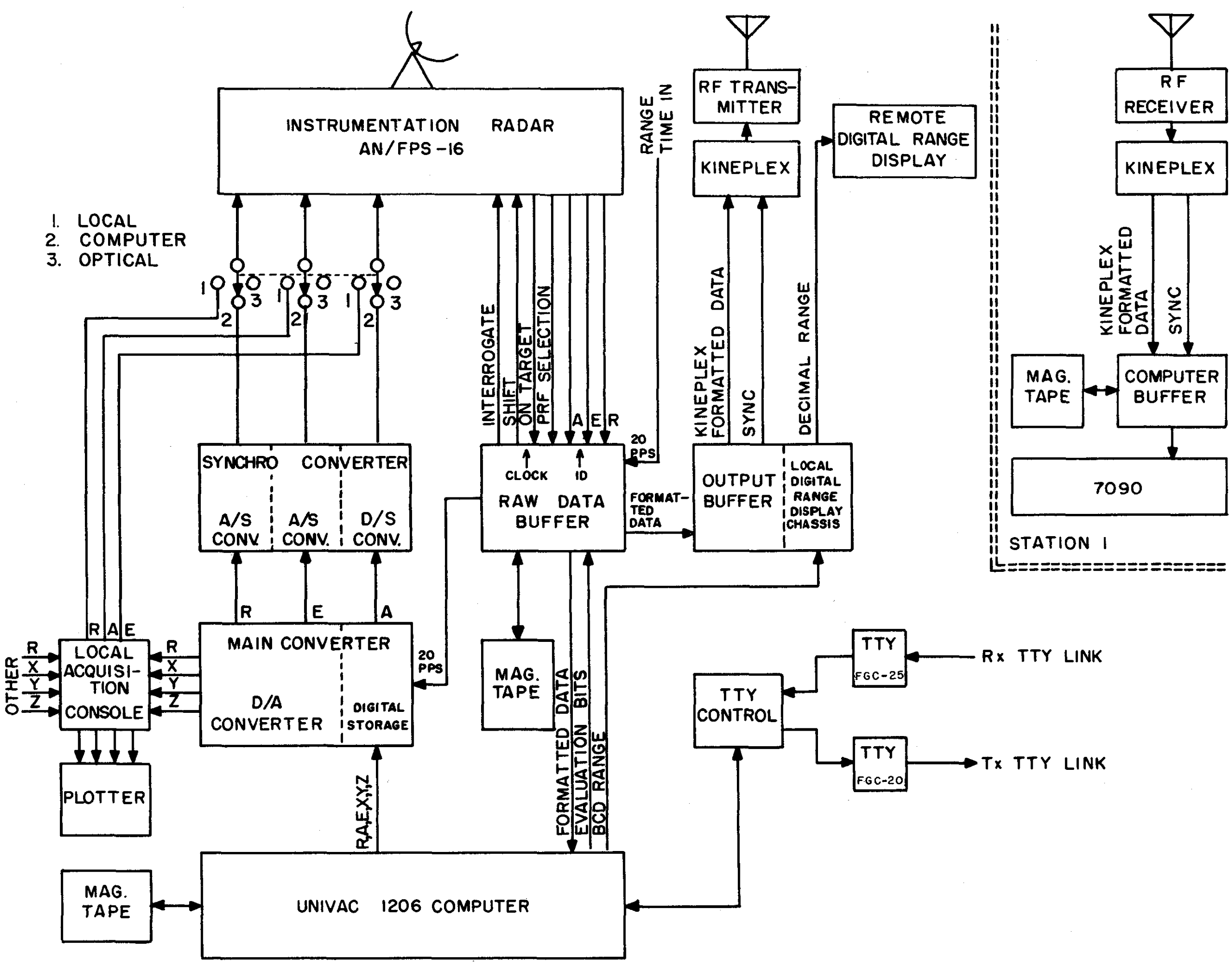


Figure 1. Ascension Island Real-Time Data Handling System.

a magnetic tape unit which records in the same format used by the raw data recorder on the Island.

The Tracking Problem

In order to provide, in real-time, acquisition data to a local tracking device and to downrange stations, and to provide current position data to a plotter, some form of prediction is necessary. An accurate prediction scheme, based on well known dynamic principles governing ballistic motion in the vicinity of the earth, can be implemented in real-time by a fast digital computer with a memory of moderate size.

Within the computer, the dynamics of ballistic flight can be simulated in real-time and used to predict the position and velocity of the vehicle. This simulation must take into account the non-sphericity of the earth and the atmospheric drag. The prediction information must then be converted to radar coordinates and fed to the radar continually. If the radar has not yet acquired, it will accept the information. After lock-on, the radar will ignore the prediction data, but will quickly switch back to the acquisition mode if track should be lost. In the following discussion, the physics and instrumentation of the problem are discussed; system, mathematical and programming considerations subsequently follow; and finally, the results are discussed and certain extrapolations made.

