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CONFERENCE ON COHERENT RADARS FOR RANGE INSTRUMENTATION

5-7 March 1974

Space and Missile Test Center
Vandenberg Air Force Base, California



KWAJALEIN MISSILE RANGE
WHITE SANDS MISSILE RANGE
YUMA PROVING GROUND

NAVAL WEAPONS CENTER
PACIFIC MISSILE RANGE
ATLANTIC FLEET WEAPONS RANGE
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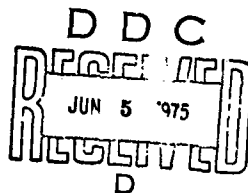
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**CONFERENCE ON
COHERENT RADARS FOR RANGE INSTRUMENTATION**

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**Space and Missile Test Center
Vandenberg Air Force Base, California**

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Range Commanders Council
White Sands Missile Range
New Mexico 88002**



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F. "Analytical Techniques and Results of Coherent Tracking of the THOR-DELTA and MINUTEMAN III" - Ginny Fagerlin, FEC	F-1
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INTRODUCTION

A conference on Coherent Radars for Range Instrumentation took place at the Space and Missile Test Center (SAMTEC), Vandenberg AFB, California, from 5-7 March 1974, under the aegis of Range Commanders Council Executive Committee Member Mr. Stan Radom (Technical Director, SAMTEC). The theme of the conference concerned "what has been the past performance and what is the future potential of Coherent Radars for test support instrumentation." In addition, emphasis was placed upon preparations for the upcoming GEOS-C launch.

This publication contains outlines and excerpts from the various conference briefings. Names and addresses of conference presenters precede each of these synopses. It is intended that this document provide a means for obtaining additional dialogue and input in the area of Coherent Radars.

UNOFFICIAL ATTENDANCE

NAME	ORGANIZATION	NAME	ORGANIZATION
Anders, Bill	TRW	G	
Allendorf, Jr	SAMTEC/ROMP	Gossett, Oscar	NWC
Baltzell, Leonard, Lt Col	SAMSO/MNN	Graves, Ken	SAMTEC/ROGE
Barber, David	Kentron	Green, Robert	WSMR
Bers, Larry, Maj	Def Mapping Agency	Greene, John	RCA/AFETR
Belgin, John	PMR	Guyton, Charles	PMR
Benn, Don	SAMTEC/ROSF	H	
Barbert, John	NASA	Hageman, Herman	Motorola
Bornholdt, John	RCA	Hagin, Dr.	FEC
Borrego, Arturo	WSMR	Hall, Edgar	FEC
Bowles, Lee	FEC	Hargrove, Wilbur, Maj	SAMSO/MNN
Brewer, Martin, Col	AFETR	Hass, Don	SAMTEC/ENI
Brooks, Dr.	FEC	Hawkins, William	NASA
Brooks, Ronald	EG&G	Hedricks, C. W.	SAMTEC/ACD
Bryant, J.C., Maj	SAMTEC/ROPR	Henry, Joe	Westinghouse
C		Hillhouse, Milton	AFETR
Cain, Jerome	PMR	Hoops, Leonard	FEC
Calhoun, John, Col	SAMTEC/RO	Hopkins, Dr.	FEC
Carney, DeVere	RCA	J	
Carpenter, Richard	PMR	Jackson, Ben	NASA
Chandler, Terry	Autonetics	Jantz, Jr	SAMTEC/ROSF
Chesebro, Ellsworth	SAMTEC/ENY	Jasen, F., Lt Col	SAMTEC/ROPR
Clin, Ball	WSMR	Johns, Milton	SAMTEC/ENI
Cianciotto, Andrew	TRW	Johnson, Roger, Col	SAMTEC/ROC
Cockerham, Frank	RCA/AFETR	Jones, Neil	SAMTEC/ROKE
Coleman, Lt Col (USAF)	Army/KRD	K	
Collins, Bill	FEC	Karbin, John	FEC
Conley, John, Col	SAMTEC/ROO	Keeney, Tom	Army/KRD
Cullen, Frank, Col	SAMTEC/ROP	Kennedy, John	RML/AFETR
Cuthbert, William	SAMTEC/ENI	Kennett, Grover	Motorola
D		Knox, Sidney	PMR
Does, D., Maj	SAMTEC/ROCA	Krabbenhoef, Bob	FEC
Dempsey, Donald	RCA	Krabill, Bill	NASA
Donohue, G.	SAMTEC/ROCA	Kranz, Edward	TRW
Dyal, T., Capt	SAMTEC/ROSO	Krieger, Bill	SAMTEC/ROMP
E		Kroeger, Otto	WSMF
Eaugh, Lawrence	AFETR	L	
Eckson, D.	SAMTEC/ROCA	Lambson, Richard	Motorola
F		Lanan, Lt Col	SAMTEC/XPP
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Favreau, Nelson	Motorola	LaVance, Cecil	Motorola
Ford, Thomas	PMR	Lichter, Dr.	FEC
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Frederick, John A.	PMR	Lyon, H.	SAMTEC/ROPR
Fuller, Ray	FED	M	
		Macy, Stephen	N Amer Rockwell/OOAMA

NAME	ORGANIZATION	NAME	ORGANIZATION
Manning, Walter	AFETR	T	FEC
Martin, John	ADTC	Tapp, Jim	SAMTEC/ROP
McGraw, William	SAMTEC/EN	Taylor, R	SAMSO/MNN
Mefford, C.W.	FEC	Thomason, Tom	FEC
Meer, M., Capt	SAMTEC/ROSO	Thompson, Dr.	SAMTEC/ENI
Meyers, R.L.	FEC	Thompson, William	PMR
Mitchell, Renzo	RCA	Tolman, Wallace	TRW
Mizuki, Dr.	FEC	Torres, Willis	
Moulds, T.	SAMTEC/ROST		
Myers, Robert	Boeing	W	
		Walsh, M.	FEC
N		Walters, Maj	6595MTG
Nefzgar, C., Capt	SAMTEC/ROCA	Warren, John	TRW
		Watts, Dwight	SAMTEC/XPP
P		Weinstein, G., LtCol	SAMTEC/ROS
Parker, Horace	RCA	Wells, William	EG&G
Pass, Jack	Army/KRD	Whitcombe, David	Aerospace
Paulus, Bill	Sandia Labs	Williams, Tal	FEC
Pease, C	SAMTEC/ROPP	Wilson, Gordon	PMR
Pike, Robert	NASA	Woosley, David	FEC
Porter, E., Lt Col	AFETR		
Preston, Robert, Lt	AFETR	Z	
Pryor, William	Vitro	Zirpoli, D	SAMTEC/ROK
R		ADDED NAMES	
Reck, Harold	SAMTEC/XPT	Myers, Robert G	Boeing, VAFB
Read, Gary	FEC	Webber, D.A.	TRW, Redondo Beach
Reif, Kenneth	RCA/AFETR	Wise, Wesley L.	FEC/ITT
Rickard, John	AFETR	Geisinger, R.	SAMTEC/ROS
Rollins, Clarence	AFETR	Toomey, R.	SAMTEC/ROS
Roy, Normand	EG&G	Morgan, Donald	Vega Corp
Roy, Russell	FEC	Patrick, John	Sandia Labs
		Spence, Robert	Sandia Labs
S		Viele, Donald	Boeing
Saladino, R.	SAMTEC/ROCA	Arlowe, Herbert	Sandia Labs
Samborsky, Lt Col	SAMTEC/XPD	Wood, Clyde	WSMR
Sayers, Herb	FEC	Herzog, T.	TRW
Schelonka, E., Lt Col	AFETR	Staicano, Capt	SAMTEC/ROP
Seastedt	SAMTEC/ENI	DeNicolai, Mr.	TRW
Selser, Alan	NASA	Butler, A.F.	TRW
Speer, Veri	TRW	Durham, C.	TRW
Spotts, Steve	WSMR	Samelka, F.	TRW
Staiger, R.J.	SAMTEC/XPD	Wilcox, L	TRW
Stanley, Ray	NASA	Haber, Jerry	J.H. Wiggins
Sylvestre, Hector	AFETR	Gabler, R.T.	J.H. Wiggins
		Boyles, Irvin	AFFTC
		Sehnert, P.J.	AFFTC
		Grinnel, F. Hugh	FEC
		Hines, Mr.	NASA

AGENDA

SAMTEC CONFERENCE ON COHERENT RADARS FOR RANGE INSTRUMENTATION

5-7 March 1974, Bldg 7000 Theatre
Vandenberg AFB, California

0900, 5 March

Coherent Radar as a Range and Range-Rate Instrumentation System —
Robert Green, White Sands Missile Range (WSMR)

Evaluation of Range-Rate Data —
Ball Chin, WSMR

Coherent Data Summary —
Bill Krabill, NASA

C-Band and TRANET Tracking Biases Relative to Collocated Lasers —
John Berbert, NASA

1330, 5 March

Influence of Range-Rate Data on ICBM Instantaneous Impact Prediction Errors —
Russell Roy, FEC

Doppler Track Evaluation--Operational Data —
Virginia Fagerlin, FEC

Coherent Signal Processing Experience at SAMTEC —
Bill Collins, FEC

Comments on SAMTEC Coherent Tracking Data —
Maj Tom Thomason, SAMSO

0900, 6 March

Problems Associated with Development of a Launch Head Range Safety System for
Containing ICBM Launches in the Kwajalein Lagoon Corridor —
Stan Radom, SAMTEC

Accuracy Requirements for Minuteman Ballistic Missile Tracking —
Maj Tom Thomason, SAMSO CLASSIFIED

Engineering Improvements for Coherent Radar Tracking —
Renzo Mitchell, RCA

GEOS-C Mission Objectives/Profile —
Ray Stanley, NASA

1330, 6 March

GEOS—C C-Band Data Handling —
Bill Krabill, NASA

GEOS—C C-Band Operations/Support —
Ben Jackson, NASA

GEOS—C Coherent C-Band Transponder Technical Characteristics —
Alan Selser, NASA

Defense Mapping Agency Test Objectives for GEOS-C —
Maj Larry Beers, DMA

Conference Summary and Group Discussion on "Where do we go from here?"

0900, 7 March

Meeting of members of GEOS—C C-Band Working Group —
Chairman, Ben Jackson, NASA

GENERAL INFORMATION

1. The telephone number to be used for receiving telephone messages is (AUTOVON 276-6190); (COMMERCIAL 805-866-6190). Telephone is located in the hall immediately outside the entrance to the theatre in Bldg 700C.

2. There will be a military bus available for use to and from the Officers Club for lunch.

3. Various telephone numbers are listed below:

Scheduled Airline Ticket Office (SATO), Rm C-105, Bldg 11777: 734-4381
Vandenberg Motel, Lompoc: 736-5605
Vandenberg Inn, Santa Maria: 922-6631
Village Inn, Vandenberg Village: 733-3571
Limousine Service to airport: 736-3636
Airways Rent-a-Car, Lompoc: 736-8521
Airways Rent-a-Car, Santa Maria: 922-1994
Hertz Rental Car, Santa Maria: 925-1306
Army Liaison Office: 276-7442/6907
NASA Western Office, SVAFB: 275-3024
Base Taxi: 276-5711

4. Mail can be received in care of the Technical Director, SAMTEC/CA, Vandenberg AFB, CA 93437

APPENDIX A

COHERENT RADAR AS A RANGE AND RANGE-RATE INSTRUMENTATION SYSTEM

BY

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And

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US Army White Sands Missile Range, New Mexico 88002

I. INTRODUCTION

US Army White Sands Missile Range (USAWSMR) has nine coherent radars in its instrumentation inventory. The locations of these radars were chosen to provide good geometry when this equipment is used as a range and range-rate instrumentation system. The measurements of range and range-rate have inherent properties which are desirable for instrumentation purposes. The magnitude of the errors present in these measurements are relatively independent of the distance to the target. This paper outlines the preliminary results of an evaluation of the USAWSMR coherent radars as a range and range-rate instrumentation system. Two methods of processing range and range-rate data were developed for this evaluation. The first method developed inputs range and range-rate from three or more coherent radars and outputs rectangular Cartesian components position and velocity. The second method inputs range and range-rate from three or more coherent radars, filters the range and range-rate data, performs a numerical differentiation to obtain range acceleration, and outputs rectangular Cartesian components of position, velocity, and acceleration. This paper includes a description of the techniques developed and an example of some data processed using the techniques.

II. POINT ESTIMATION - THREE STATIONS

In this section, the simple and geometrically pleasing notation of three dimensional vector analysis is used. The solutions obtained here are used in Sections III and IV to obtain start vectors for the Gauss-Newton iteration for the N-station data processing techniques.

Let O, A, B be three noncollinear points from which measurement of range to a point P is made. Let R_1 , R_2 , R_3 , respectively, denote the range from

O, A, B, respectively, to P, and \vec{A} , \vec{B} , respectively, the vectors from O to A, B, respectively. It is shown* that \vec{P} , the vector from O to P, is

$$\vec{P} = a\vec{A} + b\vec{B} + c\vec{C}, \quad \vec{C} = \vec{A} \times \vec{B}, \quad (2.1)$$

with

$$a = \frac{a|\vec{B}|^2 - b(\vec{A} \cdot \vec{B})}{|\vec{C}|^2}, \quad (2.2)$$

*Larry Armijo, "Determination of Trajectories Using Range Data From Three Noncollinear Radar Stations," US Army Signal Missile Support Agency, US Army White Sands Missile Range, NM, 1960.

$$b = \frac{\beta |\vec{A}|^2 - \alpha (\vec{A} \cdot \vec{B})}{|\vec{C}|^2}, \quad (2.3)$$

$$c = \frac{(R_1^2 - a\alpha - b\beta)^{1/2}}{|\vec{C}|}, \quad (2.4)$$

where

$$\alpha = \frac{1}{2}(R_1^2 - R_2^2 + |\vec{A}|^2), \quad (2.5)$$

$$\beta = \frac{1}{2}(R_1^2 - R_3^2 + |\vec{B}|^2). \quad (2.6)$$

With $(a_1^{(i)}, a_2^{(i)}, a_3^{(i)})^T$, $i = 1, 2, 3$, respectively, denoting the coordinate vector of \vec{A} , \vec{B} , \vec{C} , respectively, with respect to a rectangular Cartesian coordinate system with the same handedness as \vec{A} , \vec{B} , \vec{C} and with origin at O , (2.1) can be written as

$$x_1 = aa_1^{(1)} + ba_1^{(2)} + ca_1^{(3)}, \quad (2.7)$$

$$x_2 = aa_2^{(1)} + ba_2^{(2)} + ca_2^{(3)}, \quad (2.8)$$

$$x_3 = aa_3^{(1)} + ba_3^{(2)} + ca_3^{(3)}, \quad (2.9)$$

where $x = (x_1, x_2, x_3)^T$ is the coordinate vector of \vec{P} .

With ρ_1, ρ_2, ρ_3 , respectively, denoting the range measurements from O, A, B , respectively, to P the substitution of ρ_1, ρ_2, ρ_3 , respectively, for R_1, R_2, R_3 , respectively, lets one compute the corresponding rectangular coordinates of P from (2.7), (2.8), (2.9).

Differentiating in (2.7), (2.8), and (2.9)

$$\dot{x}_1 = \dot{a}a_1^{(1)} + \dot{b}a_1^{(2)} + \dot{c}a_1^{(3)}, \quad (2.10)$$

$$\dot{x}_2 = \dot{a}a_2^{(1)} + \dot{b}a_2^{(2)} + \dot{c}a_2^{(3)} \quad , \quad (2.11)$$

$$\dot{x}_3 = \dot{a}a_3^{(1)} + \dot{b}a_3^{(2)} + \dot{c}a_3^{(3)} \quad , \quad (2.12)$$

where (from differentiating in (2.2), (2.3), and (2.4))

$$\dot{a} = [\dot{\vec{a}}|\vec{c}|^2 - \dot{\vec{b}}(\vec{A} \cdot \vec{B})]/|\vec{C}|^2 \quad , \quad (2.13)$$

$$\dot{b} = [\dot{\vec{b}}|\vec{A}|^2 - \dot{\vec{a}}(\vec{A} \cdot \vec{B})]/|\vec{C}|^2 \quad , \quad (2.14)$$

$$\dot{c} = (2R_1\dot{R}_1 - \dot{a}c - b\dot{b} - a\dot{a} - b\dot{b})/(2c|\vec{C}|) \quad , \quad (2.15)$$

with (from (2.5) and (2.6))

$$\dot{a} = R_1\dot{R}_1 - R_2\dot{R}_2 \quad , \quad (2.16)$$

$$\dot{b} = R_1\dot{R}_1 - R_3\dot{R}_3 \quad . \quad (2.17)$$

If in addition to ρ_1, ρ_2, ρ_3 measurements of range rate, $\dot{\rho}_1, \dot{\rho}_2, \dot{\rho}_3$ are available, (2.10), (2.11), and (2.12) can be used to compute $\dot{x}_1, \dot{x}_2, \dot{x}_3$.

Differentiating again,

$$\ddot{x}_1 = \ddot{a}a_1^{(1)} + \ddot{b}a_1^{(2)} + \ddot{c}a_1^{(3)} \quad , \quad (2.18)$$

$$\ddot{x}_2 = \ddot{a}a_2^{(1)} + \ddot{b}a_2^{(2)} + \ddot{c}a_2^{(3)} \quad , \quad (2.19)$$

$$\ddot{x}_3 = \ddot{a}a_3^{(1)} + \ddot{b}a_3^{(2)} + \ddot{c}a_3^{(3)} \quad , \quad (2.20)$$

where

$$\ddot{a} = [\dot{a}|\vec{B}|^2 - \ddot{B}(\vec{A} \cdot \vec{B})]/|\vec{C}|^2, \quad (2.21)$$

$$\ddot{b} = [\dot{b}|\vec{A}|^2 - \ddot{A}(\vec{A} \cdot \vec{B})]/|\vec{C}|^2, \quad (2.22)$$

$$\ddot{c} = \frac{[2(R_1\ddot{R}_1 + \ddot{R}_1^2) - \alpha\ddot{a} - 2\alpha\dot{a} - \dot{a}\dot{a} - \beta\ddot{b} - 2\beta\dot{b} - \dot{b}\dot{b} - 2\dot{c}^2|\vec{C}|^2]}{2c|\vec{C}|^2}, \quad (2.23)$$

and

$$\ddot{a} = R_1\ddot{R}_1 + \dot{R}_1^2 - R_2\ddot{R}_2 - \dot{R}_2^2, \quad (2.24)$$

$$\ddot{b} = R_1\ddot{R}_1 + \dot{R}_1^2 - R_3\ddot{R}_3 - \dot{R}_3^2. \quad (2.25)$$

With measurements $\dot{\rho}_1, \dot{\rho}_2, \dot{\rho}_3$ also available, (2.18), (2.19), and (2.20) can be used to compute $\ddot{x}_1, \ddot{x}_2, \ddot{x}_3$.

III. GAUSS-NEWTON POINT ESTIMATION - N-STATIONS

In Section II, it was convenient to use the three dimensional vector analysis notation. We now change to a more general notation, leading to a systematic formulation of the Gauss-Newton method for solving the N-station problem.

Let $A_i, i = 1, 2, \dots, N$, denote the points at which the stations are located and $a_1^{(i)}, a_2^{(i)}, a_3^{(i)}$, respectively, the first, second, third, respectively, coordinates of A_i with respect to a right-handed coordinate system, so that the coordinate vector of A_i is

$$a^{(i)} = (a_1^{(i)}, a_2^{(i)}, a_3^{(i)})^T.$$

Let

$$x = (x_1, x_2, x_3)^T$$

denote the coordinate vector of P. Let

$$R = (R_1, R_2, \dots, R_N)^T, \quad (3.1)$$

where the components of R are the ranges from A_i to P, given by

$$R_i = \left[\sum_{k=1}^3 (x_k - a_k^{(i)})^2 \right]^{1/2}. \quad (3.2)$$

(Notice that (3.1) and (3.2) give R explicitly as a function of x. We will sometimes use $R(x)$ for this function. Formulas for various derivatives associated with (3.2) are given in Appendix A.)

Three problems in point estimation are posed, and their solution by the Gauss-Newton iteration described. A brief description of the Gauss-Newton iteration is given in Appendix B.

PROBLEM 3.1

Given $\rho = (\rho_1, \rho_2, \dots, \rho_N)^T$, a vector whose i^{th} component is a (noisy) measurement of the range from A_i to P, find an estimate of x.

PROBLEM 3.2

Given ρ as in Problem 3.1, and $\dot{\rho}$, an N-vector whose i^{th} component is a noisy measurement of the time derivative of the range from A_i to P, find an estimate of x and \dot{x} .

PROBLEM 3.3

Given ρ and $\dot{\rho}$ as in Problem 3.2 and $\ddot{\rho}$ an N-vector whose i^{th} component is a noisy measurement of the second time derivative of the range from A_i to P, find an estimate of x, \dot{x} , and \ddot{x} .

The description in Appendix B of the Gauss-Newton estimate is phrased so as to include these three problems as special cases. For each of the problems we first identify the appropriate vectors of the problem with the vectors m, u, f. The elements of the corresponding $F(u)$ are then obtained from Appendix A and the start vector from Section II.

For Problem 3.1,

$$m = \rho, \quad u = x, \quad f(u) = R(x),$$

and the start vector, $u^{(0)}$, is obtained from (2.7), . . . , (2.9) with R_1 , R_2 , R_3 replaced by ρ_1 , ρ_2 , ρ_3 in (2.2), . . . , (2.6).

For Problem 3.2,

$$m = \begin{pmatrix} \rho \\ \dot{\rho} \end{pmatrix}, \quad u = \begin{pmatrix} x \\ \dot{x} \end{pmatrix}, \quad f(u) = \begin{pmatrix} R(x) \\ \dot{R}(x, \dot{x}) \end{pmatrix},$$

and the start vector, $u^{(0)}$, is obtained by extending the above start vector by replacing R_1 , R_2 , R_3 by $\dot{\rho}_1$, $\dot{\rho}_2$, $\dot{\rho}_3$ in (2.13), . . . , (2.17) and computing $\dot{x}^{(0)}$ from (2.10), . . . , (2.12).

For Problem 3.3,

$$m = \begin{pmatrix} \rho \\ \dot{\rho} \\ \ddot{\rho} \end{pmatrix}, \quad u = \begin{pmatrix} x \\ \dot{x} \\ \ddot{x} \end{pmatrix}, \quad f(u) = \begin{pmatrix} R(x) \\ \dot{R}(x, \dot{x}) \\ \ddot{R}(x, \dot{x}, \ddot{x}) \end{pmatrix},$$

and the start vector, $u^{(0)}$, is obtained by extending the $u^{(0)}$ of Problem 3.2 by means of Equations (2.18), . . . , (2.25).

It is worth noting that for Problem 3.2, the objective function involves both ρ and $\dot{\rho}$. Hence, \hat{x} , the estimate of position for this problem depends on range-rate measurements as well as on range measurements. For Problem 3.3, the objective function involves ρ , $\dot{\rho}$, and $\ddot{\rho}$. In this case, \hat{x} and $\dot{\hat{x}}$, the estimate of position and velocity depends on range, range-rate, and range acceleration measurements. This attribute provides for additional redundancy in the estimation of position in the case of Problem 3.2, and position and velocity for Problem 3.3 that would not be used if position, velocity, and acceleration were estimated sequentially.

IV. RANGE AND RANGE-RATE FILTERING AND DIFFERENTIATION

Measurements of range acceleration are not normally available from the coherent radars at USAWSMR. In order to use the estimation technique described as Problem 3.3 in Section III of this paper, it is necessary to have estimates of range acceleration. This information was derived using a numerical differentiation technique. We chose to do the smoothing and differentiation on the measurements instead of the components of position

and velocity to avoid correlation in the error statistics of the data being filtered. It also permits the use of additional redundancy in the point estimation process. The filtering process developed makes use of "a priori" information. In post flight data processing, it is relatively easy to make use of "a priori" information and the improvement in data quality is dramatic. In processing orbital information, the use of "a priori" information is a standard practice. Most of the data generated at USAWSMR is from powered flight or intra-atmospheric free-flight. This makes the use of differential equations of motion for "a priori" information very difficult. Since the process we developed requires that each set of range and range-rate measurements be filtered, the filter process is not optimal but was chosen to provide near optimal filtering that also provides computational efficiency. The process developed during this study is a recursive filter which uses a cubic spline as the predictor. The "a priori" information about the trajectory is introduced as a step function for the third derivative. Integration of this step function is used to derive a predicted trajectory. This prediction is combined with the measured range and range-rate data to provide filtered estimates of range, range-rate, and range acceleration. The filtering process is described as follows.

Let J_1, J_2, \dots, J_M be the set of M steps of a step function that approximate the third derivative profile of the trajectory under consideration.

Let T_1, T_2, \dots, T_M be the set of time intervals over which the estimated acceleration rates J_1, J_2, \dots, J_M are used, respectively.

Let δt be the time interval between data samples.

Let A_0, V_0 , and P_0 be the initial values of range acceleration, range-rate, and range, respectively. The predicted range acceleration is given by

$$A_k = J_j(\delta t) + A_{k-1} \quad (4.1)$$

The predicted range-rate is generated using

$$V_k = \frac{[J_j(\delta t)^2]}{2} + A_{k-1}(\delta t) + V_{k-1} \quad (4.2)$$

The predicted range values are obtained using

$$P_k = \frac{[J_j(\delta t)^3]}{6} + \frac{[A_{k-1}(\delta t)^2]}{2} + V_{k-1}(\delta t) + P_{k-1} \quad (4.3)$$

where $j = 1, 2, 3, \dots, M$.

The filter is mechanized to provide estimates of range, range-rate, and range acceleration that are a weighted average of the present measurement and a prediction based on the previous estimate and the acceleration rate profile. The values used for the measured range acceleration are generated using the equation

$$\ddot{R}_k = \frac{(\dot{R}_k - \dot{R}_{k-1})}{(\delta t)} + 0.5J_1(\delta t) \quad (4.4)$$

The filtered estimates of range, range-rate, and range acceleration are generated using the equations

$$\hat{R}_k = \ddot{R}_k(w_1) + (J_1(\delta t) + \hat{R}_{k-1})(1 - w_1) \quad (4.5)$$

$$\hat{\dot{R}}_k = \dot{R}_k(w_2) + \left(\frac{J_1(\delta t)^2}{2} + \hat{\dot{R}}_{k-1}(\delta t) + \hat{R}_{k-1}\right)(1 - w_2) \quad (4.6)$$

$$\hat{\ddot{R}}_k = \ddot{R}_k(w_3) + \left(\frac{J_1(\delta t)^3}{6} + \frac{\hat{\ddot{R}}_{k-1}(\delta t)^2}{2} + \hat{\dot{R}}_{k-1}(\delta t) + \hat{R}_{k-1}\right)(1 - w_3) \quad (4.7)$$

where w_1 , w_2 , w_3 are weighting values. These weighting values are chosen empirically based on the trajectory being processed. The filtering process just described operates on a series of range and range-rate measurements as a function of time, while the point estimation techniques described in Sections II and III of this paper operate on a collection of measurements from several stations at a single point in time.

V. RANGE AND RANGE-RATE DATA PROCESSING RESULTS

The techniques displayed in this paper were applied to a set of data collected at USAWSMR on 12 September 1973 (Appendix C). The data was collected by three coherent radars tracking a LOKI Sphere. This test provides a very good radar target. An aluminized mylar balloon one meter in diameter is ejected at high altitude. Radar is the only instrumentation available at USAWSMR that can collect data on this target. This limitation makes assessment of data accuracy very difficult.

A segment of data 130 seconds long was processed using the range and range-rate point estimation technique. This data was encoded at 20 samples per second and then averaged to 5 samples per second. No other smoothing was

performed on this data. The first 20 seconds of this data contains some errors. It should be noticed that the errors are not propagated along the trajectory using this technique. The remaining 110 second segment of data is free of ambiguities. This 110 second segment was processed using the recursive filter to smooth the range and range-rate data and generate the required range acceleration data. A comparison of the position and velocity data generated by the two processes shows that filtering of the range and range-rate data did not change these results significantly. The acceleration data generated is smooth and represents the kind of accelerations that one might intuitively expect this vehicle to undergo. Visual comparisons with the range user's single radar data reduction indicated good agreement. The following table shows the "a priori" information that was used to obtain the acceleration estimates.

TABLE 5.1 "A PRIORI" ESTIMATES OF RANGE ACCELERATION RATE

Time Interval	Radar 354 \ddot{R}_1 (ft/sec ³)	Radar 123 \ddot{R}_2 (ft/sec ³)	Radar 352 \ddot{R}_3 (ft/sec ³)
20	.573	.720	.492
20	1.746	2.937	4.503
20	-.990	-1.701	-2.178
20	-.513	-.666	-1.023
20	.009	-.063	-.138
10	.120	.126	.018

Notice that the "a priori" information used is simple. Evaluations of this technique that have been performed at USAWSMR indicate that this filter is not particularly sensitive to errors in the "a priori" information. It appears that the coherent radars are capable of producing high quality trajectory data when they are operated as a range and range-rate instrumentation system.

VI. SUMMARY

This paper has presented data processing methods that are applicable to coherent radar when used as a range and range-rate instrumentation system. A technique for smoothing and differentiating range and range-rate data has been presented. This technique permits "a priori" trajectory information to be used easily and with high computational efficiency. A description of point estimation techniques that can be

used to obtain rectangular Cartesian components of position, velocity, and acceleration from range and range-rate measurements is included. A description of results obtained from application of the techniques described in this paper to actual flight test data is included. Analysis of the data obtained indicates that coherent radars are a potential source of very good quality trajectory data when used as a range and range-rate instrumentation system.

APPENDIX A
VARIOUS DERIVATIVE FORMULAS

Various derivatives needed in the point estimation problems of Section III are obtained here.

The basic range equation is

$$R_1^2 = \sum_{k=1}^3 (x_k - a_k^{(1)})^2 \quad (A.1)$$

Successively differentiating with respect to time,

$$R_1 \dot{R}_1 = \sum_{k=1}^3 \dot{x}_k (x_k - a_k^{(1)}) \quad (A.2)$$

$$\dot{R}_1^2 + R_1 \ddot{R}_1 = \sum_{k=1}^3 [\ddot{x}_k (x_k - a_k^{(1)}) + \dot{x}_k^2] \quad (A.3)$$

Differentiating (A.1) with respect to x_j , \dot{x}_j , \ddot{x}_j yields

$$R_1 \frac{\partial R_1}{\partial x_j} = \sum_{k=1}^3 (x_k - a_k^{(1)}) \delta_{kj} = x_j - a_j^{(1)} \quad (A.4)$$

$$\frac{\partial R_1}{\partial \dot{x}_j} = 0 \quad (A.5)$$

$$\frac{\partial R_1}{\partial \ddot{x}_j} = 0 \quad (A.6)$$

Differentiating (A.2) with respect to x_j , \dot{x}_j , \ddot{x}_j and using (A.5) and (A.6),

$$\frac{\partial R_1}{\partial x_j} \dot{R}_1 + R_1 \frac{\partial \dot{R}_1}{\partial x_j} = \dot{x}_j \quad (A.7)$$

$$R_1 \frac{\partial \dot{R}_1}{\partial \dot{x}_j} = x_j - a_k^{(1)} \quad , \quad (A.8)$$

$$\frac{\partial \dot{R}_1}{\partial \ddot{x}_j} = 0 \quad . \quad (A.9)$$

Differentiating (A.3) with respect to x_j , \dot{x}_j , \ddot{x}_j and using (A.5), (A.6), and (A.9),

$$2\dot{R}_1 \frac{\partial \dot{R}_1}{\partial x_j} + \frac{\partial R_1}{\partial x_j} R_1 + R_1 \frac{\partial \ddot{R}_1}{\partial x_j} = \ddot{x}_j \quad , \quad (A.10)$$

$$2\dot{R}_1 \frac{\partial \dot{R}_1}{\partial \dot{x}_j} + R_1 \frac{\partial \ddot{R}_1}{\partial \dot{x}_j} = 2\dot{x}_j \quad , \quad (A.11)$$

$$R_1 \frac{\partial \ddot{R}_1}{\partial \ddot{x}_j} = x_j - a_j^{(1)} \quad . \quad (A.12)$$

From (A.1), . . . , (A.12) successively,

$$R_1 = \left[\sum_{k=1}^3 (x_k - a_k^{(1)})^2 \right]^{1/2} \quad , \quad (A.13)$$

$$\dot{R}_1 = \frac{1}{R_1} \sum_{k=1}^3 \dot{x}_k (x_k - a_k^{(1)}) \quad , \quad (A.14)$$

$$\ddot{R}_1 = \frac{1}{R_1} \left(\sum_{k=1}^3 [\ddot{x}_k (x_k - a_k^{(1)}) + \dot{x}_k^2] - \dot{R}_1^2 \right) \quad , \quad (A.15)$$

$$\frac{\partial R_1}{\partial x_j} = \frac{1}{R_1} (x_j - a_j^{(1)}) \quad , \quad (A.16)$$

$$\frac{\partial R_1}{\partial \dot{x}_j} = 0 \quad , \quad (A.17)$$

$$\frac{\partial \dot{R}_i}{\partial \ddot{x}_j} = 0 \quad , \quad (A.18)$$

$$\frac{\partial \dot{R}_i}{\partial \dot{x}_j} = -\frac{1}{R_i} (\dot{x}_j - \frac{\partial R_i}{\partial \dot{x}_j}) \quad , \quad (A.19)$$

$$\frac{\partial \dot{R}_i}{\partial \dot{x}_j} = -\frac{1}{R_i} (x_j - a_j^{(1)}) \quad , \quad (A.20)$$

$$\frac{\partial \ddot{R}_i}{\partial \ddot{x}_j} = 0 \quad , \quad (A.21)$$

$$\frac{\partial \ddot{R}_i}{\partial \dot{x}_j} = \frac{1}{R_i} (\ddot{x}_j - 2\dot{R}_i \frac{\partial \dot{R}_i}{\partial \dot{x}_j} - \frac{\partial R_i}{\partial \dot{x}_j} \ddot{R}_i) \quad , \quad (A.22)$$

$$\frac{\partial \ddot{R}_i}{\partial \dot{x}_j} = \frac{1}{R_i} (2\dot{x}_j - 2\dot{R}_i \frac{\partial \dot{R}_i}{\partial \dot{x}_j}) \quad , \quad (A.23)$$

$$\frac{\partial \ddot{R}_i}{\partial \dot{x}_j} = \frac{1}{R_i} (x_j - a_j^{(1)}) \quad . \quad (A.24)$$

From the above formulas, we can form various Jacobian matrices. For example, with \ddot{R} written $\ddot{R}(u) = \ddot{R}(x, \dot{x}, \ddot{x})$, where $u^T = (x^T, \dot{x}^T, \ddot{x}^T)^T$ and $\partial \ddot{R}(u)/\partial x$ the N , 3 dimensional matrix whose element in the i^{th} row and j^{th} column is $\partial \ddot{R}_i / \partial \dot{x}_j$, the elements of $\partial \ddot{R} / \partial \dot{x}$ are given by (A.23).

APPENDIX B

GAUSS-NEWTON ITERATION

A Gauss-Newton iteration general enough for the problems of Section III is described without discussion of its limitation.

Let u denote a $p, 1$ vector of independent real variables and f , or $f(u)$, a vector valued function of dimension q , $p \leq q$. Let m denote a $q, 1$ dimensional constant vector. Consider the equation

$$m = f(u) \quad (B.1)$$

u is a least squares solution if \hat{u} minimizes the objective function

$$T(u) = ||m - f(u)||^2 = \sum_{i=1}^q (m_i - f_i(u))^2 \quad (B.2)$$

If m is a measurement vector, we will say the \hat{u} is a Gauss estimate of u for the measurement m .

The Gauss-Newton iteration is described as follows.

$$\hat{u}(u, \delta) \stackrel{D}{=} ||m - f(u) - F(u)\delta||^2 \quad (B.3)$$

where $F(u)$ is the q, p dimensional matrix such that the element in the i^{th} row and j^{th} column is

$$\frac{\partial f_i}{\partial u_j}(u) = \frac{\partial f_i(u)}{\partial u_j} \quad .$$

With $u^{(i-1)}$ a given vector, let $\delta^{(i)}$ denote the vector of least norm which minimizes $\hat{T}(u^{(i-1)}, \delta)$. We consider only the case where

$$\delta^{(i)} = F(u^{(i-1)})^+(m - f(u^{(i-1)})) \quad (B.4)$$

where

$$F(u^{(i-1)})^+ = [F(u^{(i-1)})^T F(u^{(i-1)})]^{-1} F(u^{(i-1)})^T \quad (B.5)$$

With $u^{(0)}$ a given start vector, the iteration is

$$\delta^{(i)} = F(u^{(i-1)})^+(m - f(u^{(i-1)})) ,$$

$$u^{(i)} = u^{(i-1)} + \delta^{(i)} , \quad i = 1, 2, \dots$$

If $\{u^{(i)}\}$ converges, say to \tilde{u} , we say \tilde{u} is a Gauss-Newton estimate of u for the measurement m . In computation, a way to stop the iteration must be used. With $u^{(r)}$ the last computed iterate we use

$$\hat{u} \approx \tilde{u} \approx u^{(r)} .$$

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TIME	X	Y	Z	X	Y	Z	X	Y	Z	DATE 101073	X	Y	Z	PAGE
101 SPT 10 SEPT SHOOTED # AND ROOT														7
23400-125	-07702-09	28549-114	272045-75	-152-99	832-13	-250-38	9-23	-132-33	19-20					
23400-124	-07701-09	28563-144	272052-75	-152-61	836-27	-250-38	3-23	-133-54	20-79					
23400-123	-07700-09	28601-3-00	272053-48	-158-77	836-92	-252-52	9-09	-133-92	21-39					
23400-122	-07699-09	28615-61-1	272054-48	-158-77	836-92	-252-52	9-09	-133-92	21-39					
23400-121	-07698-09	28630-10	272055-47	-154-21	831-11	-252-52	9-09	-134-29	22-47					
23400-120	-07697-09	28645-12	272056-47	-154-12	828-26	-252-52	9-09	-134-50	23-34					
23400-119	-07696-09	28660-15	272057-46	-155-87	823-01	-252-52	9-09	-134-50	24-25					
23400-118	-07695-09	28675-18	272058-45	-155-87	823-01	-252-52	9-09	-134-50	25-12					
23400-117	-07694-09	28690-21	272059-44	-155-87	823-01	-252-52	9-09	-134-50	26-03					
23400-116	-07693-09	28705-24	272060-43	-155-87	823-01	-252-52	9-09	-134-50	26-35					
23400-115	-07692-09	28720-27	272061-42	-155-87	823-01	-252-52	9-09	-134-50	27-26					
23400-114	-07691-09	28735-30	272062-41	-155-87	823-01	-252-52	9-09	-134-50	28-17					
23400-113	-07690-09	28750-33	272063-40	-155-87	823-01	-252-52	9-09	-134-50	29-08					
23400-112	-07689-09	28765-36	272064-39	-155-87	823-01	-252-52	9-09	-134-50	29-99					
23400-111	-07688-09	28780-39	272065-38	-155-87	823-01	-252-52	9-09	-134-50	30-90					
23400-110	-07687-09	28795-42	272066-37	-155-87	823-01	-252-52	9-09	-134-50	31-81					
23400-109	-07686-09	28810-45	272067-36	-155-87	823-01	-252-52	9-09	-134-50	32-72					
23400-108	-07685-09	28825-48	272068-35	-155-87	823-01	-252-52	9-09	-134-50	33-63					
23400-107	-07684-09	28840-51	272069-34	-155-87	823-01	-252-52	9-09	-134-50	34-54					
23400-106	-07683-09	28855-54	272070-33	-155-87	823-01	-252-52	9-09	-134-50	35-45					
23400-105	-07682-09	28870-57	272071-32	-155-87	823-01	-252-52	9-09	-134-50	36-36					
23400-104	-07681-09	28885-60	272072-31	-155-87	823-01	-252-52	9-09	-134-50	37-27					
23400-103	-07680-09	28900-63	272073-30	-155-87	823-01	-252-52	9-09	-134-50	38-18					
23400-102	-07679-09	28915-66	272074-29	-155-87	823-01	-252-52	9-09	-134-50	39-09					
23400-101	-07678-09	28930-69	272075-28	-155-87	823-01	-252-52	9-09	-134-50	40-00					
23400-100	-07677-09	28945-72	272076-27	-155-87	823-01	-252-52	9-09	-134-50	40-91					
23400-099	-07676-09	28960-75	272077-26	-155-87	823-01	-252-52	9-09	-134-50	41-82					
23400-098	-07675-09	28975-78	272078-25	-155-87	823-01	-252-52	9-09	-134-50	42-73					
23400-097	-07674-09	28990-81	272079-24	-155-87	823-01	-252-52	9-09	-134-50	43-64					
23400-096	-07673-09	29005-84	272080-23	-155-87	823-01	-252-52	9-09	-134-50	44-55					
23400-095	-07672-09	29020-87	272081-22	-155-87	823-01	-252-52	9-09	-134-50	45-46					
23400-094	-07671-09	29035-90	272082-21	-155-87	823-01	-252-52	9-09	-134-50	46-37					
23400-093	-07670-09	29050-93	272083-20	-155-87	823-01	-252-52	9-09	-134-50	47-28					
23400-092	-07669-09	29065-96	272084-19	-155-87	823-01	-252-52	9-09	-134-50	48-19					
23400-091	-07668-09	29080-99	272085-18	-155-87	823-01	-252-52	9-09	-134-50	49-10					
23400-090	-07667-09	29095-102	272086-17	-155-87	823-01	-252-52	9-09	-134-50	50-01					
23400-089	-07666-09	29110-105	272087-16	-155-87	823-01	-252-52	9-09	-134-50	50-92					
23400-088	-07665-09	29125-108	272088-15	-155-87	823-01	-252-52	9-09	-134-50	51-83					
23400-087	-07664-09	29140-111	272089-14	-155-87	823-01	-252-52	9-09	-134-50	52-74					
23400-086	-07663-09	29155-114	272090-13	-155-87	823-01	-252-52	9-09	-134-50	53-65					
23400-085	-07662-09	29170-117	272091-12	-155-87	823-01	-252-52	9-09	-134-50	54-56					
23400-084	-07661-09	29185-120	272092-11	-155-87	823-01	-252-52	9-09	-134-50	55-47					
23400-083	-07660-09	29200-123	272093-10	-155-87	823-01	-252-52	9-09	-134-50	56-38					
23400-082	-07659-09	29215-126	272094-09	-155-87	823-01	-252-52	9-09	-134-50	57-29					
23400-081	-07658-09	29230-129	272095-08	-155-87	823-01	-252-52	9-09	-134-50	58-20					
23400-080	-07657-09	29245-132	272096-07	-155-87	823-01	-252-52	9-09	-134-50	59-11					
23400-079	-07656-09	29260-135	272097-06	-155-87	823-01	-252-52	9-09	-134-50	60-02					
23400-078	-07655-09	29275-138	272098-05	-155-87	823-01	-252-52	9-09	-134-50	60-93					
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23400-076	-07653-09	29305-144	272100-03	-155-87	823-01	-252-52	9-09	-134-50	62-75					
23400-075	-07652-09	29320-147	272101-02	-155-87	823-01	-252-52	9-09	-134-50	63-66					
23400-074	-07651-09	29335-150	272102-01	-155-87	823-01	-252-52	9-09	-134-50	64-57					
23400-073	-07650-09	29350-153	272103-00	-155-87	823-01	-252-52	9-09	-134-50	65-48					
23400-072	-07649-09	29365-156	272104-99	-155-87	823-01	-252-52	9-09	-134-50	66-39					
23400-071	-07648-09	29380-159	272105-98	-155-87	823-01	-252-52	9-09	-134-50	67-30					
23400-070	-07647-09	29395-162	272106-97	-155-87	823-01	-252-52	9-09	-134-50	68-21					
23400-069	-07646-09	29410-165	272107-96	-155-87	823-01	-252-52	9-09	-134-50	69-12					
23400-068	-07645-09	29425-168	272108-95	-155-87	823-01	-252-52	9-09	-134-50	70-03					
23400-067	-07644-09	29440-171	272109-94	-155-87	823-01	-252-52	9-09	-134-50	70-94					
23400-066	-07643-09	29455-174	272110-93	-155-87	823-01	-252-52	9-09	-134-50	71-85					
23400-065	-07642-09	29470-177	272111-92	-155-87	823-01	-252-52	9-09	-134-50	72-76					
23400-064	-07641-09	29485-180	272112-91	-155-87	823-01	-252-52	9-09	-134-50	73-67					
23400-063	-07640-09	29500-183	272113-90	-155-87	823-01	-252-52	9-09	-134-50	74-58					
23400-062	-07639-09	29515-186	272114-89	-155-87	823-01	-252-52	9-09	-134-50	75-49					
23400-061	-07638-09	29530-189	272115-88	-155-87	823-01	-252-52	9-09	-134-50	76-40					
23400-060	-07637-09	29545-192	272116-87	-155-87	823-01	-252-52	9-09	-134-50	77-31					
23400-059	-07636-09	29560-195	272117-86	-155-87	823-01	-252-52	9-09	-134-50	78-22					
23400-058	-07635-09	29575-198	272118-85	-155-87	823-01	-252-52	9-09	-134-50	79-13					
23400-057	-07634-09	29590-201	272119-84	-155-87	823-01	-252-52	9-09	-134-50	80-04					
23400-056	-07633-09	29605-204	272120-83	-155-87	823-01	-252-52	9-09	-134-50	80-95					
23400-055	-07632-09	29620-207	272121-82	-155-87	823-01	-252-52	9-09	-134-50	81-86					
23400-054	-07631-09	29635-210	272122-81	-155-87	823-01	-252-52	9-09	-134-50	82-77					
23400-053	-07630-09	29650-213	272123-80	-155-87	823-01	-252-52	9-09	-134-50	83-68					
23400-052	-07629-09	29665-216	272124-79	-155-87	823-01	-252-52	9-09	-134-50	84-59					
23400-051	-07628-09	29680-219	272125-78	-155-87	823-01	-252-52	9-09	-134-50	85-50					
23400-050	-07627-09	29695-222	272126-77	-155-87	823-01	-252-52	9-09	-134-50	86-41					
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73480.725	-99359.51	298276.44	234674.74	-38.86	101.00	-2387.65	-38.86	101.00	-2387.65	10-74	2.84	-21.68	42.40	
73490.725	-99354.35	298324.64	234795.29	-39.19	97.24	-2418.30	-39.19	97.24	-2418.30	10-74	2.81	-21.75	42.40	
73500.725	-99349.19	298372.84	234915.84	-39.52	93.48	-2448.95	-39.52	93.48	-2448.95	10-74	2.78	-21.82	42.40	
73510.725	-99344.03	298421.04	235036.39	-39.85	89.72	-2479.60	-39.85	89.72	-2479.60	10-74	2.75	-21.89	42.40	
73520.725	-99338.87	298469.24	235156.94	-40.18	85.96	-2510.25	-40.18	85.96	-2510.25	10-74	2.72	-21.96	42.40	
73530.725	-99333.71	298517.44	235277.49	-40.51	82.20	-2540.90	-40.51	82.20	-2540.90	10-74	2.69	-22.03	42.40	
73540.725	-99328.55	298565.64	235398.04	-40.84	78.44	-2571.55	-40.84	78.44	-2571.55	10-74	2.66	-22.10	42.40	
73550.725	-99323.39	298613.84	235518.59	-41.17	74.68	-2602.20	-41.17	74.68	-2602.20	10-74	2.63	-22.17	42.40	
73560.725	-99318.23	298662.04	235639.14	-41.50	70.92	-2632.85	-41.50	70.92	-2632.85	10-74	2.60	-22.24	42.40	
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73590.725	-99302.75	298806.64	235999.79	-42.49	59.64	-2724.80	-42.49	59.64	-2724.80	10-74	2.51	-22.45	42.40	
73600.725	-99297.59	298854.84	236120.34	-42.82	55.88	-2755.45	-42.82	55.88	-2755.45	10-74	2.48	-22.52	42.40	
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73780.725	-99204.71													

