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LOW ANGLE-OF-ATTACK LONGITUDINAL AERODYNAMIC PARAMETERS OF NAVY T-2 TRAINER AIRCRAFT EXTRACTED FROM FLIGHT DATA: A COMPARISON OF IDENTIFICATION TECHNIQUES. VOLUME I. DATA ACQUISITION AND MODIFIED NEWTON-RAPHSON ANALYSIS

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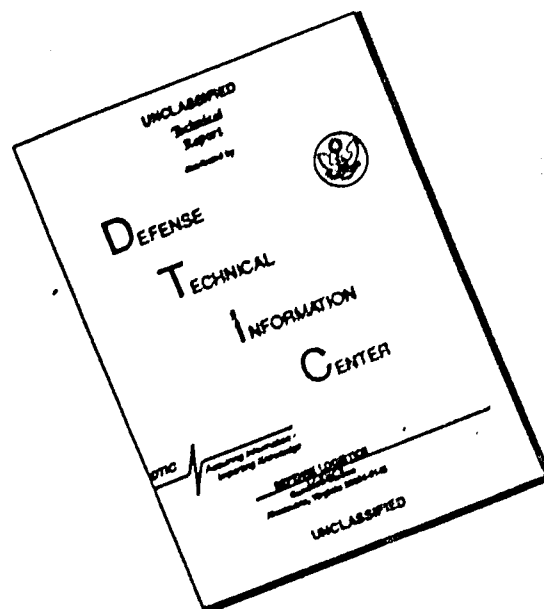
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**LOW ANGLE-OF-ATTACK LONGITUDINAL AERODYNAMIC PARAMETERS  
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A COMPARISON OF IDENTIFICATION TECHNIQUES**

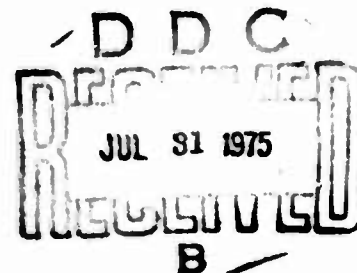
**VOLUME I**

**DATA ACQUISITION AND MODIFIED NEWTON-RAPHSON ANALYSIS**

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Warminster, Pennsylvania 18974

23 June 1975

FINAL REPORT  
IR TASK R000-01-01/MF-9-01



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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>A Navy T-2 jet trainer aircraft was instrumented to measure and record all motion variables. Motion time histories were recorded for a variety of carefully selected pilot inputs. A unique problem with the data was the high noise level in the measurement of the control input. Longitudinal motion data were analyzed with three digital computer parameter identification techniques: modified Newton-Raphson, Kalman filtering/smoothing, and maximum likelihood. Reported in Volume I are data gathering and modified Newton-Raphson analysis. |                       |                                                                                           |

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# ACKNOWLEDGEMENTS

As with any research and development program involving full scale experimental work (e.g., flight testing), literature search, and comparison with other current work, analysis, and contractual assistance, this project involved a large number of people. Some of these participants will be authors or co-authors of papers and/or reports related to this project, but for the most the only recognition will be a brief mention here. The author, then, wishes to express his thanks for the cooperation and assistance of the following people who made particularly significant contributions:

Mr. A. Piranian, who served as flight test engineer, performing all the daily tasks essential to gathering the flight data;

Mr. John Eney, who conceived this program while project engineer for the variable stability T-2;

Messrs. Joe Dapkiewicz, Joe Ozer, and Al Ortiz, who operated the aging telemetry and recording equipment to the best of their abilities;

LCDR Dennis Laack, principal pilot for the project, who also served as unofficial liaison between the engineers and the military personnel involved in the flight testing;

Mr. Larry Taylor of NASA-Langley Research Center and Mr. Ken Iliff of NASA-Flight Research Center, who provided advice and counsel concerning the identification process;

Messrs. Ed Rynaski and Robert Chen of Calspan Corp., and Messrs. James Tyler, Dave Stepner, and Earl Hall of Systems Control, Inc., who patiently awaited the arrival of the flight data while providing guidance on identification techniques, flight instrumentation, and pilot control input selection; and

Mr. Steve Williams of NAVAIRTESTCEN, who performed the analog to digital conversion of the flight data.

While this program began under Independent Research and Development funding from the Technical Director of NAVAIRDEVCE, substantial delays in gathering the flight data pushed the program into FY74, and the program could not be fully supported by IR&D money any longer. Consequently, the completion of the program was financed largely under the Naval Air Systems Command High Angle of Attack Aircraft Parameter Identification Program (one task area under the Combat Effectiveness and Safety AIRTASK). Without the cooperation and understanding of the program sponsor, Mr. Ray Siewert, NAVAIR-320D, it is unlikely that this research could have been completed.