Physics of the Problem

The specification of a method of orbit determination (or more properly in this case, orbit improvement) embraces a number of items, all of which are interrelated. These are:

- The parameters to be used to describe the orbit
- The coordinate system(s) to be used
- The physical features to be included in (and excluded from) the simulation model
- Mathematical representation of the model
- Mathematical methods to be utilized in manipulating the model
- The form and rate of available input data
- The form and rate of the required output data
- The time available for the computations

Since Ascension Island is one of several stations widely spaced over the earth, a geocentric inertial coordinate system is the most convenient choice for purposes of communication among them. This coordinate system is also a convenient one in which to express the dynamic parameters of orbit improvement and prediction. Furthermore, the position coordinates and their time derivatives, together with the time at which they are valid, constitute a convenient set of orbital parameters since they uniquely specify the orbit.

The dynamic principles governing the motion of the object to be tracked are expressed in a set of simultaneous differential equations. Newton's laws of motion applied to the two-body problem provide principal terms in these equations. Smaller terms arise out of the effect of the asphericity of the earth's gravitational potential. These terms depend only on the position coordinates of the bodies involved. In addition, when the altitude of the orbiting vehicle is low enough, the retarding effect of the atmosphere gives rise to drag terms which are velocity-dependent. Drag terms depend upon the density of the atmosphere, the shape of the vehicle, the orientation of the vehicle with respect to its velocity vector and the orientation of the velocity vector with respect to the computational coordinate system. Logic must therefore be provided to insert the drag terms whenever the altitude is below a specified limit. An assumed-atmosphere model and the drag characteristics of the vehicle must also be included in the program.

Prediction essentially means solving the set of differential equations for a certain epoch (time), given a sufficient set of initial conditions. The presence of terms other than the principal terms in the differential equations precludes a solution in closed form. Numerical integration methods must be used to approximate the solution. These methods advance the solution in stepwise fashion, predicting ahead by a 2-second time increment. The results obtained from one step in the process become the inputs to the next step.

Instrumentation

The choice of particular devices wherewith to implement the system must take into account many ancillary factors, most of which can be satisfactorily handled either by the computer program itself or by hardware buffers. As in many other systems utilizing a digital computer, there exists the problem of converting from analog to digital form and vice versa, as well as the problem of matching the data rates demanded by external equipments.

Some peculiarities of the external equipment are accommodated by the computer program. For example, after the predicted position has been found in the computational coordinate system, it must be represented to the external buffering devices both in the format and coordinates demanded by the devices and with the required scaling. The radar and the X-Y plotter both work in topocentric ("topos" = place) coordinate systems, the radar in spherical polar coordinates, and the plotter in Cartesian. In addition, data for the radar must be modified by inclusion of the refraction errors. It has not proven necessary, however, to compensate for possible errors in the dynamic response of the radar servo systems (although this may be done and is done on the other systems).

Similarly, at the input end, a major task of the computer is to interpret the input data properly. In particular, a pulse radar, if it has the capability of tracking beyond the range which corresponds to the time between pulses, has an ambiguity in its range data because the equipment has no way of associating a return with the initial pulse which caused the return. Consequently, range data both to and from the radar are given modulo R_0 where $2R_0$ is the speed of light divided by the pulse repetition frequency (prf) of the radar. In the Ascension Island system there is the additional complication that the prf can be selected at will by the radar operator from among a number of alternatives. The computer program must contain logic to add R_0 the correct number of times in order to resolve the ambiguity.

Communications

The system must communicate with the operator and with the outside world at both input and output ends. As mentioned previously, the system must receive nominal orbital parameters before launch. These data are used as back-up in the event of a communications failure later on. After burn-out, the system receives orbital parameters based on measured up-range track data. These are de-formatted and checked for reasonableness in the computer, as a guard against error in the communications system. Initial acquisition data for the radar are based on them. If they are garbled, or not received at all, the nominal values are used.

As output, the best set of orbit parameters is transmitted downrange. During this phase of the program, the computer formats the data for transmission.

Because of the relatively slow rate of data transmission, input-output functions consume little computer time. The narrow bandwidth of the communications system makes it desirable that only one "point" be transmitted from up range and lends importance to the computer's function of stepwise prediction from a distant point to yield many acquisition points for the radar.