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 101 SQUARE 12 SEPT 5000' AED R AND FOOT

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73000-186	-95698-703	279159-180	293400-579	-196-899	955-002	2537-916				
73000-187	-95728-977	279352-453	292895-834	-196-899	955-002	2537-916				
73000-188	-95758-251	279545-726	292390-579	-196-899	955-002	2537-916				
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73000-190	-95818-800	279932-272	291380-579	-196-899	955-002	2537-916				
73000-191	-95848-074	280125-545	290875-834	-196-899	955-002	2537-916				
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73000-194	-95938-896	280704-364	289360-579	-196-899	955-002	2537-916				
73000-195	-95968-169	280897-637	288855-834	-196-899	955-002	2537-916				
73000-196	-95998-443	281090-910	288350-579	-196-899	955-002	2537-916				
73000-197	-96028-717	281283-183	287845-834	-196-899	955-002	2537-916				
73000-198	-96058-991	281476-456	287340-579	-196-899	955-002	2537-916				
73000-199	-96088-265	281669-729	286835-834	-196-899	955-002	2537-916				
73000-200	-96118-539	281862-002	286330-579	-196-899	955-002	2537-916				

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TIME	X	Y	Z	X̂	Ŷ	DATE 101073	PAGE	Z1
LOST SPHERE 12 SEPT SMOOTHED R AND ROOT								
73464-925	-97835-885	287964-340	245921-924	-150-105	802-190	-2511-743		
73467-128	-97875-289	288147-409	245914-387	-150-538	794-382	-250-074		
73467-324	-97907-317	288102-607	245910-607	-151-240	794-407	-250-074		
73467-520	-97939-513	288102-607	245910-607	-151-240	794-407	-250-074		
73467-725	-97976-710	288147-409	245927-724	-147-673	790-348	-2476-597		
73467-925	-97998-252	288777-088	243425-773	-147-846	782-630	-2464-912		
73468-125	-98027-022	288932-088	243425-773	-147-846	782-630	-2464-912		
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73469-125	-98170-074	289402-025	240985-830	-148-192	763-075	-2424-931		
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73469-725	-98264-021	289402-025	240985-830	-148-192	763-075	-2424-931		
73469-925	-98290-021	289402-025	240985-830	-148-192	763-075	-2424-931		
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73470-324	-98330-713	290246-078	258133-514	-138-411	719-305	-2330-671		
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73471-520	-98472-742	291413-409	254932-332	-124-001	649-259	-2236-107		
73471-725	-98511-535	291536-309	254932-332	-124-001	649-259	-2236-107		
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73477-725	-98720-135	292286-646	252286-646	-110-597	629-252	-2157-800		
73477-925	-98720-135	292286-646	252286-646	-110-597	629-252	-2157-800		
73478-125	-98720-135	292286-646	252286-646	-110-597	629-252	-2157-800		

TIME	X	Y	Z	X	Y	Z	X	Y	DATE 101n73	PALE	25
73512-524	-99203-541	302530-957	204612-994	24-194	89-176	-744-300					
73512-726	-99177-979	302455-496	204670-201	24-647	88-322	-745-538					
73512-928	-99194-724	302449-484	204551-533	24-548	87-287	-745-004					
73513-125	-99186-454	302440-160	204340-928	24-922	85-421	-745-982					
73513-324	-99183-221	302539-130	204061-035	25-085	83-504	-738-275					
73513-524	-99182-093	302540-421	203913-816	25-488	82-583	-736-512					
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73514-524	-99171-244	302612-894	203494-939	26-130	76-235	-727-864					
73514-725	-99134-382	302631-258	203048-463	25-497	75-032	-726-156					
73515-125	-99136-467	302550-977	202895-967	26-010	74-021	-725-248					
73515-324	-99171-005	302672-742	202735-270	25-540	72-537	-725-040					
73515-524	-99070-087	302703-073	202645-845	25-057	70-727	-720-742					
73515-725	-99134-080	302714-154	202321-973	25-998	68-707	-717-145					
73516-125	-99090-854	302722-424	20189-074	24-915	67-570	-715-380					
73516-324	-99094-651	302727-023	201045-474	24-472	64-537	-713-411					
73516-524	-99070-087	302735-082	203709-084	24-284	63-059	-711-842					
73516-725	-99056-351	302747-473	203467-999	23-377	62-492	-710-374					
73517-125	-99075-687	302789-215	203454-242	23-710	60-879	-704-453					
73517-324	-99089-355	302799-215	203319-207	22-991	59-445	-705-011					
73517-524	-99072-470	302809-084	203173-837	22-514	58-472	-704-842					
73517-725	-99071-712	302814-297	202896-432	21-530	56-481	-704-489					
73518-125	-99054-508	302859-629	202752-873	22-035	53-894	-697-534					
73518-324	-99051-079	302864-792	202418-273	22-928	52-614	-695-666					
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73518-725	-99042-558	302865-492	202345-557	21-079	49-740	-691-905					
73519-125	-99048-190	302865-639	202070-271	20-448	48-197	-689-765					
73519-324	-99037-694	302902-031	201933-299	20-715	46-752	-688-541					
73519-524	-99050-704	302903-793	201781-418	20-033	43-337	-685-208					
73519-725	-99059-940	302918-129	201645-822	20-382	42-220	-683-095					
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73521-524	-98994-307	302992-375	200404-187	21-158	29-640	-668-945					
73521-725	-98992-494	303002-336	200164-543	20-959	28-707	-665-582					
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73522-324	-98981-082	303010-048	199770-501	20-533	26-800	-661-267					
73522-524	-98982-088	303022-039	199635-281	20-487	25-278	-659-930					
73522-725	-98976-172	303019-914	199507-346	20-656	24-214	-658-430					
73523-125	-98964-488	303029-265	199381-037	20-740	23-779	-656-942					
73523-324	-98946-278	303034-285	199257-953	20-326	22-206	-654-984					
73523-524	-98940-440	303033-285	199130-244	20-160	21-543	-653-921					
73523-725	-98942-420	303039-484	198949-453	19-754	21-543	-652-752					

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TIME	SPHERE	12 SEPT	SMOOTHED R	AND	ADDT	Y	Z	X	Y	DATE 101073	PAGE	27
73535.324			-98423.809		303199.748	303199.748	191872.083	32.909	32.909	8.928	-562.250	
73535.324			-98450.205		303198.344	303198.344	191746.558	33.485	33.485	9.543	-580.894	
73535.324			-98475.871		303197.640	303197.640	191626.250	34.289	34.289	9.957	-579.442	
73535.324			-98498.953		303196.727	303196.727	191510.773	34.139	34.139	10.787	-576.528	
73535.324			-98521.185		303195.752	303195.752	191398.529	33.898	33.898	10.995	-577.119	
73535.324			-98545.744		303194.744	303194.744	191289.409	33.934	33.934	11.015	-576.899	
73535.324			-98567.944		303193.703	303193.703	191154.491	34.305	34.305	11.387	-575.559	
73535.324			-98581.882		303192.203	303192.203	191053.193	34.874	34.874	11.941	-573.255	
73535.324			-98592.023		303191.491	303191.491	190931.754	35.070	35.070	12.129	-571.942	
73535.324			-98608.988		303190.703	303190.703	190821.521	34.705	34.705	12.096	-570.767	
73535.324			-98629.535		303189.375	303189.375	190712.605	34.524	34.524	11.983	-568.495	
73535.324			-98649.942		303188.453	303188.453	190588.258	35.221	35.221	12.186	-566.004	
73535.324			-98669.018		303187.219	303187.219	190478.646	35.499	35.499	12.207	-564.734	
73535.324			-98689.620		303185.966	303185.966	190369.450	35.850	35.850	12.290	-562.495	
73535.324			-98709.777		303184.584	303184.584	190253.166	34.104	34.104	12.244	-561.495	
73535.324			-98729.724		303183.184	303183.184	190131.080	34.489	34.489	12.301	-561.745	
73535.324			-98749.705		303181.105	303181.105	190012.383	34.982	34.982	12.371	-560.421	
73535.324			-98769.843		303179.344	303179.344	189917.482	34.941	34.941	12.421	-559.424	
73535.324			-98789.731		303177.977	303177.977	189776.152	34.352	34.352	11.893	-558.273	
73535.324			-98809.729		303176.949	303176.949	189686.322	34.856	34.856	11.821	-557.188	
73535.324			-98829.687		303175.137	303175.137	189582.160	34.925	34.925	11.771	-556.987	
73535.324			-98849.040		303173.242	303173.242	189466.619	34.731	34.731	11.978	-554.798	
73535.324			-98869.252		303171.129	303171.129	189344.138	37.031	37.031	11.355	-553.571	
73535.324			-98889.364		303169.805	303169.805	189254.028	34.713	34.713	11.119	-552.382	
73535.324			-98909.257		303168.671	303168.671	189165.400					

APPENDIX B

EVALUATION OF RANGE-RATE DATA

BY

BALL CHIN
Electronics Division

Instrumentation Directorate
US Army White Sands Missile Range, New Mexico 88002

PRELIMINARY RESULTS OF WSR PULSE DOPPLER RADARS TRACKING TESTS

WSR PULSE DOPPLER RADARS

- OPERATIONAL

THREE FPS-16(AV) RADARS

THREE MPS-36 RADARS

- OTHER

THREE MPS-36 RADARS (OPERATIONAL IN 90 DAYS)

P 2

OBJECTIVES

- ESTABLISH PULSE DOPPLER RADARS TRACKING CAPABILITY
- DETERMINE IMPROVEMENTS REQUIRED FOR PRECISE AND RELIABLE VELOCITY DATA
- INTEGRATE VELOCITY DATA WITH RANGE DATA TO PROVIDE FOR
REAL-TIME EVENTS AND POSITION DETERMINATION
FLIGHT SAFETY IMPACT PREDICTION
MORE PRECISE POST FLIGHT TRAJECTORY ANALYSIS

TEST RESULTS

- A-4 AIRCRAFT TRACKING TEST, 14 DECEMBER 1973

RADAR

	R113	R123	R127	R352	R354	R393
RELIABILITY DOP VEL WHEN TARGET IS RECEDING (%)	99.1	99.4	97.8	96.1	97.7	93.4
RELIABILITY DOP VEL WHEN TARGET IS APPROACHING (%)	99.5	81.5	78.9	91.4	94.2	78.6
RADAR RANGE TRACKING RELIABILITY (%)	99.7	100.0	99.8	100.0	99.9	100.0
RELIABILITY OF R DOT DATA (%)	95.4	92.2	88.7	94.1	96.2	87.3

- SPHERE DROP TEST, 16 FEBRUARY 1974

RELIABILITY OF ALL SIX RADARS WAS BELOW 40 PERCENT

OTHER ACCOMPLISHMENTS

- COMPUTER PROGRAM TO PROCESS DOPPLER DATA FROM REAL TIME FIELD TAPES IN 24 HOURS (REFER TO INTERNAL MEMO 148)
- FLOW CHART FOR MPS-36 DOPPLER COMPUTER PROGRAM

FUTURE PLANS

- EXAMINE AND VERIFY ALIGNMENT, CALIBRATION, AND PERMISSION CHECKOUT PROCEDURES
- CONDUCT SYSTEM ANALYSIS, INCLUDING TRANSPONDER AND AIRBORNE ANTENNA RADIATION PATTERN AND TARGET DYNAMICS PRIOR TO EACH TEST
- PARTICIPATE IN GEOS-C SATELLITE TRACKING TESTS

SOURCE OF ADDITIONAL INFORMATION

- DR. ROBERT H. PAUL, TECHNICAL DIRECTOR
INSTRUMENTATION DIRECTORATE
WHITE SANDS MISSILE RANGE
NEW MEXICO 88002

INTERNAL MEMORANDUM NUMBER 148

DESCRIPTION AND USERS MANUAL
FOR THE
NR-AM-I KRTLST COMPUTER PROGRAM

FEBRUARY 1974

Prepared by

O. P. Kroeger
Physical Scientist

Reviewed by

Kenneth C. Grover
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Chief, Instru Intrg Sec

Woodrow W. Page
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Chief, Math Svcs Br

Approved by

W. A. McCool
W. A. MCCOOL
Acting Chief, Anal & Cmpt Div

MATHEMATICAL SERVICES BRANCH
ANALYSIS AND COMPUTATION DIVISION
NATIONAL RANGE OPERATIONS DIRECTORATE
US ARMY WHITE SANDS MISSILE RANGE
NEW MEXICO 88002

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DESCRIPTION AND USERS MANUAL
FOR THE NR-AM-I KRTLST COMPUTER PROGRAM

I. ABSTRACT. The KRTLST computer program dumps and analyses radar range rate data recorded at the real-time facility. It is a very simple program to operate and requires no programming experience to use it. Anyone who has a legitimate computer project accounting number (PAN) can schedule runs at the WSMR 1108 Computer B Facility.

II. INTRODUCTION. The KRTLST computer program was written by O. P. Kroeger (Instrumentation Integration Section) as part of an inter-organizational task effort by Analysis and Computation Division, Data Collection Division and Instrumentation Directorate to evaluate the existing WSMR radar range rate system.

The KRTLST program uses as inputs the data recorded in real-time at the Real Time Systems Section's computer facility in Bldg 300. These inputs are data gathered by radars transmitted from the radar site via Lenkurt modems and recorded on analog tape recorded all in real-time. Either in real-time (or in deferred time by analog tape playbacks) digital log tapes of the mission data are generated on the WSMR 1108 real-time computer. The KRTLST program cannot be used unless this real-time recording has been range scheduled and accomplished.

The KRTLST program outputs setup cards for checks, radar data samples of time, range, azimuth, elevation, range rate, computed estimates of range rate from range derivatives, differences of range rate and range derivatives, acceleration, data one sigma error estimates, and flags of various predetermined errors. At the end of the data listing an automated written consolidated report of error and reliability statistics is furnished.

III. DESCRIPTION OF ALL STEPS NECESSARY TO ACCOMPLISH KRTLST OUTPUTS.

STEP NR 1. Prior to mission, range schedule a real time recording of all radars supporting the mission. Real-time recordings are only made on missions which have been scheduled specifically as "real-time transmission and record".

STEP NR 2. Obtain the mission code (FC = Foxtrot Charley, AB = Alpha Bravo, etc.), mission date, and mission start and stop times if available.

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Obtain "PSL Real Time Playback Request" cards from PSL Input Office, Bldg 300. Fill out request card (see Fig (1A)) with:

1. Requestor - your name.
2. Acct Code - your accounting code.
3. Mission - put in mission code.
4. Program - put in "UNILog"
5. Date - put in the mission firing date.
6. Phone - your duty phone
7. Building - put in X in the 300 block.
8. Timing - put an X in the range block.
9. Remarks - put "log all radars" plus mission start time and mission stop time if available.
10. Bottom Line - put an X in the deliver box along with your name and nearest PSL delivery point.

FIGURE (1A) shows my request for an 1108 computer log tape of an aircraft track mission fired on 14 Dec 73. The mission was Charley Foxtrot (FC).

FIGURE (1B) shows my request card after the logging procedure was accomplished. PSL operations filled in the following:

1. Analog reel block.
2. Tape classification block.
3. Tape location block.
4. Tape reel number block.
5. Marked the ID's of the radars available in the input blocks and their associated computer sub-channels.

FIGURE (1B) shows that radar R113, R123, R127, R352, R354 and R373 were recorded and the input tape for the KRTLST is labeled W385/42703. With this information we are ready to set up the deck for a KRTLST computer run.

STEP NR 3. The KRTLST run deck consists of seven punched IBM cards and one request card. (See FIGURE (2)) Only two cards have to be punched for each run. The others remain constant. The two cards to be punched are:

1. Card Nr 1 - Punch the input data tape location in columns 16, 17, 18, 19. Punch the input data tape reel number in columns 28, 29, 30, 31, 32. For example, FIGURE (3) shows data punch for Card Nr 1 for the aircraft mission designated on the playback request card shown in FIGURE (2B). (W385/42703)

2. Card Nr 6 - The data card is the most complicated and is used to control the radar to be dumped, the portions of the run to be dumped, and the long or short print control options. (See FIGURE (4))

Columns 1 to 4 are the easiest. They simply contain the name of the radar to be dumped. The only allowable characters for the dump are:

Columns 1 2 3 4

R 1 1 3
R 1 2 3
R 1 2 7
R 3 5 4
R 3 5 2
R 3 9 3
R 3 5 0
R 3 5 1

Columns 11 to 20 contain the range time of the desired start time of the run. (Three decimals) (Example: 67350.000)

Columns 21 to 30 contain the range time of the desired stop time of the run. (Three decimals) (Example: 68650.000)

Columns 59 and 60 are an index to be used with Columns 67, 68, 69 and 70 to control specific segments of the trajectory to be dumped such as first, second, third -- ninety-ninth segment.

Columns 67, 68, 69 and 70 contain a time segment of seconds (0000 to 9999) to be dumped. (Always use in conjunction with Columns 59 and 60. For example, if column 60 had a "3" in it and Columns 68, 69 and 70 had 100 in them, the program would print only the third 100 seconds of data on the tape. If Columns 59 and 60 and 67, 68, 69 and 70 are used then the start time (Columns 11 to 20) and the stop time (Columns 21 to 30) should be blank. (And vice-versa.)

If none of the print time controls are used i.e. Columns 11 to 20, 21 to 20, 59, 60, 67 to 70 are all blank, then all data on the log tape will be processed.

Column 80 controls short or long print. If Column 80 is "1", only error flagged data and check prints every five seconds on good data are printed. If Column 80 is "0" every processed sample (20 samples/second) is printed.

EXAMPLES

Figure (5A). Shows data card which instructs the program to dump all data on the input tape for radar R113. (Long print)

Figure (5B). Shows data card which instructs the program to dump all data between times 67350.000 to 68650.000 seconds of the mission for radar R113. (Long print)

Figure (5C). Shows data card which instructs the program to dump error flagged data (short print) during the third 200 seconds of data recorded on the tape.

STEP NR 4. The run request card is depicted in Figure (6). As can be seen, there are three major blocks to be filled out: input, output and identification. (Be sure and correctly label all classification blocks. If they are not labeled, PSL will not make the run. Do not use classified input tapes for this dump program because the outputs of the of the program will become classified. As a rule run only data from unclassified projects.

In the input tape block two tapes have to be entered. The program tape is always E725/39027 until after Feb 74. Call Kroeger (678-1620)

for new program tape designations and at four month intervals after that. The second tape will be the input data log tape you have requested from the PSL Real Time Playback Facility. The number of cards will always be seven.

In the output section (under PRINT\$) always put NORM unless you have changed the deck to get one or more carbons.

In the identification block check R under option block, fill in your RUN ID, PAN, requestor's name, phone, organization, check Computer 8, put your delivery destination point. The time estimate and page estimate is computed as follows:

TIMING ESTIMATE

1. Four minutes for first 0 to 200 seconds of flight.
2. Add 1.1 minutes for each additional 50 seconds of flight.
3. Round fractional times up when equal to .5 seconds and greater.

EXAMPLE NR 1 - For a 556 second flight.

$$\begin{array}{r}
 556 \text{ sec} \\
 200 - \text{first seg} \\
 \hline
 356 \\
 7 \\
 50 \overline{) 356} \\
 \underline{350}
 \end{array}
 \left. \vphantom{\begin{array}{r} 556 \text{ sec} \\ 200 - \text{first seg} \\ \hline 356 \\ 7 \\ 50 \overline{) 356} \\ \underline{350} \end{array}} \right\} 4 \text{ min}$$

$$7 \times 1.1 = 7.7 = 8$$

TOTAL TIME = 12 MIN

EXAMPLE NR 2 - For a 320 second flight.

$$\begin{array}{r}
 320 \\
 200 \\
 \hline
 120 \\
 2 \\
 50 \overline{) 120}
 \end{array}
 \left. \vphantom{\begin{array}{r} 320 \\ 200 \\ \hline 120 \\ 2 \\ 50 \overline{) 120} \end{array}} \right\} 4 \text{ min}$$

$$2 \times 1.1 = 2.2 = 2 \text{ min}$$

TOTAL TIME = 6 MIN

EXAMPLE NR 3 - For a 1298 second flight.

1298	} 4 min
200	
<u>1098</u>	
21	
50 <u>1098</u>	21 * 1.1 = 23.2 = 23
<u>100</u>	
98	
<u>TIME = 4 + 23 = 27 MIN</u>	

PAGES OF PRINT ESTIMATE

Ten pages plus one page for every 2.5 seconds of flight data.

EXAMPLE - For 1300 seconds flight.

10 pages	520
<u>520</u>	2.5 <u>13000</u>
530	

530 PAGES

IV. INTERPRETATION OF OUTPUT LISTING. The output listing has four parts. The first part is a three page computer summary of loading parameters which includes the tape assignments for checks. The second part is a one page listing printed by the program giving the data card setup and the error code definitions. The third part (the longest) is the listing of the data as follows (left to right)

1. Radar name or the error code if an error has been detected. The following list gives error code definitions.

E100000)	= DOPPLER DVES VALID FLAG HAS CHANGED.
E 20000)	= DOPPLER 2IPT RAW DATA SIGMA HAS CHANGED.
E 3000)	= VELOCITY EEOR G.T. 14.31 F.P.S.
E 400)	= TIME HAS A GAP (NOT .05 SEC) DERIVATIVES BAD.
E 50)	= RADAR HAS CHANGED ITS TRACK MODE.
E 6)	= NOT PRESENTLY ASSIGNED.
E 20050)	= ERRORS 2 AND 5 BOTH PRESENT (EXAMPLE).

2. Time - seconds.
3. Time difference - seconds for missing data checks. (This may be changed later to display AGC.
4. Radar track mode:
S = skin track
B = beacon track
N = no track
5. DVES valid flag:
1 = valid flag yes
0 = valid flag no
6. Doppler skin return flag:
1 = yes
0 = no
7. Doppler COHO beacon flag:
1 = yes
0 = no
8. Range - feet.
9. Azimuth - degrees.
10. Elevation - degrees.
11. Second derivative of range (acceleration) 51 pt filter ft/sec^2 .
12. Doppler velocity derivative (acceleration) 51 pt filter ft/sec^2 .
13. Range first derivative (velocity) one sigma error estimate
 ft/sec . (21 pt filter)
14. Raw doppler velocity error estimate (21 pt filter) ft/sec .
15. First derivative of range (velocity) 21 pt filter ft/sec .
16. Raw doppler velocity ft/sec .

17. Velocity error (difference between raw doppler velocity and 51 pt range derivative) ft/sec.

18. Velocity error (difference between raw doppler velocity and 21 pt range derivative) ft/sec.

The long print (data card COL 80=0) gives the above information for each and every point. (20 SAM.SEC.)

The short print (data card COL 80=1) prints only flagged errors (see 1. above) plus 24 consecutive samples prior to a flagged error and 24 consecutive samples past the same flagged error. Also, during long stretches of good data, a checkpoint will be printed every five seconds.

The fourth part of the listing is a written statistical report of the entire run. The basic criteria for most percentages and reliability estimates are based on the premise that when the radar is in track (either skin or beacon), there should be valid unambiguous velocity data (with valid vel flags). The run printout will not commence until the radar has been in solid track for at least two seconds. The radar reliability number is based on outages versus skin or beacon track once the run has begun.

If the computer run aborts, check the last page of your listing for such things as tape problems, max time, max pages. If either max time or pages is indicated, your estimates on your run request card are wrong and should be increased.

V. PROGRAM LISTING. For those who wish to know what the program KRTLST coding looks like, a listing of the program is included.

For those who wish to have deck of the program for their own purposes may easily do so. The Fortran elements are on the program input tape. To punch (on line) the deck during a run place the following cards directly after the copin card in the data deck:

- | | |
|------------|-------------|
| 1. @PCH,SC | TPF\$.ROYSA |
| 2. @PCH,SC | TPF\$.ROYSO |
| 3. @PCH,SC | TPF\$.LOG |
| ↑ | ↑ |
| COL 1 | COL 14 |

APPENDIX A
REAL TIME PLAYBACK REQUEST CARDS

REQ. REAL TIME PLAYBACK REQUEST	REQUESTOR KRØGER 2139		ADST. CODE 2139		NRD NRD		NAME OF REQUESTOR NRD		MISSION NRD		PROGRAM NRD	
	DATE 12 14 73		TIME 1620		PHONE 678-1620		BUILDING NRD		TIMING NRD		LIFT OFF NRD	
	ANALOG REEL # NRD		CLASS GROUP NRD		OUTPUT REEL NRD		LOCATION NRD		REEL NUMBER NRD		CLASS GROUP NRD	
	INPUT NRD		SUBCH NRD		INPUT NRD		SUBCH NRD		INPUT NRD		SUBCH NRD	
REMARKS: LOG ALL RADARS (GIVE MISSION TIMES (START-STOP) IF AVAILABLE)												
<input type="checkbox"/> FROM TAPE LOCATION & REEL # TO: _____ <input checked="" type="checkbox"/> DELIVER JOB TO: KRØGER 2139 BLD 300 RM 2W												

FIGURE (1A)

REQ. REAL TIME PLAYBACK REQUEST	REQUESTOR KRØGER 2139		ADST. CODE 2139		NRD NRD		NAME OF REQUESTOR NRD		MISSION NRD		PROGRAM NRD	
	DATE 12 14 73		TIME 1620		PHONE 678-1620		BUILDING NRD		TIMING NRD		LIFT OFF NRD	
	ANALOG REEL # NRD		CLASS GROUP NRD		OUTPUT REEL NRD		LOCATION NRD		REEL NUMBER NRD		CLASS GROUP NRD	
	INPUT NRD		SUBCH NRD		INPUT NRD		SUBCH NRD		INPUT NRD		SUBCH NRD	
REMARKS: LOG ALL RADARS												
<input type="checkbox"/> FROM TAPE LOCATION & REEL # TO: _____ <input checked="" type="checkbox"/> DELIVER JOB TO: KRØGER 2139 BLD 300 RM 2W												

FIGURE (1B)

SAMPLE DECK AND REQUEST CARD

The image shows a sample deck of seven punched cards and a request card below them. The cards contain various alphanumeric data and punch holes. The request card is a form with fields for name, address, and other information.

NAME	ADDRESS	PHONE	DATE	TIME	REMARKS
E725 39027W	NORM U	2139	11/27/66	600	KATIST
W385 42703W					KROEGER
					679-1420
					NR-AM-T
					300
					SW

FIGURE (2)

FIGURE (3)

FIGURE (4)

The image shows a vintage 'Punch Card' time clock. The card is rectangular with a grid of 10 columns and 10 rows of punch holes. The columns are labeled 'ONE' through 'EIGHT' at the bottom. The rows are labeled 'START TIME' and 'STOP TIME' on the left, and 'TIME' and 'S.A.' on the right. The card is filled with handwritten numbers and letters, indicating a record of time spent on various tasks. The card is mounted on a dark background.

FIGURE (5A)

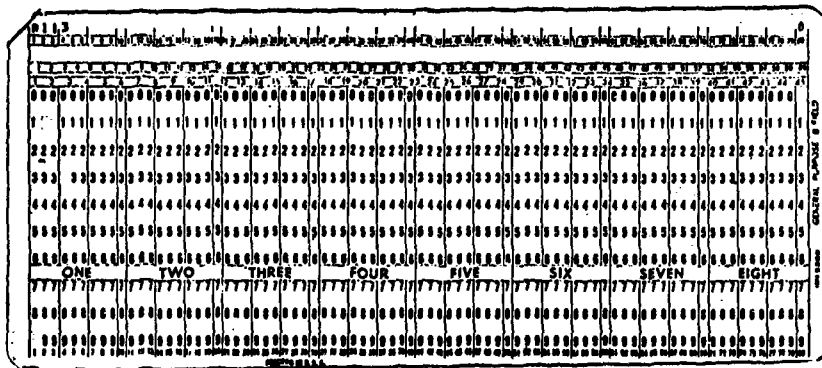
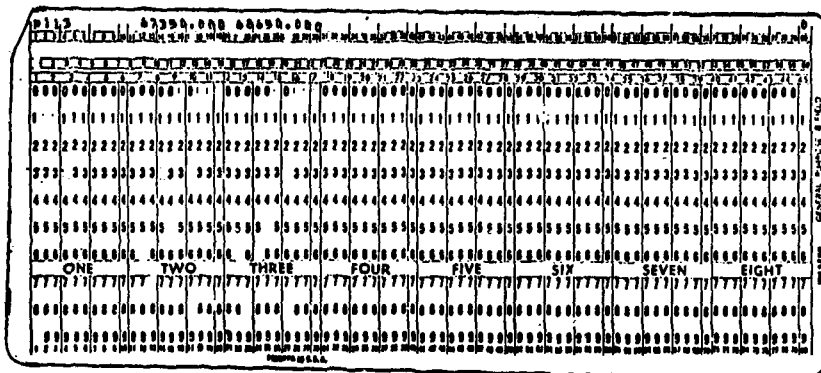


FIGURE (5B)



DATA CARD (PROCESS THE THIRD 200 SECOND INTERVAL ON THE TAPE - SHORT PRINT)
FIGURE (5C)

0112		0113		0114		0115		0116		0117		0118		0119		0120		0121		0122		0123		0124		0125		0126		0127		0128		0129		0130		0131		0132		0133		0134		0135		0136		0137		0138		0139		0140		0141		0142		0143		0144		0145		0146		0147		0148		0149		0150		0151		0152		0153		0154		0155		0156		0157		0158		0159		0160		0161		0162		0163		0164		0165		0166		0167		0168		0169		0170		0171		0172		0173		0174		0175		0176		0177		0178		0179		0180		0181		0182		0183		0184		0185		0186		0187		0188		0189		0190		0191		0192		0193		0194		0195		0196		0197		0198		0199		0200		0201		0202		0203		0204		0205		0206		0207		0208		0209		0210		0211		0212		0213		0214		0215		0216		0217		0218		0219		0220		0221		0222		0223		0224		0225		0226		0227		0228		0229		0230		0231		0232		0233		0234		0235		0236		0237		0238		0239		0240		0241		0242		0243		0244		0245		0246		0247		0248		0249		0250		0251		0252		0253		0254		0255		0256		0257		0258		0259		0260		0261		0262		0263		0264		0265		0266		0267		0268		0269		0270		0271		0272		0273		0274		0275		0276		0277		0278		0279		0280		0281		0282		0283		0284		0285		0286		0287		0288		0289		0290		0291		0292		0293		0294		0295		0296		0297		0298		0299		0300		0301		0302		0303		0304		0305		0306		0307		0308		0309		0310		0311		0312		0313		0314		0315		0316		0317		0318		0319		0320		0321		0322		0323		0324		0325		0326		0327		0328		0329		0330		0331		0332		0333		0334		0335		0336		0337		0338		0339		0340		0341		0342		0343		0344		0345		0346		0347		0348		0349		0350		0351		0352		0353		0354		0355		0356		0357		0358		0359		0360		0361		0362		0363		0364		0365		0366		0367		0368		0369		0370		0371		0372		0373		0374		0375		0376		0377		0378		0379		0380		0381		0382		0383		0384		0385		0386		0387		0388		0389		0390		0391		0392		0393		0394		0395		0396		0397		0398		0399		0400		0401		0402		0403		0404		0405		0406		0407		0408		0409		0410		0411		0412		0413		0414		0415		0416		0417		0418		0419		0420		0421		0422		0423		0424		0425	
------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--	------	--

THE RUN REQUEST CARD
FIGURE (6)

[illegible]

SA,ROYNA
-01/23/74-11158154 (1,0)

UNPACK ENTRY POINT 000415

01 CODE(1) 0004271 DATA(0) 0063241 BLANK COMMON(2) 000000

ICK51

000323
F 000004
ATE 000132
000002

REFERENCES (BLOCK, NAME)

AN
US
28
R38

IGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

010 10L	0001	000363	110L	0001	000276	118L	0001	000374	120L
127 128L	0001	000015	15L	0001	000107	155L	0001	000016	20L
1046 30L	0001	000053	35L	0000	004266	84F	0004	000000	ENDF
1037 1A	0004	1	000002	1CONTR	0003	1	000171	1D	0000
264 11	0000	1	004265	118K	0004	1	000003	1LIFT	0000
001 1R	0003	1	000133	1RO	0000	1	004262	1RSTAT	0003
1074 1VAL1B	0005	1	000000	1VAL1D	0005	1	000036	1VAL1S	0000
255 L	0000	1	004254	LCODE	0000	1	004256	M	0000
260 NORAD	0004	1	000001	PARITY	0004	R	000001	SKIP	0003

SUBROUTINE UNPACK
COMMON/INT/T,1(130),1A(130),1E(130),1RO(130),1Q(130),1TQ(130),1STAT(130)
COMMON/EOFF/ENDFIL,PARITY,1CONTR,1LIFT
COMMON/FBRATE/1VAL1D(130),1VAL1S(130),1VAL1B(130)
COMMON/NRK/KK,SKIP
DIMENSION TAPREC(3241)
INTEGER ENDFIL,PARITY
DATA N/O/PARITY/O/
DATA 1ONES/0777777600000/
DATA MASK/07777400000000/
IF (ENDFIL.NE.O) GO TO 10
IF (PARITY.NE.O) GO TO 15
IF (N.GT.O) GO TO 35
10 ENDFIL = O
CALL NTRAN (2,1U)
15 PARITY = O
20 N = O

SHORT FORM
#16 DATA BITS, ONE SIGN
#113 OCT 73

POSITION TAPE TO LOAD POINT

APPENDIX B

```

CALL NTRAN(2,2,324,TAPREC,LCODE)  @READ 1 PHYSICAL RECORD
CALL NTRAN(2,22)
IF (LCODE.GT.0) GO TO 30          @RECORD OK
IF (LCODE.EQ.-3) GO TO 110        @TEST FOR BAD RECORD
IF (LCODE.EQ.-2) GO TO 120        @TEST FOR EOF
30 ICONTR = BOOL(TAPREC(1))        @CONTROL WD 0=RAD,1=MET,2=RAD+MET
L=2
M = 0
35 N = N + 1
IF (N.GT.20) GO TO 20
IRJ=FLD(18,18,TAPREC(L))
ILIFT= FLD(0,6,TAPREC(L))
NORAD = (1WC-1)/5
T=TAPREC(L+1)/1000.
DO 60 I=1,NORAD
IRSTAT = BOOL(TAPREC(M+4))
IDT = FLD(20,7,IRSTAT)
II = IDT+1
IF(II.GT.30) II = 30
IF(IDT.EQ.44) II=14
IF(IDT.EQ.40) II=25
IF(IDT.EQ.41) II=26
IF(IDT.EQ.42) II=15
IF(IDT.EQ.47) II=16
                                @NO. OF RADARS PER LOGICAL REC
                                @ RADAR 394
                                @ R350
                                @ R351
                                @ RADAR 352
                                @RADAR 393A

```

C ISTAT IS A NEW STATUS WORD. EXAMPLE 025007010330, 0250 =
 C ALT+SYNC, 07 = CONF. COUNTER, 01 = RUN NO., 03 = TGT NO.,
 C 30 = SUBCHANNEL NO.

```

FLD(4,8,ISTAT(1)) = FLD(12,8,IRSTAT)
FLD(12,6,ISTAT(1)) = FLD(6,6,IRSTAT)
FLD(21,3,ISTAT(1)) = FLD(0,3,IRSTAT)
FLD(27,3,ISTAT(1)) = FLD(3,3,IRSTAT)
FLD(30,6,ISTAT(1)) = FLD(6,6,IRSTAT)
ID(1) = IDT
IR(1) = FLD(12,24,TAPREC(M+5))  @ RADAR ID
IA(1) = FLD(12,17,TAPREC(M+6))  @ RANGE
IE(1) = FLD(12,17,TAPREC(M+7))  @ AZIMUTH
IRD(1) = FLD(13,23,TAPREC(M+8))  @ ELEVATION
ITQ(1) = FLD(33,3,IRSTAT)+16    @ RANGE RATE
IVALID(1) = 0                   @NOV73 FOR MPS36
                                @ NOV73 FOR MPS36
IVALID(1)=FLD(32,1,IRSTAT)
IVALIS(1)=FLD(31,1,IRSTAT)      @ DOPPLER SKIN FLAG
IVALB(1)=FLD(30,1,IRSTAT)      @ DOPPLER BEACON FLAG
IF(II.GT.8) GO TO 118           @ MPS 36 NOV 73
GO TO 121

```

```

118 CONTINUE
IF(FLD(12,1,TAPREC(M+8)).EQ.1) IRD(1)= IRD(1)+(-1)
84 FORMAT(2(1X,012))
119 CONTINUE
GO TO 128

```

C FPS 16 NEG ROOT NOV 73

```

121 CONTINUE
IF(FLD(12,1,TAPREC(M+8)))127,128,127
127 IRD(1)= IRD(1)+1
IRD(1)= ORIMASK,IRD(1)

```

C

FPS 16 NEG ROOT NOV 73

128 CONTINUE

C

TIME SKIP
IF(T.LT.SKIP) GO TO 3

IIBK = FLDIO,36,1RSTAT)

IF(I1+EQ+KK) WRITE(6,84) IIBK, IIBK @ HOUSEKEEPING
W HOUSEKEEPING

3 CONTINUE

M = M+5

60 CONTINUE

M = M+2

80 L = L+WC+1

RETURN

110 PARITY = LCODE
CALL NTRAN(2,22)

@ SET FLAG FOR PARITY ERROR

RETURN

120 ENDFIL = 1

@ SET END OF FILE FLAG

RETURN

END

COMPILATION: NO DIAGNOSTICS.

1040 IRAD	0004 I 000133 IRD	0000 I 001132 IRSIG	0000 I 001155 IRUA
154 IRUN	0000 I 001135 ISPTS	0004 I 000265 ISTAT	0003 I 000012 ITO
202 ITEST	0003 I 003214 ITIME	0004 I 000227 ITQ	0003 I 000011 ITR
217 IUM10	0003 I 003215 IUM6	0003 I 003216 IUM9	0006 I 000074 IVAL1
1036 IVALIS	0000 I 001130 IVNEG	0000 I 001123 IVPOS	0000 I 001156 J
157 K	0000 I 001160 L	0000 I 001163 NPOINT	0005 I 000001 PAR11
152 RTDG	0000 R 001151 SCALE	0000 R 001212 SOREL	0003 000032 SDVL2
1027 SIGR21	0000 R 001167 SIG	0000 R 000223 SPR1	0000 R 001213 SRREL
176 T	0000 R 001175 TEST	0000 R 001207 TF	0000 R 001162 TI
1044 TLIFT	0003 R 000035 TSTART	0003 R 000036 TSTOP	0003 R 000021 VEL
206 VLPR	0000 R 001216 VPP	0000 R 001215 XPER	0000 R 001165 XRAW
1000 Z			

```

COMMON/MAIN/ IERR IE(4), TIN,DT,ITR,ITD(3),ITD3,R,A,E,VEL,
IDRS1,DR21,VEL21,DDR51,DVEL21,SIGR21,SGDR21,SVEL21,SDVL21,
ZDEL51,DEL21,TSTART,TSTOP,INAM,IRAD,IRDOE(3),TLIFT,DELT,
3BUFF(20,81),INAME(9),ICHAN(9),ITIME,IUM6,IUM9,IUM10,IPT
COMMON/INT/2,IR(30),IA(30),IL(30),IRP(30),IS(30),ITQ(30),ISTAT(30)
COMMON/EOFF/ENDFIL,PARITY,ICONTR,ILIFT
COMMON/FRATE/IVAL10(30),IVAL15(30),IVAL1B(30)
DIMENSION FINVAR(8)
DIMENSION HOLD(2,4,8), IPT(2)
DIMENSION SPR(18,25)
INTEGER ENDFIL,PARITY
DATA IMODE/IMB,IMS,IMN/
DATA INAME/4HR113,4HR123,4HR127,4HR354,4HR352,4HR393,4HR350,4HR35,
1,4H /
DATA ICHAN/2,5,8,14,15,16,25,26,30/
IPOSPT=0          @ COUNTER OF POS VEL POINTS(GT 100 FPS)
INEGPT=0          @ COUNTER OF NEG VEL POINTS(LT 100 FPS)
IVPOS =0          @ VALID POS DOPP
IVNEG =0          @ VALID NEG DOPP
IOSIG=0
IRSIG=0
INNN =0           @ RADAR INTRACK (MUST BE GT 50 FOR PROGRAM TO RUN)
INPTS=0           @ NUMBER OF POINTS PROCESSED
ISPTS=0           @ COUNTER FOR DOPPLER SKIN RETURN POINTS
IBPTS=0           @ COUNTER FOR DOPPLER COMO BEACON RETURN POINTS
IDBF1=0           @ DATA IS BAD BUT FLG SAYS GOOD
IDGF0=0           @ DATA IS GOOD BUT FLG SAYS BAD
IKP=0
IPTCE=0
IPTC=0
IPTC8=0
IOOP1=0
IOOP2=0
IPT(1)=21
IPT(2)=51
READ(5,2002) INAM,IUM6,TSTART,TSTOP,DELT,TLIFT,IUM10,ITIME,IUM9,
1,IPT
WRITE (6,213)
WRITE (6,214)
WRITE (6,212)
WRITE (6,215) INAM

```

```

WRITE (4,216) TSTART
WRITE (4,217) TSTOP
WRITE (4,218) DELT
WRITE (4,212)
WRITE(4,220)
WRITE(4,221) IUM10,ITIME
WRITE(4,212)
IF(I0PT.EQ.0) WRITE (4,223)
IF(I0PT.EQ.1) WRITE (4,222)
IF(I0PT.LT.0.OR.I0PT.GT.1) WRITE(4,224)
3000 FORMAT(55H THE FOLLOWING LIST GIVES ERROR CODE DEFINITIONS. )
3001 FORMAT(55H E100000) =DOPPLER DVES VALID FLAG HAS CHANGED. )
3002 FORMAT(55H E 20000) =DOPPLER 2IPT RAW DATA SIGMA HAS CHANGED. )
3003 FORMAT(55H E 3000) =VELOCITY ERROR G.T. 14.31 F.P*5. )
3004 FORMAT(55H E 400) =TIME HAS A GAP(NOT .05 SEC) DERIVATIVES BAD )
3005 FORMAT(55H E 50) =RADAR HAS CHANGED ITS TRACK MODE. )
3006 FORMAT(55H E 6) =NOT PRESENTLY ASSIGNED. )
3007 FORMAT(55H )
3008 FORMAT(55H E 20050) =ERRORS 2 AND 5 BOTH PRESENT(EXAMPLE) )
WRITE(4,212)
WRITE(4,3000)
WRITE(4,3007)
WRITE(4,3001)
WRITE(4,3002)
WRITE(4,3003)
WRITE(4,3004)
WRITE(4,3005)
WRITE(4,3006)
WRITE(4,3007)
WRITE(4,3008)
WRITE(4,3007)
WRITE(4,213)
WRITE (4,225)
WRITE (4,226)
WRITE (4,227)
WRITE (4,3080)
WRITE (4,225)

```

```

C
C FROM DATA CARDS COMPUTE RADAR ID FOR UNPACK AND SET FLAGS,CONSTANTS
C

```

```

DO I =1,9
1RR=ICHAN(I)
IF(INAME(I).EQ.INAM)GO TO 3
1 CONTINUE
2 FORMAT(99H THE RADAR SPECIFIED ON THE DATA CARD IS NOT CATALOGED A
IS A RANGE RATE RADAR IN THIS PROGRAM; STOP.)
WRITE(4,212)
WRITE(4,212)
WRITE(4,2)
WRITE(4,212)
WRITE(4,212)
STOP
3 CONTINUE
SCALE = 3.14159265358979300/12.*8.*65 D ANGLE IN RADIANS
RTDG = 57.2957795131 D ANGLE IN DEGREES
IRUA=TSTART*1000.*TSTOP*1000.
IRUN=IRUA + IUM10*ITIME