## S U M M A R Y

A Navy T-2 jet trainer aircraft was instrumented to measure and record all airframe motion variables. Motion time histories were recorded for small perturbation responses to a variety of carefully selected pilot inputs. Two flight conditions were considered: a relatively high speed power approach configuration and a high speed cruise condition. Noise levels in the data were found to be significant, and it was determined that measurement noise was a larger problem in this case than process noise. A unique noise problem was the high level of measurement noise on the control inputs.

Although all motion variables were recorded, only longitudinal motion time histories were used for analysis. Three digital computer parameter identification techniques were applied to the data: modified Newton-Raphson (in-house at NAVAIRDEVCEEN), Kalman filtering/smoothing (Calspan Corp.), and maximum likelihood (Systems Control, Inc.). The objective was the determination of the relative accuracy and utility of the three techniques. Volume I reports the data gathering effort and the modified Newton-Raphson analysis.

For the in-house analysis, a linear mathematical model was used, containing nine stability derivatives to be identified. In general, the identification effort was successful in matching model response to flight data and obtaining consistent sets of stability derivatives from the various data segments, but the time history matches are far from perfect and some anomalies do exist in the stability derivative results.

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# LIST OF SYMBOLS

| <u>Symbol</u>               | <u>Definition</u>                                       | <u>Dimension</u>         |
|-----------------------------|---------------------------------------------------------|--------------------------|
| A                           | angle of attack                                         | deg                      |
| A/D                         | analog/digital                                          | -                        |
| AX                          | longitudinal acceleration                               | ft/sec <sup>2</sup>      |
| AZ                          | normal acceleration                                     | ft/sec <sup>2</sup>      |
| a <sub>x</sub>              | AX                                                      | -                        |
| a <sub>z</sub>              | AZ                                                      | -                        |
| C <sub>D</sub>              | drag coefficient                                        | -                        |
| C <sub>L</sub>              | lift coefficient                                        | -                        |
| C <sub>m<sub>s</sub>e</sub> | $\partial C_m / \partial \delta_e$                      | 1/deg                    |
| C <sub>D<sub>r</sub></sub>  | $\partial C_D / \partial \alpha$                        | -                        |
| CDC                         | Control Data Corp.                                      | -                        |
| c                           | mean aerodynamic chord                                  | ft                       |
| c.g.                        | center of gravity                                       | %c                       |
| DE                          | elevator deflection                                     | deg                      |
| DEZ                         | elevator deflection set to zero after significant input | -                        |
| F                           | matrix of stability derivatives                         | -                        |
| FM                          | frequency modulation                                    | -                        |
| G                           | matrix of control derivatives                           | -                        |
| g                           | acceleration due to gravity                             | 32.2 ft/sec <sup>2</sup> |
| h                           | altitude                                                | ft                       |
| I <sub>x</sub>              | moment of inertia about roll axis                       | slug/ft <sup>2</sup>     |
| I <sub>y</sub>              | moment of inertia about pitch axis                      | slug/ft <sup>2</sup>     |
| I <sub>z</sub>              | moment of inertia about yaw axis                        | slug/ft <sup>2</sup>     |

LIST OF SYMBOLS (CON'T)

| <u>Symbol</u>      | <u>Definition</u>                             | <u>Dimension</u>                    |
|--------------------|-----------------------------------------------|-------------------------------------|
| L                  | roll moment                                   | ft-lb                               |
| $L_p$              | $1/I_x \partial L / \partial p$               | 1/sec                               |
| $L_r$              | $1/I_x \partial L / \partial r$               | 1/sec                               |
| $L_{\dot{\alpha}}$ | $1/I_x \partial L / \partial \dot{\alpha}$    | 1/sec <sup>2</sup>                  |
| $L_{\delta_a}$     | $1/I_x \partial L / \partial \delta_a$        | $\frac{1}{\text{sec}^2\text{-deg}}$ |
| $L_{\delta_r}$     | $1/I_x \partial L / \partial \delta_r$        | $\frac{1}{\text{sec}^2\text{-deg}}$ |
| M                  | pitching moment                               | ft-lb                               |
| $M_q$              | $1/I_y \partial M / \partial q$               | 1/sec                               |
| $M_u$              | $1/I_y \partial M / \partial u$               | $\frac{1}{\text{ft-sec}}$           |
| $M_{\dot{\alpha}}$ | $1/I_y \partial M / \partial \dot{\alpha}$    | 1/sec <sup>2</sup>                  |
| $M_{\dot{\alpha}}$ | $1/I_y \partial M / \partial \dot{\alpha}$    | 1/sec                               |
| $M_{\delta_e}$     | $1/I_y \partial M / \partial \delta_e$        | $\frac{1}{\text{sec}^2\text{-deg}}$ |
| m                  | mass                                          | slugs                               |
| N                  | yawing moment                                 | ft-lb                               |
| NASA               | National Aeronautics and Space Administration | -                                   |
| NAVAIRDEVCE        | Naval Air Development Center                  | -                                   |
| $N_p$              | $1/I_z \partial N / \partial p$               | 1/sec                               |
| $N_r$              | $1/I_z \partial N / \partial r$               | 1/sec                               |
| $N_{\dot{\alpha}}$ | $1/I_z \partial N / \partial \dot{\alpha}$    | 1/sec <sup>2</sup>                  |
| $N_{\delta_a}$     | $1/I_z \partial N / \partial \delta_a$        | $\frac{1}{\text{sec}^2\text{-deg}}$ |