Man-machine communication is achieved by means of a radio Teletype unit attached to the computer or to the radio link, the selection being made manually. This device permits entering the required data into the computer and also allows the operator to monitor, to a limited extent, the operation of the computer. However, the switching from pre-acquisition mode to acquisition mode to tracking mode is fully automatic.

As indicated above, communication between the computer and the radar is via input and output buffers. The buffers control the data rates also, sending an "interrupt" to the computer to signal the presence of input data or a demand for output data. These demands are quickly handled by the program, which accepts and stores the input data and provides output data from previous computations. Between interrupts, the mathematical calculations are carried forward in preparation for future demands. The mathematical formulations and methods and their coding are such that the computation always stays ahead of these demands.

System Operation

The interface between the data-handling system and the other parts of the tracking instrumentation includes points of contact at the radar acquisition inputs, the radar outputs, the local acquisition console (for displays), the RF transmitter at Ascension, the RF receiver at the Cape, and, finally, the

7090 computer at the Cape. Figure 1 lists the specific kinds of data exchanged across this interface.

In order to explain the operation of the system, a hypothetical mission is described below in terms of the function of each equipment shown in the system block diagram.

Prior to a mission, usually at least a day before, the nominal or planned trajectory parameters, drag tables, and refraction data are transmitted to Ascension Island and introduced into the computer via radio Teletype link for use during the actual mission. These parameters are stored on magnetic tape along with a copy of the program to be used during the mission. Many subsystem and system confidence checks are also run at this time.

During countdown, the complete system is exercised by feeding the raw radar data stored on the raw data tape unit into the raw data buffer and thence to the rest of the system. The Kineplex transmission link to the Cape may be tested in this manner. Radar calibration values (zero sets) are also given to the computer at this time.

Shortly after burn-out of the last stage of the missile, tracking instrumentation at the Cape determines a final set of orbital parameters (X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$), all valid at some time, $\underline{t}$. This set—together with lift-off time and time $\underline{t}$—is transmitted to Ascension Island, entered into the computer, tested for reasonableness, and copied onto the back-up program magnetic tape. The computer program substitutes the second set for the first set as soon as the second set is received. In the event of communication failure, however, the program will continue to operate on the first set.

The parameter set is in an inertial, geocentric system. Time $\underline{t}$ is an instant in the flight occurring after burn-out. Based on this information, the UNIVAC 1206 integrates the trajectory by stepwise integration to that portion of the flight regime within range of the Ascension Island radar. The computer also establishes a time, t_o, at which acquisition will occur and sends the associated look angles and range to the radar.

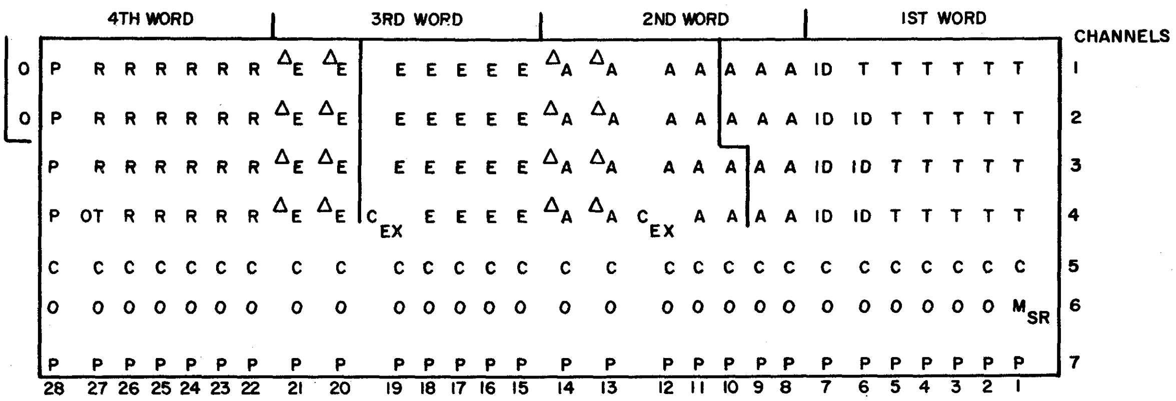
When t_o occurs, acquisition computations are updated. Predicted values of slant range (R), azimuth (A), elevation (E), and local x, y, and z are transmitted, at the rate of 20 samples per second to the output converters, which change the digital values to analog form. Local x, y, and z are used by the local acquisition bus and the plotters. The analog (polar) R, A, and E values are converted to synchro signals and fed to the radar servo system, where they maintain the radar dish in position for acquisition. At the same time, the computer generates a recommended mode of radar scan (circular or raster) and displays it to the radar operator. This recommendation is based on the probability of target presence as determined in part by the reasonableness of the measured set of orbital parameters.