```

```

      IRUB=IUMIO+ ITIME
C
C SHIFT DATA HOLDING ARRAYS
C
100 DO 20 J=1,8
    DO 10 J=1,80
      K= J+1
    10 BUFF(I,J)=BUFF(I,K)
    20 CONTINUE
      DO 40 I=1,9
        K=I+8
        DO 30 J=1,40
          L=J+1
        30 BUFF(K,J)=BUFF(K,L)
        40 CONTINUE
C
C LOAD INPUT VALUES FROM REALTIME LOG TAPE
C
      CALL UNPACK          W BUFF(1,81) = NEWEST POINT
C
      BUFF(5,81)= -100.0          @ TRACK MODE  NEGATIVE= NO TRACK
      ITQ(IIRR)=ITQ(IIRR)-16
      IF(ITQ(IIRR).EQ.4)BUFF(5,81)=4.0      @ TRACK MODE  IS BEACON
      IF(ITQ(IIRR).EQ.3)BUFF(5,81)=3.0      @ TRACK MODE  IS SKIN
      BUFF(1,81)=IR(IIRR)              @ RANGE YDS
      BUFF(1,81)=BUFF(1,81)*3.0          @ RANGE FT
      BUFF(2,81)=IRD(IIRR)              @ RANGE RATE
      BUFF(2,81)=BUFF(2,81)*.0075        @ RANGE RATE IN F.P.S.
      BUFF(3,81)=IA(IIRR)                @ AZIMUTH
      BUFF(3,81)=BUFF(3,81)* SCALE       @ AZIMUTH IN RADIAN$
      BUFF(4,81)=IL(IIRR)                @ ELEVATION
      BUFF(4,81)=BUFF(4,81)* SCALE       @ ELEVATION ,N RADIAN$
      Z=Z-.090
      BUFF(15,41)=Z-2.0
      BUFF(6,81)=IVALID(IIRR)
      BUFF(7,81)=BOOL(IVALIS(IIRR))
      BUFF(8,81)=BOOL(IVALIB(IIRR))
C
C
      IF(IRUN.EQ.0) GO TO 440      @ IF TRANSFER, PROCESS WHOLE TAPE
      IF(IRUB.EQ.0) GO TO 441      @ IF TRANSFER,USE TSTART & TSTOP
      IF(IUMIO.LT.2) GO TO 441    @ IF TRANSFER,PROCESS 1ST ITIME PTS
      ITST = (IUMIO-1)*(ITIME*20)
      100P1=100P1+1              @ SPACE TAPE OVER 1ST N ITIMES
      IF(100P1.LT.ITST) GO TO 100
      IRUN=0
      GO TO 440
      441 IF (BUFF(15,41).LT.TSTART) GO TO 100
      IRUN=0
      440 CONTINUE
C
C THE FOLLOWING TEST DOES NOT PERMIT RUN TO BEGIN UNTIL DATA ARRAYS
C HAVE ENOUGH IN-TRACK RADAR DATA TO INITIALIZE FILTERS
C (5) CONSECUTIVE POINTS IN BEACON OR SKIN TRACK)
C
      IF(INNN.GT.50)GO TO 1002

```



```

      INNN = 0
      DO 1001 I=1,51
      J= I+15
      IF(BUFF(5,J).GT+.0.0) INNN=INNN+1
1001  CONTINUE
      T1= BUFF(15,41)      @ START TIME OF FUN
      GO TO 100
1002  CONTINUE
C
C      SMOOTH RANGE AND RANGE RATE USING 21 AND 51 POINT SMOOTHING
C
      DO 41 J=1,2              @ FIT 21PT THEN 51PT
      NPOINT = IPT(1)
      DERKEY = 1+0
      DO 42 J=1,2              @ FIT RANGE THEB R GERATE
      DO 43 K=1,81              @ LOAD RAW DATA (81 PT ARRAY)
43  F(INVAR(K))=BUFF(J,K)
C
C      CALL LLL      LLS IS AN UNCONSTRAINED LEAST SQUARES, 2ND ORDER
C                     MOVING ARC FILTER. IT IS COMPLETELY COMPATABLE
C                     THE THE STANDARD WSMR DATA REDUCTION VAA PROGRAM.
C
      CALL LLL(NPOINT,DERKEY,F(INVAR,XRAW,XSM,SIGX,DXSM,DSIGX,DDXSM,
      JDDSIGX,CVAR)
      HOLD(1,J,1)=XRAW          @ RAW MID POINT VALUE
      HOLD(1,J,2)=XSM          @ SMOOTH MID POINT VALUE
      HOLD(1,J,3)=DXSM          @ SMOOTH MID POINT 1ST DERIVATIVE
      HOLD(1,J,4)=DDXSM          @ SMOOTH MID POINT 2ND DERIVATIVE
      HOLD(1,J,5)=SQRT(SIGX)     @ SMOOTH MID POINT 1 SIGMA ERR. EST.
      HOLD(1,J,6)=SQRT(DSIGX)    @ 1ST DERIVATIVE 1 SIGMA ERR. EST.
      HOLD(1,J,7)=SQRT(DDSIGX)   @ 2ND DERIVATIVE 1 SIGMA ERR. EST.
      HOLD(1,J,8)=CVAR          @ VARIANCE OF THE TOTAL CURVE DATA
42  CONTINUE
41  CONTINUE
C
C      LOAD INTO DATA BUFFER ALL SMOOTH DATA, FLAGS, AND VARIANCES
C      THAT ARE TO BE SAVED FOR A TWO SECOND INTERVAL ...USED FOR PRINT/EDIT
C
      BUFF(9,41)= HOLD(2,1,4)    @ RANGE 2ND DERIVATIVE 51PT
      BUFF(10,41)=HOLD(1,2,3)    @ RANGE RATE DERIVATIVE 21PT
      BUFF(11,41)=HOLD(1,1,6)    @ RANGE 1ST DERIV. SIGMA 21PT
      BUFF(12,41)=HOLD(1,2,5)/.3279 @ RANGE RATE SIGMA 21PT
      BUFF(13,41)=HOLD(2,1,3)    @ RANGE 1ST DERIV. 51PT
      BUFF(14,41)= HOLD(1,2,2)    @ RANGE RATE (SMOOTH) 21PT
C
C      TEST      ERROR PRINT OUTS AND SEY FLAGS
C
      IE(1)=0
      IF(IE(1).NE.0) IE(1)=100000 @ HAS OOP FLAG CHANGED
      IE(2)=0
      IF(BUFF(12,41).GT+.1,2) IE(2)=20000 @VEL SIGMA GT 1.2 FPS
      IE(3)=0
      TEST=ABS(HOLD(2,1,3)-HOLD(1,2,1))
      IF(TEST.GT+.14,31) IE(3)=3000 @VEL ERROR GT 14.31 FPS
      IE(4)=0

```

```

TEST= ABS(BUFF(15,4))-BUFF(15,40)
IF(TEST.GT.06.OR.TEST.LT.-045) IE(4)=400 W TIME GAP ERROR TEST
IE(5)=0
STIC* THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
IF(BUFF(5,40).NE.BUFF(5,41)) IE(5)=50 W RADAR CHANGED TRK NO
IE(6)=0 W NOT USED

C
C
C
C FLAGS FOR ERRORS PRINTED ON THE OUTPUT LISTING IN THE FIRST
C COLUMN AND WILL APPEAR AS FOLLOWS (OR IN COMBINATIONS):
C
C IERR=0
C IERR= IE(1)+IE(2)+IE(3)+IE(4)+IE(5)+IE(6)
C BUFF(17,41) = IERR
C
C L100000 ) = DOPPLER TRACK FLAG HAS CHANGED
C E020000 ) = DOPPLER 1 SIGMA G.T. 1.2 FPS
C E003000 ) = VELOCITY ERROR G.T. 14.3 FPS
C E000400 ) = TIME HAS A GAP - DERIVATIVES BAD
C E000050 ) = RADAR HAS CHANGED TRACK
C E000004 ) = ( FLAG NOT USED )
C
C
C E020050 ) = ERRORS 2 AND 5 ARE BOTH PRESENT
X
C
T=BUFF(15,41)-TLIFT
DT=BUFF(15,40)-BUFF(15,41)
IF(BUFF(5,41).GT.1) ITR= IMODE(2) W SKIN TRK
IF(BUFF(5,41).GT.3) ITR= IMODE(1) W BEACON TRK
IF(BUFF(5,41).LT.0) ITR= IMODE(3) W NO TRK
ITD(1)=BUFF(6,41) W VEL MODE
ITD(2)=BOOL(BUFF(7,41))
ITD(3)=BOOL(BUFF(8,41))
R=BUFF(1,41) W RANGE FT.
A=BUFF(3,41)* RTDG W AZ DEG
E=BUFF(4,41)* RTDG W EL DEG
DDR51 = BUFF(9,41) W RANGE ACC
DEL21 = BUFF(10,41) W VEL ACC
SGDR21= BUFF(11,41) W RVEL SIG
SVEL21=BUFF(12,41) W DOP SIG
DR21 =BUFF(13,41) W RANGE VEL
VEL=HOLD(1,2,1)
DEV21 =HOLD(1,1,3) - HOLD(1,2,1) W RDOT= RAW VEL
DEV51 =HOLD(2,1,3) - HOLD(1,2,1) W RDOT= RAW VEL
INPTS=INPTS+1
IF(BUFF(5,41).LT.0) GO TO 3010 W ONLY COUNTERERRORS RADAR INTRAC
C
C TEST COUNT FOR GOOD DOPP EITHER APPROACHING OR LEAVING RADAR
C COUNT MADE ONLY FOR VEL G.T. ABS(100 FPS)
C
IF(ABS(HOLD(2,1,3)).LT.100.0) GO TO 556 W IF TRANSFER CIRCLING
IF(HOLD(2,1,3).LT.-100.0) GO TO 557
IPOSPT=IPOSPT+1 W TARGET RECEEDING
IF(ABS(DEV51).LT.14.3) IVPOS=IVPOS+1 W TARGET RECEEDING
GO TO 56 W TARGET RECEEDING
CONTINUE W TARGET APPROACHING
557 INEGPT=INEGPT+1 W TARGET APPROACHING
IF(ABS(DEV51).LT.14.3) IVNEG=IVNEG+1 W TARGET APPROACHING

```

556 CONTINUE

```

C
C
      IF(ITD(2).EQ.1) ISPTS=ISPTS+1      @ COUNT DOP SKIN PTS
      IF(ITD(3).EQ.1) IBPTS=IBPTS+1      @ COUNT DOP COMO PTS
      IF(BUFF(11,4).LT.6.00) IRSIG =IRSIG+1
      IF(BUFF(12,4).LT.1.20) IDSIG =IDSIG+1

C TEST ERROR WHEN DATA IS BAD BUT DVES VALID SAYS ITS GOOD
C
      IF(ABS(DEVS1).GE.14.31.AND.ITD(1).EQ.1) IDBF1=IDBF1+1

C TEST ERROR WHEN DATA IS GOOD BUT DVES VALID SAYS ITS BAD
C
      IF(ABS(DEVS1).LT.14.31.AND.ITD(1).EQ.0) IDGFD=IDGFD+1
3010 CONTINUE

C
      IF(IOPT.NE.1) GO TO 399      @ SKIP PRINT ERROR ONLY LOGIC
      DO 350 JJ=1,24
      JJ=JJ
      DO 351 I=1,18
351  SPRI(I,JJ)=SPRI(I,J)
350  CONTINUE
      SPRI(1,25)=BOOL (IERR)
      SPRI(2,25)=T
      SPRI(3,25)=DT
      SPRI(4,25)=BOOL(ITR)
      SPRI(5,25)=BOOL(ITD(1))
      SPRI(6,25)=BOOL(ITD(2))
      SPRI(7,25)=BOOL(ITD(3))
      SPRI(8,25)=R
      SPRI(9,25)=A
      SPRI(10,25)=E
      SPRI(11,25)=DPRS1
      SPRI(12,25)=DEL21
      SPRI(13,25)=SGDR21
      SPRI(14,25)=SVEL21
      SPRI(15,25)=DR21
      SPRI(16,25)=VEL
      SPRI(17,25)=DEV21
      SPRI(18,25)=DEV51
      IKP=IKP+1
      ITEST=0
      DO 352 I=1,25
352  ITEST=ITEST+(BOOL(SPRI(I,1)))
      IF(ITEST.EQ.0) GO TO 398      @ NO ERRORS
      IKP=0
      ITEST=ITEST-(BOOL(SPRI(1,25)))
      IF(ITEST.NE.0) GO TO 399      @ IF TRANSFER, PREV. 25 ALREADY DUMPED
      DO 353 I=1,25
      IERR= BOOL (SPRI(1,1))      @
      T = (SPRI(2,1))      @ DUMP
      DT = (SPRI(3,1))      @
      ITR = BOOL(SPRI(4,1))      @ PREVIOUS
      ITD(1)=BOOL(SPRI(5,1))      @
      ITD(2)=BOOL(SPRI(6,1))      @ 25
      ITD(3)=BOOL(SPRI(7,1))      @

```

```

R      = SPR(18,1)          W DATA
A      = SPR(19,1)          W
E      = SPR(110,1)         W POINTS
DDR51  = SPR(111,1)
DEL21  = SPR(112,1)
SGDR21 = SPR(113,1)
SVEL21 = SPR(114,1)
DR21   = SPR(115,1)
VEL     = SPR(116,1)
DEV21  = SPR(117,1)
DEV51  = SPR(118,1)

IF(IERR.EQ.0) GO TO 355
WRITE(6,2000) IERR,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR51,DEL21
1,SGDR21,SVEL21,DR21,VEL,DEV51,DEV21
GO TO 356
355 CONTINUE
WRITE(6,2001) INAM,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR51,DEL21
1,SGDR21,SVEL21,DR21,VEL,DEV51,DEV21
356 CONTINUE
353 CONTINUE
GO TO 398
399 CONTINUE
IF(IERR.EQ.0) GO TO 460
WRITE(6,2000) IERR,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR51,DEL21
1,SGDR21,SVEL21,DR21,VEL,DEV51,DEV21
GO TO 461
460 CONTINUE
WRITE(6,2001) INAM,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR51,DEL21
1,SGDR21,SVEL21,DR21,VEL,DEV51,DEV21
461 CONTINUE
398 CONTINUE
IF(LOPT.NE.1) GO TO 501
IF(IKP.LT.100) GO TO 500
WRITE(6,2001)
WRITE(6,2001) INAM,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR51,DEL21
1,SGDR21,SVEL21,DR21,VEL,DEV51,DEV21
WRITE(6,2001)
501 IKP=0
500 CONTINUE
C
IF(BUFF15,41),LT=0,GO TO 300
IPTC=IPTC+1          W TOT NO PTS COUNTER
IF(IERR.NE.0) IPTCE = IPTCE +1      W TOT ERRORS COUNTER
IF(I(3).NE.0) IPTCB = IPTCB +1      W BIAS ERROR COUNTER
300 CONTINUE
IF(ENDFIL.EQ.1) GO TO 462
C
IF(1TIME.EQ.0.AND.TSTOP.LT.1.0) GO TO 100 W/ TRANSFER CONT.PROC.
IF(1TIME.EQ.0) GO TO 443
TST=1TIME*20          W PROCESS ALL REQ. TIME POINTS
100P2=100P2+1
IF(100P2.LT.175) GO TO 100
GO TO 449
443 IF(BUFF15,41).LT. TSTOP) GO TO 100 W PROCESS TO TSTOP
GO TO 449
C
462 CONTINUE

```

```

449 FNUM = IPTC*100                                @ CALCULATE
FDEN = IPTC                                         @ PERCENTAGES OF
ERPR = FNUM/FDEN                                   @ TOTAL ERRORS AND
FNUM = IPTC*100                                    @ BIAS ERRORS
VLPR = FNUM/FDEN                                   @ AND PRINT
WRITE(6,213)
WRITE(6,215) INAM
WRITE(6,212)
IF(INNN.LT.51)WRITE (6,4500)
4500 FORMAT(55H RADAR NEVER SHOWED BEACON OR SKIN TRACK - NO DATA )
TF= BUFF(15,41)
WRITE(6,4501) T1,TF
4501 FORMAT(14H START OF RUN=,F10.3,14H ,END OF RUN=,F10.3)
WRITE(6,212)
WRITE(6,4502)IPTC
4502 FORMAT(37H NO. OF POINTS OF INTRACK RADAR DATA=,I10)
4503 FORMAT(37H TOTAL NUMBER OF RAD. PTS. PROCESSED=,I10)
WRITE(6,3007)
WRITE(6,4503)INPTS
WRITE(6,212)
WRITE(6,450) ERPR,VLPR
WRITE(6,212)
450  FORMAT(22H PERCENTAGE OF ERRORS=,F5.1,34H          PERCENTAGE OF BIA
ISED DATA=,F5.1)
WRITE(6,3007)
FNUM= IDBF1*100
EDBF1=FNUM/FDEN
FNUM= IDGFO*100
EDGFO=FNUM/FDEN
3011 FORMAT(42H PERCENTAGE OF INVALID OYES W/GOOD DATA = ,F5.1)
3012 FORMAT(42H PERCENTAGE OF VALID OYES W/BAD DATA = ,F5.1)
WRITE(6,3011) EDGFO
WRITE(6,3007)
WRITE(6,3012) EDBF1
WRITE(6,212)
WRITE(6,3007)
SDREL =(IDSIG*1000) /IPTC
SDREL =(SDREL/10.0)+.05
SRREL =(IISIG*1000) /IPTC
SRREL =(SRREL/10.0)+.05
WRITE(6,4508)SRREL
WRITE(6,3007)
WRITE(6,4509)SDREL
4508 FORMAT(42H RELIABILITY OF LOW NOISE ON RANGE SERVO= ,F5.1,8H PERCE
INT)
4509 FORMAT(42H RELIABILITY OF LOW NOISE ON DOPP. SERVO= ,F5.1,8H PERCE
INT)
WRITE(6,212)
GDFLG= 100.0-(EDGFO+EDBF1)
3014 FORMAT(31H RELIABILITY OF VALID TRK FLG= ,F5.1,9H PERCENT.)
WRITE(6,3014)GDFLG
WRITE(6,3007)
XPER=(ISPT5*1000)/IPTC
XPER=XPER/10.0+.05
WRITE(6,4505)XPER
4505 FORMAT(39H RELIABILITY OF DOPP SKIN RETURN FLAG= ,F5.1,8H PERCENT)
WRITE(6,3007)

```



```

1DEG11 F/52 1 F/52 1 FPS 1 FPS 1 F.P.S. 1 F.P.S. 111 51PTS. 1
2 21PTS. 11
2000 FORMAT(2H L,16,2H) ,F10,3,1H ,F7,3,1H ,A1,3(1H ,1),1H ,F8,0,
17(1H ,F6,2),2(1H ,F7,0),2(1H ,F6,2),2(1H ,F9,2),2H ,2(1H ,F8,2))
2001 FORMAT(5H ,A4,1H ,F10,3,1H ,F7,3,1H ,A1,3(1H ,1),1H ,F8,0,
17(1H ,F6,2),2(1H ,F7,0),2(1H ,F6,2),2(1H ,F9,2),2H ,2(1H ,F8,2))
2002 FORMAT(A4,16,4,10,3,110,110,19,11)
STOP
END

```

COMPILATION:

2 DIAGNOSTICS.

LOGRB
-01/23/74-1115917 (1,0)

LLL ENTRY POINT 001065

D: CODE(1) 0011531 DATA(0) 0033241 BLANK COMMON(2) 000000

REFERENCES (BLOCK, NAME)

R35

IGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

040 100L	0301	000032	1306	0001	000056	1376	0001	000104	1636
113 1426	0001	000146	1746	0001	000180	1776	0001	000193	2036
210 2206	0001	000213	2246	0001	000246	2346	0001	000280	2416
420 2676	0001	000330	2776	0001	000276	300L	0001	000363	3026
574 304L	0001	000723	304L	0001	000447	3246	0001	000457	3276
576 3616	0001	000606	3646	0001	000641	3746	0001	000726	4146
761 4306	0001	000025	500L	0001	000147	501L	0001	000202	502L
035 99L	0000 D	000116	A	0000 D	000110	CON	0000 D	001044	D
514 DVV	0000 D	003006	DVVV	0000 D	000000	D21	0000 D	000022	D31
066 D81	0000 I	003220	I	0000 I	003215	FLAG	0000	003262	INJP
221 J	0000 I	003222	K	0000 I	003217	KSET	0000 R	003223	SUM
207 XINC	0000 R	003204	XPT	0000 D	003211	XTIME	0000 R	003224	ZSTX

```
SUBROUTINE LLL(NPOINT,DERKEY,FINVAR,XRAW,XS,SIGX,DASH,DSIGX,
1 DDASH,DDSIGX,CVAR)
  DIMENSION D21(3,3),D31(3,3),D51(3,3),D81(3,3)
  DIMENSION CON(3),A(81,3),D1(3,81),DV(3,51),DVV(3,31),DVVV(3,21)
  DIMENSION FINVAR(81),XPT(3)
  DOUBLE PRECISION CON,XINC,XTIME,A,D,DV,DVV,DVVV,TIMEZ
  DOUBLE PRECISION D21,D31,D51,D81
  DATA D21/0.713245564504146D+01,-0.1885384876010168D-16,
  A -0.6538084341288005D+00,-0.1885384876010168D-16,
  B 0.5194805194805196D+00,0.3101458121036724D-17,
  C -0.6538084341288005D+00,0.3101458121036724D-17,
  D 0.1075514874141874D+00/
  DATA D31/0.1011224592982102D+01,0.3621543955470748D-17,
  A -0.2022449185964203D+00,0.3621543955470748D-17,
  B 0.1612903225806453D+00,-0.1301952241991733D-17,
  C -0.2022449185964203D+00,-0.1301952241991733D-17,
  D 0.7270704823541305D+01/
  DATA D51/0.8363287259751505D+01,0.6722254535623794D-18,
  A -0.4530113932365392D+01,0.6722254535623794D-18,
  B 0.3619909502262448D+01,-0.3641221206796216D-18,
  C -0.4530113932365392D+01,-0.3641221206796216D-18,
  D 0.4414E96027090573D+01/
  DATA D81/0.8266057954158927D+02,0.42224367647005D+10,
  A -0.11294580708384D+01,0.42224367647005D+10,
  B 0.3619909502262448D+01,-0.3641221206796216D-18,
  C -0.4530113932365392D+01,-0.3641221206796216D-18,
  D 0.4414E96027090573D+01/
```


B 0.9033423667570026D-02,-0.6761193449725742D-18,
 C -0.1129694587068384D-01,-0.6761193449725741D-18,
 D 0.2778483836894690D-01/
 DATA IFLAG/1/

SYMBOLIC DICTIONARY

NPOINT = NO. OF PTS. OVER WHICH CURVE IS TO BE FITTED.
 DERKEY = 1.0, COMPUTE DERIVATIVES OF SECOND DEG. EQ.
 DERKEY = 0.0, NO DERIVATIVES COMPUTED. SIMPLY FIT INPUT DATA.
 FINVAR = INPUT DATA ARRAY WHICH IS ALWAYS 81-PTS.
 XRAW = RAW INPUT VALUE AT THE 41-PT.
 XSM = SMOOTH VALUE AT THE 41-PT.
 SIGX = VARIANCE OF POSITION AT THE 41-PT.
 DXSM = SMOOTH FIRST DERIVATIVE AT THE 41-PT.
 DSIGX = VARIANCE OF FIRST DERIVATIVE AT THE 41-PT.
 ODXSM = SMOOTH SECOND DERIVATIVE AT THE 41-PT.
 DDSIGX = VARIANCE OF SECOND DERIVATIVE AT THE 41-PT.
 CVAR = VARIANCE OF SECOND DEG. CURVE FIT.
 XINC = TIME INCREMENTING CONSTANT FOR--A--MATRIX.
 XTIME = TIME GENERATED FOR--A--MATRIX.
 TIME2 = TIME SQUARED GENERATED FOR--A--MATRIX.
 A(1,1) = TRANSFORMATION MATRIX TO TRANSFORM THE CONSTANTS OF
 A SECOND DEGREE EQ. TO SMOOTH POSITION.
 CON(3) = A(1,3) = 1.0, OF TRANSFORMATION MATRIX.
 CON(2) = A(1,2) = TIME OF PT. RELATIVE TO STARTING
 TIME OF CURVE FIT.
 CON(1) = A(1,1) = TIME SQUARED OF PT. RELATIVE TO STARTING
 TIME OF CURVE FIT.
 IX = NO. OF PTS. SECOND DEGREE EQ. IS TO BE FITTED OVER.
 KSET = NO. OF PTS. TRAVERSED TO THE RIGHT AND LEFT ABOUT
 MID-PT. REFERENCE TIME. REFERENCE TIME STARTS AT ZERO.
 THIS SYMBOL (-) IS NOT A MINUS SIGN; IT IS A DASH IN THE EQS.
 D2I = (A-TRANPOSE*A)-INVERSE MATRIX FOR A 21-PT. CURVE FIT.
 D3I = (A-TRANPOSE*A)-INVERSE MATRIX FOR A 31-PT. CURVE FIT.
 D5I = (A-TRANPOSE*A)-INVERSE MATRIX FOR A 51-PT. CURVE FIT.
 D8I = (A-TRANPOSE*A)-INVERSE MATRIX FOR A 81-PT. CURVE FIT.
 D = MATRIX TO TRANSFORM 81-PTS. OF DATA INTO THE 3 PARAMETERS
 OF THE SECOND DEG. EQ.
 DV = MATRIX TO TRANSFORM 51-PTS. OF DATA INTO THE 3 PARAMETERS
 OF THE SECOND DEG. EQ.
 DVV = MATRIX TO TRANSFORM 31-PTS. OF DATA INTO THE 3 PARAMETERS
 OF THE SECOND DEG. EQ.
 DVVV = MATRIX TO TRANSFORM 21-PTS. OF DATA INTO THE 3 PARAMETERS
 OF THE SECOND DEG. EQ.

THE SET OF INSTRUCTIONS BETWEEN STATEMENT NUMBERS 500 AND 300
 ARE EXECUTED ONLY ONCE. INITIALLY, IFLAG IS SET TO ONE IN
 ORDER TO EXECUTE SUCH INSTRUCTIONS.
 IX--IS SET FOR AN 81-PT. CURVE FIT.
 KSET--IS SET TO THE LOWER AND UPPER BOUND SPAN ABOUT MID-PT.
 REFERENCE. REFERENCE TIME STARTS AT ZERO AND INCREMENTS BY
 0.05 SECONDS.
 SET CON(3) TO ONE FOR--A--MATRIX.

```

C      IF(IIFLAG.EQ.0)GO TO 300
      IX = 81
      KSET = 41
      CON(3) = 1.0

C      GENERATE TIME INCREMENT(XINC), TIME(CON(2)), AND TIME SQUARED
C      (CON(1)) FOR--A(I,J)--MATRIX.
C      LOAD COMPUTED VALUES(CCN(1)) INTO--A(I,J)--MATRIX.
C
500    DO 5 J=1,IX
        XINC = 1-KSET
        XTIME = 5.00-U2*XINC
        CON(1) = XTIME**2
        CON(2) = XTIME
        DO 5 J=1,3
            A(I,J) = CCN(J)

C      SELECT THE 51-PT., OR 31-PT., OR 21-PT. PATH DETERMINED BY
C      THE PRESET VALUE OF --IX.
C
      IF(IX.EQ.51) GO TO 501
      IF(IX.EQ.31) GO TO 502
      IF(IX.LQ.21) GO TO 503

C      GENERATE THE DATA TRANSFORMATION MATRIX--D--FOR THE 81-PT. FIT.
C
      DO 7 J=1,3
          DO 7 K=1,81
              D(I,J) = 0.0
          DO 7 K=1,3
              D(I,J) = D(I,J)+D8(I,K)*A(J,K)
          IX = 51
          KSET = 26
          GO TO 500

C      GENERATE THE DATA TRANSFORMATION MATRIX--DV--FOR THE 51-PT. FIT.
C
501    DO 8 J=1,3
        DO 8 K=1,51
            DV(I,J) = 0.0
        DO 8 K=1,3
            DV(I,J) = DV(I,J)+D51(I,K)*A(J,K)
        IX = 31
        KSET = 16
        GO TO 500

C      GENERATE THE DATA TRANSFORMATION MATRIX--DVV--FOR 31-PT. CURVE FIT,
C
C
502    DO 9 J=1,3
        DO 9 K=1,31
            DVV(I,J) = 0.0
        DO 9 K=1,3
            DVV(I,J) = DVV(I,J)+D31(I,K)*A(J,K)
        IX = 21
        KSET = 11
        GO TO 500

```

```

C
C      GENERATE DATA TRANSFORMATION MATRIX=DVVV=FOR 21-PT. CURVE FIT.
C
503  DO 10 I=1,3
      DO 10 J=1,21
        DVVV(I,J) = 0.0
      DO 10 K=1,3
        DVVV(I,J) = DVVV(I,J)+DZ1(I,K)*A(I,K)
10  C
C      SET IFLAG TO ZERO TO SKIP STATEMENT NUMBERS 500 THROUGH 300.
C
      IFLAG=0
C
C      SET--SUM--TO ZERO. (SUMMATION OF RESIDUALS SQUARED)
C      SET PARAMETERS--A,B,C--(XPT(1))--OF SECOND DEG. EQ. TO ZERO.
C
300  SUM = 0.0
      XPT(1) = 0.0
      XPT(2) = 0.0
      XPT(3) = 0.0
C
C      SELECT THE APPROPRIATE PATH FOR THE NO. OF PTS. USED IN CURVE FIT
C
      IF(INPOINT.EQ.1)GO TO 306
      IF(INPOINT.EQ.5)GO TO 304
      IF(INPOINT.EQ.3)GO TO 302
C
C      COMPUTE PARAMETERS, A,B,C--(XPT(1)) FOR SECOND DEG. EQ.
C      FOR A 21-PT. CURVE FIT.
C      LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
C      COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
C
      DO 301 I=1,3
        DO 301 J=31,51
          K=J-30
301  XPT(I) = XPT(I)+DVVV(I,K)*F(INVAR(J))
          XSM = XPT(3)
        DO 401 I=1,21
          XINC = 1-11
          XTIME = 5.00-D2*XINC
          TIME2 = XTIME**2
          ZSTX = XPT(1)+TIME2*XPT(2)+XTIME*XPT(3)
          K=I+30
401  SUM = SUM+(F(INVAR(K))-ZSTX)**2
C
C      LOAD CURVE VARIANCE INTO--CVAR.
C      CALCULATE 11D-PT. VARIANCE OF POSITION--SIGX.
C
      CVAR = SUM/18.0
      SIGX = 0.597508263E-02*SUM
C
C      IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE--(DXSM),
C      COMPUTE VARIANCES OF FIRST DERIVATIVE--(DSIGX), AND VARIANCE OF
C      THE SECOND DERIVATIVE--(DDSIGX).
C
STIC* THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(DERKEY.EQ.0.0)GO TO 100

```

```

DXSM = XPT(2)
DSIGX = 0.288600288E-01*SUM
DDSIGX = 0.158499013E-01*SUM
GO TO 99

```

```

C
C COMPUTE PARAMETERS, A,B,C=(XPT(1)) FOR SECOND DEG. EQ.
C FOR A 31-PT. CURVE FIT.
C LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
C COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
C

```

```

302 DO 303 I=1,3
    DO 303 J=26,56
    K=J-25
303 XPT(1) = XPT(1)+D*V(I,K)*FINVAR(J)
    XSM = XPT(3)
    DO 402 I=1,31
    XINC = I-16
    XTIME = 5.0D-02*XINC
    TIME2 = XTIME**2
    ZSTX = XPT(1)+TIME2*XPT(2)+XTIME*XPT(3)
    K=I-25
    SUM = SUM+(FINVAR(K)-ZSTX)**2
402

```

```

C
C LOAD CURVE VARIANCE INTO--CVAR.
C CALCULATE MID-PT. VARIANCE OF POSITION--SIGX.
C

```

```

CVAR = SUM/28.0
SIGX = 0.259668025E-02*SUM

```

```

C
C IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE-(DXSM),
C COMPUTE VARIANCES OF FIRST DERIVATIVE-(DSIGX), AND VARIANCE OF
C THE SECOND DERIVATIVE-(DDSIGX).
C

```

```

STIC THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
IF(DERKEY.EQ.0.0)GO TO 100
DXSM = XPT(2)
DSIGX = 0.576036860E-02*SUM
DDSIGX = 0.144460648E-02*SUM
GO TO 99

```

```

C
C COMPUTE PARAMETERS, A,B,C=(XPT(1)) FOR SECOND DEG. EQ.
C FOR A 51-PT. CURVE FIT.
C LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
C COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
C

```

```

304 DO 305 I=1,3
    DO 305 J=16,66
    K=J-15
305 XPT(1) = XPT(1)+D*V(I,K)*FINVAR(J)
    XSM = XPT(3)
    DO 403 I=1,51
    XINC = I-26
    XTIME = 5.0D-02*XINC
    TIME2 = XTIME**2
    ZSTX = XPT(1)+TIME2*XPT(2)+XTIME*XPT(3)
    K=I-15
    SUM = SUM+(FINVAR(K)-ZSTX)**2
403

```

```

C
C      LOAD CURVE VARIANCE INTO--CVAR.
C      CALCULATE MID-PT. VARIANCE OF POSITION--SIGX.
C
C      CVAR = SUM/48.0
C      SIGX = 0.919707498E-03*SUM
C
C      IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE-(DXSM),
C      COMPUTE VARIANCES OF FIRST DERIVATIVE-(DSIGX), AND VARIANCE OF
C      THE SECOND DERIVATIVE-(DDSIGX).
C
STIC* THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IFIDERKEY=EQ.0.0)GO TO 100
      DXSM = XPT(2)
      DSIGX = 0.754147804E-03*SUM
      DDSIGX = 0.696940604E-02*SUM
      GO TO 99
C
C      COMPUTE PARAMETERS, A,B,C-(XPT(1)) FOR SECOND DEG. EQ.
C      FOR A 81-PT. CURVE FIT.
C      LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
C      COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
C
306 DO 307 I=1,3
      DO 307 J=1,81
307   XPT(1) = XPT(1)+D(1,J)*FINVAR(J)
      XSM = XPT(3)
      DO 404 I=1,81
      XINC = 1-41
      XTIME = 5.00-02*XINC
      TIME2 = XTIME**2
      ZSTX = XPT(1)+TIME2*XPT(2)+XTIME*XPT(3)
404   SUM = SUM+(FINVAR(I)-ZSTX)**2
C
C      LOAD CURVE VARIANCE INTO--CVAR.
C      CALCULATE MID-PT. VARIANCE OF POSITION--SIGX.
C
C      CVAR = SUM/78.0
C      SIGX = 0.356215871E-03*SUM
C
C      IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE-(DXSM),
C      COMPUTE VARIANCES OF FIRST DERIVATIVE-(DSIGX), AND VARIANCE OF
C      THE SECOND DERIVATIVE-(DDSIGX).
C
STIC* THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IFIDERKEY=EQ.0.0)GO TO 100
      DXSM = XPT(2)
      DSIGX = 0.115813123E-03*SUM
      DDSIGX = 0.423900405E-02*SUM
C
C      CALCULATE VARIANCE OF SECOND DERIVATIVE-(DDXSM).
C      LOAD IN RAW POSITION AT 41-PT. INTO--XRAW.
C
99   DDXSM = 2.0*XPT(1)
100  XRAW = FINVAR(41)
      RETURN
      END

```

APPENDIX C

POTENTIAL BENEFITS
OF
COHERENT C-BAND DOPPLER RANGE-RATE DATA

By

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POTENTIAL BENEFITS OF COHERENT C-BAND
DOPPLER RANGE-RATE DATA

C-Band tracking radars equipped with Coherent Signal Processors (CSP) provide precision range-rate data for various applications. The following discussion will attempt to display the utility of range-rate data in terms of Best Estimate of Trajectory (BET) improvement and feature extraction. All of the data shown were collected by the AN/FPQ-6 radar at Wallops Island.

Figure 1 displays a classic problem for launch ranges - trajectory determination during staging. The velocity vs. time trace in figure 1 is from the BET solution of standard skin track range, azimuth, and elevation (RAE) data from a typical NIKE launch at Wallops Island. The computer software that was used to process the trajectory is a state-of-the-art Kalman Filter, similar in design to many range safety real-time filters used nationally. A familiar technique of destroying the memory of the filter at known staging times was utilized in this data analysis to assist in transient response at burn and burn out, but the velocity solution still exhibits classic overshoot and subsequent undershoot. The velocity trace in figure 2 was made with exactly the same computer set-up, except the CSP range-rate data was weighted in the solution.

Figures 3, 4, and 5 are from the tracking data of a super-critical designed fuselage that was dropped from an aircraft. The purpose of the test was to determine the drag coefficient of the body as the velocity passed through mach 1. The test was designed so as to maximize the

velocity vector in the direction of the radar range to obtain high quality range-rate information from the CSP. Figure 3 and 4 contrast the solution of acceleration vs. velocity without and with range-rate data. In this case the experiment was looking for a transient in the trajectory, and the CSP was able to contribute greatly to the feature extraction. Figure 5 displays the range-rate residuals to the trajectory displayed in figure 4. The RMS noise (skin track), with four measurements edited, was 8 cm/sec.

As was discussed in figures 1 and 2, the classic problem of any real time or end-point filter such as the Kalman, is overshoot, or equivalently, filter lag. This is particularly evident when solving for high order terms, such as velocity and acceleration, from measurements of position, such as RAE. The filter must process a series of position measurements before the higher order terms are observable, and the result is a time lag. One such observable parameter is aircraft bank angle. The computer software used for most of this paper has an optional dynamic model for aircraft tracking, with bank angle and longitudinal acceleration being the highest order terms in the model. Figure 6 displays the X-Y ground trace of an aircraft flight tracked by the Wallops AN/FPQ-6 radar. The aircraft was equipped with a coherent transponder, and CSP range-rate data was collected along with the normal beacon track RAE (gross spectrum) data. Figures 7 and 8 contrast the BET bank angle without and with range-rate. Notice the time lag of approximately 3

seconds in the solution without range rate. Figure 9 displays the range-rate residuals, here with an RMS of 2.9 cm/sec. Some shadowing of the transponder may have occurred in this data, since other segments of the track exhibit 2.0 cm/sec RMS.

The purpose of the above track was to provide an altitude standard with which to compare the measurements from the NRL nanosecond radar altimeter that was on the aircraft. Figure 10 displays the solution for altitude above the spheroid as determined by the altimeter (stars) and as determined by the radar (solid line). The agreement between the two systems is generally 10-20 cm over this one minute span of data, showing the potential for both CSP tracking data and microwave altimetry.

To round out the spectrum of CSP applications, a short span (20 seconds) of skin track range-rate data from a GEOS-II track was integrated to generate precise range data. Figure 11 displays the orbital accuracy by comparing range measurements from a collocated laser ranging system. The X's represent the laser residuals to an orbit determined by 20 seconds of normal range data. The dotted circles represent the laser residuals to an orbit determined by integrated ranges from the same 20 second time span. The integrated ranges were then smoothed, and the third trace represents the laser residuals to the smoothed CSP ranges.

In conclusion, the above data demonstrate the utility, accuracy, and precision of CSP range-rate measurements. Furthermore, the advantages of precision range-rate for solution of high order terms, such as velocity or acceleration, has been shown.

NIKE CAJUN FPQ-6

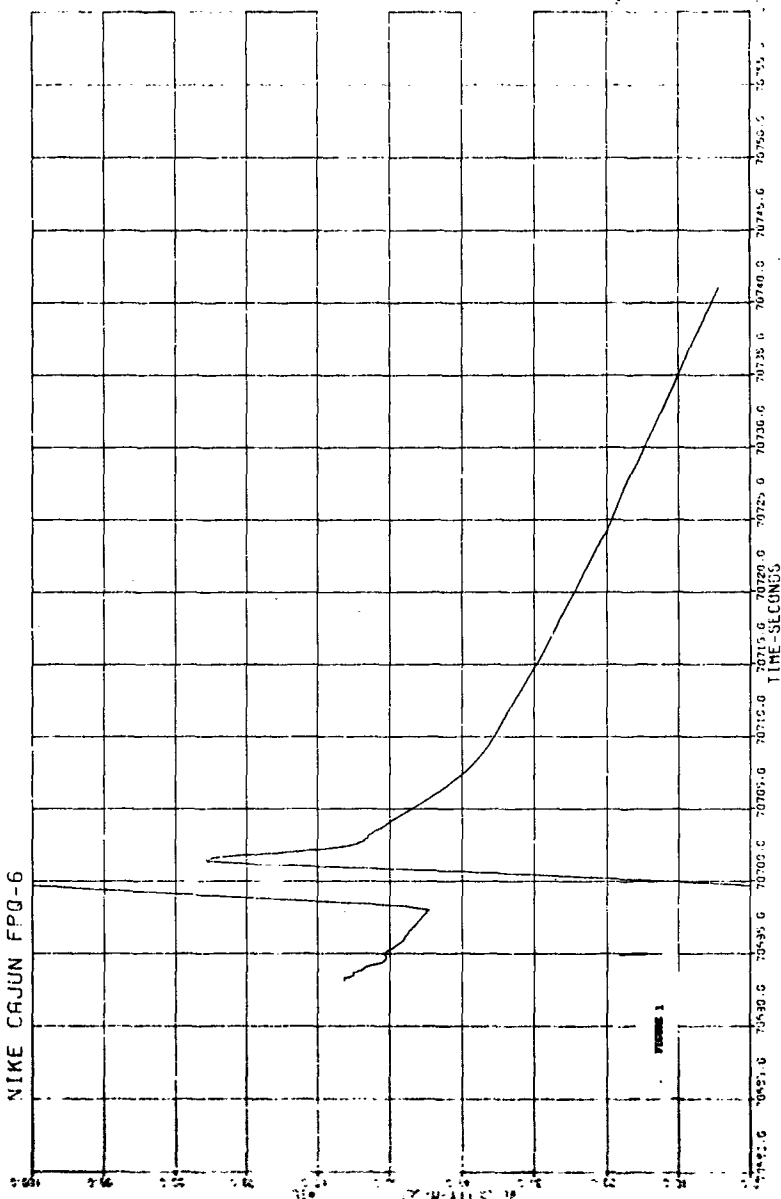


FIGURE 1

NIKE CAJUN FPQ-6

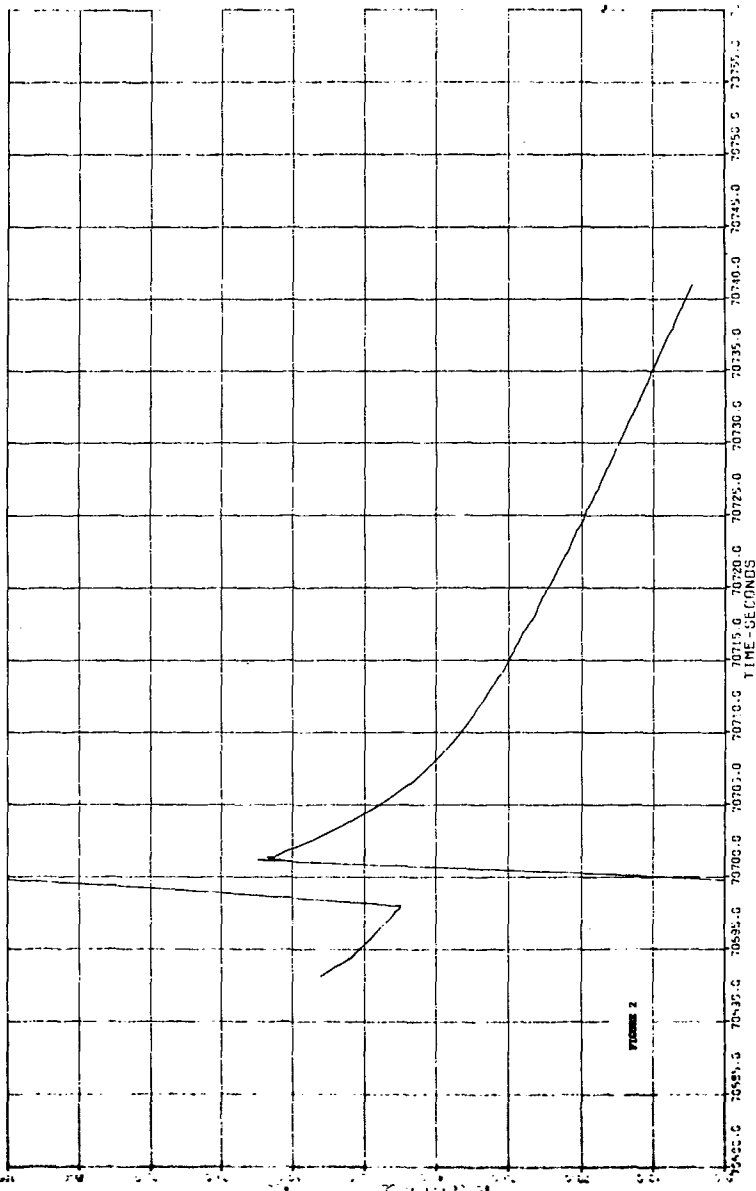


FIGURE 2

HIRAD 3 Q6

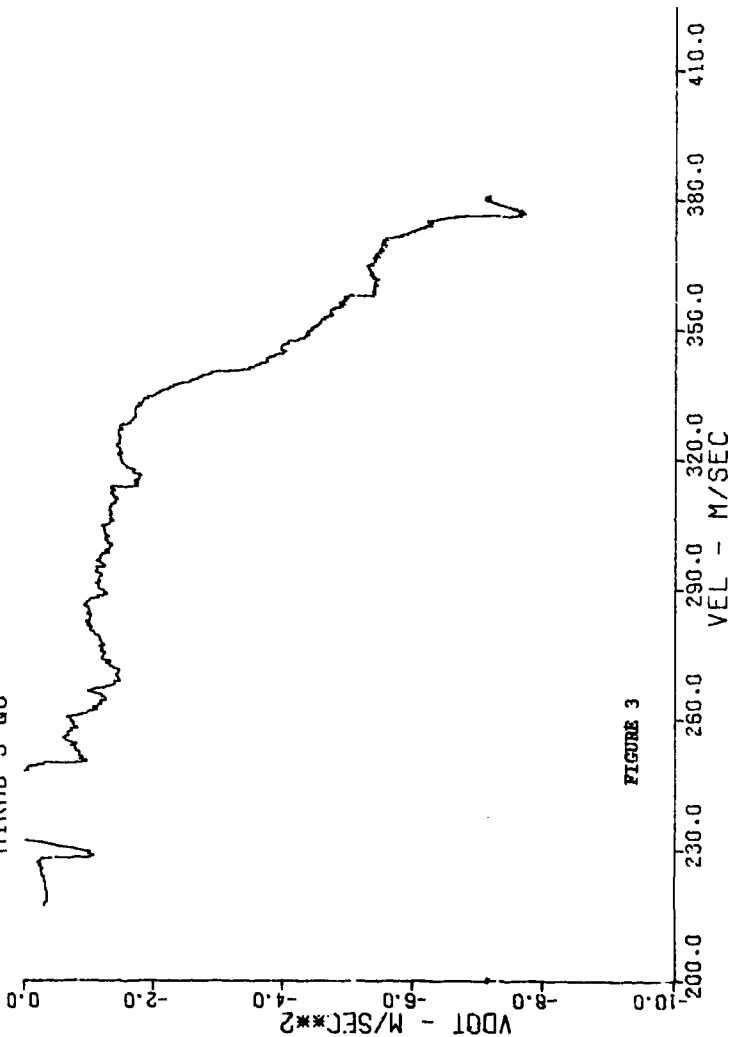


FIGURE 3

HIRAD 3 Q6 WITH DOPPLER

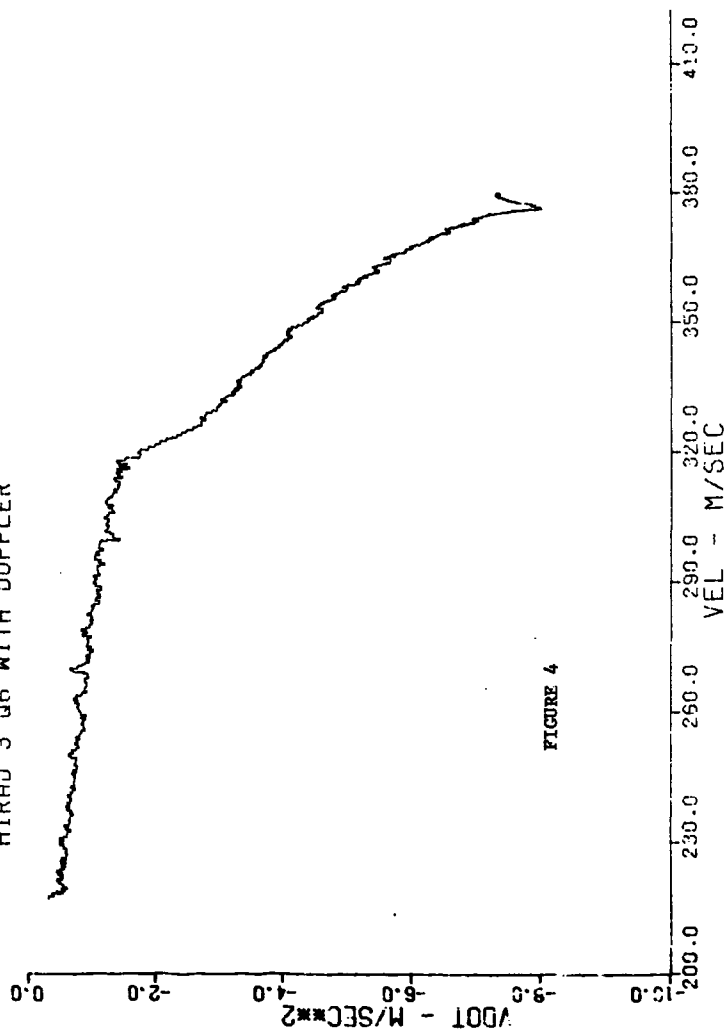


FIGURE 4

HIRAD 3 FPQ-6 WITH DOPPLER

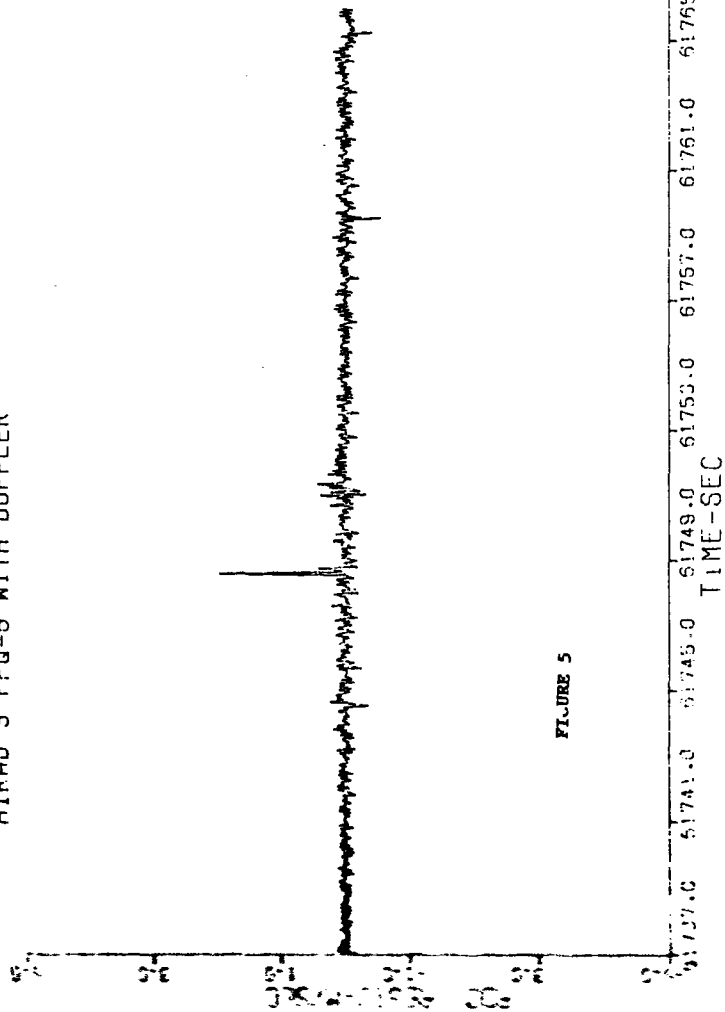
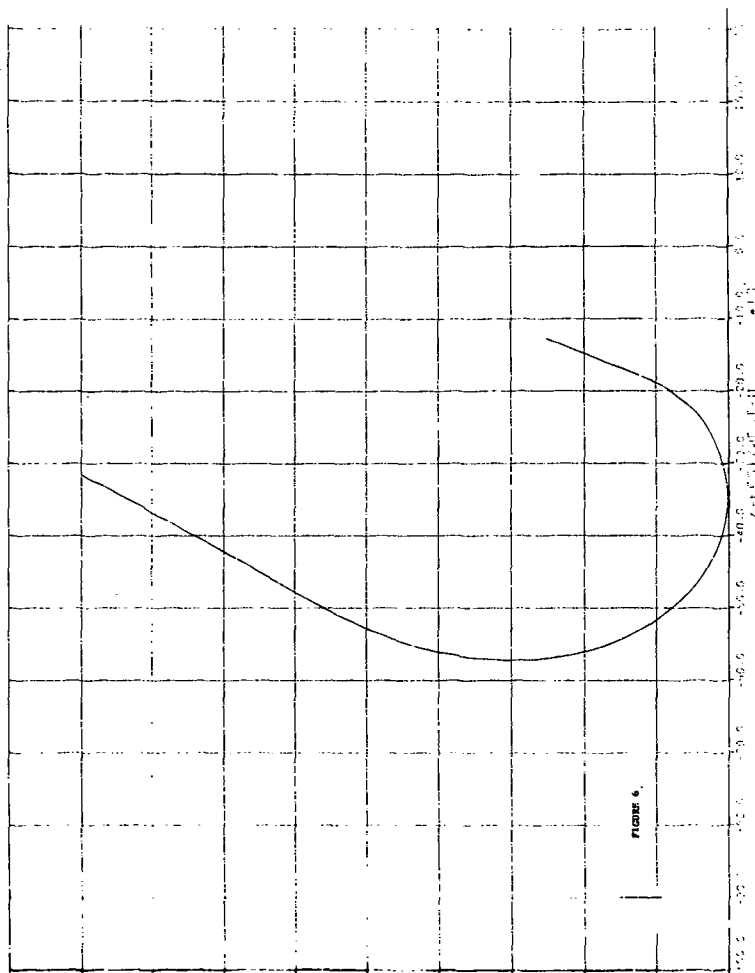
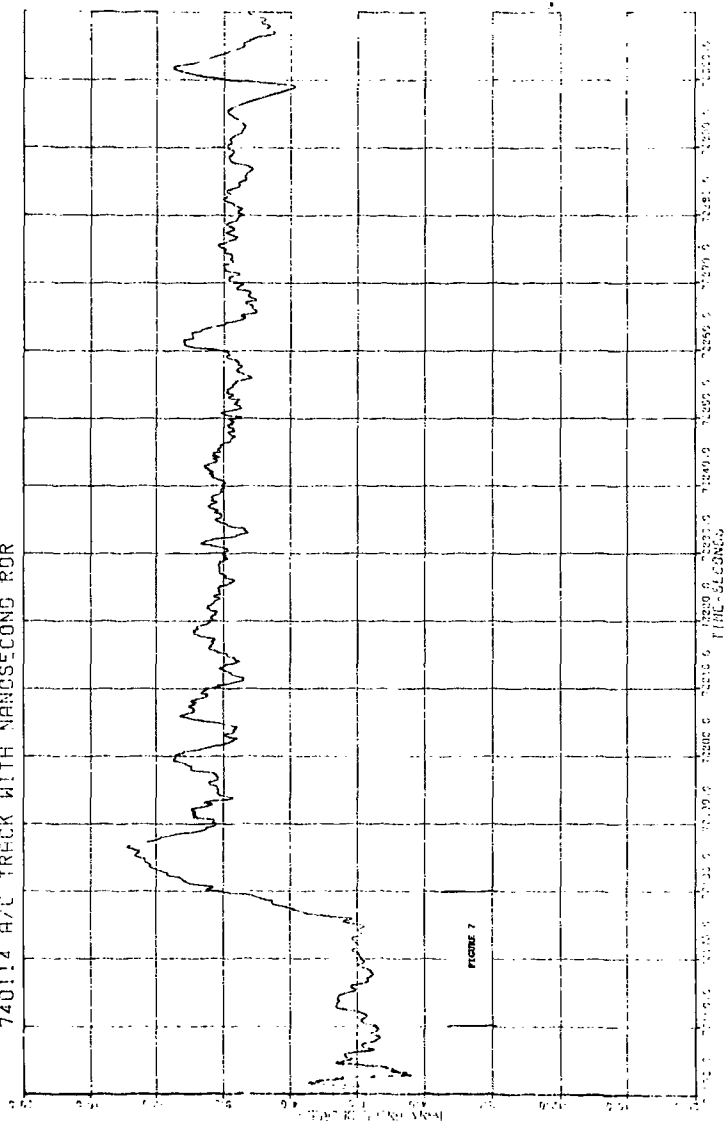


FIGURE 5

240114 G C TRACK WITH NANOSECONDS RDR



740114 A/C TRACK WITH NANOSECOND BOR



740114 R/C TRACK WITH NANOSECOND RDR

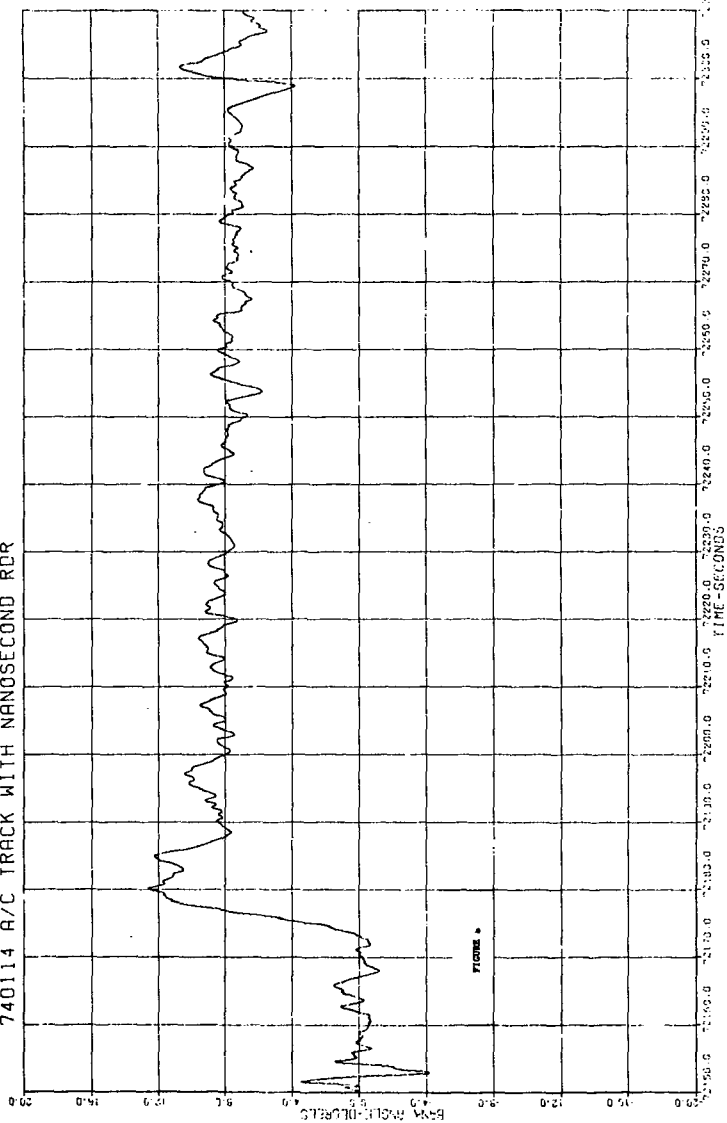
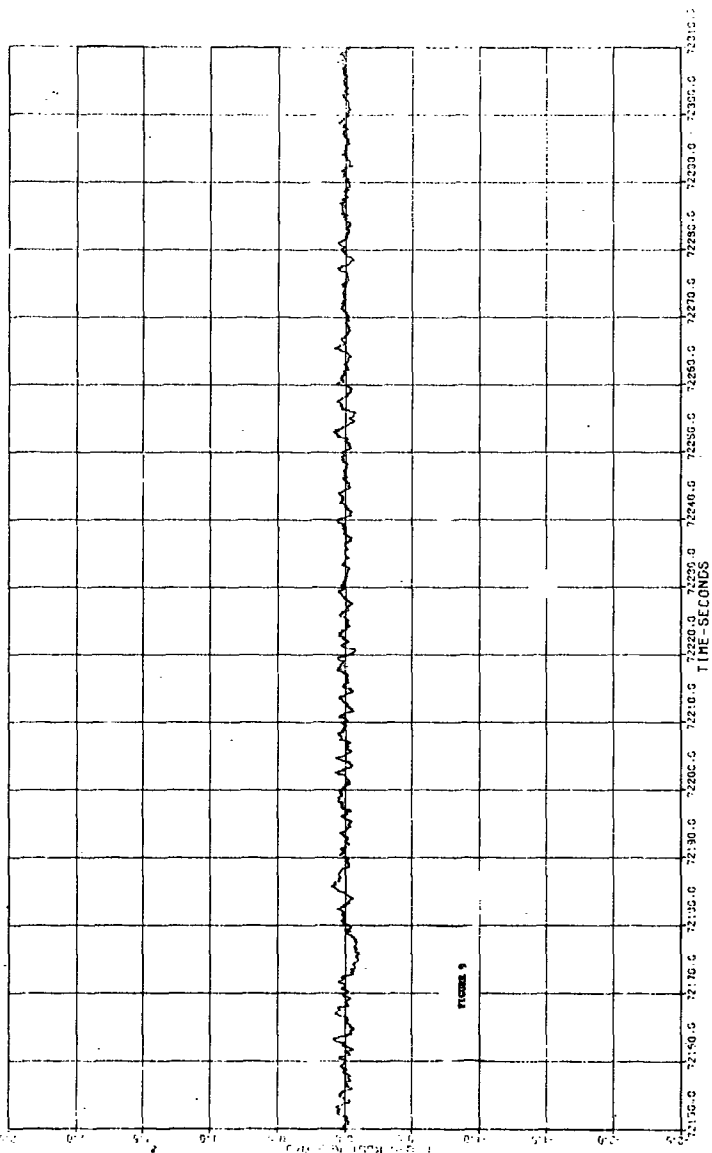


FIGURE 1

740114 R/C TRACK WITH NANOSECOND RDR



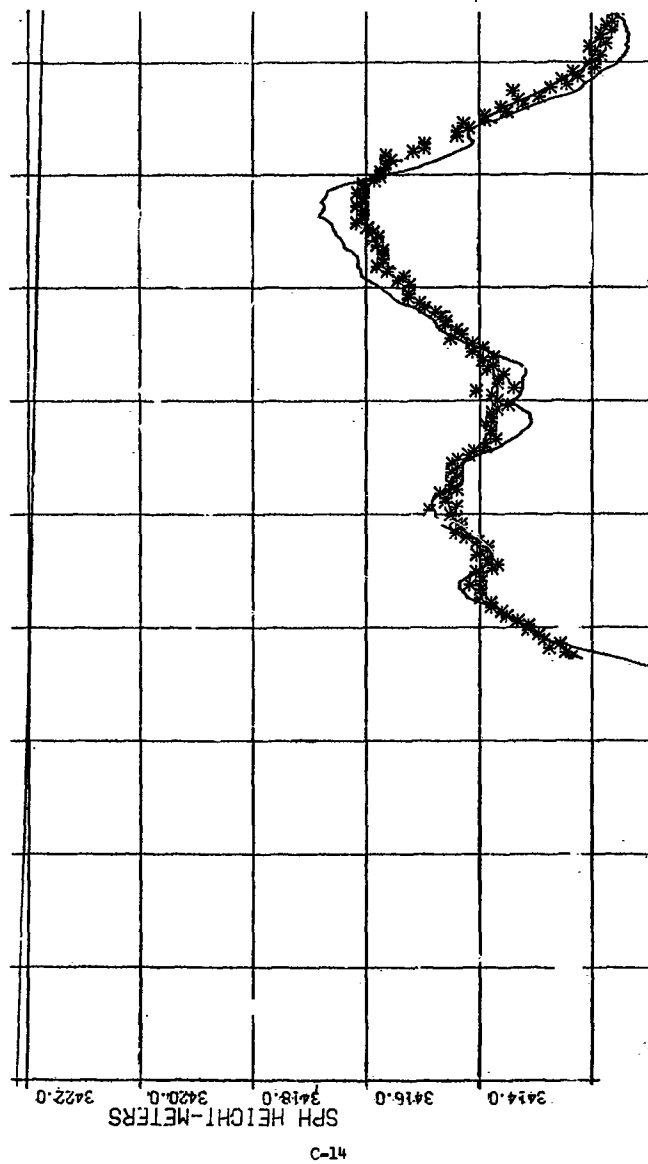
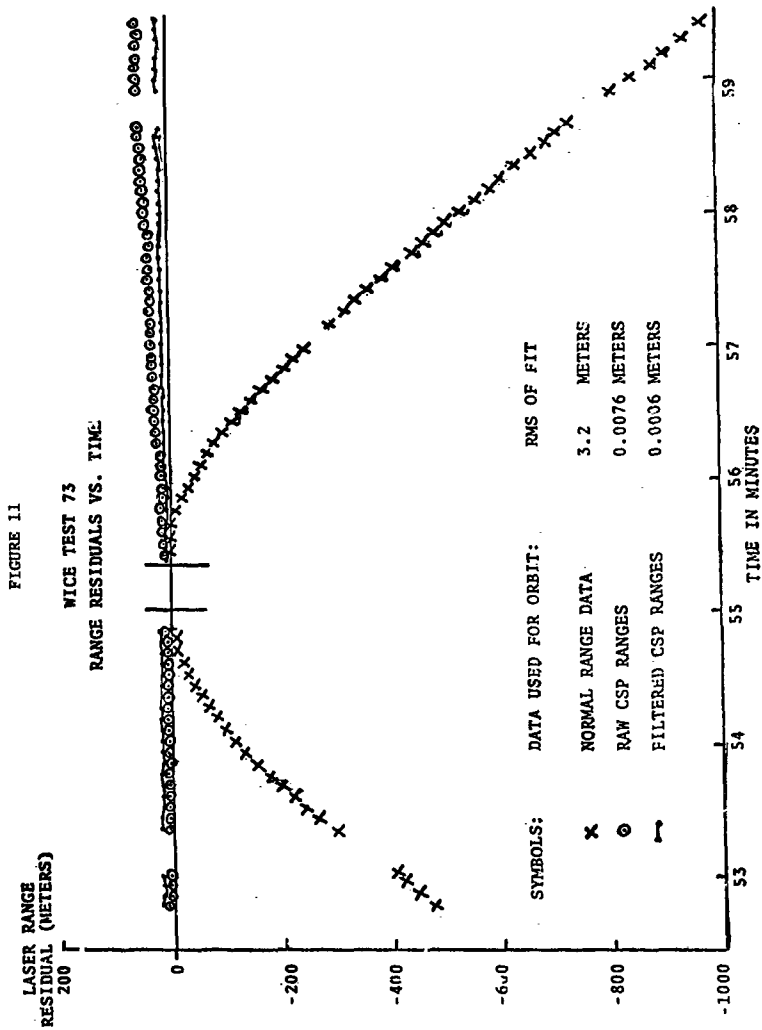


FIGURE 10



APPENDIX D

C-BAND AND TRANET TRACKING BIASES
RELATIVE TO A COLLOCATED LASER

By

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ABSTRACT

C-BAND AND TRANET TRACKING BIASES RELATIVE TO A COLLOCATED LASER

D. V. Carney
H. C. Parker
J. H. Berbert

As part of the GEOS-II Observation Systems Intercomparison Investigation, the Wallops Island Collocation Experiment (WICE) was conducted during April through June 1968. Among the collocated tracking systems were a NASA laser and an AN/FPQ-6 C-band radar equipped with a coherent signal processor (CSP). The FPQ-6 tracked GEOS both in a beacon mode and in a skin tracking mode. During four of the skin track segments, C-band doppler data was successfully taken and recorded for analysis.

The laser data were used to form reference orbits against which the doppler data were compared with the NONAME orbit determination program. Simple error models, consisting of measurement and timing bias terms, were then fit to the data. The RMS noise of the residuals varied from 2.7 cm/sec to 13.3 cm/sec, and the derived range rate measurement bias varied from -1.3 ± 0.5 cm/sec to 6.7 ± 0.7 cm/sec with an average value of 2.5 cm/sec. The timing bias ranged from 0.01 ± 0.20 milliseconds to 0.45 ± 0.20 milliseconds.

1.1

INTRODUCTION

The GEOS-II Observation Systems Intercomparison Investigation was designed to evaluate the relative accuracies of various geodetic observation systems. As a part of this effort, the Wallops Island Collocation Experiment (WICE) (Reference 1) was conducted during the period of April through June 1968. A NASA laser, two C-band radars (an AN/FPQ-6 and an AN/FPS-16), several cameras, a Navy TRANET doppler, and an Army SECOR comprised the tracking systems employed. These trackers were collocated with one another in order to minimize relative station survey errors (determined to better than 10 cm.) and earth gravity field errors that might otherwise be aliased into tracking biases. The NASA laser range, azimuth, and elevation (RAE) data were weighted at 2 meters, 200 arc seconds, and 200 arc seconds, respectively, and were used to form the reference orbits against which the other systems were compared.

The AN/FPQ-6 C-band radar used a coherent signal processor (CSP) to provide doppler range rate measurements on GEOS-II during the WICE (References 2 and 3). However, since GEOS did not have a coherent beacon, the CSP could only be used during a skin track. The skin tracks were augmented by a Van Atta retro-reflector array on the GEOS spacecraft. Of the 34 FPQ-6 tracks simultaneous with the laser, 10 were taken both in the beacon and skin track modes. For those 10 passes, the FPQ-6 was calibrated for the skin track portion, tracked the first third of the pass with the beacon, was switched to skin track for the second third of the pass, and back to the beacon for the final third. Doppler tracking was attempted during nine passes, successfully on eight of the nine. Of the eight, the four for which we received data (on May 30, June 5, June 11 and June 12) are covered in this report.

1.2

SOFTWARE

The FPQ-6 doppler data forwarded to us from Wallops Station were known to contain a hardware truncation error with a maximum value of 2.8575 cm/sec. Similarly, the zero-set bias correction normally measured at Wallops had not been applied or recorded (Reference 4). Neither of these errors were recoverable. The data, as received, were corrected for a known error in the speed of light constant representation which existed in the radar hardware system at that time (Reference 5) and were preprocessed with the RCA C-band Pre-processing Program (Reference 6) for time tag and tropospheric refraction corrections.

As in the WICE report (Reference 1), the NONAME Orbit Determination Program (ODP) (Reference 7) was used to reduce the laser RAE data through a least squares fit procedure to form the reference orbits against which the FPQ-6 and TRANET range rate data were compared. Simple error models for measurement bias and timing bias were then fit to the range rate residuals with the ODP.

1.3 A PRIORI DATA AND ERROR MODEL WEIGHTINGS

For the purposes of this report, a specific error model is defined as any distinct combination of bias uncertainty terms and the values assigned to those terms, i.e., different value combinations for the bias uncertainty terms create different error models.

Of the four available passes, two were simultaneous with TRANET doppler data, on June 11 and June 12. Previous analyses of the TRANET data have established appropriate weightings for that data and confidence in the results. It was determined that, due to the fairly high correlation of the range rate bias to the timing bias, the TRANET time bias had to be constrained to 0.2 milliseconds (ms) in order to get reasonable estimates of the measurement bias. However, the first FPQ-6 error model allowed an increase to 1 millisecond in the a priori timing uncertainty in an attempt to estimate the relatively unknown timing bias for the new C-band doppler data. Since reasonable estimates of the timing and measurement bias were not recovered, it was again assumed that due to the accuracies of the collocation techniques, the relative timing bias was as accurate as that of the TRANET. Thus, in the second error model, the a priori FPQ-6 timing uncertainty was reduced to 0.2 milliseconds, matching the TRANET error model terms.

The first two rows of Table I give the a priori weights (SIGMA) assigned to the laser measurements used to form the reference orbits. The third row indicates the SIGMA applied to the FPQ-6 range rate data in the unmodeled runs for each of the four passes. For both remaining stations, the columns show the error model number, the SIGMA, the initial estimate of the measurement bias (BIAS), the uncertainty about that measurement bias (BIAS SIGMA), the initial estimate of the measurement timing bias (TIME BIAS), and the uncertainty about that time bias (TIME SIGMA). Error model 1 was used in the original analyses of the FPQ-6 range rate data; models 2 and 3 came from the WICE TRANET error modeling study.

In all of the error model recovery runs, the laser reference orbit was held fixed by weighting the position and velocity state vector components at 10^{-6} meters and 10^{-12} meters per second, respectively, thus forcing the error model coefficients to fit the C-band residuals.

2.1 RESULTS

Figure I is a display of the plots of the unmodeled range rate residuals against the laser RAE reference orbits for each of the four passes. Each plot shows the FPQ-6 residuals sampled every five seconds and the time-location of the doppler skin track portion within the laser pass. None of the FPQ-6 range rate initial points are coincident with the first range point of the skin track; rather, the range rate data starts later by 58, 65, 79 and 109 seconds, respectively, for the four passes taken in chronological order. Further, the point of the closest approach (PCA) of the satellite consistently occurs at the second time point of each range rate track and lies between 71° and 88° elevation.

The lower two plots, i.e., the June 11 and 12 passes, also show the unmodeled TRANET residuals for comparison. These data were smoothed over a 32-second interval during the Naval Weapons Laboratory (NWL) preprocessing and are shown without further sampling.

Figure II illustrates the residuals as they appear after the second error model was applied during both the FPQ-6 and TRANET data reductions.

Table II summarizes the pass statistics for the residuals and the derived measurement and timing bias error model terms for the four FPQ-6 tracks and the two simultaneous TRANET tracks. The RMS noise values are given for both the first and final iterations to show the effective noise reduction resulting from modeling the systematic trends within each pass. The mean value of the residuals for iteration one is given for comparison to the measurement bias term derived in subsequent iterations, when the residual mean has been reduced to zero. When both the biases and their associated uncertainties are considered, the best results appear to be obtained with the second error model.

The third error model was used in an attempt to display the effects caused by assuming the measurement bias to be fairly well known and the timing bias relatively unknown.

Table III is a summary of the statistics for each item of interest averaged over the four FPQ-6 passes, the two simultaneous passes of the low frequency TRANET pair (Lo), and finally, for reference, over the 26 passes of the low and the 16 passes of the high-frequency TRANET pairs taken during the WICE.

It has been shown in a separate set of runs not given here, that when no time bias error term is solved for, the derived measurement bias for the final iteration is equal to the residual mean value from the first iteration. The measurement errors are forced into the range rate bias with a slight degradation (0.0 to 0.1 cm/sec.) in the RMS noise; i.e., if a timing bias does indeed exist, it can be aliased into a measurement bias with an appropriate error model. Conversely, if no measurement bias term is allowed and the time bias uncertainty is set large at ± 1 second, the residual mean values are reduced to a near-zero level. The time bias term will now absorb most of the measurement error, varying from -0.30 milliseconds to 2.51 milliseconds. This indicates that the range rate and timing biases are highly correlated and points out the need to assign relative uncertainties which approximate reality. Due to the careful relative time synchronization techniques, we believe that the clocks were indeed synchronized to at least 200 μ secs. (0.2 millisecond.), as used in error model 2.

The C-band doppler tracks are all one-sided, starting a few seconds before PCA and then continuing down to an elevation of between 45° and 60° . The doppler data were offset from the start of the skin track due to difficulties in "locking on" for range rate. Had the passes been more nearly symmetrical, the bias terms should have been more separable.

Figure III consists of two overlays of the FPQ-6 range rate biases on plots of the WICE TRANET measurement biases. In both cases, the TRANET range rate biases were derived with the second error model. The first (top) plot shows the FPQ-6 biases as they were originally derived with the first error model (Reference 8). The second (bottom) plot compares the FPQ-6 biases as derived with the second model to the TRANET biases. It is apparent that the more realistic second model yields FPQ-6 measurement biases that generally agree more closely with the laser reference orbit and the TRANET than does the first model.

Figure IV is an overlay of the FPQ-6 skin track range biases on plots of the FPQ-6 beacon mode, the FPS-16 C-band, and the SECOR range biases from the WICE. It is included as supplementary information, showing the degree of agreement

between the ranging biases for the skin track portion (X) and the beacon track portion (V) with the laser reference orbit and the other systems during that period.

It has been reported (Reference 9) that the phase center of the TRANET antenna was on the order of 1 meter different from the geometric antenna center that we have been using. Runs were made for the June 11 and June 12 TRANET passes using the modified phase center coordinates. The measurement biases recovered using error model 2 deviated from the previous results by less than 0.4 cm/sec. The timing biases did not change.

3.1

CONCLUSIONS

While it is understood that, due to the sparse number of passes, these results are not very conclusive, they are an indication of what was achieved in early GEOS-II attempts to utilize CSP doppler data available from the Wallops AN/FPQ-6 radar operating in a skin track mode. The data in this study is somewhat corrupted with non-recorded zero-set and truncation errors, yet the results appear reasonable for a C-band range rate system at that time, particularly for the last (6/12) pass.

Considering error model 2, the FPQ-6 range rate biases range from -1.3 cm/sec to 6.7 cm/sec with timing biases of 0.01 milliseconds to 0.45 milliseconds. For the two simultaneous TRANET passes, the range rate biases are 1.9 cm/sec and 1.2 cm/sec with timing biases of 0.00 ms. and 0.05 ms.

The measurement range rate bias results are significantly better with less uncertainty when the time bias term is more tightly constrained (from 1 second, or 1 millisecond, down to 0.2 millisecond uncertainty), indicating that, due to the correlation between the range rate and timing bias coefficients, it is important to use realistic time bias constraints. By using the more realistic estimate of the uncertainty in the FPQ-6 clock, the results are substantially improved over previous analyses.

REFERENCES

1. "Comparison of C-band, SECOR, and TRANET with a Collocated Laser and Camera on 35 Tracks of GEOS-2". Berbert, J., Parker, H., Carney, D., NASA/GSFC X-550-72-451, November, 1972.
2. "Pre-Processing of Wallops AN/FPQ-6 GEOS-2 Data", Brooks, R., Vetter, J., Editors, NASA/Wallops Station CR-62076, February, 1970.
3. "Calibration and Evaluation of the Wallops AN/FPQ-6 Radar Utilizing the GEOS-2 Satellite", NASA/Wallops, X-16-68-1, August, 1968.
4. "Review of FPQ-6 Skin Track Data Taken at Carnarvon and Wallops Island", memo from J. M. Hlavin, RCA to R. Reich, RCA, October 12, 1970.
5. "Beacon/Skin Tracks of the GEOS-2 Satellite by the Wallops AN/FPQ-6 Radar", Brooks, R., Proceedings of the GEOS-2 C-band Project Technical Conference, June, 1969.
6. "RCA C-band Pre-Processing Program Documentation", memo from J. M. Hlavin, RCA to H. R. Stanley, Wallops Station, October 9, 1969, with confirmation to J. A. Haik, RCA, December 9, 1969.
7. "NONAME, Volumes I through IV", O'Neil, B., Contract NAS5-9756-710, August, 1968.
8. "Geodetic System Accuracy Intercomparison", Berbert, J., I.U.G.G. Conference, August 1971..
9. "Operation of TRANET Station 203 at Wallops Island", Tucker, A., Tupa, B., DRL-TR-68-23, August 7, 1968.

TABLE I
A PRIORI DATA AND ERROR MODEL TERM WEIGHTS

Station	Meas. Type	Units	Error Model	Sigma	Bias	Bias Sigma	Time Bias (secs)	Time Sigma (secs)
Laser Laser	Range Az/EI	meters arc secs.	Reference Orbits	2.0 200.0	— —	— —	— —	— —
FPQ-6 FPQ-6 FPQ-6 FPQ-6	R. Rate R. Rate R. Rate R. Rate	m/sec. m/sec. m/sec. m/sec.	Unmodeled 1 2 3	0.04 0.04 0.04 0.04	— 0.0 0.0 0.0	— 10.0 10.0 0.08	— 0.0 0.0 0.0	— 0.0010 0.0002 1.0
TRANET TRANET TRANET	R. Rate R. Rate R. Rate	m/sec. m/sec. m/sec.	1 2 3	0.04 0.04 0.04	0.0 0.0 0.0	10.0 10.0 0.08	0.0 0.0 0.0	0.0010 0.0002 1.0

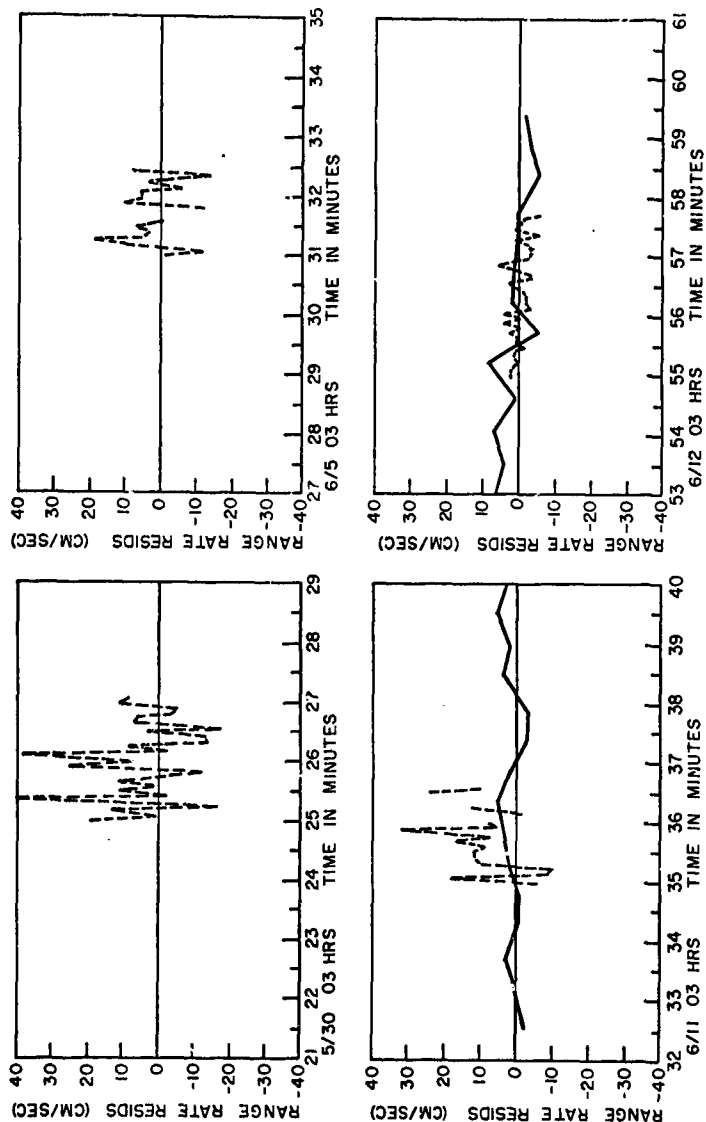


FIGURE I. UNMODELED FPQ-6 AND TRANET RANGE RATE RESIDUALS VS TIME

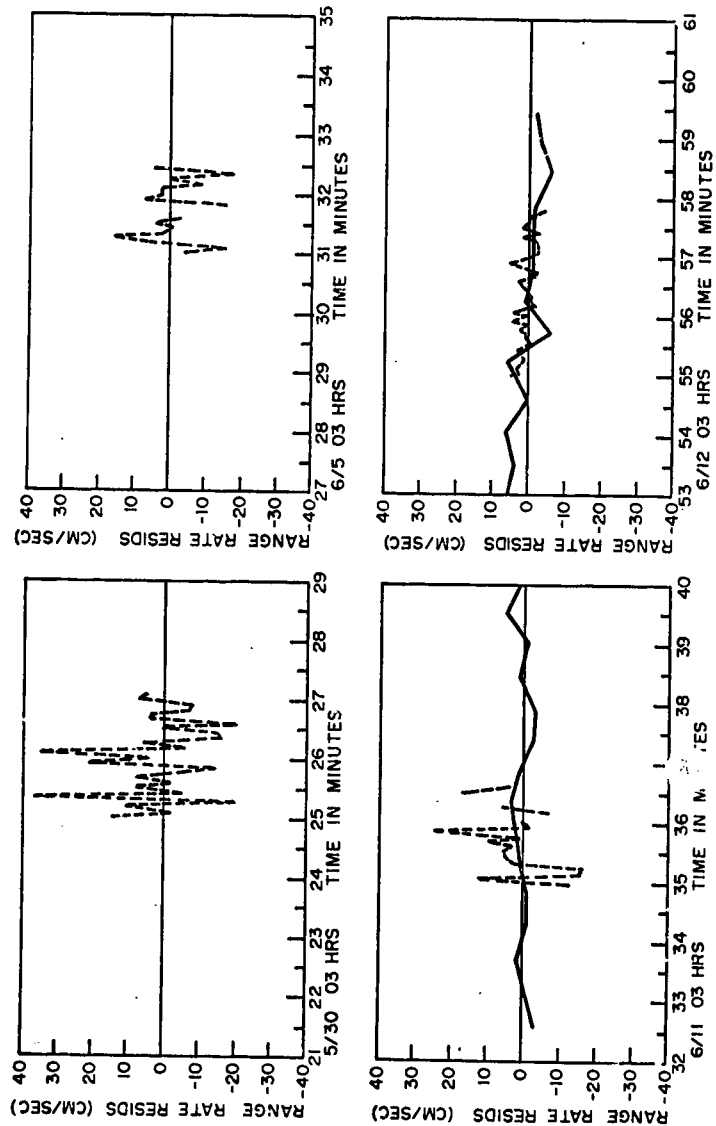


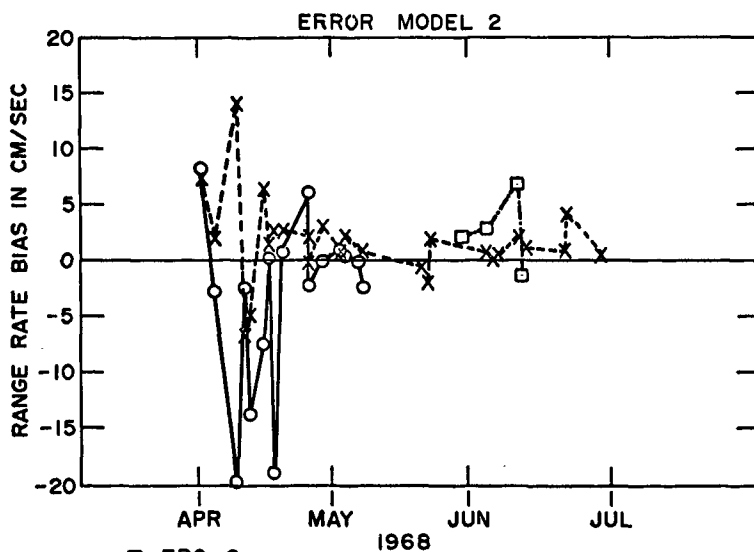
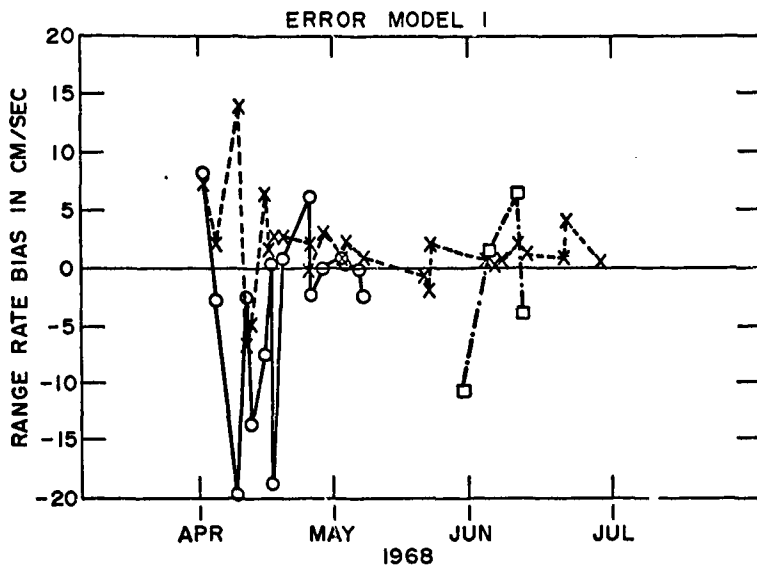
FIGURE II. ERROR MODEL 2, FPQ-6 AND TRANET RANGE RATE RESIDUAL VS TIME

TABLE II
FPQ-6 AND TRANET RANGE RATE RESIDUAL STATISTICS AND BIAS VALUES

Station	Model	Epoch	RMS		Mean (cm/sec)	Bias Value Sigma (cm/sec)	Time Bias Value Sigma (millisec)
			Iter. 1 (cm/sec)	Iter. 3 (cm/sec)			
FPQ-6	Unmodeled	5/30	13.7	13.7	3.2	—	—
		6/5	12.9	12.9	2.5	—	—
		6/11	12.6	12.6	3.7	—	—
		6/12	2.9	2.9	-0.9	—	—
FPQ-6	1	5/30	13.7	12.9	3.2	-10.9 ± 1.8	5.17 ± 0.66
		6/5	12.9	12.6	2.5	1.2 ± 2.6	0.46 ± 0.92
		6/11	12.6	10.7	6.7	6.2 ± 2.5	0.17 ± 0.92
		6/12	2.9	2.5	-0.9	-4.2 ± 1.3	1.40 ± 0.53
FPQ-6	2	5/30	13.7	13.3	3.2	2.0	0.45 ± 0.20
		6/5	12.9	12.6	2.5	2.5 ±	0.02 ± 0.20
		6/11	12.6	10.7	6.7	6.7 ± 0.7	0.01 ± 0.20
		6/12	2.9	2.7	-0.9	-1.3 ± 0.5	0.18 ± 0.19
FPQ-6	3	5/30	13.7	12.8	3.2	-19.8 ± 2.3	8.48 ± 0.84
		6/5	12.9	12.6	2.5	-3.3 ± 5.0	2.09 ± 1.78
		6/11	12.6	10.7	6.7	2.2 ± 5.0	1.68 ± 1.87
		6/12	2.9	2.5	-0.9	-5.3 ± 1.5	1.88 ± 0.62
TRANET	Unmodeled	6/11	3.2	3.2	1.9	—	—
		6/12	4.6	4.6	1.3	—	—
TRANET	1	6/11	3.2	2.6	1.9	1.9 ± 2.0	-0.02 ± 0.85
		6/12	4.6	4.0	1.3	-0.5 ± 2.0	0.91 ± 0.83
TRANET	2	6/11	3.2	2.6	1.9	1.9 ± 1.1	0.00 ± 0.20
		6/12	4.6	4.3	1.3	1.2 ± 1.2	0.05 ± 0.20
TRANET	3	6/11	3.2	2.6	1.9	1.7 ± 3.0	0.07 ± 1.49
		6/12	4.6	3.7	1.3	-4.0 ± 3.0	2.66 ± 1.40

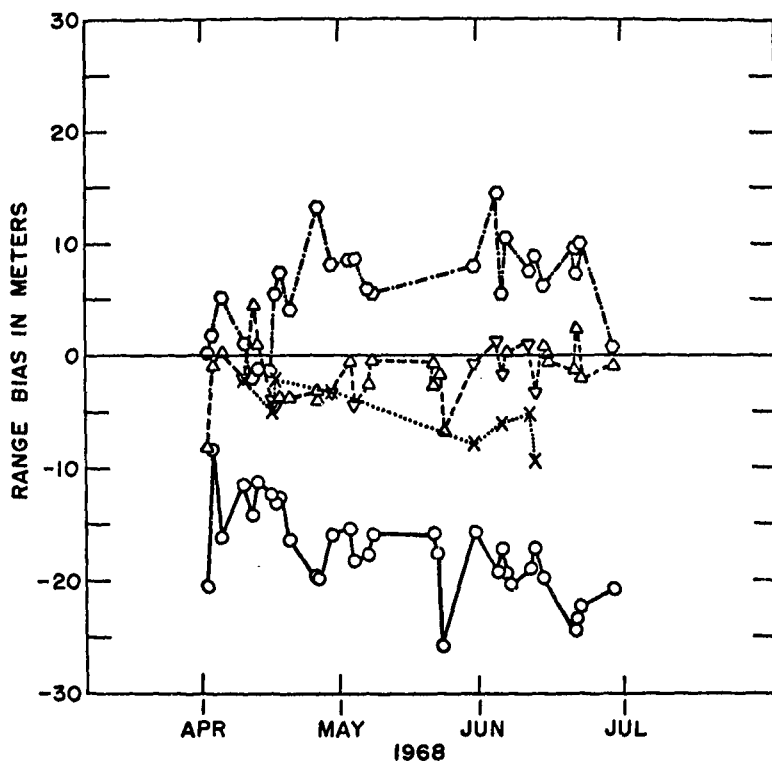
TABLE III
AVERAGED STATISTICS FOR THE RANGE RATE PASSES

Station	Model	Sample Size	RMS (cm/sec)	Iter. 3 Mean (cm/sec)	Meas. Bias (cm/sec)	Time Bias (millisec)
FPQ-6	Unmodeled	4	10.5 ± 4.4	2.9 ± 2.7	—	—
	1	4	9.7 ± 4.2	—	-1.9 ± 6.4	1.80 ± 2.00
	2	4	9.3 ± 4.2	—	2.4 ± 2.9	0.17 ± 0.18
	3	4	9.7 ± 4.2	—	-6.5 ± 8.1	3.50 ± 2.00
FPQ-6	Unmodeled	2	7.8 ± 4.9	2.9 ± 3.8	—	—
	1	2	6.6 ± 4.1	—	1.0 ± 5.2	0.79 ± 0.62
	2	2	6.7 ± 4.3	—	2.6 ± 4.0	0.10 ± 0.09
	3	2	6.6 ± 4.1	—	-1.5 ± 3.8	1.78 ± 0.10
TRANET (LO)	Unmodeled	2	3.9 ± 0.6	1.6 ± 0.3	—	—
	1	2	3.3 ± 0.7	—	0.7 ± 1.2	0.45 ± 0.47
	2	2	3.5 ± 0.9	—	1.5 ± 0.3	0.01 ± 0.01
	3	2	3.2 ± 0.6	—	1.2 ± 2.9	1.37 ± 1.30
<u>WICE</u> TRANET (LO) TRANET (HI)	2	26	4.5 ± 2.0	—	1.4 ± 3.5	0.00 ± 0.10
	2	16	6.1 ± 7.0	—	-3.2 ± 7.5	0.00 ± 0.01