R, A, and E values appearing at the output of the radar are sampled by the raw buffer at the rate of 20 samples per second. These data are formatted along with range time, ID (identification) bits, and parity checks, and recorded on the raw data magnetic tape. Figure 2 illustrates the recording format. Concurrently, the data are given to the computer in a similar format.

When the radar succeeds in locking on the target, it generates an on-track signal. This signal is detected by the computer, and if the accompanying position data pass a reasonableness test, the computer program switches from acquisition mode to track mode. If RF propagation conditions permit, these same data from the raw data buffer are converted to three 40-bit words by the output buffer and transmitted via Kineplex to the Cape at 80 words per second. There, a Kineplex receiver terminal reconverts the three 40-bit words back to the original 28-character format. The data are then recorded on a second raw data magnetic tape, making the information available to the Impact Predictor at the Cape.

If while tracking the radar should lose the target—during re-entry for example—the computer will respond to the absence of the on-track signal and immediately switch back to acquisition mode. Acquisition data at such times are based on past tracking data. Further, if the missile is low enough in altitude to be affected by them, drag forces must necessarily be taken into account in calculating the acquisition data.

For missions where the vehicle will impact within the radar's line of sight, the computer automatically prints out a predicted impact point. In the case of flights of longer range, the computer calculates acquisition data, which are then transmitted downrange for use by other tracking stations.



T = TIME (21 BITS)
ID = IDENTIFICATION (7 BITS)
A = AZIMUTH (19 BITS)
Δ_A = AZIMUTH SERVO ERROR (8 BITS)
R = SLANT RANGE (23 BITS)
C = CLOCK
C_{EX} = COMPUTER EVALUATION (2 BITS) BIT RATE = 3.5 KC
M_{SR} = MARK START RECORD (1 BIT) TRUE INTERROGATE TIME

E = ELEVATION (19 BITS)
Δ_E = ELEVATION SERVO ERROR (8 BITS)
OT = ON-TARGET (1 BIT)
O = NO DATA
P = PARITY

Figure 2. Format of Recorded Data.

Univac 1206 Computer

The computer used in this installation is the UNIVAC 1206 Military Real-Time Computer. This unit is a general-purpose, high-speed, digital machine of modular construction and ruggedized to meet military specifications. In the configuration employed at Ascension Island, the computer has the following characteristics:

- Internal core memory of 16,384 30-bit words (expandable to 32,768),
- 8-microsecond cycle time
- Single-address, indexed instructions
- Wired-in bootstrap memory for initial loading and recovery purposes
- Fixed-point, one's complement, subtractive arithmetic
- Seven input and three output channels
- Internal 7-day clock, with granularity of 2^{-10} second
- Over-all size of $30 \times 37 \times 65$ inches

Program Philosophy

The main concern of the computer program is the meshing of each component of the tracking system into a single, operable, real-time unit. The specific objects which must be mathematically related are the earth, the vehicle being tracked, and the radar. Past experience by many groups has shown that computer simulation of a vehicle in ballistic flight can be made very precise since gravitational, atmospheric, and drag parameters can be determined quite accurately. However, missile simulation is notoriously time-consuming; therefore, much effort was spent in tailoring the simulation exactly to the particular real-time problem at hand. Numerical integration of the equations of motion of a vehicle in ballistic flight about an oblate spheroid, with drag terms when applicable, was chosen as the most desirable method of simulation.

With the use of numerical integration, the program can be made very symmetrical—that is, numerical integration can continue at all times, with the only changing factor being the input or initial conditions. If the radar is delivering high-quality track data, these are used as the input to the numerical integration; however, if high-quality track data are unavailable, the integration will continue using the results of the previous integration step as shown in Figure 3. Radar data must pass a reasonableness test, be on-track, and must have variance within a specified range to be considered of high quality.

A 2-second interval of integration was chosen after a study of the accuracy of numerical integration versus the integration interval. Two seconds was found to be a reasonable interval over all portions of the flight; however, the integration interval could have been much greater in the exo-atmosphere phase, and perhaps smaller during re-entry.

The time sequence of the calculations is: collect and smooth radar data; combine with past data, and then use the results as input to the numerical integration. Since all this consumes time, extrapolation is used to yield data three seconds "ahead of the clock." If the radar should lose track, the extrapolated data are available for predicting future look angles. If the radar is not transmitting high-quality track data, the combination sequence is bypassed, but the integration and extrapolation continue.

Mathematical Model

The importance of having a proper mathematical description of the earth and vehicle, particularly during re-entry, is apparent. Although the vehicle has traversed thousands of miles since it was last observed, its position must be pinpointed within the beamwidth of the radar. Therefore, one system design goal was that it should never be necessary to scan the radar to acquire the vehicle, although scanning is utilized to increase the probability of acquisition.