□ FPQ-6
 ○ TRANET HIGH FREQUENCY PAIR
 X TRANET LOW FREQUENCY PAIR

FIGURE III. FPQ-6 AND TRANET RANGE RATE BIASES VS. DATE



○ SECOR
 ○ FPS-16
 △ FPQ-6 (BEACON TRACK)
 ▽ FPQ-6 (BEACON TRACK SEGMENT)
 X FPQ-6 (SKIN TRACK SEGMENT)

FIGURE IV. WICE RANGE BIASES VS. DATE
(LASER REFERENCE ORBITS)

APPENDIX E

**INFLUENCES OF RANGE-RATE MEASUREMENTS
OF
ICBM INSTANTANEOUS IMPACT PREDICTION ACCURACY**

By

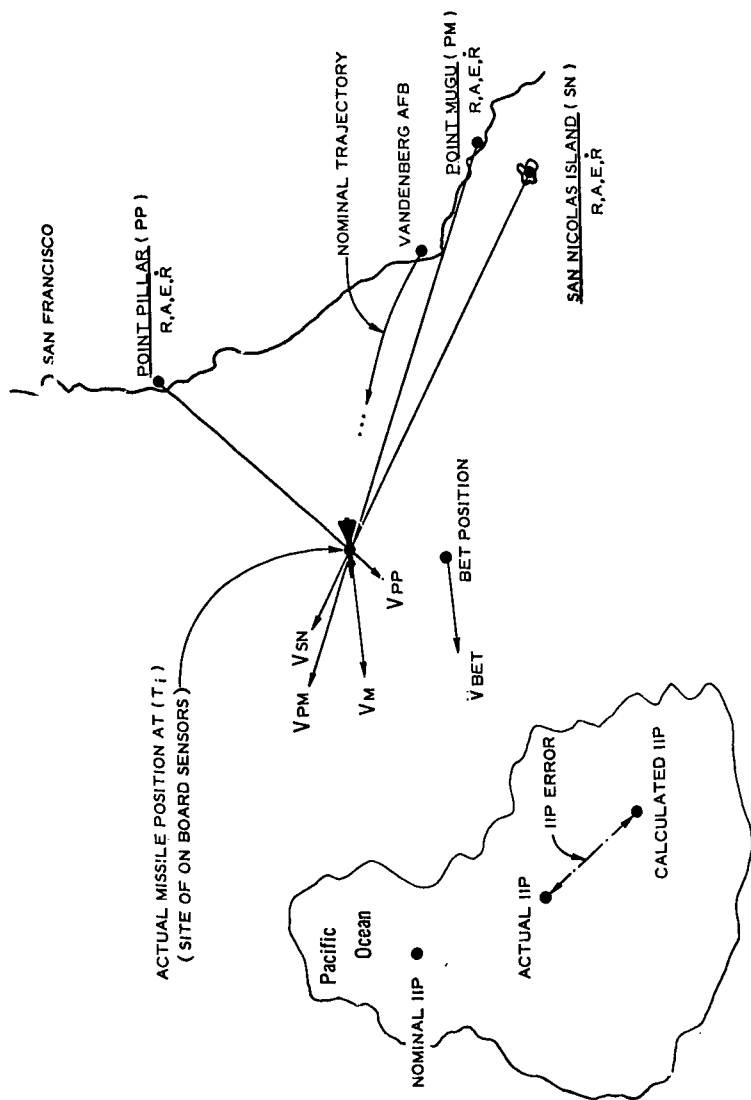
RUSSELL ROY, FEC

**Federal Electric Corporation ITT
Vandenberg AFB, California 93437**

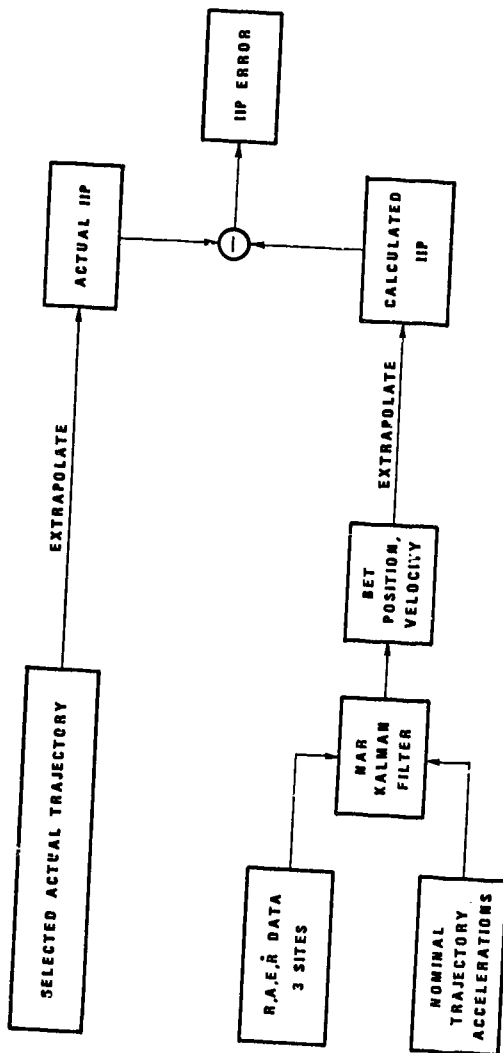
O U T L I N E

- GENERAL EXPLANATION OF PROBLEM
 - MISSILE/SENSOR GEOMETRY
 - \dot{R} MEASUREMENTS
 - IIP POSITIONS, IIP ERRORS
- DESCRIPTION OF SOLUTION TECHNIQUES
 - COMPUTER SIMULATION (ARMS)
 - TWO KALMAN FILTERS (ARMS)
- SPECIFICATION OF CONDITIONS SIMULATED
- DISPLAYS OF IIP ERRORS
 - \dot{R} DATA PRESENT
 - \dot{R} DATA ABSENT
- SUMMARY REMARKS

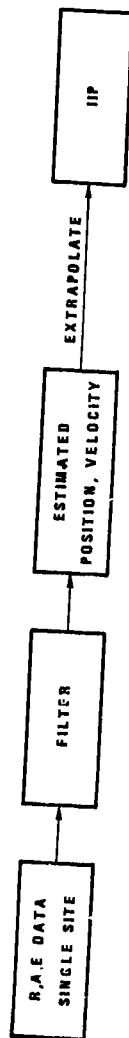
GEOMETRY OF \dot{R} , IIP POSITION, IIP ERROR



FLOW OF ARMS SIMULATOR
WITH NOMINAL ACCELERATION / RADAR FILTER (NAR)

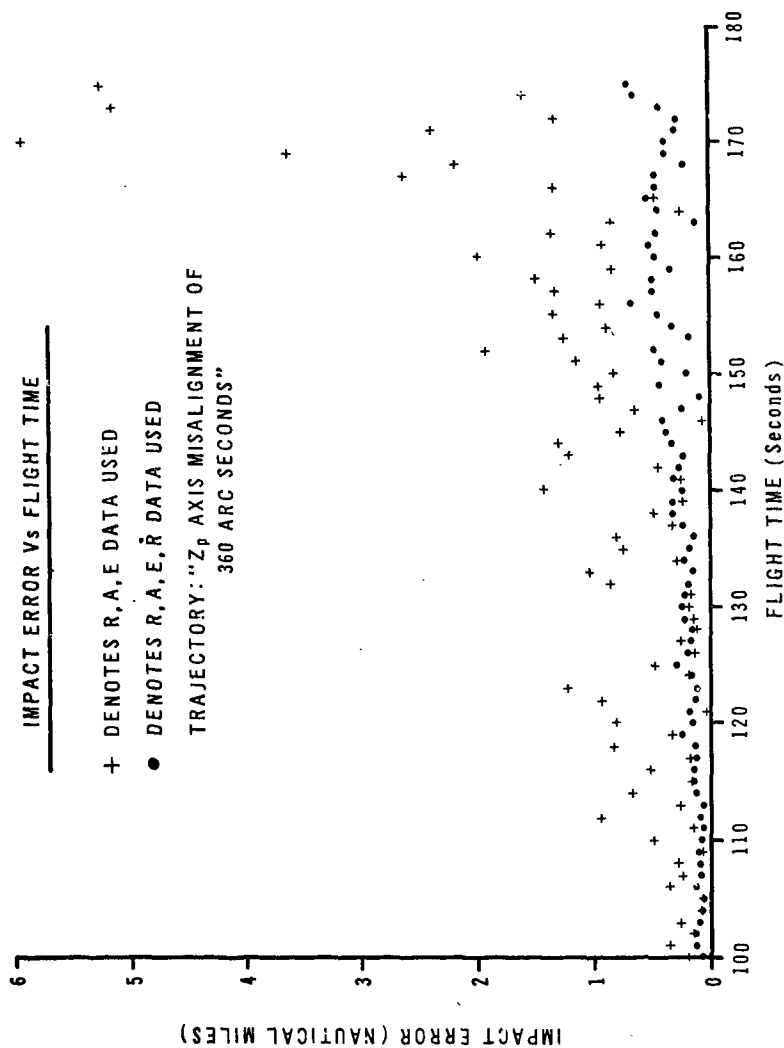


FLOW OF CURRENT OPERATIONAL SOFTWARE



INFORMATION PERTINENT TO RESULTS

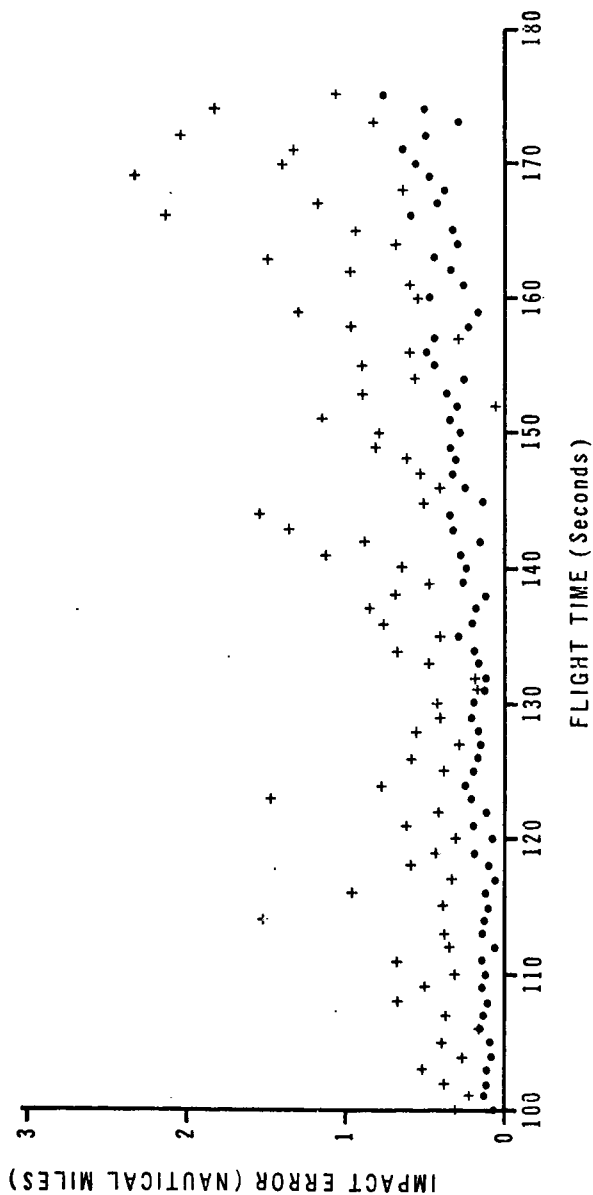
- 1 "NOMINAL" AND 3 "ACTUAL" MINUTEMAN III TRAJECTORIES WERE SIMULATED
 - PLATFORM MISALIGNMENT ABOUT Z_p AXIS OF 360 ARC SECONDS
 - 0.1 % SCALE FACTOR ERROR IN Y PIGA (PENDULOUS INTEGRATING GYROSCOPIC ACCELEROMETER) AXIS
 - Y PIGA FAILURE AFTER 100 SECONDS OF FLIGHT
- SECOND AND THIRD STAGE TRAJECTORY SEGMENT WAS USED
- DATA TYPICAL OF CALIBRATED RADARS WITH TYPICAL RANDOM ERRORS WERE SIMULATED
- R, A, E, \dot{R} DATA FROM POINT MUGU (FPS-16), SAN NICOLAS ISLAND (FPS-16), AND POINT PILLAR (FPQ-6) WERE PROCESSED BY THE NAR FILTER
- COMPANION DATA SETS WITHOUT \dot{P} WERE PROCESSED



IMPACT ERROR VS FLIGHT TIME

- + DENOTES R, A, E, DATA USED
- DENOTES R, A, E, \dot{R} DATA USED

TRAJECTORY: "0.1% SCALE FACTOR ERROR"

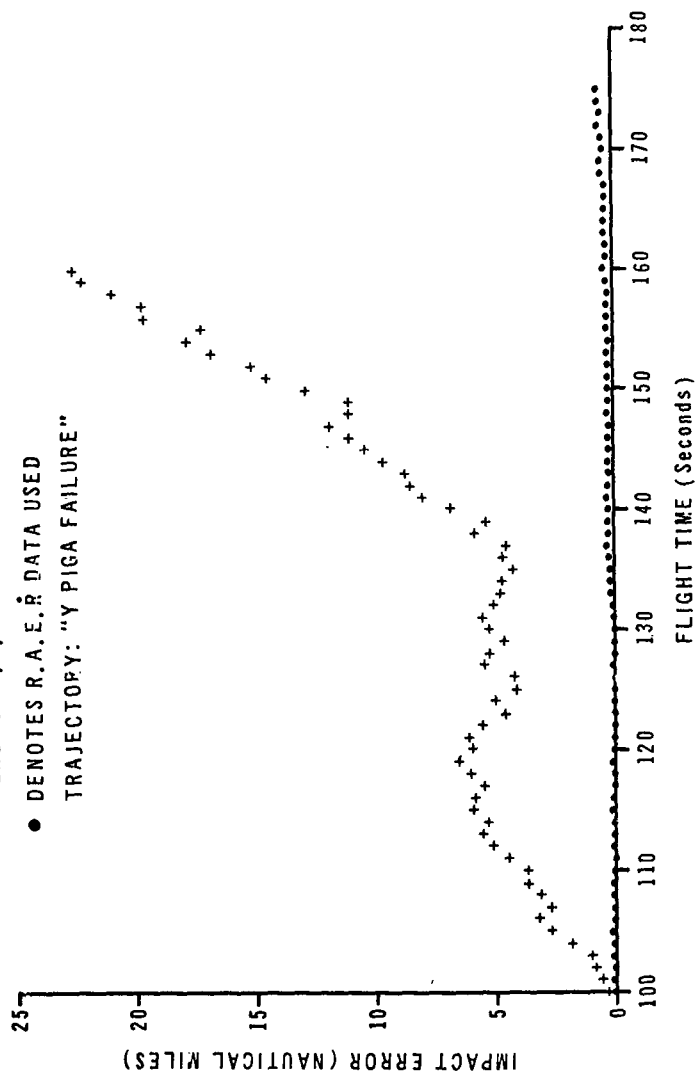


IMPACT ERROR VS FLIGHT TIME

+ DENOTES R, A, E DATA USED

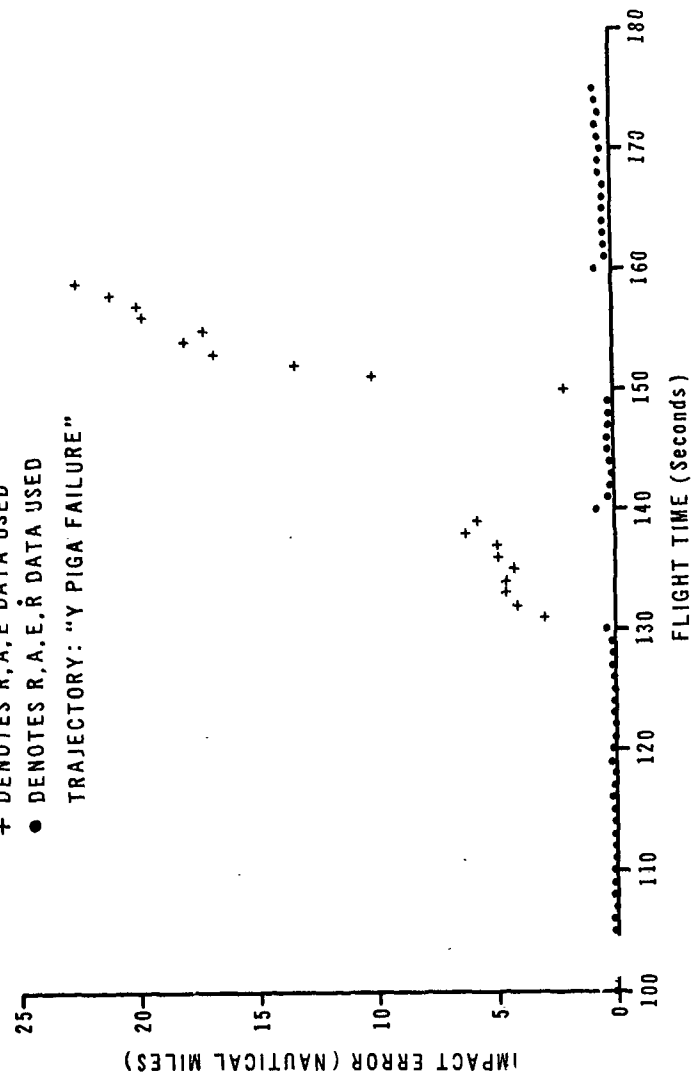
• DENOTES R, A, E, R DATA USED

TRAJECTORY: "Y PIGA FAILURE"



IMPACT ERROR VS FLIGHT TIME

- + DENOTES R, A, E DATA USED
 - DENOTES R, A, E, R DATA USED
- TRAJECTORY: "Y PIGA FAILURE"



SEQUENTIAL TABULATION OF IIP ERRORS FROM NAR

TRAJECTORY: "Y PIGA FAILURE"

RELATIVE TO A GIVEN FLIGHT TIME, R, A, E, Ṙ DATA FROM 3 SITES
WERE PROCESSED IN THE ORDER SHOWN BELOW.

IIP ERROR (NAUTICAL MILES)

FLIGHT TIME (SECONDS)	POINT MUGU	SAN NICOLAS ISLAND	POINT PILLAR
100	0.1	0.1	0.1
105	0.4	0.3	0.1
110	0.6	0.3	0.1
115	0.6	0.3	0.1
120	0.6	0.3	0.1
125	0.4	0.2	0.1
130	0.5	0.4	0.1
135	1.0	1.0	0.3
140	1.4	1.6	0.4
145	1.7	1.5	0.3
150	2.1	1.9	0.3
155	2.6	2.1	0.3
160	3.3	2.6	0.4
165	4.2	3.3	0.4
170	5.0	4.0	0.4
175	6.2	4.7	0.6

IMPACT ERROR VS FLIGHT TIME

NOTE: ARMS SIMULATOR WITH INERTIAL GUIDANCE
FILTER (IGR)

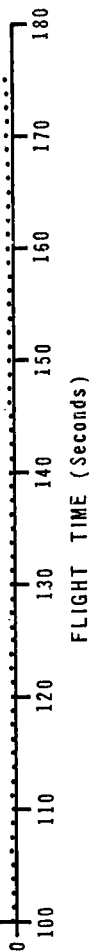
TELEMETERED INERTIAL GUIDANCE DATA (TWIG) USED

R, A, E DATA USED

TRAJECTORY: "Z_p AXIS MISALIGNMENT OF 360 ARC SECONDS"

IMPACT ERROR (NAUTICAL MILES)

11-3



SUMMARY REMARKS

- \dot{R} MEASUREMENTS CAN PROVIDE
 - SMALLER IIP ERRORS AND
 - LESS NOISY IIP ERRORS
- SUBSTANTIAL IMPROVEMENTS OF IIP ACCURACY CAN BE OBTAINED WHEN
 - POINTING AXES OF AT LEAST 3 RADAR SITES ARE NOT IN THE SAME PLANE AND
 - BENEFITS OF \dot{R} MEASUREMENTS ARE EXPLOITED BY THE SOFTWARE USED AND
 - GOOD MISSILE VELOCITY OR ACCELERATION COMPONENTS ARE NOT AVAILABLE FROM OTHER SOURCES

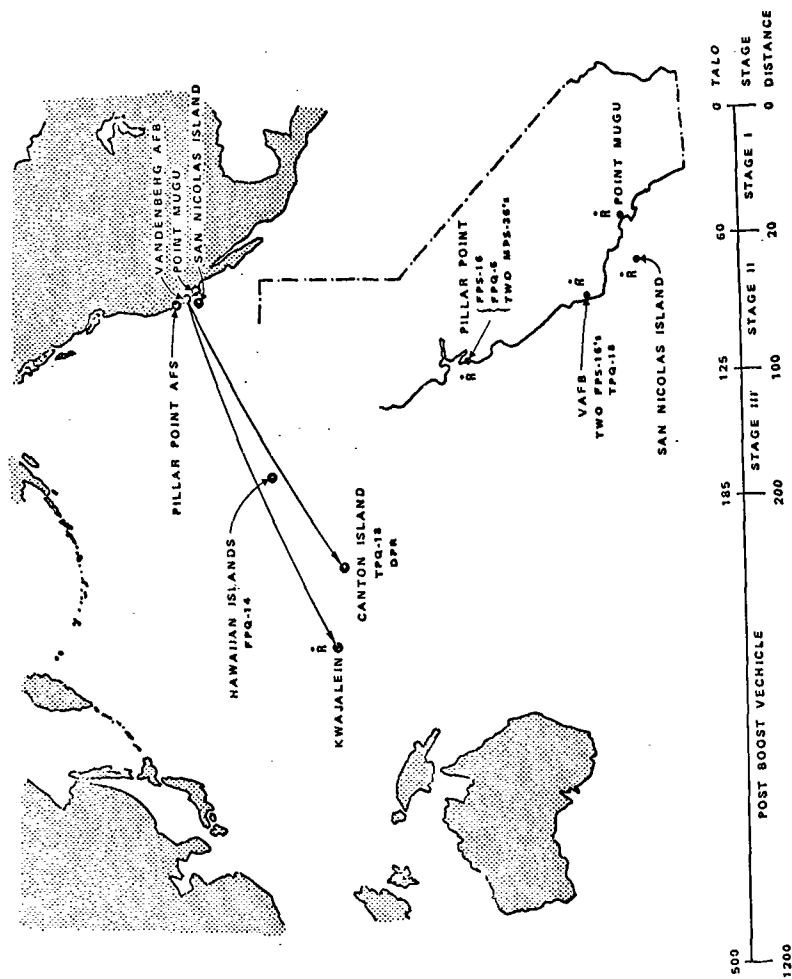
APPENDIX F

**ANALYTICAL TECHNIQUES AND RESULTS OF COHERENT TRACKING
OF
THE THOR-DELTA AND MINUTEMAN III**

By

VIRGINIA FAGERLIN, FEC

**Federal Electric Corporation ITT
Vandenberg AFB, California 93437**



ANALYTICAL TECHNIQUES USED FOR POSITION DATA

● RANDOM ERROR AND SERVO ERROR EVALUATION

● RADAR COVERAGE (R, A, E DATA)

● SYSTEMATIC ERROR EVALUATION

1. BEST ESTIMATE OF TRAJECTORY (BET) FORMED FROM RADAR DATA
2. SYSTEMATIC ERRORS ESTIMATED FOR RADAR MEASUREMENTS USING BET STANDARD
3. RESIDUAL ERRORS FORMED BY TRANSFORMING BET TO EACH RADAR SITE AND DIFFERENCING WITH RADAR R, A, E DATA CORRECTED FOR ESTIMATED ERRORS

● POST LAUNCH INSTRUMENTATION ACCURACY REPORT (PLIAR)

ANALYTICAL TECHNIQUES USED FOR DOPPLER \dot{R} DATA

- RANDOM ERROR EVALUATION
- DOPPLER \dot{R} DATA COVERAGE
- DOPPLER \dot{R} DATA QUALITY MONITORING
- SYSTEMATIC ERROR EVALUATION

11

1. BEST ESTIMATE OF TARGET VELOCITY (WEIGHTED LEAST SQUARES SOLUTION)
FORMED BY COMBINING:

- DIFFERENTIATED RADAR POSITION DATA WITH DOPPLER \dot{R} DATA
- INERTIAL GUIDANCE $\dot{X}, \dot{Y}, \dot{Z}$ DATA WITH DOPPLER \dot{R} DATA

2. INERTIAL GUIDANCE DATA

3. INERTIAL GUIDANCE BET

POTENTIAL STANDARDS FOR SYSTEMATIC ERROR EVALUATION

- BEST ESTIMATE OF TARGET VELOCITY FORMED BY COMBINING DOPPLER \dot{R} MEASUREMENTS FROM FOUR RADARS (REDUNDANT SOLUTION).

- BEST ESTIMATE OF TARGET POSITION AND VELOCITY FORMED USING RADAR POSITION (R,A,E) DATA AND:

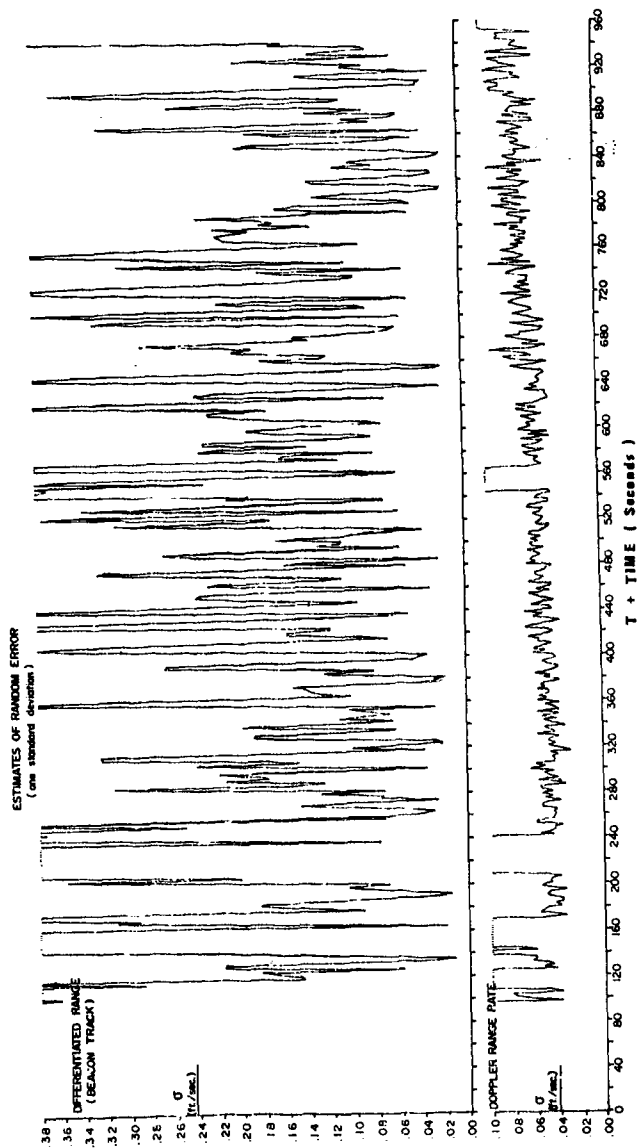
1. EQUATIONS OF MOTION (COHERENT BEACON LOCATED IN OBJECT IN FREEFALL).
2. POINT TO POINT CONSTRAINTS DURING POWERED FLIGHT.

(CURRENT SOFTWARE DOES NOT PERMIT POINT TO POINT CONSTRAINTS IN DETERMINING TRAJECTORY NOT IN FREEFALL. COHO BEACON HAS ALWAYS BEEN LOCATED IN A BOOSTER VEHICLE)

OPERATION NUMBER	LAUNCH DATE	TYPE OF LAUNCH	COMPARISON STANDARD	REPORT TITLE
4834	3/31/71	THOR - DELTA	WEIGHTED LEAST SQUARES SOLUTION COMBINING R, A, E AND DIFFERENTIATED R, A, E FROM TPQ-18, FPQ-6, PL. MUGU #4, AND SNI #3, WITH DOPPLER R FROM TPQ-18, FPQ-6, AND PL. MUGU #4.	C-BAND DOPPLER RANGE RATE ACCURACY ANALYSIS
3782	6/11/71	MM III	WEIGHTED LEAST SQUARES SOLUTION COMBINING RADAR POSITION DATA (R, A, E), INERTIAL GUIDANCE X, Y, Z DATA, AND DOPPLER R DATA FROM TPQ-18, FPQ-6, AND PL. MUGU #4.	PLIAR, OPERATION 3782
3782	6/11/71	MM III	INERTIAL GUIDANCE DATA	C-BAND DOPPLER RANGE RATE DATA EVALUATION, OPERATIONS 3782, 6448, and 8482
6448	10/20/71	MM III	INERTIAL GUIDANCE DATA AND IG BET	
8482	12/15/71	MM III	INERTIAL GUIDANCE DATA	

ADDITIONAL MINUTEMAN III OPERATIONS USING
INERTIAL GUIDANCE DATA AS A STANDARD

5477	5/31/72
1560	6/6/72
3519	6/18/72
7243	8/2/72
5179	1/30/73
3546	4/26/73
5411	5/31/73
4109	8/23/73
3686	12/22/73

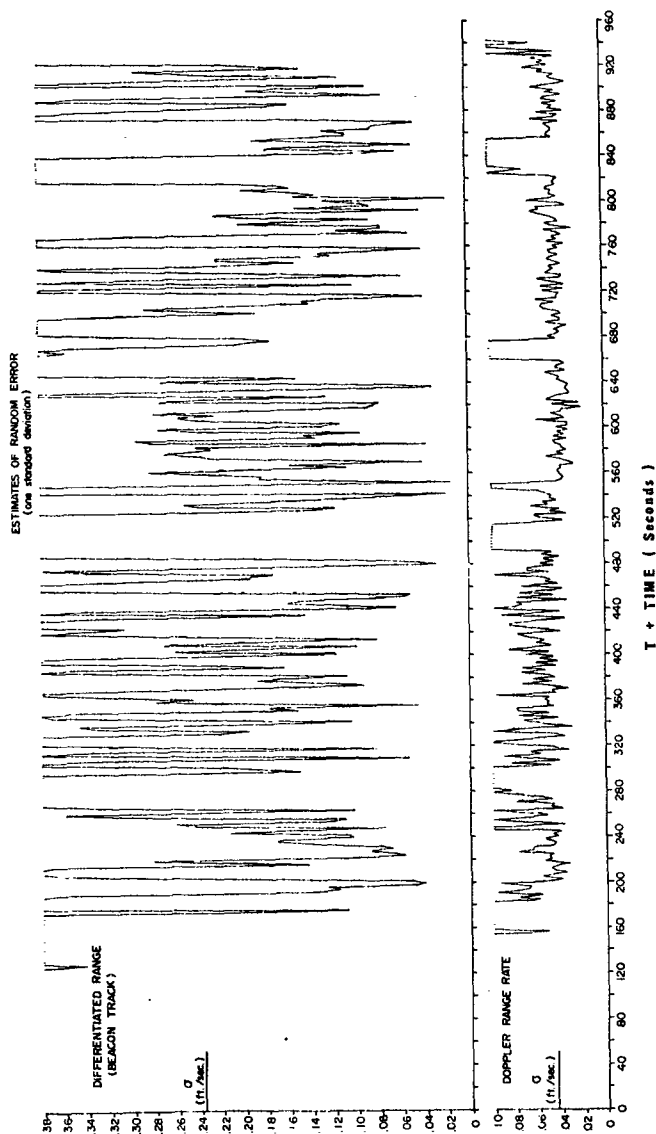


F-8

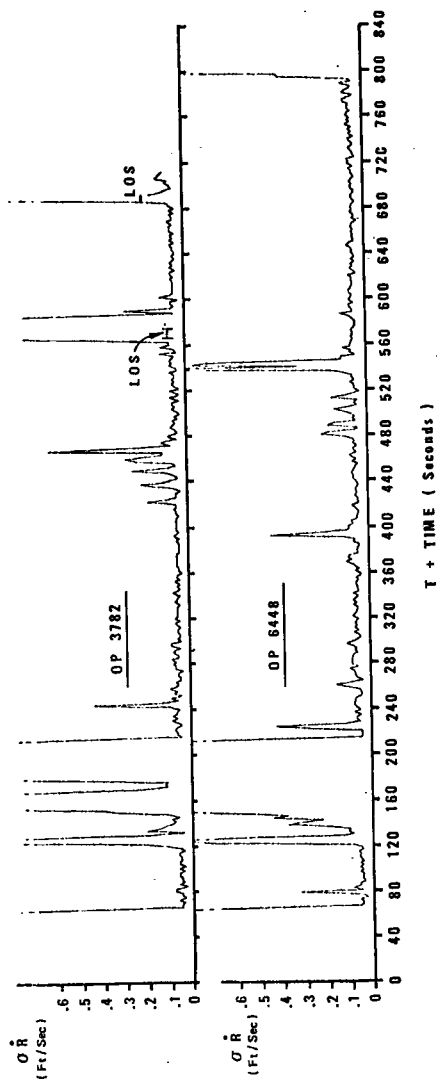
SVAFB TPQ-18 THOR-DELTA, OPERATION 4834

RANDOM ERROR EVALUATION

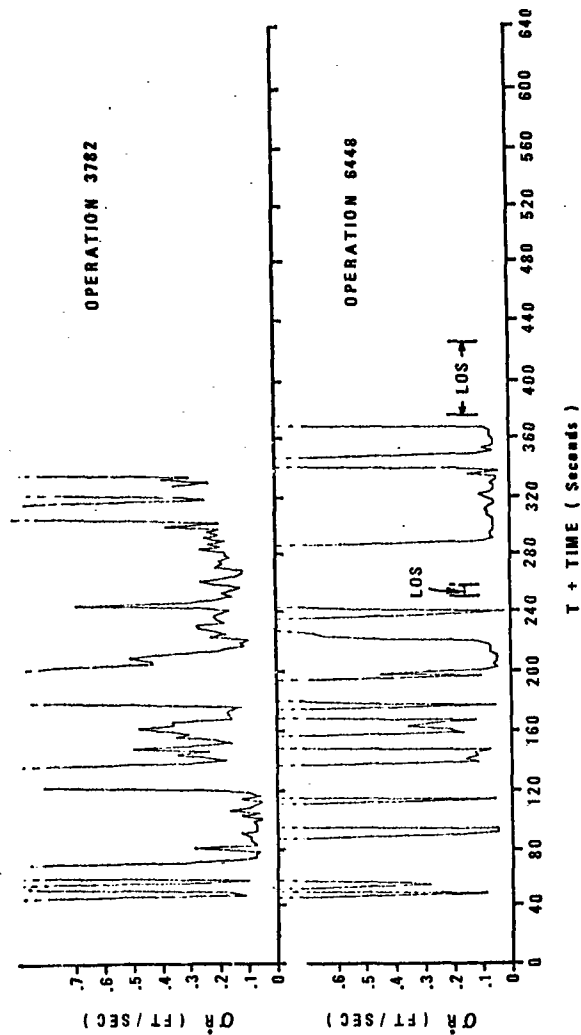
- MEASURE OF PRECISION OR REPEATABILITY
- POLYNOMIAL SMOOTHING (67 POINTS)
- ONE STANDARD DEVIATION (1σ) VALUES FORMED AND PLOTTED EVERY TWO SECONDS



POINT PILLAR FPQ-6 THOR-DELTA, OPERATION 4834



PILLAR POINT FPQ-6 RANDOM ERRORS, OPERATIONS 3782 and 6448



F-12

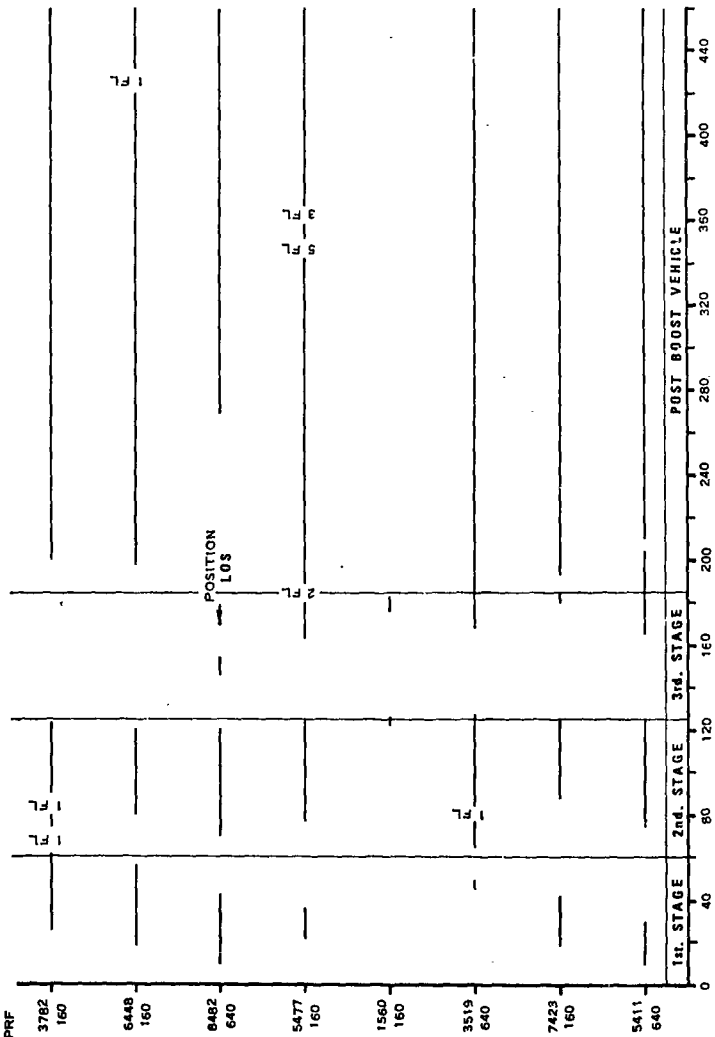
POINT MUGU FPS-16 #4 RANDOM ERRORS, OPERATIONS 3782 and 6448

DOPPLER DATA COVERAGE

- DETERMINED BY EXAMINING INERTIAL GUIDANCE Versus DOPPLER \dot{R} RESIDUALS
- DETERMINE WHETHER DOPPLER SIGNAL IS ON CENTER FINE LINE
- DETERMINE WHETHER DOPPLER SIGNAL IS ON i^{th} FINE LINE
- INERTIAL GUIDANCE DATA USUALLY ENDS BEFORE DOPPLER DATA

SVAFB TPO-18

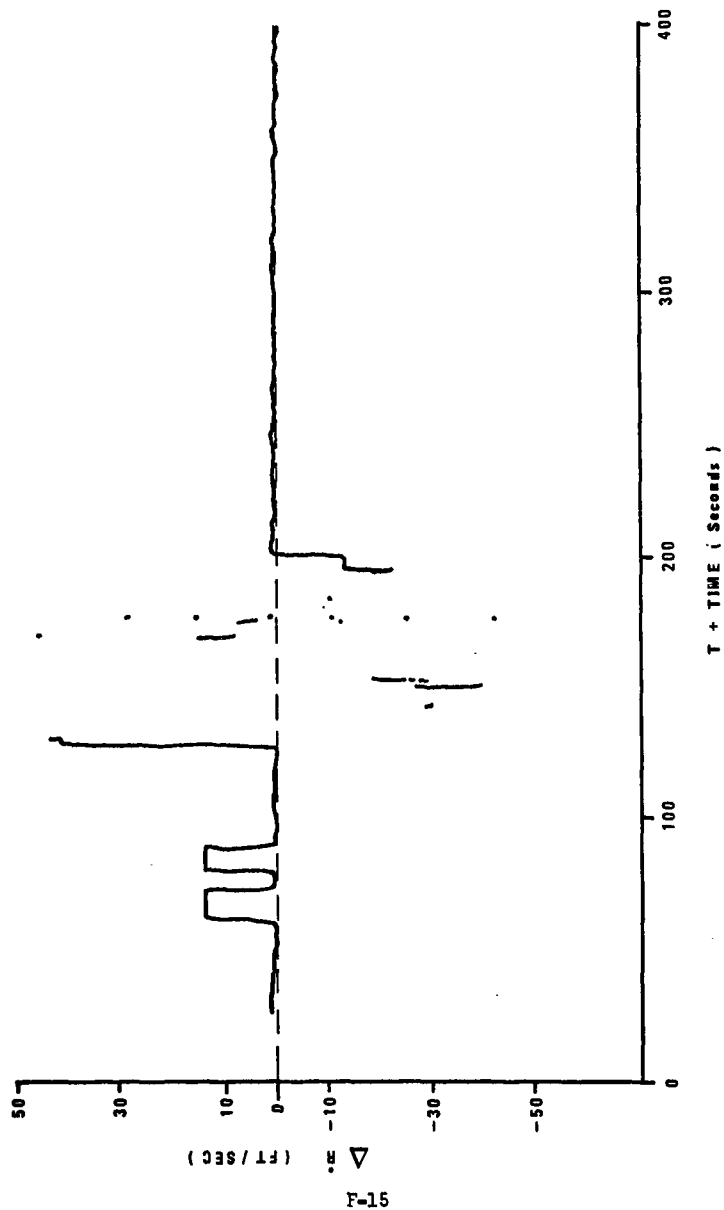
OPERATION /
PRF



F-14

T + TIME (Seconds)

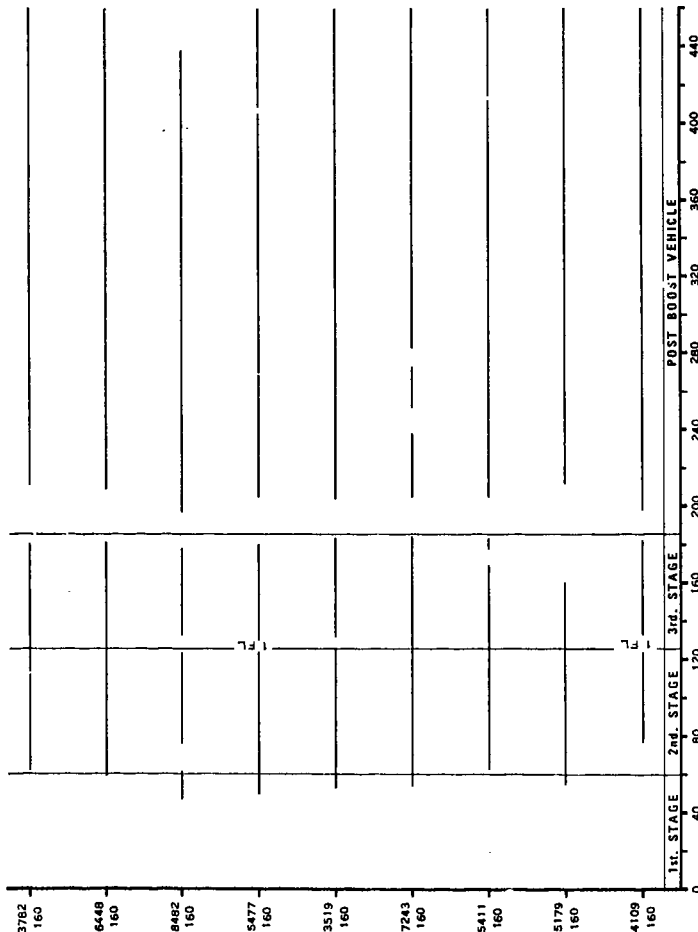
DOPPLER COVERAGE, MINUTELMAN III OPERATIONS



SVAFB TPQ-18 \dot{R} Versus INERTIAL GUIDANCE, OPERATION 3782, 11 June 1971

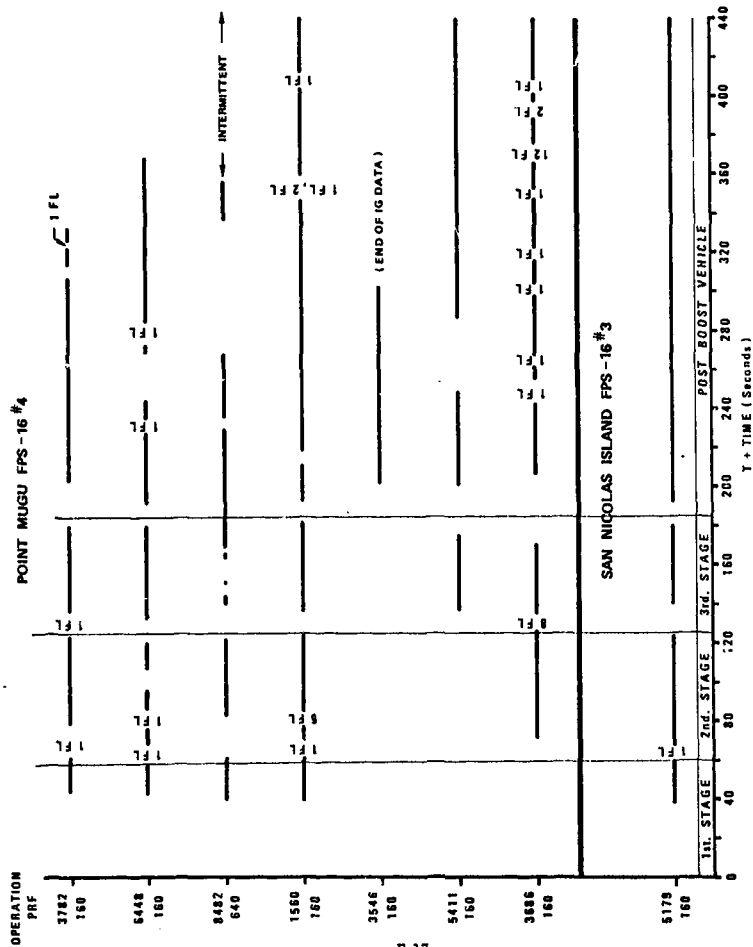
POINT PILLAR FPO-6

OPERATION /
PRF



F-16

T + TIME (Seconds)
DOPPLER COVERAGE, MINUTEMAN III OPERATIONS



SYSTEMATIC ERROR EVALUATION

INERTIAL GUIDANCE RESIDUALS USED FOR SYSTEMATIC ERROR EVALUATION

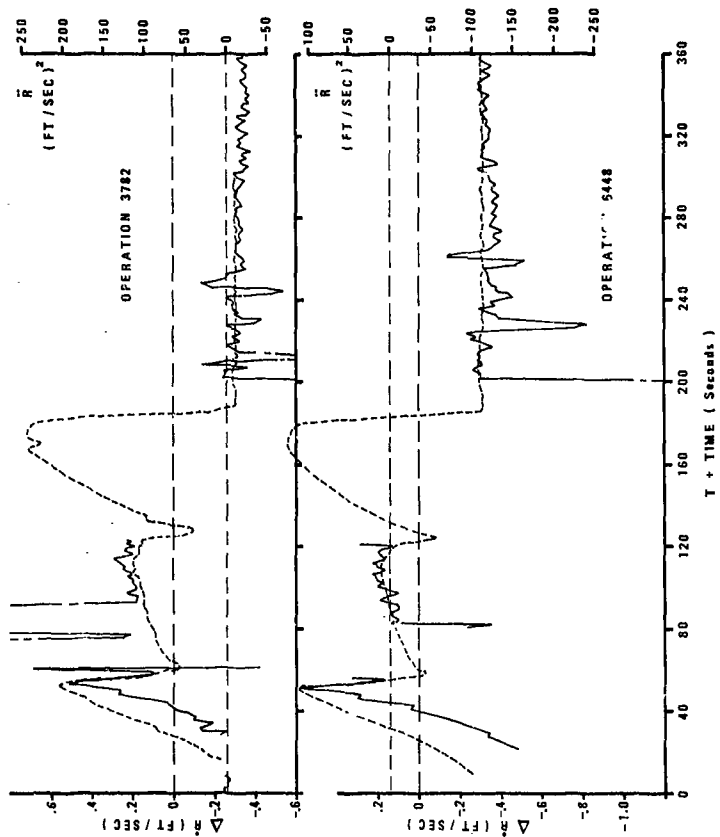
● ADVANTAGES

- MOST TIMELY STANDARD CURRENTLY AVAILABLE
- USEFUL IN EVALUATING \dot{R} REFRACTION ERRORS, \dot{R} BIAS ERRORS

● DISADVANTAGE

INADEQUATE FOR EVALUATION OF ACCELERATION DEPENDENT ERROR WHICH COULD BE CAUSED BY:

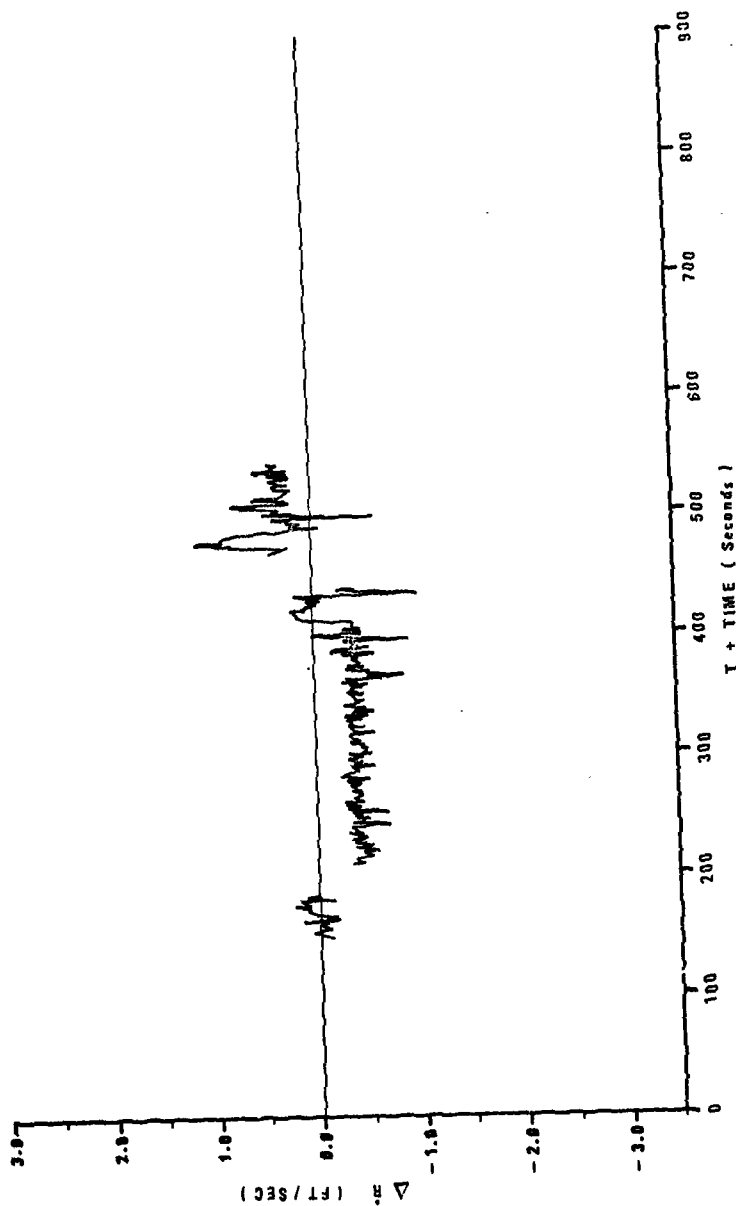
- DOPPLER TIME TAG ERROR
- DYNAMIC LAG
- INERTIAL GUIDANCE AND RADAR TIMING ERROR
- INERTIAL GUIDANCE DATA TIME DEPENDENT ERROR



\ddot{R} AT SVAFB TPQ-18 and TPQ-18 \ddot{R} Versus INERTIAL GUIDANCE,
OPERATIONS 3782 and 6448

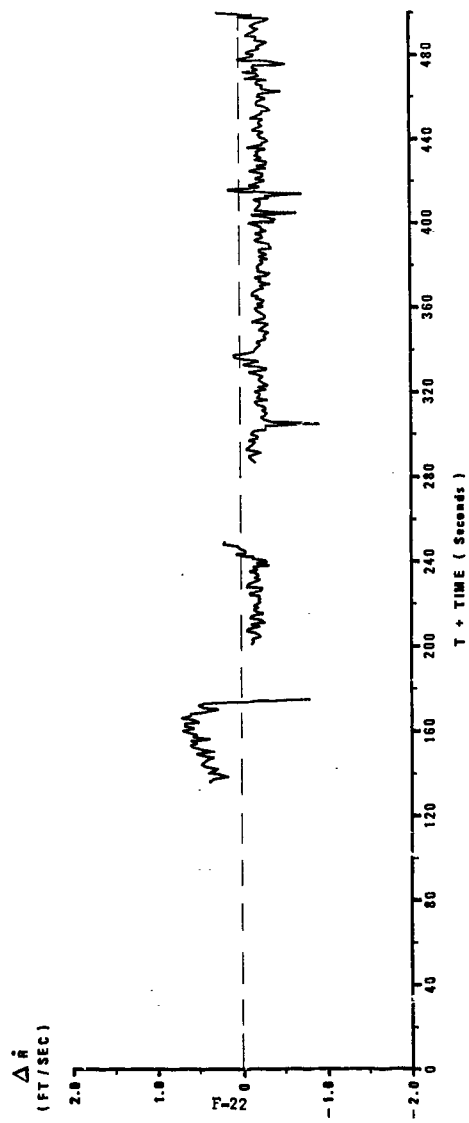
DOPPLER DATA EVALUATION STANDARD - IN SUMMARY

- TARGET VELOCITY BEST ESTIMATE FROM REDUNDANT \dot{R} DATA - HAS HAD LIMITED SUCCESS DUE TO LARGE \dot{R} SYSTEMATIC ERRORS, AND LIMITED NUMBER OF \dot{R} SENSORS.
- INERTIAL GUIDANCE DATA SATISFACTORY FOR PERFORMANCE AND COVERAGE MONITORING.
- INERTIAL GUIDANCE DATA NOT ENTIRELY SATISFACTORY FOR SYSTEMATIC ERROR EVALUATION
- BETTER POSSIBILITY OF OBTAINING A BEST ESTIMATE OF TARGET VELOCITY FROM COMBINED DOPPLER \dot{R} MEASUREMENTS (DEPENDING ON STATUS OF PMR DOPPLER RADARS).
- IMPROVED SOFTWARE TO APPLY TRAJECTORY CONSTRAINTS DURING POWERED FLIGHT WOULD ENABLE DOPPLER DATA EVALUATION USING POSITION OR POSITION AND VELOCITY DATA
- GEOS - C - COHERENT BEACON

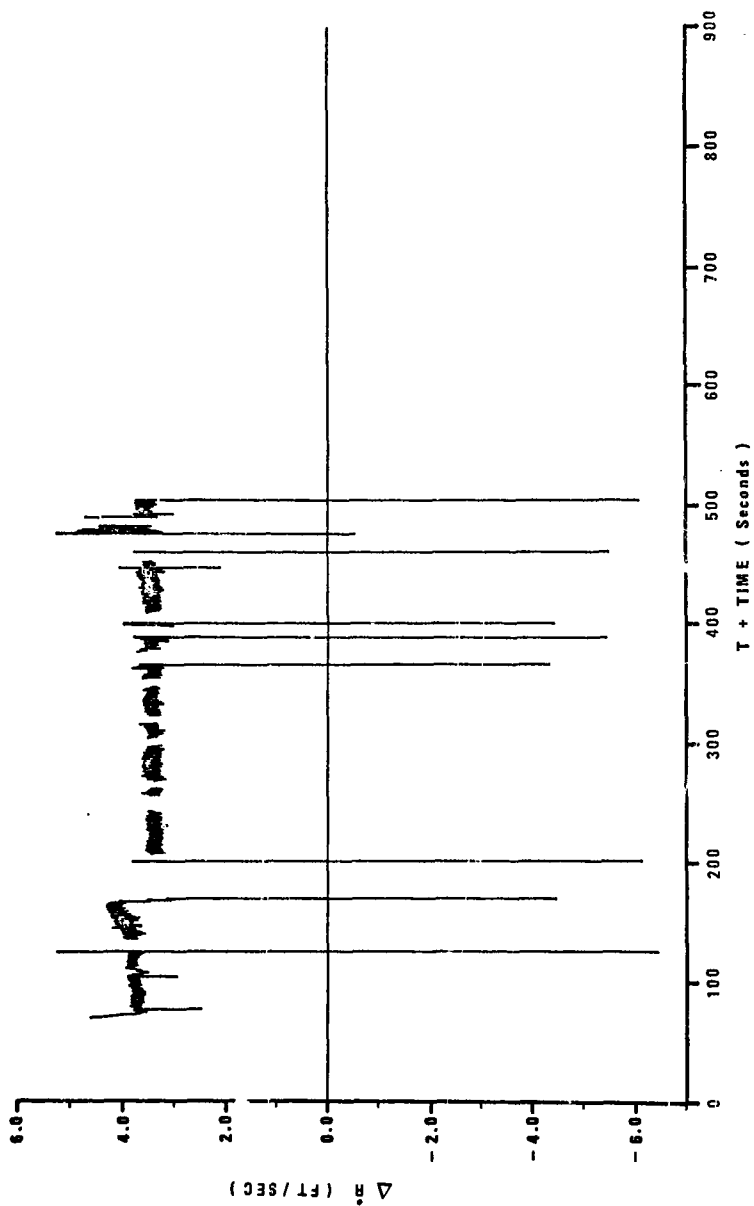


F-21

POINT PILLAR FPQ-6 R Versus INERTIAL GUIDANCE, OPERATION 3686

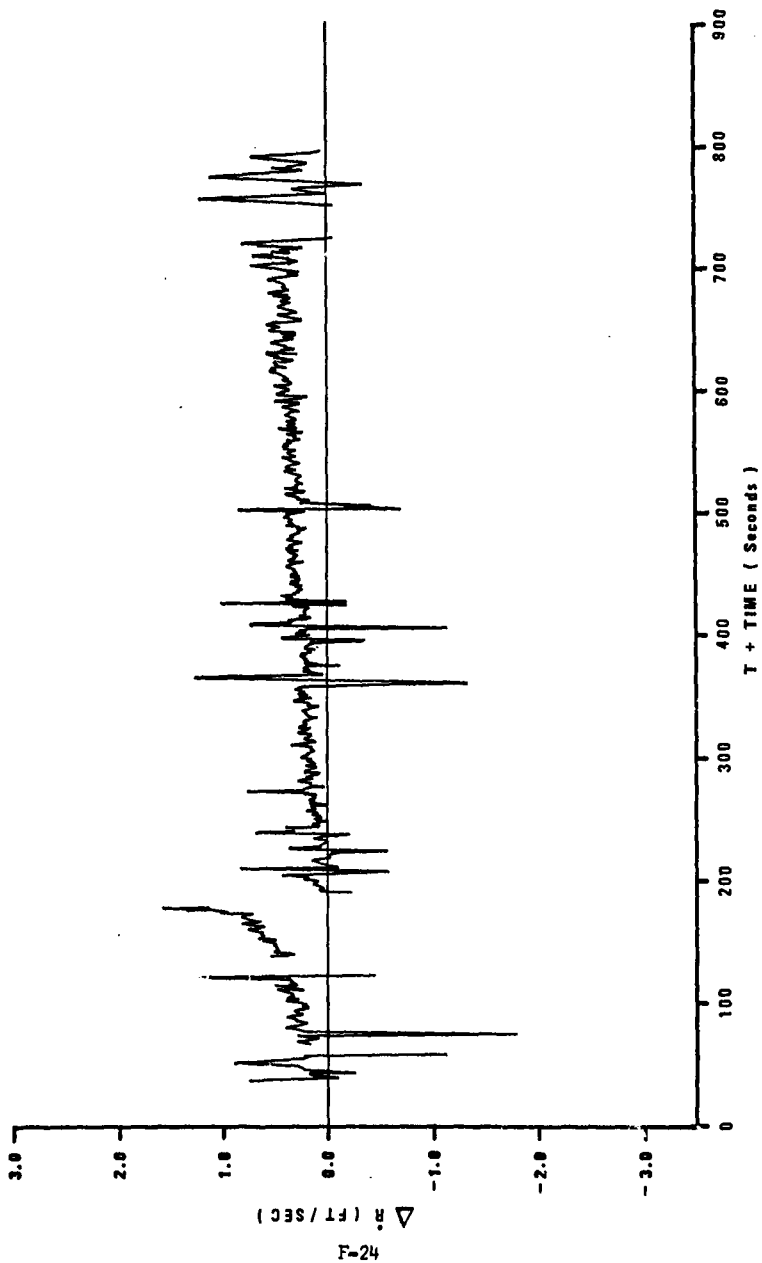


POINT MUGU FPS-16^{#4} \dot{R} Versus INERTIAL GUIDANCE, OPERATION 5411

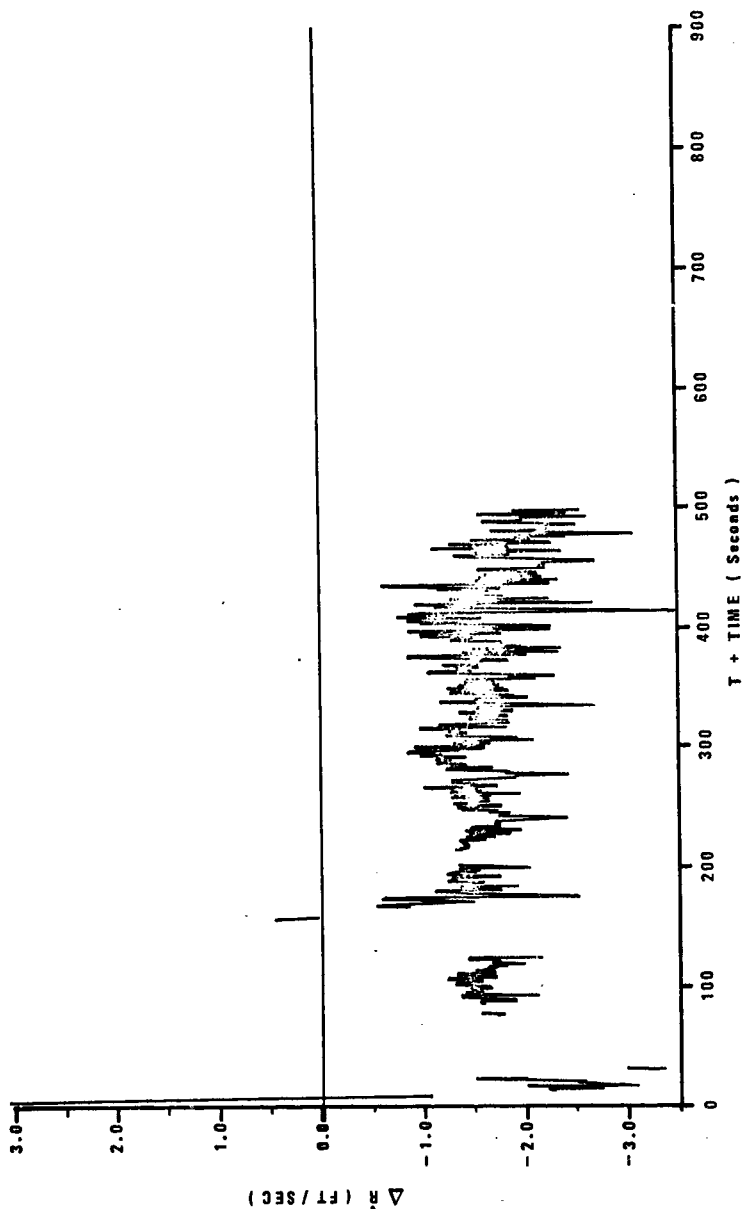


F-23

POINT MUGU FPS-16 #4 \dot{R} Versus INERTIAL GUIDANCE, OPERATION 3686



SAN NICOLAS ISLAND FPS-16 #3 \dot{R} Versus INERTIAL GUIDANCE, OPERATION 5179



SVAFB TPQ-18 \dot{R} Versus INERTIAL GUIDANCE, OPERATION 5411

DOPPLER DATA - IN SUMMARY

BASED ON THE DATA ANALYZED

- R DATA SHOWS A PRECISION OF 0.1 fps
- R DATA IS PRESENTLY ACCURATE TO 1 fps (EXCLUDING BIAS)
- NEVER HAD USABLE DOPPLER DATA FROM ALL FOUR RADARS
SIMULTANEOUSLY FOR A REDUNDANT SOLUTION
- NEVER HAD USABLE DOPPLER DATA FROM THE THREE RADARS
NECESSARY FOR IMPACT PREDICTION

APPENDIX G

**COHERENT TRACKING OF MINUTEMAN III
MEASUREMENT SYSTEM PROBLEMS AND EVALUATION**

By

WILLIAM COLLINS, FEC

**Federal Electric Corporation - ITT¹
Vandenberg AFB, California 93437**

INSTALLATION OF PULSE DOPPLER EQUIPMENT AT WTR

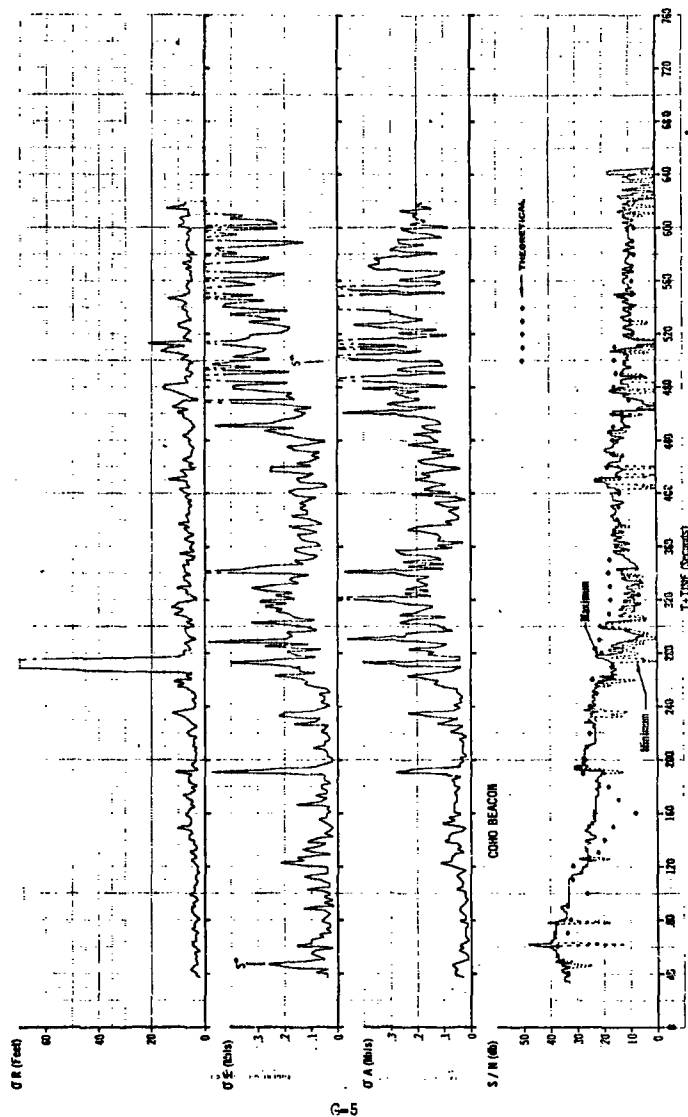
SVAFB	023003	TPQ-18	CSP INSTALLED	JUNE 1968
PILLAR POINT	213002	FPQ-6	CSP INSTALLED	JANUARY 1971
MOBILE	213003	MPS-36	CAT II COMPLETED	FEBRUARY 1972
MOBILE	213004	MPS-36	CAT II COMPLETED	FEBRUARY 1972
POINT MUGU	003004	FPS-16	VESS INSTALLED	OCTOBER 1968
SAN NICOLAS	013003	FPS-16	VESS INSTALLED	OCTOBER 1968

ADVANTAGES TO BE GAINED BY USE OF DOPPLER RANGE RATE

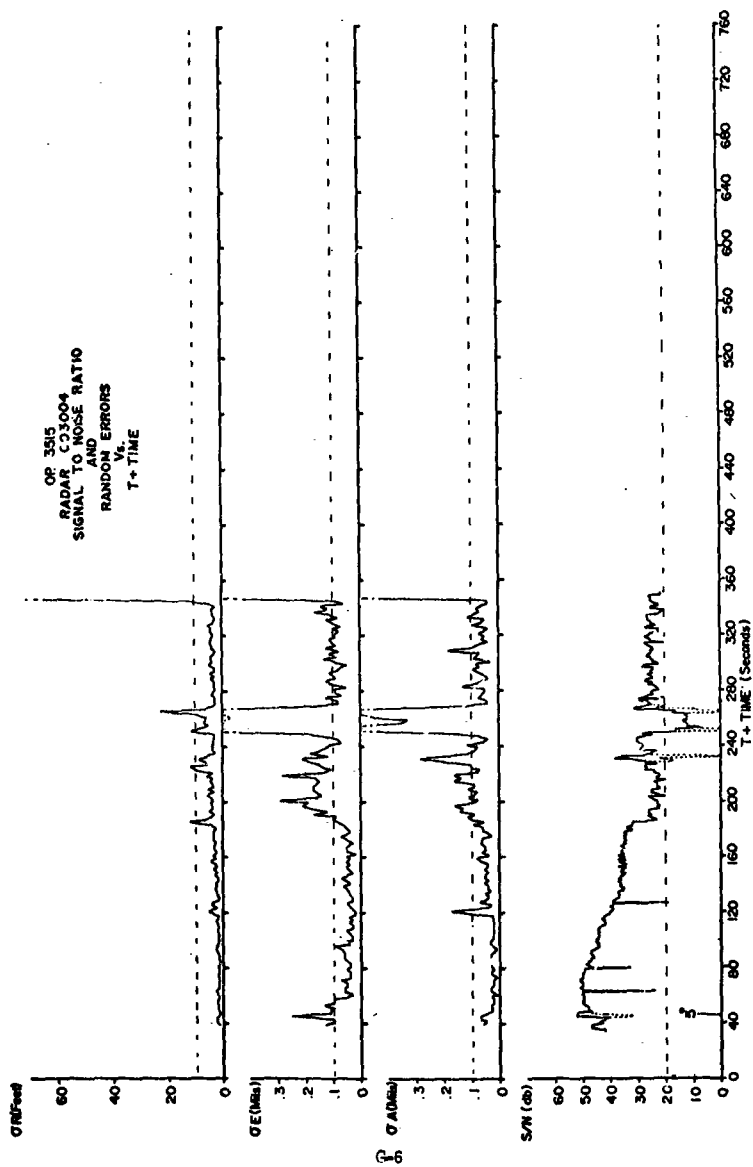
- RANGE RATE DATA HAS VERY LOW RANDOM ERRORS (ABOUT 0.05 Ft/Sec)
- RANGE RATE DATA HAS HIGH ACCURACY (CURRENTLY < 1 Ft/Sec) (0.1 Ft/Sec ACHIEVABLE)
- TARGET VELOCITY WITH IMPROVED ACCURACY AND LOWER GEOMETRIC DILUTION OF PRECISION WITH MULTILATERATION TYPE SOLUTION
- IMPROVED IMPACT PREDICTION
- IMPROVED DATA TO RANGE USERS

SYSTEM PROBLEMS

- LOSS OF DATA DURING THIRD STAGE FOR TPQ-13
- LOSS OF DATA AT STAGING EVENTS
- AMBIGUITY RESOLUTION PROBLEM (6 SECOND MINIMUM)
- INABILITY OF FPQ-6 TO OPERATE AT 640 PRF WITH DOUBLE PULSE CODED BEACON
- ACCELERATION SENSITIVE ERROR IN SAMTEC AND PMR DOPPLER RADARS
- CLUTTER INTERFERES WITH PRE LAUNCH CHECKOUTS AND INITIAL ACQUISITION
- LOW BEACON TRANSMITTER POWER

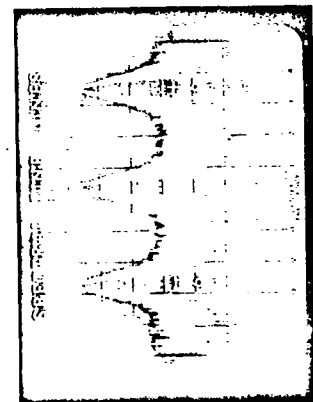


RADAR BEACON SIGNAL TO NOISE RATIO AND RANGE ERROR PLOTS

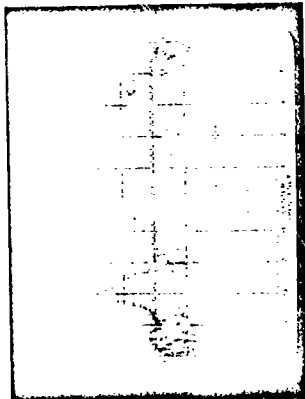


LOSS OF RANGE RATE DATA DURING THIRD STAGE BY TPQ-18

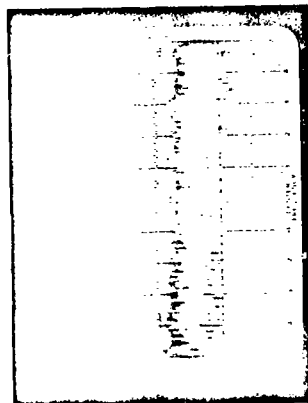
- CAUSE OF PROBLEM IS FLAME MODULATION OF RF SIGNAL
- TPQ-18 PRIMARILY AFFECTED
- ALL RADARS SUSCEPTIBLE IF MISSILE ATTITUDE WERE CHANGED
- 640 PRF REDUCES EFFECT



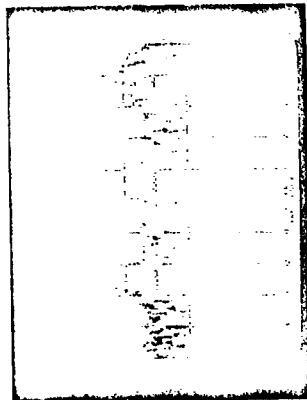
T + 100 Seconds



T + 120 Seconds



T + 165 Seconds

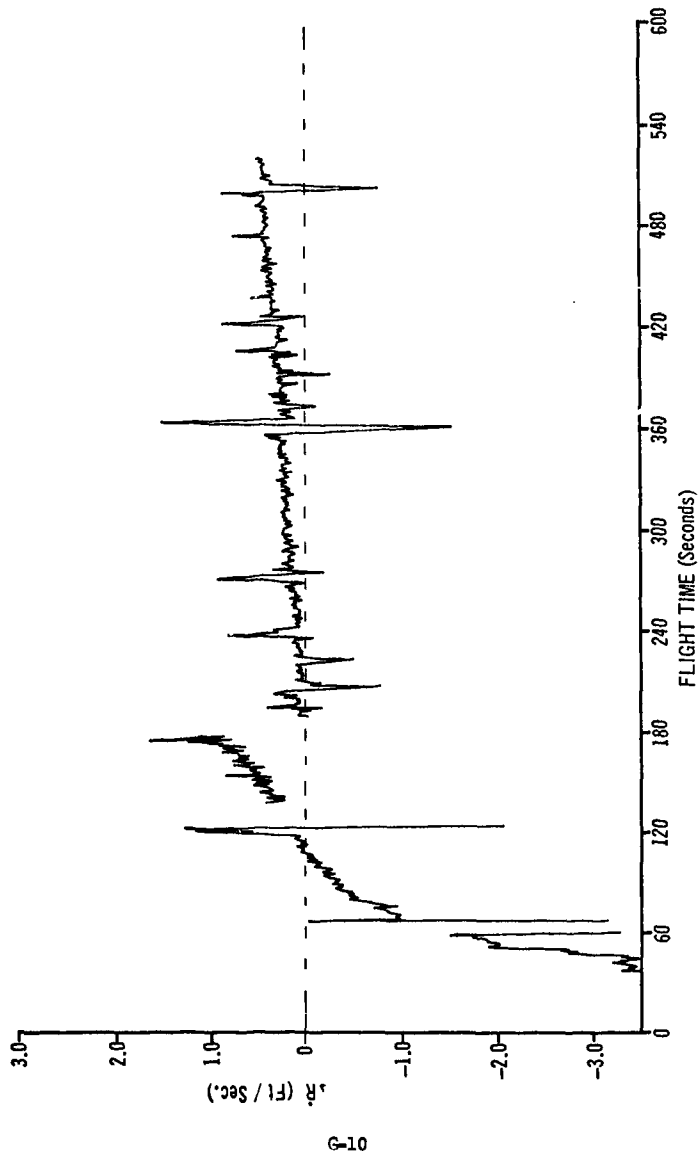


T + 185 Seconds

SIGNAL SPECTRUM
TPQ-18, OP. 3519

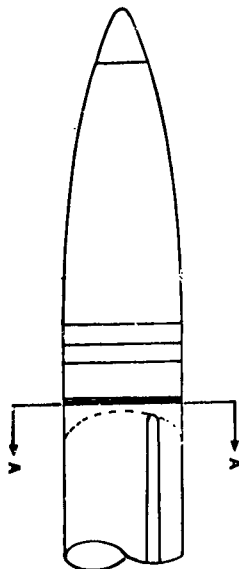
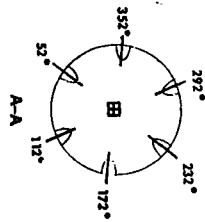
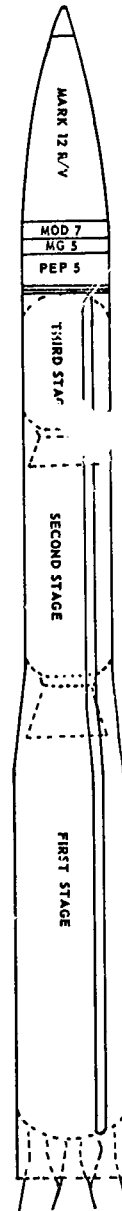
LOSS OF DATA DURING STAGING EVENTS

- VEHICLE "JERK" APPEARS TOO LOW TO CAUSE PROBLEM
- FLAME MODULATION APPEARS MOST LIKELY CAUSE
- TELEMETRY SIGNALS DEGRADED AT SAME TIME
- ALL RADARS HAVE OCCASIONALLY SEEN PROBLEM
- FPQ-6 UNABLE TO OPERATE AT 640 PRF WITH DOUBLE PULSE CODE BEACON



OPERATION 5179
MODE FBV BEACON

RADAR SNI, FPS-16, SYS. 3
DATE 31 JANUARY 1973

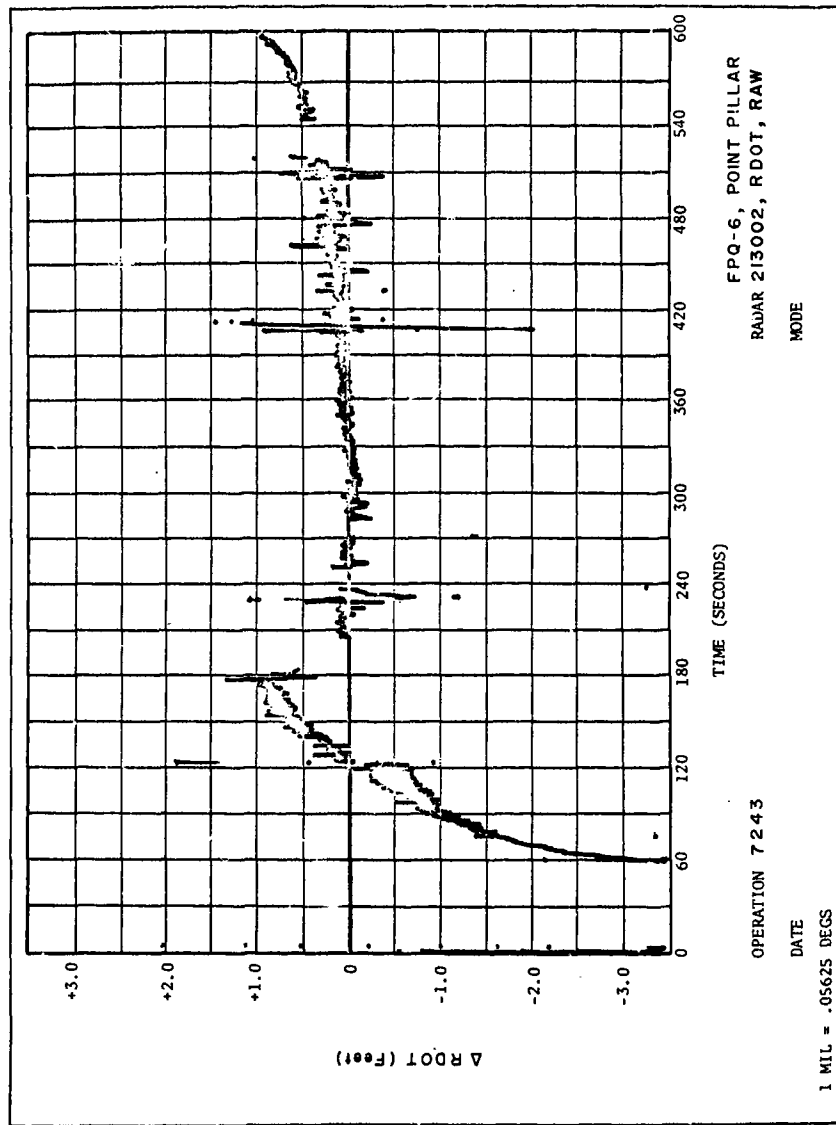


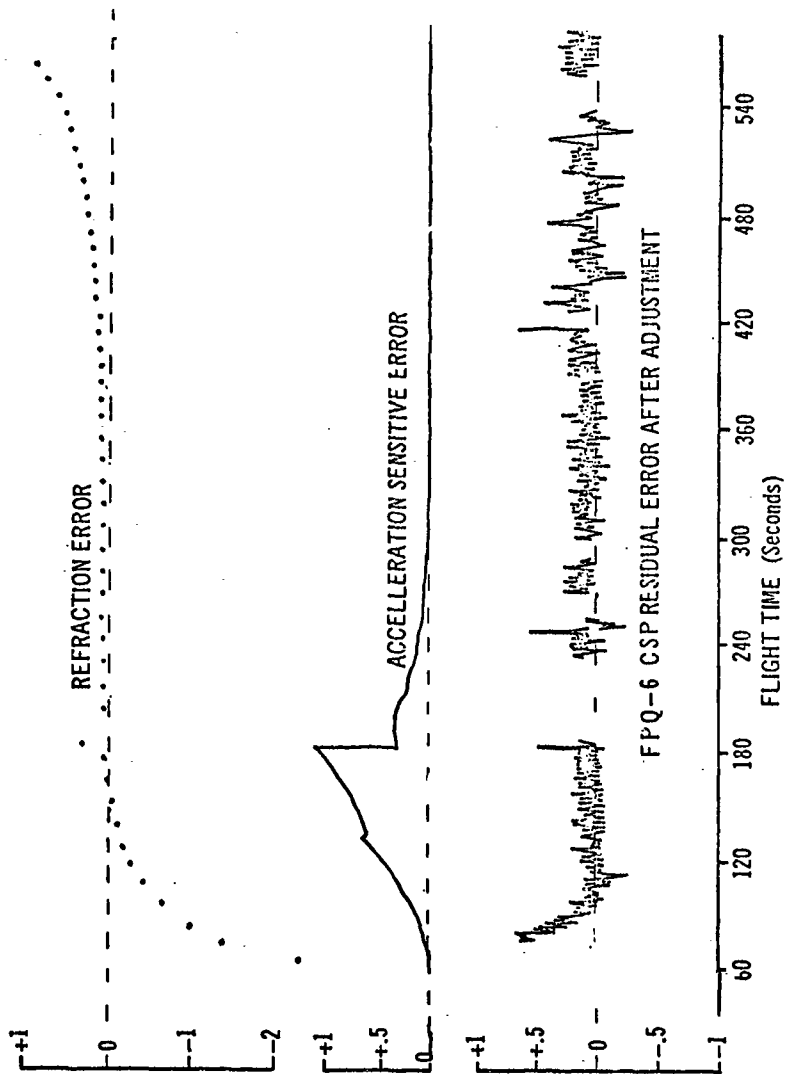
AMBIGUITY RESOLUTION TIME

- 6 SECOND MINIMUM WITH CURRENT MATHEMATICS
- MINOR PROBLEM FOR POSTFLIGHT DATA USE
- MAJOR PROBLEM FOR RANGE SAFETY USE

ACCELERATION SENSITIVE ERROR

- ERROR SIGN, SHAPE, AND MAGNITUDE SAME AS READING VELOCITY LATE
- ERROR DETECTED BY SPAD, TRW, AND AUTONETICS
- CAUSE OF ERROR UNKNOWN
- POSSIBILITY OF ERROR IN INERTIAL GUIDANCE DATA NOT COMPLETELY ELIMINATED





SUMMARY

- PREFLIGHT BIAS DETERMINATION SOFTWARE IS AWAITING CERTIFICATION
- A SOURCE AND FIX FOR ACCELERATION SENSITIVE ERROR SHOULD BE DETERMINED
- FASTER MATHEMATICS FOR AMBIGUITY RESOLUTION SHOULD BE INVESTIGATED
- RANGE RATE DATA CAN BE CURRENTLY FURNISHED WITH LESS THAN 1 FT / SEC ERROR
- 0.1 FT / SEC RANGE RATE DATA CAN BE ACHIEVED WITH A REASONABLE RESOURCE EXPENDITURE

APPENDIX H

**COHERENT TRACKING DATA
FOR
MINUTEMAN III EVALUATION**

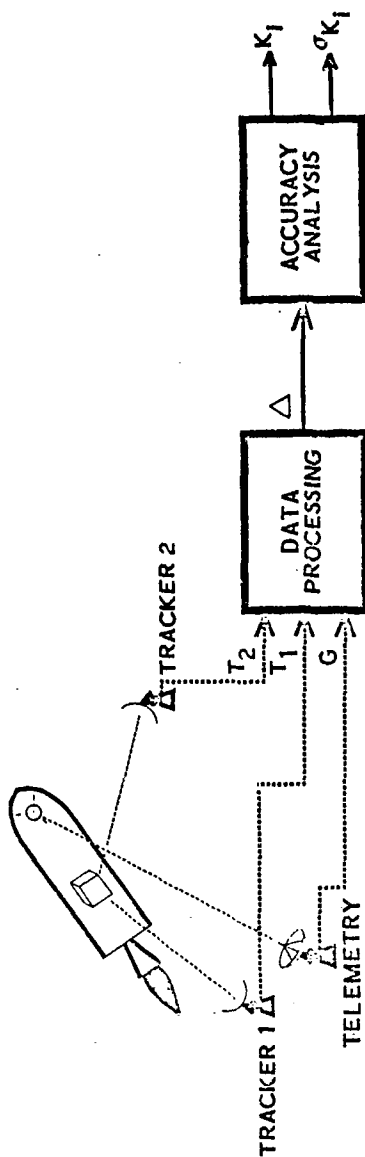
By

**MAJ. TOM THOMASON, SAMSO
MNNC**

Norton AFB, California 92401



ACCURACY MEASUREMENT FROM FLIGHT DATA



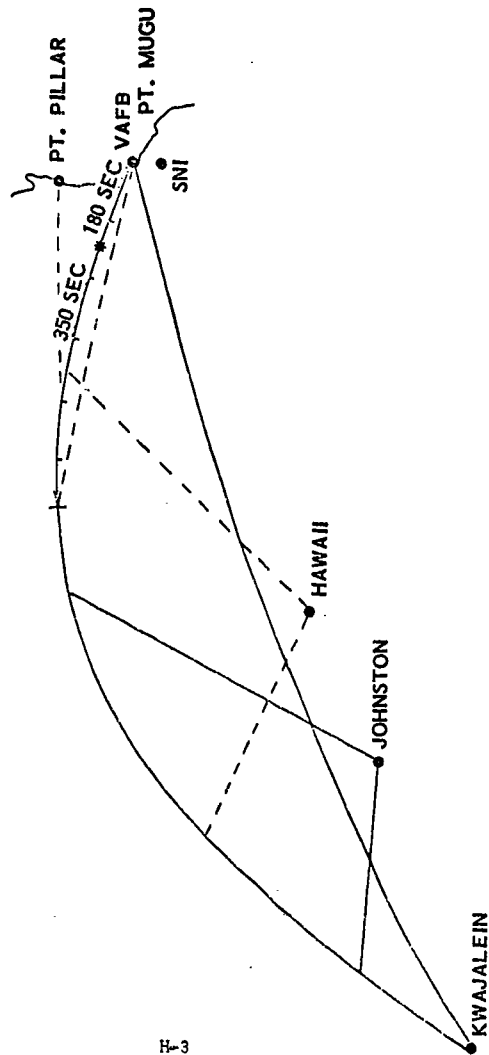
H-2

$$\Delta = K_0 + K_1 V + K_2 \int_0^t \alpha^2 dt + \dots K_3 R + K_4 \cos E + \dots$$

GUIDANCE MODEL
TRACKING MODEL



AFWTR RADAR COVERAGE



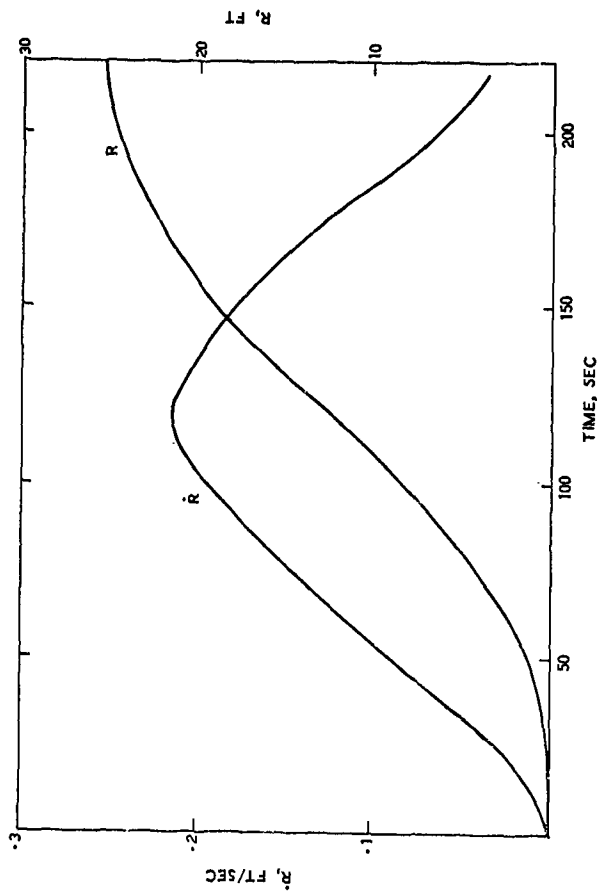


COHERENT DATA UTILIZATION

- COHERENT DATA IMPROVES FREQUENCY RESPONSE
 - ADVANTAGE OF LIMITED USE FOR GUIDANCE FLIGHT ANALYSIS
 - USEFUL FOR IDENTIFICATION OF GUIDANCE ANOMALIES
 - USEFUL FOR ISOLATION OF CERTAIN GUIDANCE ERROR TERMS
- REAL TIME ACCURACY IMPROVEMENT (RANGE/SAFETY APPLICATION) SIGNIFICANT
- GEOMETRY CONSIDERATION LIMITS USEFULNESS AT AFWTR
- PROVIDES 10 TO 30% POTENTIAL OVERALL IMPROVEMENT FOR GUIDANCE EVALUATION
- PROVIDES INCREASED CONFIDENCE IN EVALUATION RESULTS



PROPAGATION OF GUIDANCE ERROR IN PT. PILLAR RANGE RATE COORDINATES





COHERENT SYSTEM TEST RESULTS

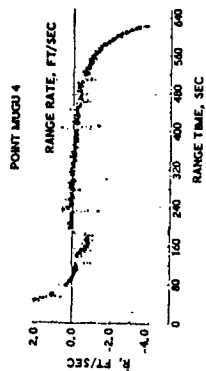
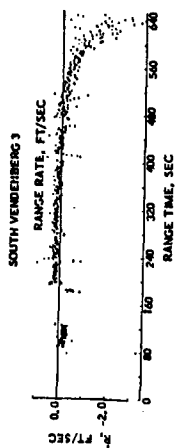
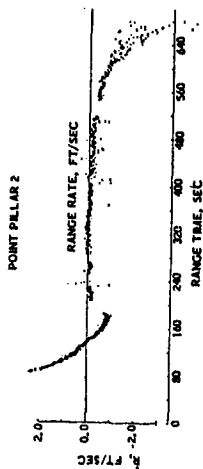
- COHERENT DATA OBTAINED ON RECENT FLIGHTS (STM-7W, PVM-2, -4, -3)
- COMPARISON OF IMU OUTPUT CORRECTED FOR ESTIMATED ERROR* WITH COHERENT DATA YIELDS EXCELLENT MEASURE OF COHERENT QUALITY (COMPARISONS ACCURATE TO ~ 0.03 FT/SEC RANDOM ERROR; 0.5 TO 0.10 FT/SEC SYSTEMATIC ERROR)

H-6

*ESTIMATION BASED ON R, A, E POWERED FLIGHT DATA FROM UPRANGE AND MIDRANGE RADARS.



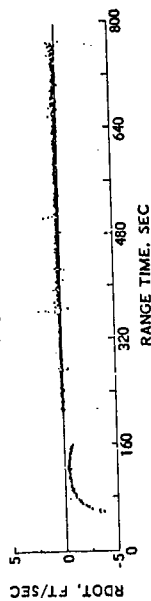
POSTFIT RESIDUALS FOR STM-7W



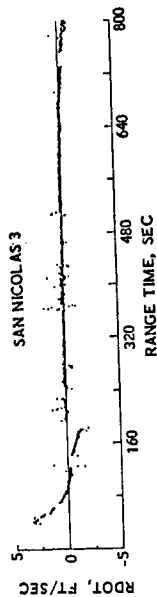


RDOT RESIDUALS FOR PVM-2

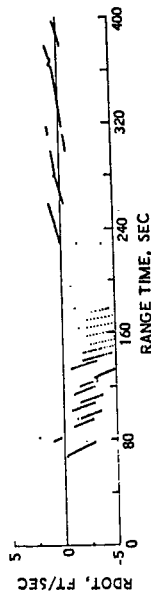
PT. PILLAR 2



SAN NICOLAS 3



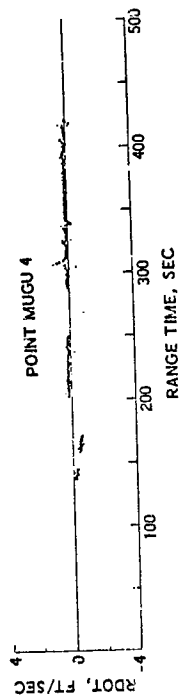
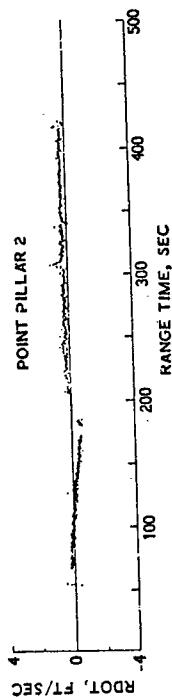
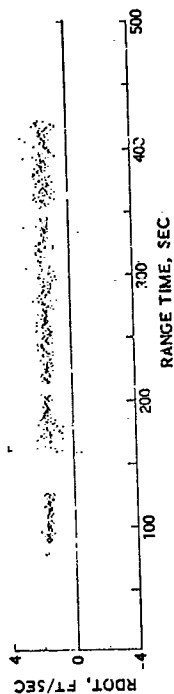
PT. MUGU 4





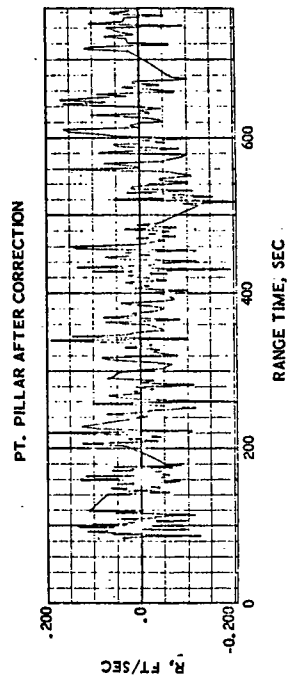
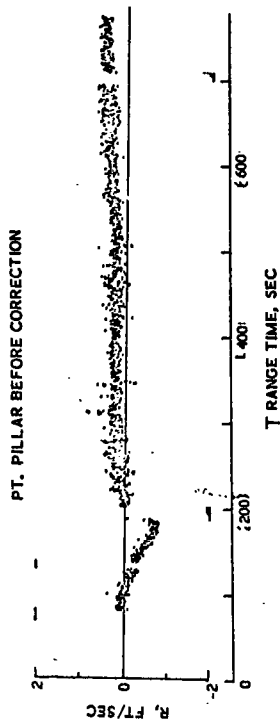
RANGE RATE RESIDUALS FOR PVM-4


SVAFB





RANGE RATE RESIDUALS FOR PVM-3





SUMMARY

- LARGE SYSTEMATIC ERRORS NOTED IN EARLIER FLIGHT TEST RESULTS ELIMINATED
- RANDOM AND SYSTEMATIC ERRORS IN NON-DYNAMIC PORTIONS OF TRAJECTORY APPROACHING SPECIFICATION ACCURACY LEVELS
- ERRORS OBSERVED IN DYNAMIC OR BOOST PHASE OF FLIGHT MUST BE ELIMINATED TO ACHIEVE EXPECTED OVERALL ACCURACY IMPROVEMENT OF 10 TO 30%
- LIMITATIONS IN POWER OF COHERENT BEACON DEGRADING ACCURACY OF NON-COHERENT MIDRANGE DATA
- LIMITATION IN POWER SUSPECTED OF CAUSING DEGRADATION IN BOOST DATA QUALITY

SUMMARY OF TEST RESULTS

FLIGHT	DATE	RADAR			
		SVAFB 3	PT. PILLAR	SAN NICOLAS	PT. MUGU
STM-7W	8/2/72	0.3 fps IN BOOST-SEVERE REFRACTION ERROR	2 TO 4 fps BOOST ERROR (TIMING SUSPECTED) PLUS 2 TO 3 fps REFRACTION ERROR	N/A	SIMILAR TO PT. PILLAR
PVM-2	1/31/73	N/A	REFRACTION ERROR CORRECTED, BUT 3 fps POWERED FLIGHT ERROR	3 fps POWERED FLIGHT ERROR	50 fps ERROR (MISSED AMBIGUITY SLOT)
PVM-4	6/1/73	1 fps NOISE 2 fps BIAS	POWERED FLIGHT ERROR < 0.3 fps, NOISE ~ 0.1 fps	N/A	SIMILAR TO PT. PILLAR
PVM-3	8/24/73	N/A	~1 fps POWERED FLIGHT ERROR	N/A	N/A

APPENDIX I

**PROBLEMS ASSOCIATED WITH DEVELOPMENT OF A
LAUNCH HEAD RANGE SAFETY SYSTEM FOR CONTAINING
ICBM LAUNCHES IN THE KWAJALEEN LAGOON CORRIDOR**

By

**STAN RADOM
SAMTEC-CA**

**Space and Missile Test Center
Vandenberg AFB, California 93437**

PROBLEMS ASSOCIATED WITH DEVELOPMENT OF A LAUNCH HEAD RANGE SAFETY SYSTEM FOR CONTAINING ICBM LAUNCHES IN THE KWAJALEIN LAGOON CORRIDOR

Stan Radom, SAMTEC

(Verbatim Transcript from Tape)

I am using a viewgraph made in 1966 in order to give you an idea of why we got into coherent tracking in the first place. There's some interesting history attached to it. I'd like to go over briefly why the very large expenditures were made here, San Nicolas Island, Pillar Point, and Point Mugu to get into the range and range rate business.

When the Western Test Range was formed, the Air Force took over PMR responsibilities for instrumentation of ballistic launches and space launches from the west coast. The Electronics System Division of the Air Force was assigned the task of attempting to outguess our needs. They were going to tell us what we were going to need to accomplish our objectives.

Back in about 1966 there was a detachment of ESD people here. When they took a look at this problem they said, "Yes, you are suffering from a lack of downrange islands so something drastic has to be done." The requirement was thrust upon us to start impacting ICBMs in the Kwajalein area. That was because a great deal of money was being spent in the Roi-Namur complex for TRADEX and other radars associated with evaluation of reentry systems. Then they added the requirement to score impacts, and recover warheads. The recovery dictated the need for the lagoon impacts. They not only wanted an accurate score, they also wanted to get the warhead (or pieces) back. That dictated negotiation with the Marshallese to evacuate a corridor 32 miles wide through the middle of the Kwajalein lagoon.

(See Viewgraph)

This basic problem and why I brought it up, points out the need and justifies the expenditure for the coherent modifications to the FPQ-6 at Pillar Point and the FPS-16's at PMR. The TPQ-18 was already programmed for coherent mod by the ETR before it was delivered to Vandenberg.

So this is generally the problem. A much different situation because you have natives, plus military and civilian dependents on Kwajalein and you have a population up at Roi-Namur. This was drastically different than the situation at Eniwetok where there were no natives, no dependents, and where shelter was provided for all essential personnel. It was a good place to do extra-hazardous testing. At that time we had developed an underwater scoring system for the Eniwetok lagoon that exceeded our expectations, and we had a 1 Sigma circular accuracy of 34 feet on impacts. Of course, you can't argue when the recovery barge is vectored into position, and the diver dives down about 200 feet and steps on the warhead! But with this requirement at Kwajalein, we had to do something drastic, so, ESD initiated a study with the help of MITRE, to see if multilateration radars bearing down on the trajectory might provide a range safety system that could contain the impacts in the corridor without inadvertent destruction of good missiles.

So we took a look at what the geometrical configuration could do. We had some simulation software; we had a contract with RCA to take a look at this situation, along with the work being done by ESD, and what little work we did in-house at the time. This generally is what the situation looks like.

(First Overlay)

With a single FPS-16 at the launch head, and a computer, you have an uncertainty of something like 42 miles, bigger than the corridor itself — its just out of the question! The future impact prediction was just not useful. There was no question but that it was inadequate. The multilateration mode, that I'm going to show you here, closely correlates both the ESD study and RCA analysis, and what everyone took a look at.

Lets take a look at adding radars, and, although we don't have downrange islands, lets see what we can do with bilateration.

(Next Overlay)

This reduced the IIP uncertainty in order of something like 10 miles. Still unsatisfactory - it didn't allow enough latitude for the excursion that a MINUTEMAN, for example, might make in the last few seconds of powered flight. Adding another sensor — if you had conventional pulse radars, Point Pillar and San Nicolas Island giving you the longest baseline for bilateration plus trilateration, using a ship providing a data link, as you can see you then have an uncertainty ellipse that looks like your improving things. Of course, the ship can give you the Z-component, measuring altitude in an optimum position near burnout. Of course, its the Z-component when you go a quarter of the way around the earth, 4300 miles to the target area at Kwajalein, thats your major source of error. So you can see why there was a dramatic improvement here, but it was still not satisfactory. The risk would be too great to say that, if we had conventional pulse radars, bilateration, plus a ship and real time. So then we took a look at what range and range rate would do for you.

(Next Overlay)

As soon as you went coherent in a bilateration mode, when reading range and range rate directly, you can see that the size of the uncertainty ellipse narrowed down, moved about 90 degrees. But when you're bouncing back and forth against the corridor lines, it still hasn't done enough good.

Lets take a look at what happens when you put a ship in the solution. This is a ship near burnout with a conventional pulse radar, but providing real-time data reliably into the computation center. It reduces your uncertainty ellipse to something like 2 by 3 miles. And that looks good! Theory showed that this is the way to go!

Lets go coherent at Point Pillar and give the Navy the money to modify radars at San Nick, Point Mugu, and away we go!

In those days we had ships also. This convinced the people reviewing the budget, and everyone else, that this was a sound method of approach. All the problems you've been

hearing about, some of the presentations that our folks have shown you, kept talking about the IIPs and Kwajalein, this was the compelling requirement. The problem has been taking the theory and reducing it to practice.

As in MINUTEMAN, the problem of having a range safety system for a multi-stage solid rocket, with high accelerations is that it requires that action be taken in the last half-second of powered flight. You have to measure lateral acceleration near burnout to reliably contain the impact within the boundaries of the Kwajalein lagoon corridor. That means you are going to have to have computer abort. You can't have a guy at a console with his finger on a button. The brain-to-finger response time alone is out of the question.

As soon as we started talking about computer abort, the Range Commander who has the safety responsibility and can't delegate it, asked the great question: "How reliable is my system, what is the possibility of that computer blowing a good 'bird'?"

So, my small analysis group started looking at reliability figures for radars in general, data links, everything associated with getting the data into the computer. Assuming that we had the software that worked at the time, what were the chances of a dropout that would cause a computer abort? It turns out that the Range Safety Officer would buy about 5 percent of the birds. So, each Commander, when given that information, said "I'm going to take my chances, I don't want computer abort. I'd rather go with the waiver before I design into the system an assured method of blowing 1 out of 20 'birds'." Generals Bleymaier, Kronauer, Wilson and Lowe felt the same way. We haven't had a Commander who has felt differently. As a result, this kind of put the hiatus on where we were going with this system. Furthermore, we didn't have the computational power, as an example, even if we had a system that could work reliably. Because we did not demonstrate a positive system of range safety, we couldn't tell our users, "you must carry a coherent beacon."

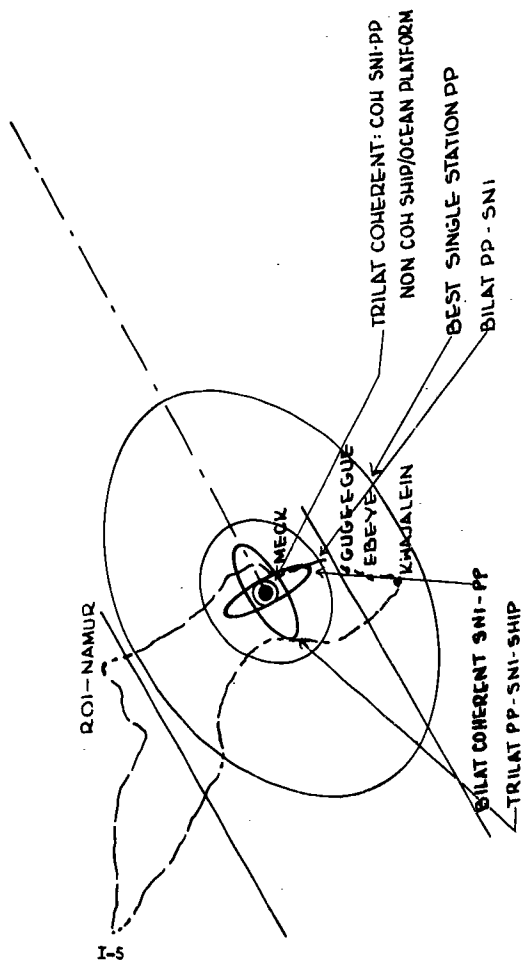
That is essentially where we are today, and one of the reasons for this conference. We have coherent mods. We know a lot more about beaconry and we know a lot more about the reliability of data links. So we need another appraisal - maybe an agonizing reappraisal of whether we're going to take another stab at this system, take a look at GERTS for MINUTEMAN, or whatever means we can. Maybe an interferometric system? I'm not talking about a floating MISTRAM or something like that, but by taking another look at whatever technology is available to us, so we can go from the waiver mode to a positive system of range safety for Kwajalein.

I hope that this briefing will give you some background on why the initial investment was made in coherent radars for the West Coast launch head.



WTGT-67-3

INSTRUMENTATION IIP ACCURACY



APPENDIX J

PULSE DOPPLER INSTRUMENTATION RADARS

By

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Moorestown, New Jersey 08057**

PULSE DOPPLER INSTRUMENTATION RADARS

Renzo Mitchell, RCA

FPO-6/TPQ-18

**VAFB
PILLAR POINT
WALLOPS ISLAND**

FPS-16

**PT. MUGU
SAN NICOLAS**

MPS-36

2 -- SAMTEC (MRSS)

1 -- TONOPAH

2 -- KWAJALEIN

3 -- GERMANY

6 -- WSMR

DESIGN PERFORMANCE CAPABILITY

FPO-6/TPQ-18

RANGE RATE 0.1 FT./SEC.

COHERENT INTEGRATION IN RANGE AND ANGLES

FPS-16

RANGE RATE 0.1 FT./SEC.

MPS-36

1.0 FT./SEC. (SPEC.)

0.1 FT./SEC. DESIGN CAPABILITY

MPS-36 FINE LINE TRACK

FINE LINE TRACK IN RANGE AND ANGLES.

DECREASED DOPPLER AMBIGUITY RESOLUTION TIME.

CAPABILITY OF TRACKING THROUGH CLUTTER.

IMPROVEMENTS IN CAPABILITY

-SOFTWARE ENCHANCEMENT TO MAINTAIN DOPPLER TRACK DURING STAGING.
-SOFTWARE ENHANCEMENT TO MAINTAIN DOPPLER TRACK DURING EVENTS THAT CAUSE SPECTRAL SPREADING - FLAME EFFECTS.
-SATELLITE COMPUTER TO RELIEVE 4101 OR DDP-124.
-AUTO CHECKOUT TO ASSURE OPERATIONAL READINESS.
-VELOCITY/ACCELERATION PROCESSING IMPROVEMENTS TO ENHANCE INITIAL LOCK-ON CAPABILITY AT LOW PRF AND HIGH ACCELERATION.
-DRIVER STROBE RISE-TIME REDESIGN.
-SYSTEM NOISE FLOOR IMPROVEMENTS.

APPENDIX K

GEOS-C PROJECT DESCRIPTION

By

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GENERAL PROJECT DESCRIPTION

The purpose of the GEOS-C Project is to design, develop, and launch a geodetic and oceanographic satellite and to perform experiments in support of the application of geodetic satellite techniques to the Earth and Ocean Physics Applications Program.

The GEOS-C Mission will provide data with which to refine the geodetic and geophysical results of the National Geodetic Satellite Program (NGSP) and will furnish a test bed for new systems. This Mission will also contribute to fulfilling the C-band radar calibration and altimeter requirements of the Departments of Defense and Commerce.

The spacecraft for this mission was designed and fabricated by the Applied Physics Laboratory of the Johns Hopkins University. The structural configuration is based on the GEOS-2 mechanical design. Basically, the structure will be the same as GEOS-2 with the substitution of heavier trusses to accommodate the additional weight.

The GEOS-C (Geodynamics Experimental Ocean Satellite) will be launched during FY-75 from the Air Force Western Test Range (AFWTR) located at Vandenberg AFB, California. The nominal orbit parameters are:

Mean Altitude	- 843 km
Inclination	- 115 degrees
Eccentricity	- 0.006
Period	- 101.8 minutes

The orbital parameters are chosen to maximize the possibility of providing orbit traces which cover the earth's surface in a prescribed grid work pattern, i.e., $1^\circ \times 1^\circ$.

Following orbital injection, the spacecraft will employ an attitude stabilization system consisting of a gravity gradient boom with end mass and damper, momentum wheel and an electromagnet. The energized electromagnet creates a magnetic dipole moment along the boom axis of the satellite to aid in gravity gradient capture. The axis will align with the earth's magnetic field so that in the northern latitudes the proper side of the spacecraft will point earthward. At this time, the boom will be extended and the electromagnet turned off.

Power for operation of the spacecraft and experiment sub-systems will be provided by a single 11-cell battery. The battery will provide a 14.7 volt nominal power supply for the duration of the mission which is scheduled for a period of one year.

A PCM/PM telemetry system will allow two basic modes: low bit rate data transmission (1.562K bits/sec) or high bit rate data transmission (15.62K bits/sec.). Transmission of data will be either via S-band direct to ground, S-band to ground via the ATS-F satellite, and/or VHF direct to ground. Experiment sub-systems will be controlled by a series of commands either stored (delayed command) or sent directly from ground stations.

GEOS-C MISSION OBJECTIVES

The GEOS-C Mission Objectives in order of priority at launch are:

- To perform an in-orbit satellite altimeter experiment to: (1) determine the feasibility and utility of a space-borne radar altimeter to map the topography of the ocean surface with an absolute accuracy of +5 meters, and with a relative accuracy of 1-2 meters, (2) determine the feasibility of measuring the deflection of the vertical at sea, (3) determine the feasibility of measuring wave height, and (4) contribute to the technology leading to a future operational altimeter-satellite system with a 10-cm measurement capability.

- To further support the calibration of NASA and other agencies' ground C-band radar systems by providing a space-borne coherent C-Band transponder system, to assist in locating these stations in the unified earth-centered reference system, and to provide tracking coverage in support of the radar-altimeter experiment.

- To perform a satellite-to-satellite experiment with the ATS-F satellite using an S-Band transponder subsystem to directly measure the short period accelerations imparted to the spacecraft by the gravity field and to determine the position of the spacecraft. The anticipated measurement data quality of about .04 cm/sec over a ten-second integration interval will aid in improving the earth gravity model up to spherical

harmonic terms of degree and order to approximately 25 and in providing tracking coverage over mid-ocean areas to support the radar-altimeter experiment. The satellite-to-satellite system will also be used for altimeter-data relay through AFS-F.

- To further support the intercomparison of new and established geodetic and geophysical measuring systems including: the radar altimeter, satellite-to-satellite, C-Band, S-Band, laser, and doppler tracking.

- To investigate solid-earth dynamic phenomena such as polar motion, fault motion, earth rotation, earth tides, and continental drift theory with precision satellite tracking systems such as laser and doppler ground stations.

- To further refine orbit-determination techniques, the determination of interdatum ties, and gravity models with a spacecraft equipped with laser retroreflectors, C-Band and S-Band transponders and doppler beacons.

- To support the calibration of S-Band sites in the STDN by furnishing a space-borne transponder, to assist in positioning the network stations in the world reference system, and to assist in evaluating the system as a tool for geodesy and precision orbit determination.

The achievement of these objectives not only will constitute a successful mission but also will greatly enhance man's understanding of the physical properties of the planet Earth.

EXPERIMENT PACKAGE

The GEOS-C experiment package will consist of five basic instruments each of which will contribute to one or more of the mission objectives. Consistent with these objectives, the experiment sub-systems are listed in priority order as follows:

- Radar Altimeter
- Coherent C-Band Transponder
- S-Band Instrumentation for Satellite-to-Satellite Experiments
- Laser Retroreflector
- Doppler Transmitters
- Non-Coherent C-Band Transponder
- S-Band Instrumentation for Earth Tracking Experiments

Radar Altimeter

The basic objectives of the radar altimeter experiment are to demonstrate the feasibility of utilizing an on-board altimeter to measure the time-varying behavior of the ocean's surface and the departure of the sea surface from the geoid and to investigate altimeter instrumentation technology. To meet these objectives, the altimeter will have two distinct data gathering modes: Long Pulse and Short Pulse. The basic measurement goals established for the altimeter are as follows:

- Precision: Short Pulse Mode 30 cm
- Long Pulse Mode 60 cm
- Geoid Accuracy: Absolute ± 5 meters
- Relative ± 2 meters
- Sea State: 25% of S.W.H.

One of the primary goals of the experiment will be to obtain engineering data on altimeter performance. For this, it will be necessary to measure and evaluate parameters such as sea-surface roughness and spacecraft

libration as it relates to hardware performance. Another goal will be to calibrate the altimeter over an ocean area. The presently planned calibration area will be the portion of the Atlantic Ocean bounded by Wallops Island, Virginia; Merritt Island, Florida; Grand Turk; and Bermuda. Altimeter accuracy will be determined by comparing the altitude measured by the altimeter to the spacecraft altitude determined by independent tracking systems. Precision and resolution will be determined by comparing sea surface profiles resulting from altimeter measurements to profiles determined by independent methods.

C-Band System

Two C-Band radar transponders will be flown on the GEOS-C satellite to support the altimeter and C-Band system calibration as well as geometric, gravimetric, and other geodetic investigations. The C-Band System consists of the two transponders (one coherent and one non-coherent) and the associated ground tracking C-Band radars.

The non-coherent transponder, operating in conjunction with existing ground radar systems, will provide for range and angle measurements. The coherent transponder, operating in conjunction with existing coherent ground radar systems, will provide for range, range rate, and angle measurements.

Laser System

The Laser System consists of the GEOS-C spaceborne laser retroreflector subsystem and the ground-based Laser Ranging Systems. The retroreflector

will be utilized in conjunction with the ground-based laser systems to obtain precision satellite ranging data.

In the GEOS-C time frame, the NASA Laser Ranging Systems are expected to have a ranging capability of 10 cm or better. The capability of the angle data is estimated to be about 0.5 milliradian or better. Range and angle data are provided at a once-per-second rate.

Doppler System

The Doppler System consists of two spaceborne transmitters and ground doppler receiving stations. The dual frequencies (162 and 324 MHz) originate from an ultra-stable 5 MHz oscillator.

Ground observation stations measure the doppler components of the signals received from the GEOS-C spacecraft by counting cycles resulting from the difference between the received frequency and the station oscillator. The difference frequencies between the higher and lower received frequencies and the station oscillator are combined in the proper proportions to obtain both the first order ionospheric refraction correction and the refraction corrected doppler frequency.

S-Band System

The S-Band system consists of the following elements:

GEOS-C Coherent S-Band Transponder

GEOS-C S-Band Antenna System

ATS-F Spacecraft

ATS-F Ground Terminals

STDN S-Band Ground Stations

MISSION PROFILE

The GEOS-C Mission has been divided into two distinct phases. Phase I covers all activities from launch through one year of Experiment data collection and Phase II covers those activities after Phase I through the remainder of the Mission lifetime.

Phase I can be sub-divided into several phases according to the extent of experiment data collection, the type of data being collected, and various other operational and physical constraints. These sub-phases along with the dominant activity are:

<u>PHASE I PERIODS</u>	<u>TIME PERIOD</u> (Days After Launch)	<u>DOMINANT ACTIVITY</u>
Phase A	0 - 40	Launch and Operational Assessment
Phase B	40 - 130	Experiment Systems Calibration & Evaluation
Phase C	130 - 285*	Unique Experiments and Localized Grid Activity
Phase D	285*- 325*	Global Activities
Phase E	325*- 405	Localized Grid Densification

* The length of Phase D is not expected to change. However, the time of occurrence is dependent upon the time of ATS-F drift.

PHASE A - Launch and Operations Assessment

This phase begins with Launch and extends over a period of approximately 40 days in which the following activities occur:

- (a) Launch
- (b) Orbit injection
- (c) Early orbit determination and refinement
- (d) Gravity gradient capture and damping
- (e) Momentum wheel turn on
- (f) Yaw capture and stabilization damping
- (g) Spacecraft functional and electrical checkout
- (h) Operational assessment of experiment systems

It is not expected that any useful experiment data collection will be accomplished during Phase A.

PHASE B - Experiment Systems Calibration and Evaluation

It is expected that this phase will begin about 40 days after launch and continue for two or three months. It is expected that the bulk of the data collected during this period will be useful for investigation purposes. However, data distribution during this period will be slower than normal due to the more detailed analyses required to calibrate all experiment systems and to validate all data processes.

Major activities associated with this phase include the following:

- (a) Altimeter experiment systems calibration
- (b) Satellite-to-satellite experiment systems calibration

(c) Altimeter experiment systems operation globally, within the real-time ground TM station coverage areas, on those days not utilized for Altimeter Calibration activities.

(d) Ground tracking system (Laser, C-Band and Doppler) data collection activities on a global basis to the maximum extent possible commensurate with power budget, other systems calibration activities, and investigator needs.

PHASE C - Unique Experiments and Localized Grid Activities

Phase C activities are expected to begin approximately 130 days after GEOS-C launch and continue until ATS-F is maneuvered from the Western Hemisphere location (94 degrees west longitude) to the Eastern Hemisphere location (34 degrees east longitude).

It will be seen that the transition between Phase B and Phase C will not constitute a major change in the type of activities being conducted, rather only the level and extent of most activities will be reordered.

A typical day during this time period will consist of:

Ground tracking systems (Laser, C-Band and Doppler) data collections activities on a global basis to the maximum extent possible commensurate with power budget, other systems activities, and investigator needs.

Altimeter experiment data collection activities commensurate with power budget, investigator needs and globally within the constraints of the ground TM station coverage.

In addition to this major activity, intermittent calibration and evaluation activities will be conducted at a nominal rate of once per month.

PHASE D - Global Activities

Phase D activities will be conducted during the time in which ATS-F is being maneuvered from the Western to the Eastern Hemisphere.

During this period, four arcs of SSE data per day will be scheduled for a total of 160 SSE data arcs. Each arc will be about 45 minutes long (i.e., compatible with the period of mutual visibility between ATS-F and GEOS-C).

The SSE arcs will be scheduled to provide a complete 5° X 5° grid pattern within the ATS-F coverage areas. This will be accomplished by selecting two consecutive ascending and two consecutive descending passes per day (spaced about 12 hours apart so that they cross near the equator), and basically following these passes each day until the grid is complete. Arc selection as described above, will effectively accomplish the 5 degree gridwork since GEOS-C ground traces are offset by about 5 degrees to the east per day.

In addition, interface with ATS-F during the entire 40-day period should allow a redundant 5-degree grid pattern (offset by about 2 degrees to the east) to be placed in an area extending about 100 degrees in longitude. This additional 5-degree pattern will be placed approximately

midway within the ATS-F coverage area (e.e., between approximately 80 degrees west longitude and 20 degrees east longitude).

During each of the SSE arcs described above, radar altimeter data will be scheduled over most portions of the arcs which are over ocean areas. Therefore, a 5-degree gridwork of altimetry data will be collected simultaneously with the SSE data. In addition, C-Band, laser, and doppler data will be scheduled to support orbit determination for the SSE and radar altimeter data arcs scheduled during this period.

PHASE E - Localized Grid Densification

Phase E activities will begin at the time when activities associated with the ATS-F have been completed. It is expected that Phase E activities will be essentially the same as those described in Phase C except that during the latter time period the S-Band ground tracking network stations should all be modified compatible with the GEOS-C instrumentation and will assume a more active role.

INVESTIGATION PLANS

Introduction

In support of the GEOS-C Mission objectives proposals were solicited in thirteen specific investigation categories with provision for investigations in other categories if these could be shown to be compatible with long range Earth and Ocean Physics Application Program objectives. The thirteen specific investigation categories can be summarized as follows:

Ocean Geoid Determination

This proposal category includes all proposals for the determination of the geometry of mean sea level using altimetry data alone or in combination with other data types. The satellite altimeter observations will provide measurements of the height of the satellite above the ocean surface. This data can be used directly to estimate the ocean geoid, provided the satellite position can be determined with sufficient accuracy and/or errors in satellite position corrected for. Investigations in this category may call for the combination of altimeter information with geoid information obtained from existing surface gravimetry, satellite gravity field information, deflection of the vertical information and geocentric station position. The computation of improved satellite gravity fields and station positions should not be included within this investigation category.

One of the important results expected to be obtained from the GEOS-C altimeter is improved definition of the ocean geoid. At present worldwide

knowledge of the ocean geoid is only available from satellite gravity field data which, at best, define variations with widths of the order of 1500 kms or larger. Over restricted areas of the world, where dense surface gravity data is available, detailed geoids can be computed defining geoid variations with widths down to 100 kms or smaller. These detailed geoids in local areas have demonstrated that geoid variations of 10 to 20 meters are commonly generated by the wavelengths of less than 1500 kms and are not present in the satellite fields. It has also been shown that even wavelengths of less than 100 kms can, at times, produce variations of up to 10 meters. Therefore, the satellite altimeter with precision and/or accuracy of 1 to 2 meters has the potential for greatly increasing our knowledge of the ocean geoid in those substantial parts of the ocean where no detailed surface gravity exists as well as contributing to increased accuracy in those areas where surface gravity and other types of gravity data exist.

Determination of geoid heights from altimeter measurements requires that the altimeter measurements be reduced in conjunction with satellite orbit information. Questions exist as to: (1) the best method of reduction to eliminate possible systematic orbit and altimeter errors, (2) the best set of parameters to represent the geoid, and (3) the best method for combination of altimeter data with other types of data for improved geoid determination. Ten GEOS-C investigations were proposed in the geoid computation area. These investigations represent a number of approaches to geoid determination from altimeter data and are expected to provide answers to the questions posed above. In order to answer the questions posed, evaluations must be made of the actual altimeter results. Several

investigations have as their objective the carrying out of comparisons of results with external standards in order to make such evaluations.

Ocean Tides

Repeated measurements over a section of the ocean using the GEOS-C altimeter has the potential for allowing determination of the time variable effects of the tidal attractions of the sun and moon on sea surface topography. At present most measurements of ocean tides are made at coastal stations where the tidal effects are strongly influenced by local bathymetric effects. Although several theories exist which permit theoretical computation of deep ocean tides only limited numbers of measurements of deep ocean tides have been made, utilizing bottom tide meters.

The satellite altimeter has the potential for rapid global determination of ocean tides. To be of maximum use, accuracies of the order of 10cm will be required for altimeter derived tidal measurements. However, GEOS-C even with the lesser accuracy of its altimeter should allow evaluation of various techniques for recovery of tide data from satellite altimeter measurements. To be of maximum value tidal analyses of GEOS-C altimeter data must be carried out in areas where ground truth in the form of bottom tide meter data is available. Five investigations in this category were proposed.

Sea State Determinations

In addition to giving the distance between the spacecraft and the

ocean surface, the GEOS-C altimeter data, through analysis of the characteristics of the return pulse, is expected to provide information on the sea state. In particular, information on mean wave height, wave period, and wave propagation direction may be determinable. Although theoretical studies and aircraft radar altimeter data analyses have been carried out, considerable effort is needed to determine the degree to which various types of sea state data can be extracted from a satellite altimeter and to identify the best methods for carrying out extraction of the information. The bulk of the ten investigations proposed on GEOS-C for sea state determination analyses are aimed at evaluation of feasibility and identification of best methods through comparison of results obtained from the GEOS-C altimeter with ground truth information on sea state and with data obtained from aircraft-borne radar instruments. In addition to analysis of GEOS-C data in terms of sea state parameters, the objectives of investigations include development of information for use in the design of future satellite radar altimeters and determination of potential bias introduced into altimeter sea surface topography determinations due to sea state.

Quasi-Stationary Departures from the Marine Geoid

This proposal category includes all altimeter analyses designed to investigate non-periodic deviations of sea level from an equipotential surface. It also includes analyses of altimeter data to determine sea slopes associated with such phenomena as currents and wind setup. It does not include analyses relating to wave phenomena, ocean tides, or

investigations directed specifically to the determination of the geoid.

The sea surface topography which will be measured by the GEOS-C altimeter is a function primarily of variation of the force of gravity over the earth's surface, changes in atmospheric pressure from point to point on the ocean surface, density structure of the water column, surface wind effects, dynamical effects due to ocean currents, and tidal effects. If only gravitational forces (including rotation) were present, the sea surface topography would be coincident with the geoid. The effects of atmospheric pressure variations, wind forces and tides are time variable with a reasonably high temporal frequency. The effects of density structure of the water column and currents are usually considered to be quasi-stationary departures from the geoid, even though the effects of currents do shift over restricted areas of the surface. One of the primary aims of the Earth and Ocean Physics Applications Program is to determine, from altimeter measurements, departures of sea surface topography from the marine geoid due to water motion. The reason for this interest lies in the fact that the velocity and volume of water in motion can be inferred from these departures. Although the GEOS-C altimeter is not expected to be accurate enough to provide information which is scientifically useful, it is expected to be accurate enough to test out the concept and permit development of methodologies which can be used with data from latter, more accurate, satellite altimeters. Two investigations are planned in this category.

Gravity Model Improvement

This proposal category includes all analyses of GEOS-C altimeter and

tracking data whose ultimate objective is the determination of an improved earth gravity field. These include both normal perturbation analyses combining GEOS-C tracking data from other satellites and analyses in which the altimeter geoid height information, SSE rate information or other tracking data are combined with existing information for gravity field improvement.

Improvement of the existing gravity models is required to achieve EOPAP Program goals from three viewpoints. First, satisfaction of a number of EOPAP goals requires improved satellite orbit determination which is, to a large extent, dependent upon an improved gravity field. Second, determination of effects of ocean currents on sea surface topography requires high accuracy geoids with which altimeter derived sea surface topography can be compared. Increased geoid accuracy requires increased accuracy in knowledge of the gravity field. Finally, interpretation of an improved gravity field offers the potential of increased understanding of plate tectonics and, therefore, of the mechanisms producing earthquakes.

Gravity field information can be derived from GEOS-C in three ways:

- (1) By combining information on the perturbations of GEOS-C from tracking data with data from other satellites in a general perturbation analysis;
- (2) By analysis of satellite-to-satellite tracking data in the same manner as Lunar Orbiter and Apollo data was analyzed to obtain residual line-of-sight accelerations or compatible gravity anomaly information. Six GEOS-C investigations fall within these areas. Their proposed investigations often include the combination of GEOS-C data with gravity field information from other sources.

Geological Investigations

One important use of the geoid results to be derived from the GEOS-C altimeter data will be interpretation in terms of the geological and geophysical significance of the results. The GEOS-C altimeter results can be of particular value in extending information to areas where little or no surface gravity presently exists. Two investigations were proposed in this category.

Solid-Earth Dynamics

This proposal category includes all analyses involving the determination of earth tides, polar motion, and changes in rotation rate of the earth. It also includes determination of very precise positions on the earth's surface using GEOS-C tracking data for such purposes as determination of fault motion and crustal plate motion.

High precision tracking of the GEOS-C satellite, particularly by the submeter precision laser systems, will allow derivation of improved information on the dynamics of the solid earth. Determinations can be made of the gravitational and geometric effects of solid earth tides and of the motions of the earth's pole including Chandler motion, yearly motion, and the diurnal wobble. Four investigations were proposed in this category.

Intercomparison, Evaluation and Calibration of Instrumentation Systems

This investigation category includes all investigations whose objective is the evaluation and calibration of altimeter, satellite-to-satellite tracking and ground tracking instrumentation to be used with the GEOS-C mission. This includes both evaluation of the on-board

instrumentation and the ground systems. In this investigation category are placed all instrument intercomparison investigations and studies related to instrumentation technology.

The GEOS-C Project will undertake the primary evaluation and calibration activity with respect to the radar altimeter. Six investigators are planned to be associated with evaluation and calibration activities relative to ground tracking instruments and the satellite-to-satellite experiment. Calibration and evaluation of ground tracking instruments can be carried out by intercomparison analyses. These can involve both co-located intercomparisons and intercomparisons involving reference orbits. Since the satellite-to-satellite experiment involves new instrumentation, special emphasis will be given to evaluation and calibration of these results.

Ground Truth Determination

This investigation category includes all investigations whose objective is the collection of data from ground, ship, and aircraft based systems and the use of this data to evaluate the characteristics of the satellite systems.

In order to calibrate, evaluate, and utilize data taken by instruments on board the GEOS-C spacecraft, it will be necessary to have available certain types of ground truth for comparative purposes. Three investigators have proposed to provide some of this ground truth data.

Tracking Station Location Improvement

This investigation category includes all investigations whose primary objective is the determination of the location of tracking stations where the objective is geodetic in nature and is not for earth dynamic purposes.

A number of types of tracking data taken using the GEOS-C satellite can be used to provide improved station location information which will be useful in support of altimeter calibration and to support other project objectives. GEOS-C will provide data from new stations, data of higher accuracy than previously available, and data from new instrumentation types such as VLBI measurements. Five investigations have been proposed in this category.

Orbit Determination Improvement

This proposal category includes all investigations whose end objective is orbit determination improvement. Indirectly, GEOS-C can be expected to support improved orbit determination by providing improved gravity field information. However, this category will emphasize new types of tracking information such as the SSE and altimeter data and its capability to support improved orbit determination. Two investigators propose to study the use of GEOS-C data for this purpose.

Data Management/Information Processing

This proposal category includes investigations whose objective is the development of methods and techniques for managing and processing the

data taken by the various instrumentation on the GEOS-C spacecraft. This includes the development of data editing and pre-processing techniques. Specifically, investigations are directed toward those systems expected to be most useful in future earth and ocean physics applications activities and involve advanced techniques applicable to future activities.

One investigation falls in the general category of data management and/or information processing relative to the altimeter.

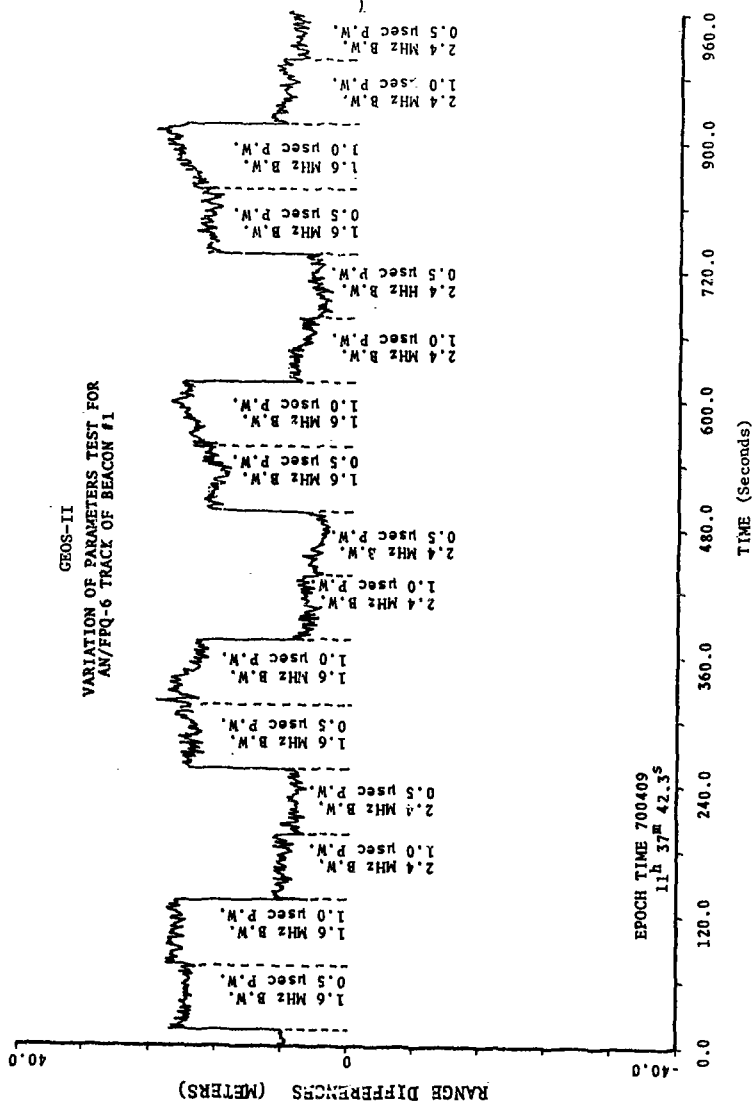
Unique System Investigations

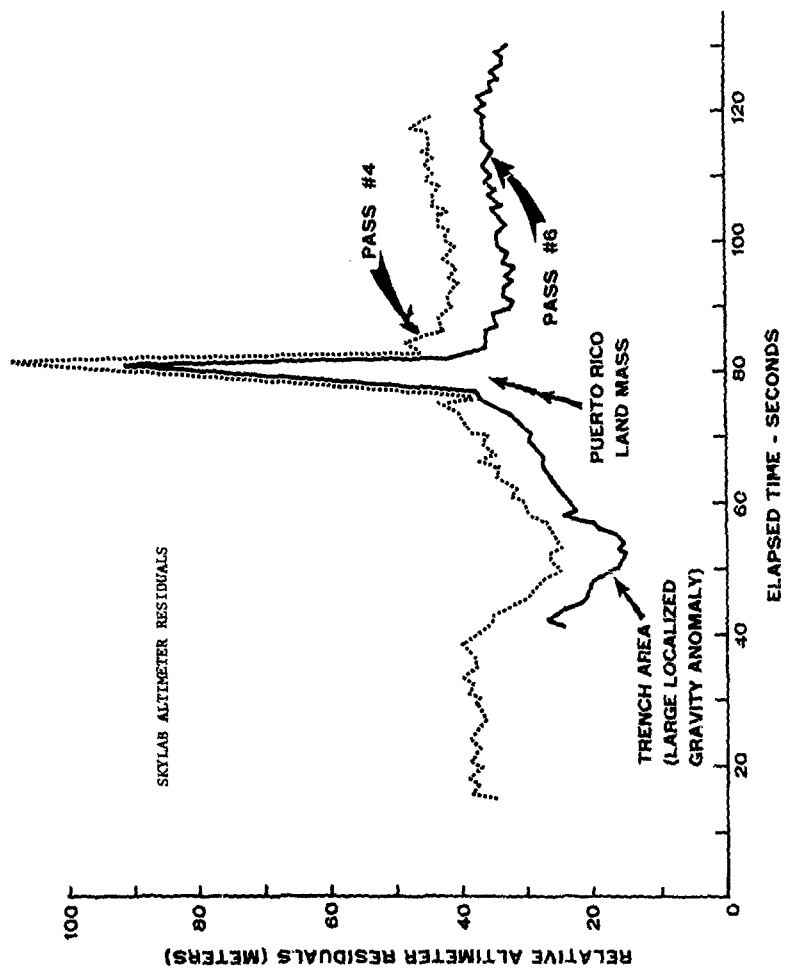
Certain GEOS-C investigations are proposed which are uniquely associated with a particular instrumentation and do not fit into any of the preceding twelve categories. Two investigations are proposed in this category and deal with the C-Band and Altimeter systems.