Studies revealed that, for trajectories of intercontinental range, negligible error was introduced by neglecting the fourth harmonic term in the earth's gravitational equations [1]. The attraction of the sun and moon was also neglected.

Atmospheric drag terms enter the computations when the vehicle descends to 300,000 feet. The values of these terms are derived from the drag characteristics of the particular nose-cone and the 1959 ARDC model atmosphere [2]. Radar range and elevation are corrected for atmospheric refraction based on the surface index of refraction computed prior to the flight [3].

An inertial reference system was chosen for all major computations since in this system the differential equations have their simplest form. The familiar equation of motion in vector form becomes:

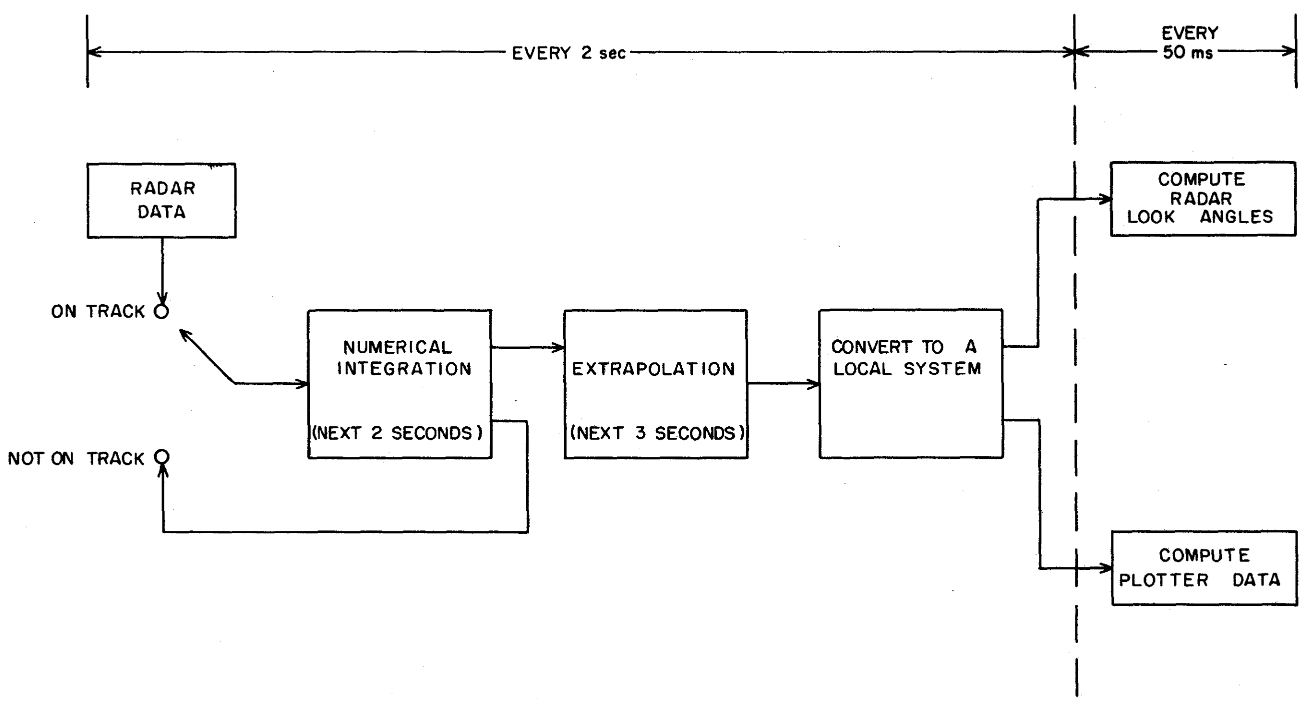


Figure 3. General Outline of Prediction Technique.

$$\ddot{\bar{R}} = \bar{G} - \bar{F}_D/m$$

where $\bar{R}$ is the position vector for the center of the earth

$\bar{G}$ is the earth gravitational force vector as "seen" by the vehicle at position $\bar{R}$. In this application $\bar{G}$ includes the second harmonic term.

$\bar{F}_D$ is the drag vector and has the form $-1/2 C_D \ \rho A \, Va \, \dot{\bar{R}}$

C_D is the drag coefficient, ρ is air density, A the cross-sectional area, Va the absolute value of vehicle velocity relative to the atmosphere, and $\dot{\bar{R}}$ the inertial velocity vector.

m is the mass of the vehicle.

Note in this equation that no lift or thrust terms are provided. Also, the vehicle is assumed to be both a point mass and a constant mass.

A fourth-order Runge-Kutta-Gill integration method was selected because of its self-starting ability and ability to change integration interval in a simple manner [4]. Since the method is basically a truncated Taylor-series expansion, the truncation error in the fourth-order integration is proportional to the fifth derivative of the integrated quantity. The fourth-order scheme makes four complete passes through the differential equations.

Processing of Raw Data

Raw radar data are collected for two seconds and fitted to a second-order polynomial by means of least-squares. This filtering and smoothing technique delivers midpoint values of radar range, azimuth, and elevation and their velocities, all valid at the filter midpoint.

Midpoint range and elevation are corrected for atmospheric refraction (the refraction error is considered constant over the 2-second period) and used in a "combination" technique. Before combination, two additional computations must be performed.

a. The variance (noise) of the raw range, azimuth, and elevation is estimated using second-order variate differences [5]. The velocity variance is considered proportional to position variance.

b. During the previous 2-second computation, the predicted position and velocity at the time t were computed by numerical integration and extrapolation. The variance of each of these quantities is also computed.

Two estimates of each parameter and the variance of each parameter are now available. If X_p, X_f are the predicted and filter midpoints respectively, and σ_p^2, σ_f^2 the variance of the predicted and filter midpoint, then the combined value and its noise are:

$$C = \frac{\left(1/\sigma_F^{\,2}\right) X_F + \left(1/K\sigma_P^{\,2}\right) X_P}{\left(1/\sigma_F^{\,2}\right) + \left(1/K\sigma_P^{\,2}\right)}$$

$$\sigma_C = \frac{1}{\left(1/\sigma_F^{\,2}\right) + \left(1/K\sigma_P^{\,2}\right)}$$

K multiplies the predicted variance, and was chosen as 1.35. Increasing the predicted variance tends to put more weight on the data from the filter.

The combined value is used as input to the numerical integration after conversion to inertial space. The results of the integration yield a new predicted parameter to be used on the following cycle; that is, after integration and coordinate conversion, C becomes the new X_p. The integration coordinate conversion also yields the σ_p that will accompany X_p.

It is thus evident that a particular X_F will indirectly enter into the combination scheme over and over again, with less weight each combination cycle because the data are getting older. Thus, the K constant controls the memory of the combination scheme; K = 1.35 weights the oldest data (18 filters old) at 1% of the entire span.

Program Organization

The computer program is organized into two parts: the initialization routine and the acquisition and tracking routine.

The initialization routine:

1. Accepts preliminary data via Teletype link;
2. Writes recovery tape;
3. Accepts in-flight message or lift-off time;
4. Develops the acquisition point.

The acquisition and tracking routine:

1. Accepts tracking information from the radar through the raw data buffer;
2. Provides designation data for the radar through the output converter;

3. Provides real-time trajectory data to the plotting boards and other instrumentation through the output converter;
4. Provides updated orbital parameters for downrange stations via the radio Teletype link;
5. Provides visual display of recommended scan mode and target range.

Each routine has its own executive routine which controls the subroutines necessary to perform its functions. As in all real-time systems, one basic problem is the sharing of time among different functions. The purpose of the executive routine is to allocate time to the various subroutines in such a manner that all functions may be performed in their proper sequences and within their time restrictions.

The basic time requirements considered in the program organization were:

1. To provide radar designation, plotter data, and visual display every 50 ms
2. To accept radar data every 50 ms
3. To maintain a 2-second prediction cycle
4. To be capable of transmitting up-dated orbital parameters downrange every 30 seconds

The computer is synchronized to range time through an external interrupt generated by the raw data buffer and output converter every 50 ms. Immediately after the program has been loaded into the computer from magnetic tape, the initialization executive routine assumes control and the following functions are performed:

1. Accept Preliminary Data

The following Teletype inputs are called for and accepted by local insertion:

a. Nominal Trajectory Message containing an inertial set at some point soon after burn-out for the theoretical trajectory; the delta time since lift-off at which the point is valid; and the physical characteristics of the nose cone.
b. Calibration Data consisting of corrections to be applied to radar data, as determined by pre-mission calibration.
c. Refraction Data consisting of temperature, barometric pressure, aqueous vapor pressure, from which the index of refraction is computed.
d. Plotting Board Scaling Data consisting of the origin and maximum values for the plotting board.

2. Write Recovery Tape

The entire program, including above inputs, is now written on magnetic tape and check-read for recovery purposes.