Slide 1

GEOS-C SPACECRAFT
K-24





GEOS-2 C-BAND TRACKING ACTIVITIES

AGENCY	USABLE PASSES	TRACK TIME (SEC)	DATA (SEC)	AA*	BB*	CC*	DD*	EE*	FF*
ETR	568	512124	424798	2	14	30	8	467	329
WTR	181	140539	137448	7	10	10	23	145	307
MSFN	1102	888951	680993	8	25	16	18	366	329
NWAL	722	818904	520635	5	18	95	4	269	158
PMR	329	204893	192199	2	8	15	6	208	519
WSMR	59	48402	49235	3	0	3	?	63	42
EDAFB	6	1327	1361	0	2	1	1	3	28
FRC	67	44733	38557	5	6	0	2	35	32
SHIPS	222	178474	167743	11	11	4	9	98	167
CNES	71	66443	55145	0	6	6	4	52	116
WRE	44	8135	14935	3	0	0	0	36	23
RAE	6	1930	1783	3	1	48	0	40	31
TOTALS	3377	810 HRS	635 HRS	49	101	228	76	1782	2081

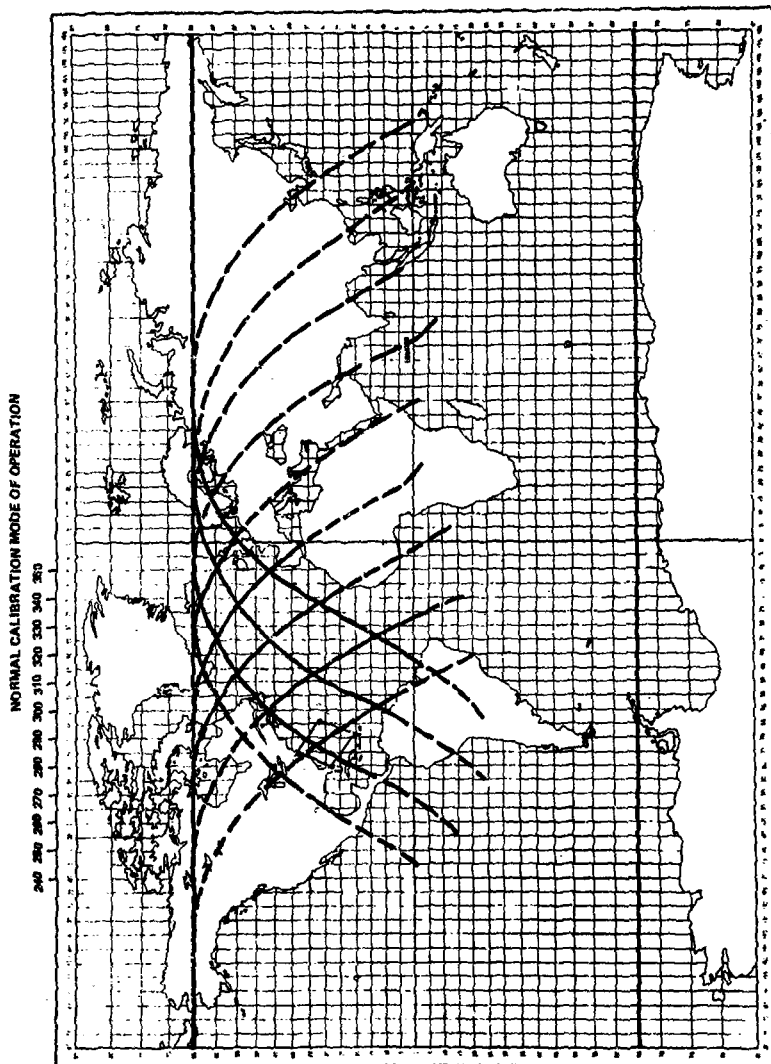
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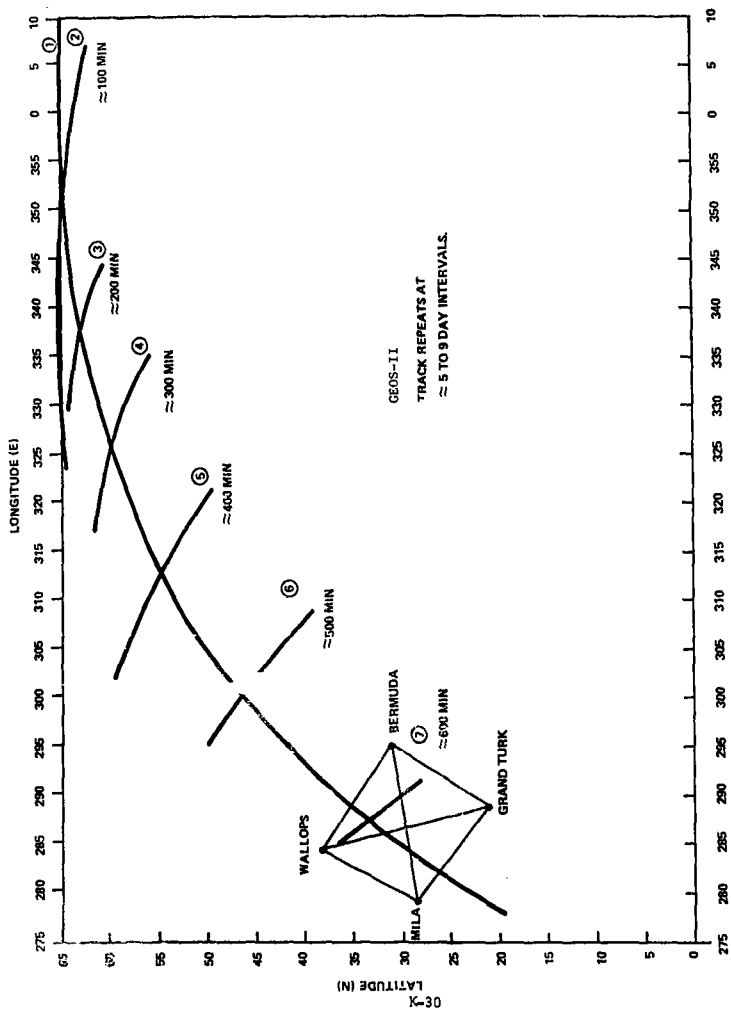
DESCRIPTION

AA Acquisition Problem
 BB Radar Problem
 CC Priority Scheduling Problem
 DD Spacecraft Problem
 EE Deleted or Cancelled
 FF Other or Unknown

CEOS-II TRACKING DATA
SUMMARY OF DATA AT WALLOPS SORTED BY AGENCY

AGENCY	USABLE	TRACK TIME	DATA	AA	BB	CC	DD	EE	FF
ETR	244	157161	155876	0	1	0	1	1	18
WTR	58	46562	45799	0	0	0	0	0	12
MSFN	802	613635	465756	1	0	0	1	0	38
NWAL	622	749761	452713	0	0	5	1	0	20
PMR	80	41232	36853	0	0	0	0	0	27
WSMR	2	1072	830	0	0	0	0	0	3
EDAFB	2	626	626	0	0	0	0	0	0
FRC	30	20483	15267	0	0	0	0	0	1
SHIPS	1	650	710	0	0	0	0	0	0
CNES	2	1730	1790	0	0	0	0	0	2
WRE	34	5462	11168	1	0	0	0	0	0
RAE	6	1930	1783	0	0	0	0	0	13
TOTALS	1883	455 HRS	330 HRS	2	1	3	3	1	134





CALIBRATION PASSES FOR ALTIMETER STABILITY EVALUATION

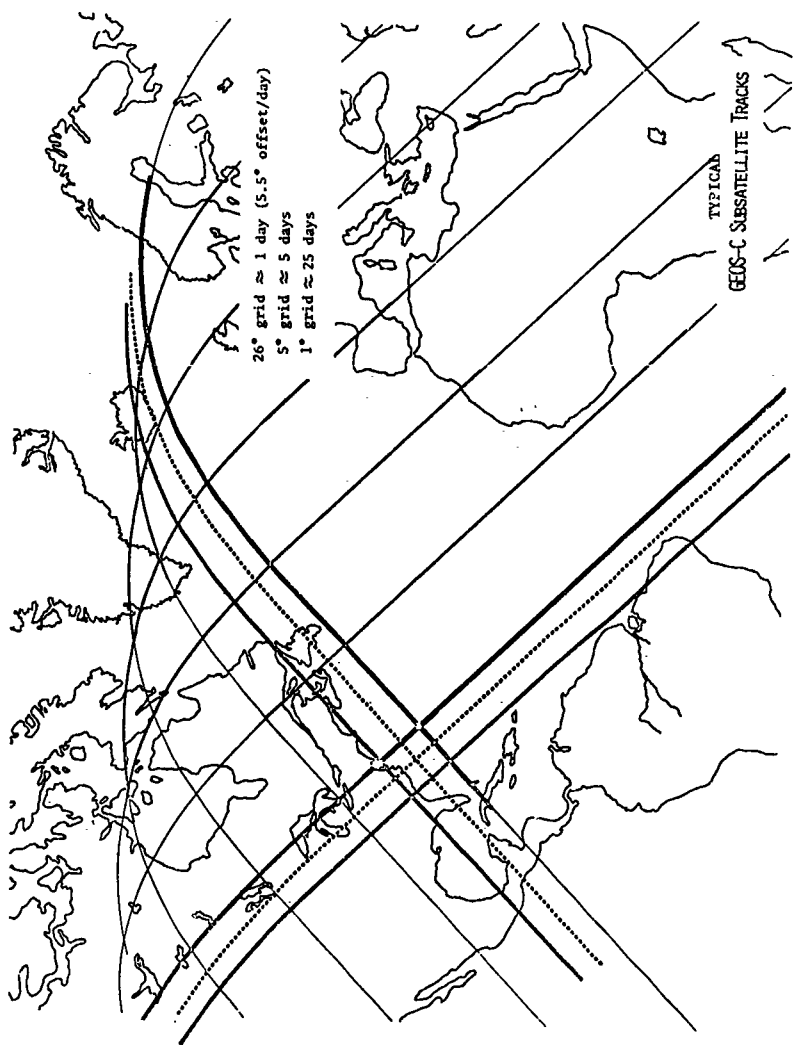
C-BAND RADAR PARTICIPATION REQUIREMENTS

The following minimum complement of C-Band radars is required for the operational lifetime of the GEOS-C radar altimeter.

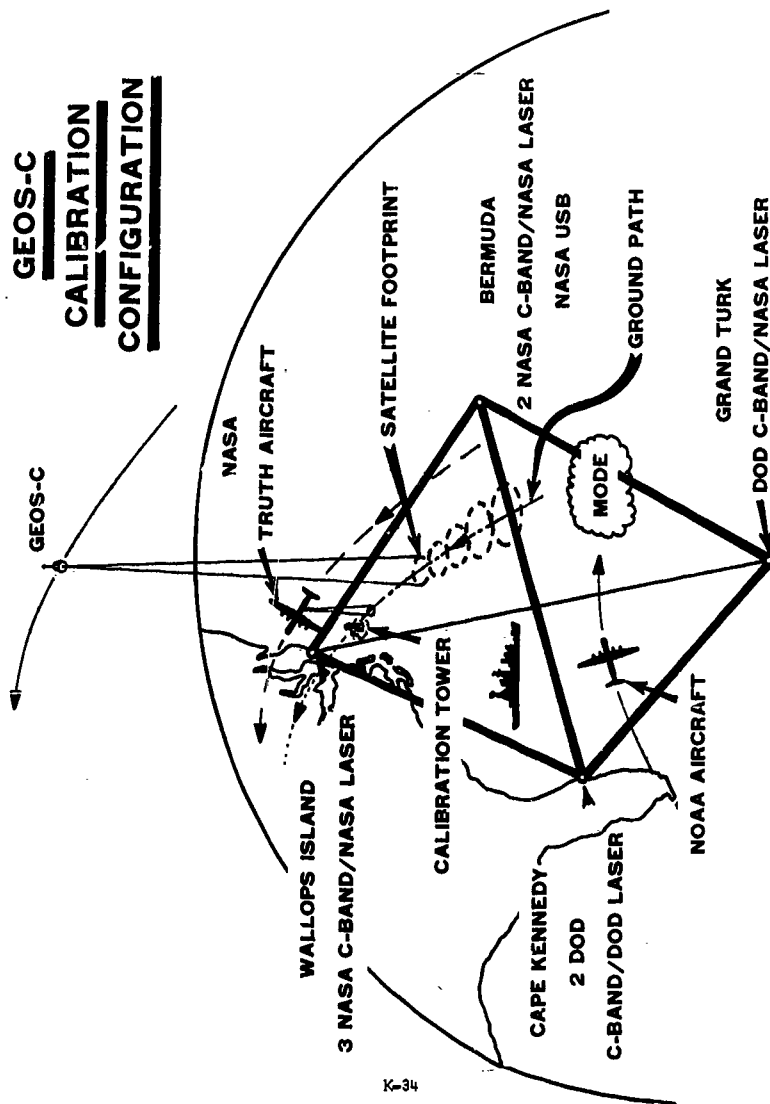
<u>Radar</u>	<u>Agency</u>	<u>Location</u>	<u>Anticipated Usage</u> <u>Avg. Tracks per Day</u>
NWAL 18	NASA/WLPS	Wallops	2 - Mission lifetime
NWAL 13	NASA/WLPS	Wallops	3 - Mission lifetime
NBER 05	NASA/GSFC	Bermuda	3 - Mission lifetime
NTANAN	NASA/GSFC	Tananarive	1 - Mission lifetime
NELHAR	NASA/ERC	Ely, Nevada	1 - 6 months
ETMRT	AFETR	Merritt Island	3 - Mission lifetime
ETRGR	AFETR	Grand Turk	3 - Mission lifetime
ETRANT	AFETR	Antigua	3 - Mission lifetime
ETRASC	AFETR	Ascension	1 - 6 months
WTRPPQ	AFWTR	Pillar Point	1 - 6 months
WTRVAN	AFWTR	Vandenberg	2 - 6 months
WTRCAN	AFWTR	Canton Island	2 - Mission lifetime
WTRKPT	AFWTR	Hawaii	2 - Mission lifetime
KJLLJ	AKWR	Krajalein	1 - 6 months
MPS-36	WSMR	White Sands	1 - 6 months
NCARV } or	NASA/GSFC	Carnarvon	2 - Mission lifetime
WOOR 38	WRE	Red Lake	2 - Mission lifetime
PARJ 13	PMR	Johnston Island	1 - 5 months
Several other radars which are highly desirable include:			
KOUROU	CNES	Kourou	1 - 6 months
HOURIN	CNES	France	1 - 6 months
CNESAZ	CNES	Azores	1 - 6 months
MPS-36	DFVLR	Germany	1 - 6 months
FPS-16	RAE	England	1 - 6 months
MPS - 36	WSMR	Green River, Utah	1 - 6 months

GEOS-C
ALTIMETER SYSTEM CHARACTERISTICS

<u>CHARACTERISTIC</u>	<u>LONG PULSE MODE</u>	<u>SHORT PULSE MODE</u>
OUTPUT TUBE	MAGNETRON	TRAVELING WAVE
OUTPUT POWER	2 Kw	2.5 Kw
PULSE WIDTH	200 N SEC.	12 N SEC.
PRF	100 PULSE BURSTS/SEC. OF 16 PULSES/BURST	100 PPS
ACQUISITION TIME	< 5 SEC.	< 5 SEC.
OUTPUT (ALTITUDE)	32 BIT AVERAGE	32 BIT AVERAGE
NOMINAL AVERAGE TIME	1 SEC.	0.1 SEC.
RANGE RESOLUTION	6.25 N SEC.	1.56 N SEC.
RANDOM ERROR CORRELATION	< 0.05	< 0.33
PRECISION	< 1 m	< 0.6 m



GEOS-C **CALIBRATION** **CONFIGURATION**



APPENDIX L

GEOS-C C-BAND OPERATIONS/SUPPORT

**By
BEN JACKSON**

**NASA/Wallops Station
Wallops Island, Virginia 23337**

C-BAND EXPERIMENT SUMMARY

THE GEOS-C SATELLITE WILL BE EQUIPPED WITH BOTH A COHERENT (VEGA MODEL 355C) AND A NON-COHERENT (VEGA MODEL 313C) C-BAND TRANSPONDER. THE CAPABILITY OF C-BAND RADARS AS VALUABLE GEODETIC INSTRUMENTS, WHILE TRACKING A NON-COHERENT TRANSPONDER, WAS WELL ESTABLISHED DURING THE GEOS-B C-BAND SYSTEMS PROJECT. THE UTILIZATION OF THE COHERENT TRANSPONDER WILL RESULT IN C-BAND TRACKING DATA, WHICH IS SIGNIFICANTLY MORE USEFUL AND ACCURATE, AND, WHICH WILL ALSO PROVIDE AN ADDITIONAL MEASUREMENT (RANGE RATE) FROM COHERENT SIGNAL PROCESSOR AND VELOCITY EXTRACTION SUBSYSTEM EQUIPPED RADARS.

DATA COLLECTION, IN SUPPORT OF BOTH THE ALTIMETER CALIBRATION EXERCISE AS WELL AS THE ALTIMETER EXPERIMENTS AND IN SUPPORT OF A COORDINATED SERIES OF INTER-RELATED C-BAND INVESTIGATIONS, WILL BE CONDUCTED AS A PART OF THE GEOS-C C-BAND EXPERIMENT. THE SERIES OF C-BAND EXPERIMENTS ARE EITHER NATURAL EXTENSIONS OF EFFORTS PREVIOUSLY CARRIED OUT DURING THE GEOS-B C-BAND SYSTEMS PROJECT, OR ARE NEW INVESTIGATIONS WHICH DERIVE FROM THE USE OF THE COHERENT C-BAND TRANSPONDER.

THE FOLLOWING IS A GENERAL DESCRIPTION AND BREAKDOWN OF THE PROPOSED ACTIVITIES INVOLVED IN THE OVERALL C-BAND EXPERIMENT.

PRE-LAUNCH ACTIVITIES

DURING THE TIME PRECEDING LAUNCH, THE EMPHASIS WILL BE ON GATHERING AND ANALYZING GROUND CALIBRATION DATA, DEVELOPING THE CALIBRATION AND OPERATIONS PROCEDURES DOCUMENTS, AND DEVELOPMENT OF THE DATA CORRECTION PROCEDURES TO BE USED FOR THE ENTIRE MISSION. IT IS PLANNED THAT THESE PROCEDURES WILL BE PUBLISHED BY THE GEOS-C C-BAND EXPERIMENT MANAGER AND DISSEMINATED THREE MONTHS PRIOR TO LAUNCH.

IN ADDITION, C-BAND TRACKING OF THE GEOS-B SATELLITE WILL BE CONDUCTED AS A PRE-MISSION SIMULATION IN CONJUNCTION WITH THE ALTIMETER CALIBRATION AREA SIMULATION.

QUICK-LOOK ACTIVITIES

DURING THE 90-DAY ALTIMETER CALIBRATION PERIOD, DATA FROM THE C-BAND RADARS TAKEN AND PROCESSED IN ACCORDANCE WITH THE AFOREMENTIONED PROCEDURES WILL BE ANALYZED AND ANY REFINEMENT TO THE PROCEDURES COORDINATED WITH THE GEOS-C C-BAND EXPERIMENT MANAGER. THE EMPHASIS DURING THIS TIME PERIOD WILL BE PRIMARILY ON OPERATIONAL SUPPORT TO THE ALTIMETER CALIBRATION EFFORT WITH CONTINUED ACTIVITIES TOWARD C-BAND CALIBRATION. DATA FROM THE ALTIMETER CALIBRATION MISSIONS WILL BE SUFFICIENT FOR THE DESIRED ACTIVITIES TOWARD REFINEMENT OF THE C-BAND CALIBRATION.

NORMAL POST-LAUNCH ACTIVITIES

FOLLOWING THE 90-DAY ALTIMETER CALIBRATION PERIOD, SCIENTIFIC DATA COLLECTION WILL BE INITIATED IN ACCORDANCE WITH THE REQUIREMENTS OF THE EXPERIMENT OBJECTIVES.

OBJECTIVES

SPECIFICALLY, THE C-BAND SYSTEMS WILL BE UTILIZED BY NASA AND THE USER AGENCIES TO ACCOMPLISH THE FOLLOWING OBJECTIVES:

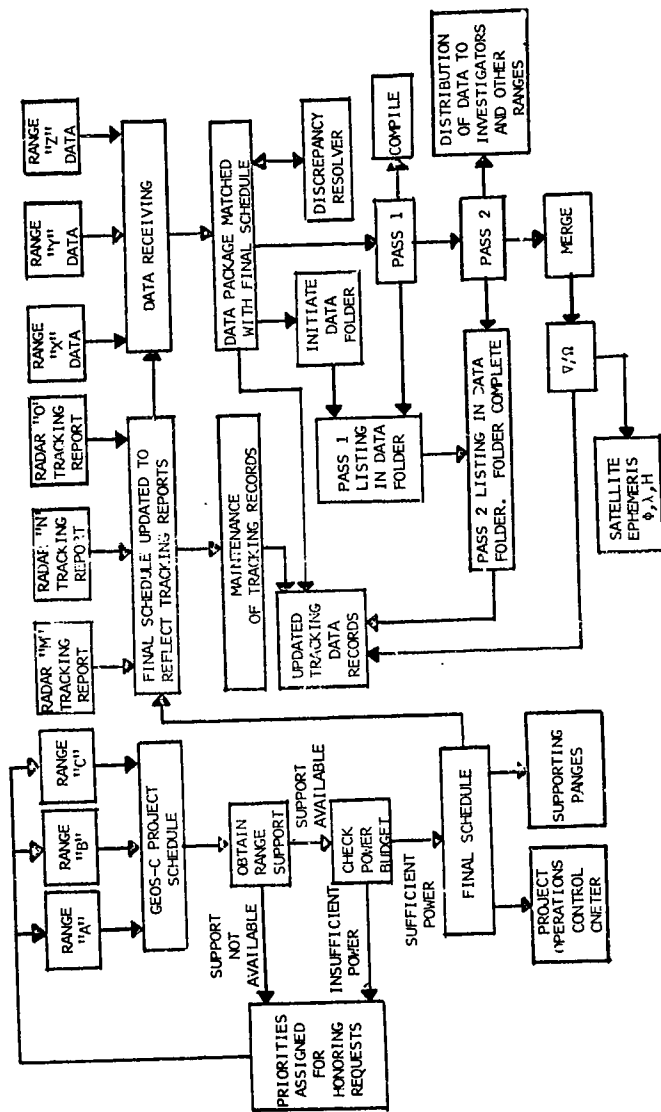
(A) TO PROVIDE DATA TO BE USED IN THE DETERMINATION OF HIGHLY PRECISE ORBITS, TO ASSIST IN THE ACCOMPLISHMENT OF THE CALIBRATION AND EVALUATION OBJECTIVES OF THE GEOS-C ALTIMETER SYSTEM PROJECT, AND TO ASSIST IN THE ACCOMPLISHMENT OF THE GRAVIMETRIC OBJECTIVES OF THE OVERALL GEOS-C PROJECT.

(B) TO BETTER DETERMINE THE ABSOLUTE ACCURACY OF THE INSTRUMENTATION RADAR SYSTEM, DEVELOP REFINED METHODS OF CALIBRATING THESE SYSTEMS, AND IMPROVE THE TECHNIQUES IN PROCESSING THE ASSOCIATED DATA:

- (1) TO INTEGRATE, WHERE POSSIBLE, THE TECHNIQUES EVOLVED INTO A PROGRAM TO MAINTAIN THE LEVEL OF RADAR ACCURACY WITHIN GIVEN OR KNOWN TOLERANCES.
- (2) TO ASSIST IN THE DETERMINATION OF METHODS FOR RAPID AND ACCURATE CALIBRATION OF C-BAND RADAR SYSTEMS.
- (3) TO EVALUATE THE PERFORMANCE AND ACCURACY OF NEW TRACKING SYSTEMS.

OBJECTIVES (CONT'D)

- (C) TO BETTER DETERMINE THE GEODETIC LOCATION OF THE C-BAND RADAR SITES AND THEIR INTERSITE DISTANCES.
- (D) TO COMPARE AND CORRELATE RESULTS OBTAINED FROM OTHER GEOS-C TRACKING SYSTEMS WITH THOSE OBTAINED BY THE C-BAND SYSTEMS, WITH PARTICULAR EMPHASIS ON EVALUATING THE POSSIBLE CONTRIBUTIONS OF C-BAND INSTRUMENTATION SYSTEM MEASUREMENTS TO GEODESY.
- (E) TO MAKE GENERALLY AVAILABLE THE RESULTS OF BOTH THE C-BAND SYSTEM CALIBRATION AND GEODETIC ENDEAVOR.



GEOS-C C-BAND SCHEDULING & DATA HANDLING PROCEDURES

APPENDIX M

**GEOS-C COHERENT C-BAND TRANSPONDER
TECHNICAL CHARACTERISTICS**

By

ALAN SELSER

**NASA/Wallops Station
Wallops Island, Virginia 23337**

COHERENT C-BAND TRANSPONDER FOR GEOS-C

MANUFACTURER - VEGA PRECISION LABORATORIES

MODEL NUMBER - 335C

PRIMARY MISSION REQUIREMENTS:

- OPERATING LIFETIME - 500 HOURS IN ORBIT OVER 2 YEARS
- POWER CONSUMPTION:
 - 1.5 WATTS MAXIMUM IN STANDBY MODE
 - 16 WATTS MAXIMUM IN OPERATE MODE
- ALLOWABLE FREQUENCY ERROR - 0.6 HZ RMS MAXIMUM
- DELAY VARIATIONS CORRECTABLE TO WITHIN 10 NSEC
(1.5 METERS) OVER OPERATING LIFETIME
- OPERATION WITH NONCOHERENT RADARS
- SIMULTANEOUS OPERATION WITH THE NONCOHERENT C-BAND TRANSPONDER ON GEOS-C

OPERATING MODES

- STANDBY - RECEIVER ONLY ON RECEPTION OF 10 VALID INTERROGATIONS:

TURN'S ON OPERATE POWER

INITIATES 42-SECOND TURN-ON DELAY

- OPERATE

TRANSPONDER RESPONDS TO ALL VALID INTERROGATIONS AT COMPLETION OF THE 42-SECOND TURN-ON DELAY.

ABSENCE OF VALID INTERROGATIONS FOR 63 SECONDS WILL CAUSE THE TRANSPONDER TO SWITCH TO STANDBY MODE.

- OVERRIDE

OPERATE POWER TURNED ON BY SPACECRAFT COMMAND.

TRANSPONDER WILL RESPOND TO ANY VALID INTERROGATION AFTER THE 42-SECOND TURN-ON DELAY.

REMOVAL OF OVERRIDE COMMAND WILL RETURN THE TRANSPONDER TO AUTOMATIC STANDBY/OPERATE MODE SWITCHING.

RECEIVER CHARACTERISTICS

FREQUENCY	5690 MHz
BANDWIDTH	16 MHz NOMINAL
SENSITIVITY	-67 DBM MINIMUM
PULSE CODE	DOUBLE PULSE
CODE SPACING	8 MICROSECONDS NOMINAL
CODE ACCEPT RANGE	7.85 TO 8.15 MICROSECONDS
CODE REJECT RANGE	<7.65 MICROSECONDS >8.30 MICROSECONDS

TRANSMITTER CHARACTERISTICS

FREQUENCY	SAME AS RECEIVED FREQUENCY OVER THE RANGE FROM 5084 TO 5094 MHz
PEAK POWER OUTPUT	> 115 WATTS
PULSE WIDTH	455 NANoseconds NOMINAL
PULSE WIDTH STABILITY	± 25 NANoseconds
OVERINTERROGATION PROTECTION	2000 PPS
BLANKING	50 MICROseconds
FREQUENCY ERROR	< 0.4 Hz RMS
INTERLINE NOISE	> 20 DB BELOW CARRIER (40 Hz BANDWIDTH)

DELAY CHARACTERISTICS

FIXED DELAY

2.5 MICROSECONDS NOMINAL

DELAY VARIATION WITH SIGNAL LEVEL

70 NANoseconds (10.7 PETERS)
(FROM -20 TO -60 DBM)

DELAY VARIATION WITH TEMPERATURE

35 NANoseconds (5.3 PETERS)

DELAY JITTER (NOISE) AS A FUNCTION OF SIGNAL LEVEL

< 5 NANoseconds (.8 PETERS) RMS
(FROM -20 TO -45 DBM)

< 10 NANoseconds (1.5 PETERS) RMS
(FROM -45 TO -60 DBM)

TELEMETRY FUNCTIONS

INPUT VOLTAGE

INPUT CURRENT

RECEIVED SIGNAL STRENGTH

RECEIVED PULSE REPETITION FREQUENCY

PEAK POWER OUTPUT

LOCAL OSCILLATOR VOLTAGE

MAGNETRON FILAMENT CURRENT

BASE PLATE TEMPERATURE

PHYSICAL CHARACTERISTICS

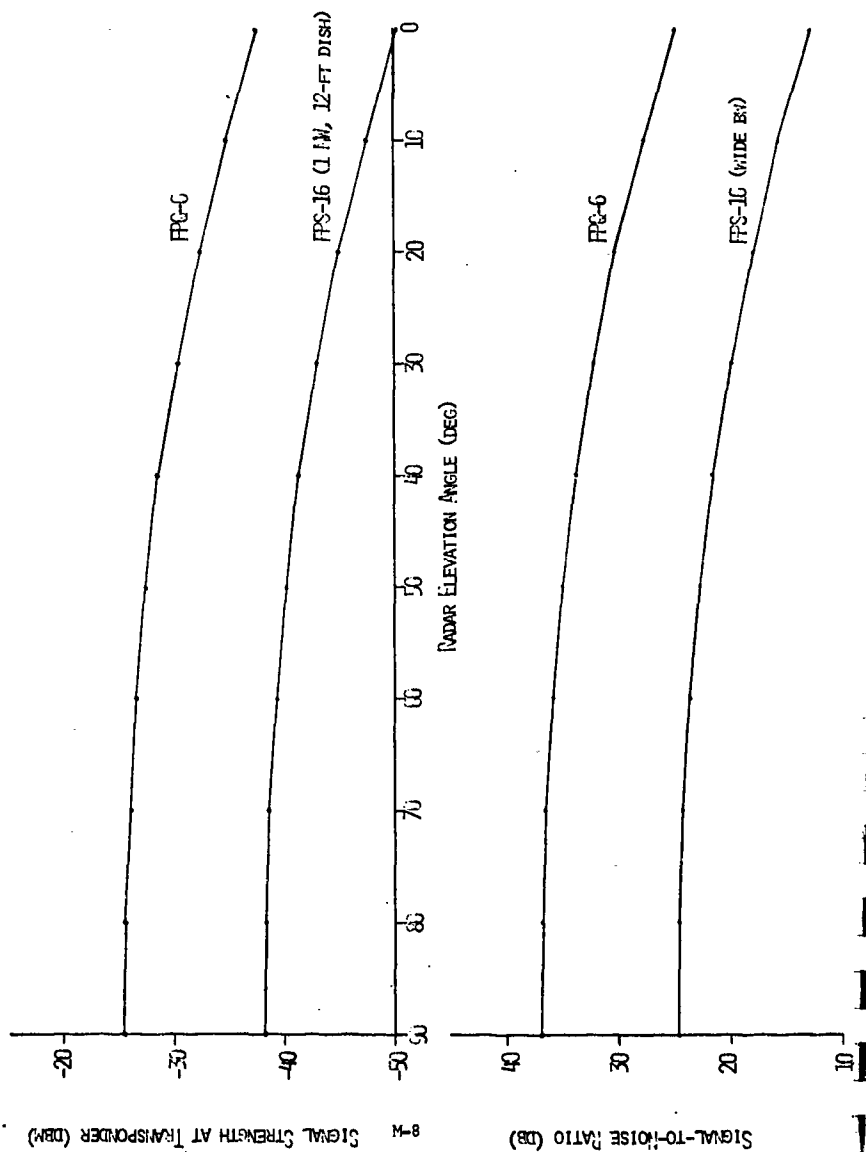
VOLUME

< 1500 cc

MASS

2.5 KG

COHERENT C-BAND TRANSPODER FOR GEOS-C LINK CALCULATIONS



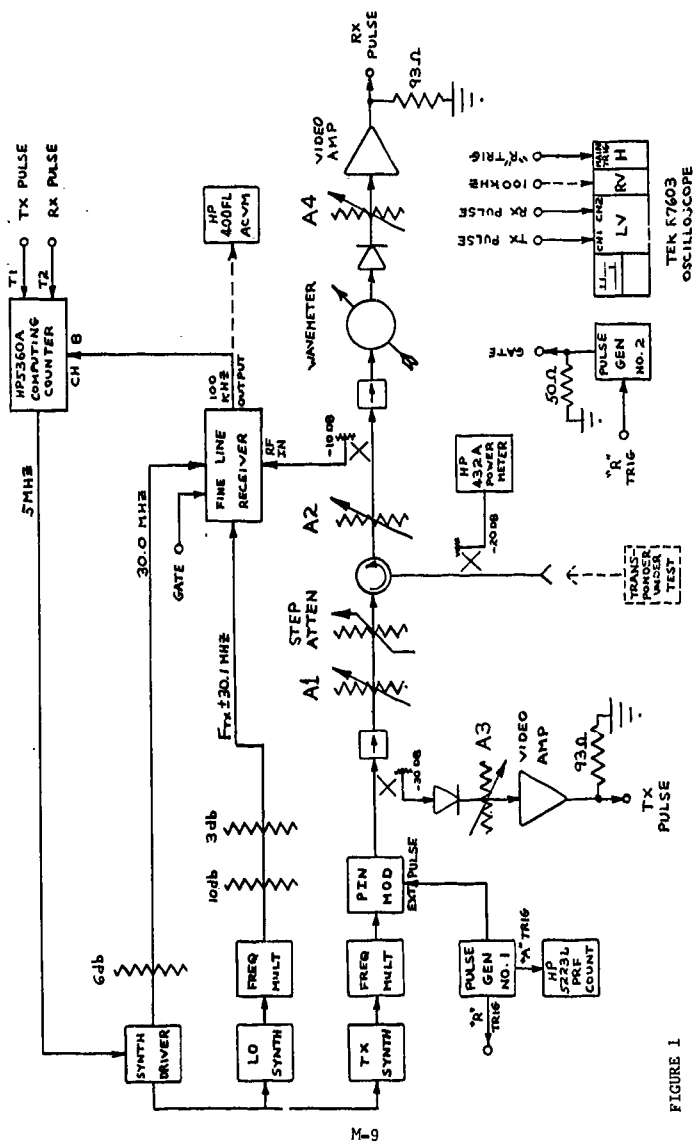


FIGURE 1

C-Band Test Console, Block Diagram, Spacecraft Level Tests

APPENDIX N

**DEFENSE MAPPING AGENCY TEST
OBJECTIVES FOR GEOS-C**

By

MAJ. LARRY BEERS

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DOD INVESTIGATIONS AND DATA REQUIREMENTS

- OBJECTIVE A - LOCAL VERTICAL AND SEA STATE INVESTIGATION REQUIRING SHORT PULSE
ALTIMETER DATA WITH COMPLETE WAVEFORM INFORMATION
- AREA A - 100 NM, 100 NM
AREA B - 50 NM, 50 NM
AREA C - 50 NM, 50 NM
- OBJECTIVE B - SST ACCURACY EVALUATION FOR PRODUCTION OF PRECISE SATELLITE
EPHEMERIDES REQUIRING SST DATA AND OTHER TRACKING DATA FOR
18 NS, 18 NS PASSES OVER CALIBRATION AREA AND 18 NS, 18 NS PASSES
OVER CONTINENTAL US
- OBJECTIVE C - GLOBAL OCEAN SURVEY REQUIRING SHORT PULSE ALTIMETER DATA WITH
PARTIAL WAVEFORM INFORMATION OVER A 5° X 5° AND 1° X 1° GRID
- OBJECTIVE D - CROSS TRACK DEFLECTION DETERMINATION REQUIRING VERY FINE GRID OF
SHORT PULSE ALTIMETER WITH COMPLETE WAVEFORM INFORMATION IN
5° X 5° PROJECTIVE OF AREA C
- OBJECTIVE E - SST GLOBAL GEOID REQUIRING GLOBAL GRID OF SST DATA (GRID DIMENSIONS
NOT DEFINED)

OBJECTIVE A

- PURPOSE - LOCAL VERTICAL AND SEA STATE INVESTIGATION
- DATA REQUIREMENTS - SHORT PULSE ALTIMETRY DATA WITH COMPLETE WAVEFORM INFORMATION AS FOLLOWS:
 - AREA A - 100 SM, 100 NS
 - AREA B - 50 SM, 50 NS
 - AREA C - 50 SM, 50 NS

SUPPORT COMPATIBILITY

AREA	SUPPORT REQUIREMENTS	COMMENTS/DEFICIENCIES
C	2 TRACKS/DAY, 4 OF 6 DAYS FOR ~ 75 DAYS	COMPLETELY SATISFIED
B	4 TRACKS/DAY FOR ~25 DAYS	AREA OVER OCEAN COMPLETELY SATISFIED - AREA OVER LAND CANNOT BE COVERED WITH ALTIMETRY DATA
A	4 TRACKS/DAY FOR ~50 DAYS	CAN PROVIDE REQUIRED DATA IN ~75% OF AREA ~25% OF AREA LACKS GROUND STATION COVERAGE

OBJECTIVE B

- PURPOSE - SST ACCURACY EVALUATION FOR PRODUCTION OF PRECISE SATELLITE EPHEMERIDES
- DATA REQUIREMENTS - SST DATA AND OTHER TRACKING DATA FOR 18 NS, 18 SN PASSES OVER CALIBRATION AREA AND 18 NS, 18 SN PASSES OVER CONTINENTAL UNITED STATES. DATA REQUIRED DURING FIRST TWO MONTHS OF OPERATIONS
- SUPPORT COMPATIBILITY -
 - SUPPORT REQUIREMENTS - SST DATA AS SPECIFIED ABOVE
 - COMMENTS/DEFICIENCIES -
 - COVERAGE EXCEEDS REQUIREMENTS IN CALIBRATION AREA
 - COVERAGE EXCEEDS SN PASS REQUIREMENT OVER $\approx 1/2$ OF UNITED STATES
 - REMAINDER OF REQUIREMENT WOULD REQUIRE MORE ATS SUPPORT THAN PRESENTLY CONSIDERED FEASIBLE
 - SST DATA DURING ATS DRIFT WOULD NOT PROVIDE DENSITY REQUIRED AND WOULD BE ACQUIRED TOO LATE IN THE MISSION TO SATISFY THIS REQUIREMENT

OBJECTIVE C

- PURPOSE - GLOBAL OCEAN SURVEY
- DATA REQUIREMENTS - SHORT PULSE ALTIMETER DATA WITH PARTIAL WAVEFORM INFORMATION OVER
A 5° X 5° AND 1° X 1° GRID
- SUPPORT COMPATIBILITY -
 - 5° X 5° COVERAGE
 - SUPPORT REQUIREMENTS - APPROXIMATELY 40 DAYS OF DATA RELAY THROUGH ATS DURING
ATS DRIFT TO EASTERN HEMISPHERE AT RATE OF 4 TRACKS/DAY
 - COMMENTS/DEFICIENCIES - COMPLETELY SATISFIED IN ATS COVERAGE AREAS; RESTRICTED
TO LOW DATA RATE, THEREFORE, PARTIAL WAVEFORM DATA IS
LIMITED TO ALL AVERAGE RETURN GATES AND INSTANTANEOUS
PLATBAU GATE
 - 1° X 1° COVERAGE
 - SUPPORT REQUIREMENTS - APPROXIMATELY 160 DAYS (80 IN EACH HEMISPHERE) THROUGH
ATS AT RATE OF 4 TRACKS/DAY
 - COMMENTS/DEFICIENCIES - REQUIRED COVERAGE LIMITED TO GROUND STATION COVERAGE
AREAS; COMPLETE WAVEFORM INFORMATION WOULD BE AVAILABLE
IN THESE AREAS; COMPLETE SATISFACTION OF THIS REQUIREMENT
WOULD REQUIRE MORE ATS SUPPORT THAN PRESENTLY CONSIDERED
FEASIBLE

OBJECTIVE D

- PURPOSE - CROSS TRACK DEFLECTION DETERMINATION
- DATA REQUIREMENTS - VERY FINE GRID OF SHORT PULSE ALTITUDE DATA WITH COMPLETE WAVEFORM INFORMATION IN 5° X 5° PROJECTION OF AREA C
- SUPPORT COMPATIBILITY -
 - SUPPORT REQUIREMENTS - APPROXIMATELY 30 MS, 30 SN TRACKS REQUIRING TWO TRACKS/FIVE DAYS FOR ≈150 DAYS
 - COMMENTS/DEFICIENCIES - COMPLETELY SATISFIED, CONTINUE TRACKING AT ABOVE RATE FOR AN ADDITIONAL 75 DAYS AFTER SATISFACTION OF OBJECTIVE A - AREA C REQUIREMENT

OBJECTIVE: E

- PURPOSE - SST GLOBAL GEOID

- DATA REQUIREMENTS - GLOBAL GRID OF SST DATA (GRID DIMENSIONS NOT DEFINED)

- SUPPORT COMPATIBILITY -

- SUPPORT REQUIREMENTS -
 - A 5° X 5° GRID IN THE ATS COVERAGE AREAS WOULD TAKE APPROXIMATELY 40 DAYS OF TRACKING WITH ATS DURING ATS DRIFT TO EASTERN HEMISPHERE AT RATE OF 4 TRACKS/DAY

- COMMENTS/DEFICIENCIES -
 - 5° X 5° GRID COMPLETELY SATISFIED IN ATS COVERAGE AREAS; DATA OBTAINED SIMULTANEOUSLY WITH OBJECTIVE C, 5° X 5° GRID

APPENDIX O

GEOS-C C-BAND WORKING GROUP

7 MARCH 1974 MEETING

Vandenberg AFB, California 93437

A G E N D A

GEOS-C C-Band Working Group

March 7, 1974 - 1330-1630 PDT

- A. C-Band Experiment Summary
- B. Summation, C-Band Systems Objectives
- C. Pre-Launch Objectives
- D. Quick-Look Activities
- E. Normal Post-Launch Objectives
- F. Scheduling and Data Handling Procedures
- G. Coherent C-Band Transponder (Vega Model 355C)
- H. Discussion

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Wallops Station
Wallops Island, Virginia 23337

REPLY TO
ATTN OF: PMS (GEOS-C)

MAY 2 1974

TO: Distribution

FROM: PMS/GEOS-C C-Band Subsystems Manager

SUBJECT: GEOS-C C-Band Working Group

The GEOS-C C-Band Working Group Meeting was held on March 7, 1974, at Vandenberg Air Force Base, California, in Building 7000 Theatre, as a part of the SAITEC Conference on Coherent Radars for Range Instrumentation. Since most of the cognizant Department of Defense C-Band instrumentation personnel were in attendance for the conference, which began on March 5, 1974, it was appropriate to conclude the conference with the C-Band Working Group Meeting.

It was easily apparent, during the entire conference, that the GEOS-C C-Band instrumentation would be of invaluable assistance to all of DOD as a means of calibrating and evaluating the performance and accuracy of their tracking systems. Several requests were made during the conference, by persons not originally members of the Working Group, to attend this session, and 38 persons (see Enclosure 1) were present. Sandia Laboratories and the Defense Mapping Agency were the new agencies represented.

A general summation of the C-Band mission objectives was given and general dialogue regarding the impact of SAITEC as lead DOD range on scheduling, coordination, and data handling ensued. The basic consensus of opinion by NASA, Wallops, and SAITEC was that NASA, Wallops, would do all advanced scheduling of DOD radars through SAITEC. Any changes to the schedule would be done directly between Wallops and the specific range involved with an information copy to SAITEC. The reverse would hold true for the schedule items originally requested by DOD for tracking support by various support ranges if conflicts arose. All ranges tracking would submit a tracking report at approximately T-1 hour via TwX to Wallops and, if the tracking was in support of NASA, Wallops, use the mails to send the data packet directly to Wallops. Questions arose concerning distant or remote sites, and it was concluded that the same procedures would be utilized for them.

Questions began to arise concerning the lack of formal information at the respective support ranges for the GEOS-C mission, and copies of

the Program Introduction (PI) Document was distributed to a representative of each range. This document formalizes the program and it becomes an official support requirement for each range. Suggestions were made that perhaps a GEOS-C team be invited to offer presentations similar to those in the SAMTEC Agenda to the Commanding Officer at each range, or that an invitation be extended to the GEOS-C team to make a presentation to the Range Commanders Conference in the near future.

Despite the factor that expenditures for direct support are required by submission of the PI according to a DOD directive being implemented, commencing July 1, 1974, most persons felt that the DOD requirements on the GEOS-C mission would offset any costs incurred by NASA.

Many topics were openly discussed and explanations offered by H. R. Stanley, W. B. Krabill, and A. R. Selser of NASA, Wallops; W. E. Hawkins and J. Berbert of NASA, GSFC; and the undersigned on the multiple facets of the GEOS-C Program. Listed below are these topics and/or the requirements as stated by the range representatives starred on Enclosure 1.

a. Sandia Laboratories at the Tonopah Test Range requested that they be permitted to commence tracking GEOS-B in preparation for the upcoming GEOS-C mission. The procedure for requesting such support was explained, as well as the available power remaining on GEOS-B, for this tracking. Suggestions were made that they coordinate these tracks for acquisition purposes with SAMTEC and WSMR.

b. The ETR must solve inhouse the interface between Range Measurement Laboratory (RML) and the remainder of the range such that a single scheduling interface be made through L. Ebaugh, AFETR Headquarters.

c. Some arrangement should be made by NASA to identify all support requests as: REQUIRED, DESIRED, or MISSION CRITICAL. It was further suggested that Major L. Beers/DMA attempt to establish military priorities for C-Band support.

d. The required NASA pre-, setup-, and post-calibrations for data collection will be made to DOD and included in the Operations Requirements (OR) Document as specifications for operations in support of GEOS-C. This is essential for ranges having multiplicities of the same type of radars, since each radar has different characteristics. Raw range data should be forwarded to Wallops.

e. The proposed 14-day advanced schedule requirements were requested to be made 30 days to allow advance planning by the support ranges.

f. All ranges have the capability of generating their own angles, if provided either the NORAD or BROUWER elements. BROUWER elements will be provided by the Project through GSFC.

g. A series of coordinated tracks will be set up utilizing GEOS-B to simulate a GEOS-C type operation including data handling. This may have to be done in segments in view of the available power for GEOS-B.

h. Many of the ranges have altered or added to their basic requirements/objectives for the GEOS-C mission and are to supply the undersigned these updated requirements/objectives by the end of March. A short summation of each is indicated below.

(1) ETR - C-Band data for self-calibration and coordination with SAMTEC for USNS ARNOLD. Laser, and possibly Doppler, data is requested from collocated sites.

(2) WSMR - C-Band data for calibration standards and inter-comparisons with other ranges.

(3) PMR - C-Band, Doppler, and Laser data coordinating with other ranges. (Doppler needs were passed on to DMA for resolution.)

(4) KMR - C-Band data for self-calibration, Doppler orbits, TM, and altimeter data are requested. The ALCOR radar was mentioned, but efforts are being made by NASA not to utilize this system. (TM, Doppler, and Altimeter needs were passed on to DMA for resolution.)

(5) Sandia - C-Band data for improved station location and calibrations with other ranges (SAMTEC, WSMR).

(6) SAMTEC - C-Band, Altimeter, and Laser data for calibration coordination with other ranges.

Much interest has been generated within the group, and the unanimous consensus of opinion is that these Working Group Meetings should be held every two months throughout the lifetime of the GEOS-C mission, possibly on a range-host rotatable basis.

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• Enclosure