3. Accept In-Flight Message or Lift-Off Time

The program accepts either an in-flight message for some point soon after burn-out (which can be introduced directly through the Teletype linkage), or a locally inserted lift-off time and delta time will give a nominal starting point for the inertial set. A "ball park" check is made on the in-flight message, and if it fails, the operator has the option of continuing or inserting lift-off time to use the theoretical inertial set for a starting point. It should be noted that any recovery procedure will cause the program to jump to the point where the in-flight message or lift-off time can be introduced into the computer. Therefore, the initial steps through writing the recovery tape can be done many hours before the shot if it is advantageous to do so.

4. Develop Acquisition Point

The inertial set of the starting point is integrated ahead by 30-second steps. After each integration step, the range, range rate, and elevation of the point with respect to the radar are calculated as is the altitude of the point with respect to the subsatellite point. Various checks are made to determine whether the point is within acquisition range of the radar, or if the target will splash before it comes into acquisition range, or will not come into acquisition range for other reasons. If the program determines no acquisition is possible, the operator is notified and the program terminates. When the point is determined to be in the acquisition range of the radar, the input to the last 30-second integration step is used to integrate the point into the acquisition range of the radar by 2-second steps. The time of the last inertial set is then checked to determine if it is at least 4 seconds ahead of t_0. If the time of this point should fail this test, the integration is continued in 30-second steps if the point is outside the atmosphere (300,000 feet), or 5-second steps if it is in the atmosphere, until either the condition is satisfied or the program terminates due to a splash or out-of-range condition. The output of the last integration becomes the point of acquisition, and its associated time to is the acquisition time. Through integration, extrapolations coordinate conversion, and interpolation, all initial conditions required for the transition to the acquisition and tracking routine are developed. The designation data to the radar, plotter data, and visual displays for the acquisition point are then continuously buffered out to the output converter while t_0 is being checked against acquisition time, T. When t_0 and acquisition time are equal, control is transferred to the acquisition and tracking executive routine.

In analyzing the mathematical functions of acquisition and tracking, it becomes apparent that three basic repeating cycles of performance are involved:

1. A data cycle that occurs every 50 ms
2. A prediction cycle that occurs every 2 seconds
3. A transmission cycle that occurs every 30 seconds

The acquisition and tracking routine was therefore organized into three major tasks or routines to correspond to these cycles and perform the functions required:

1. 50-ms task
2. 2-second task
3. 30-second task

The three major tasks are controlled by the acquisition and tracking executive routine, which allocates time to the various subroutines in the proper order and at the proper time to permit the performance of these tasks without interference with each other. The Task Flow Chart in Figure 4 indicates the logic connecting the three tasks.

The data flow revolves around the mechanics of the filter and the combination of smoothed and predicted data. The filter takes every other piece of radar data over a 2-second span. The last point into one filter becomes the first point of the next filter. The output of the filter is at the midpoint of the span. The integration is arranged so that each step is time-correlated to the output of the associated filter. The predicted values for radar designation and plotting are interpolated between 3-second extrapolations of the outputs of the integration steps. At the time of acquisition (T), after control has been turned over to the acquisition and tracking executive routine, the following quantities are provided by the initialization routine:

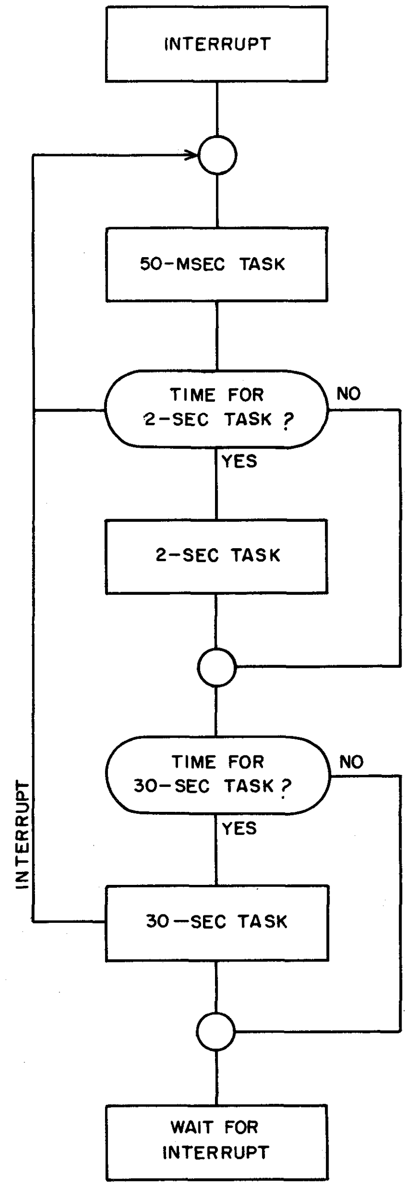


Figure 4. Task Organization of Acquisition and Tracking Routing.

1. A starting point for the integration valid at T-1 second.
2. Extrapolated points for both T and T+2 seconds.
3. Interpolated designation and plotting data at 50-ms intervals between T and T+2 seconds.

During the first 2 seconds in the acquisition and tracking routine, the following events occur:

1. Every other sample of radar data is applied to the filter;

2. The interpolated designation and plotting values between T and T+2 are outputted to the output converter at the time they are valid.

and concurrently:

3. An integration step from T-1 second to T+1 second is performed.
4. The output of the integration is extrapolated from T+1 second to T+4 seconds.
5. The extrapolated values for T+4 seconds and T+2 seconds are converted and interpolated for designation purposes.

At T+2 seconds, a new filter is started. The output of the previous filter is valid at T+1 second and corresponds to the output of the integration. The starting point of the new integration cycle is determined and the cycle is determined and the cycle repeats itself. At T+2 seconds, and every 30 seconds thereafter, the output of the integration is checked for transmittability, and if so, the downrange transmission is initiated.

Taking advantage of the range-time interrupt, the acquisition and tracking routine is able to use this feature as its sole source of control and timing. The internal computer clock is used to check for extraneous or missing interrupts. Each interrupt signals the start of a block of radar data through the raw buffer and automatically transfers control to the executive routine.

The various functions of the routine are ordered according to the following priority:

1. The interrupt routine (executive)
2. The 50-ms task
3. The 2-second task
4. The 30-second task
5. Wait (a passive subroutine executed after all other tasks are completed and the computer is awaiting the next interrupt).

The 50-ms task is initiated every time an interrupt is received. The 2-second task is initiated after every fortieth 50-ms task. The 30-second task is initiated after every fifteenth 2-second task. As noted below, the three tasks are performed in far less time than their nominal cycle times. Thus, the 2-second task can be performed in the time remaining from the 50-ms task.

Similarly, the 30-second task can be executed in the time remaining after the 50-ms and 2-second tasks have been completed.

The 50-ms task requires a maximum of 27.4 ms and an average of 17 ms. The 2-second task requires a maximum of 300 ms, and the 30-second task requires a maximum of 86 ms. Thus, an effective maximum of 35 ms per 50-ms interval is used. In other words, the computer is said to be loaded by no more than 70 per cent. The combination, integration, and extrapolation computations previously described require a maximum time of 155 ms exo-atmosphere and 186 ms endo-atmosphere. The total operational program is 12,000 instructions in length.

CONCLUSIONS

To date, three such data handling systems have been installed: at Station 12, as already described; at Station 13, near Johannesburg, South Africa; and at Station 9.1 on the Island of Antigua.

At this writing (Nov. 1962), the station at Ascension Island has successfully performed computer-aided acquisition, tracking, and reacquisition before and after reentry. Station 13, more recently installed acquired the Aurora 7 capsule on its last pass. Station 9.1 has also been tested successfully.

Many other functions and greater generality could be incorporated in the data-handling system. In the future, additional sophistication will not be optional but will be required because of the ever-increasing demands of both our space and military missions.

The most recent advance in range-tracking coverage results from the placing of tracking stations aboard ships. Here, in the calculation of acquisition data, the data-handling system must consider all ship motions which can affect the radar data. These include roll, pitch, navigation maneuvers, and even flexure of the ship which occurs between the inertial platform of the navigation equipment and the radar pedestal.

An obvious extension of downrange tracking stations is the ability to detect and measure the beginning or termination of thrust during orbit transfers and maneuvers. The implementation of this ability must await further study of signal-to-noise ratios and the sampled-data characteristics of the instrumentation. To detect low thrusts by means of tracking data alone requires very sensitive digital filters, but these take time to settle before giving an indication that thrust is detected (or terminated). This extra time (5 to 10 seconds) may easily be comparable to the thrust duration itself; hence one is fortunate to detect it, let alone measure it.

A possible solution is to receive telemetry measurements of acceleration from the Cape, but this entails decommutating and sorting a great mass of data and possibly converting analog-to-digital words suitable for computer input. These communication and data extraction problems are not known to have been solved on a real-time basis as yet.

Another attribute which will be realized some day is the assignment of some portion of the command and control function to the remote site, e.g., orbit transfer. With an "intelligent" program, certain parameters of the orbit can be measured and transmitted in error-correcting code back to the Cape via radio Teletype link. On the basis of these, the go-ahead can be teletyped back to make final measurements, check for additional deviations, check the control link, and finally to issue the command itself. The expected effects of the command can then be monitored, and predictions of the resulting orbit quickly made and relayed to other stations as well as the central control at the Cape. These are but a few of the enhancements that someday will be mandatory at such tracking stations.

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