LIST OF SYMBOLS (CON'T)

| <u>Symbol</u>      | <u>Definition</u>                          | <u>Dimension</u>                            |
|--------------------|--------------------------------------------|---------------------------------------------|
| $N_r$              | $1/I_z \partial N / \partial \dot{\phi}_r$ | $\frac{1}{\text{sec}^2\text{-deg}}$         |
| $n_x$              | longitudinal acceleration                  | g                                           |
| $n_y$              | lateral acceleration                       | g                                           |
| $n_z$              | normal acceleration                        | g                                           |
| PAM                | pulse amplitude modulation                 | -                                           |
| p                  | roll rate                                  | rad/sec                                     |
| Q                  | pitch rate                                 | rad/sec                                     |
| QD                 | pitch acceleration                         | rad/sec <sup>2</sup>                        |
| q                  | Q                                          | -                                           |
| r                  | yaw rate                                   | rad/sec                                     |
| S                  | wing area                                  | ft <sup>2</sup>                             |
| S                  | number of smoothing iterations             | -                                           |
| SCI                | Systems Control Inc.                       | -                                           |
| TH                 | pitch angle                                | deg                                         |
| U                  | airspeed                                   | ft/sec                                      |
| u                  | perturbation airspeed                      | ft/sec                                      |
| u                  | control vector                             | -                                           |
| W                  | number of weighting iterations             | -                                           |
| X                  | longitudinal (fore-aft) force              | lb                                          |
| $X_u$              | $1/m \partial X / \partial u$              | 1/sec                                       |
| $X_w$              | $1/m \partial X / \partial w$              | ft/sec <sup>2</sup>                         |
| $X_{\dot{\phi}_e}$ | $1/m \partial X / \partial \dot{\phi}_e$   | $\frac{\text{ft}}{\text{sec}^2\text{-deg}}$ |

LIST OF SYMBOLS (CON'T)

| <u>Symbol</u>      | <u>Definition</u>                        | <u>Dimension</u>       |
|--------------------|------------------------------------------|------------------------|
| x                  | state vector                             | ..                     |
| Y                  | sideforce                                | lb                     |
| $Y_p$              | $1/m \partial Y / \partial p$            | ft/sec                 |
| $Y_r$              | $1/m \partial Y / \partial r$            | ft/sec                 |
| $Y_{\delta}$       | $1/m \partial Y / \partial \delta$       | ft/sec <sup>2</sup>    |
| $Y_{\delta_a}$     | $1/m \partial Y / \partial \delta_a$     | $\frac{ft}{sec^2-deg}$ |
| $Y_{\delta_r}$     | $1/m \partial Y / \partial \delta_r$     | $\frac{ft}{sec^2-deg}$ |
| Z                  | vertical (normal) force                  | lb                     |
| $Z_q$              | $1/m \partial Z / \partial q$            | ft/sec                 |
| $Z_u$              | $1/m \partial Z / \partial u$            | 1/sec                  |
| $Z_{\alpha}$       | $1/m \partial Z / \partial \alpha$       | ft/sec <sup>2</sup>    |
| $Z_{\dot{\alpha}}$ | $1/m \partial Z / \partial \dot{\alpha}$ | ft/sec                 |
| $Z_{\delta_e}$     | $1/m \partial Z / \partial \delta_e$     | $\frac{ft}{sec^2-deg}$ |
| $\alpha$           | A                                        | -                      |
| $\beta$            | sideslip angle                           | deg                    |
| $\gamma$           | flight path angle                        | deg                    |
| $\delta_a$         | aileron deflection                       | deg                    |
| $\delta_b$         | speed brake deflection                   | deg                    |
| $\delta_e$         | elevator deflection                      | deg                    |
| $\delta_r$         | rudder deflection                        | deg                    |
| $\theta$           | TH                                       | -                      |
| $\rho$             | air density                              | slug/ft <sup>3</sup>   |
| $\phi$             | roll angle                               | deg                    |

## I N T R O D U C T I O N

The problem of extracting aerodynamic parameters, such as stability derivatives, from aircraft flight data has been the subject of considerable study over the years. In the past decade, however, the use of digital computer parameter identification techniques has given new impetus to the technology. The state of the art, except for the most recent developments, is summarized in reference (a).

The primary objective of this program was the assessment of the relative accuracy and utility of several existing parameter identification techniques. Secondary objectives were the establishment of one consensus set of stability derivatives for the T-2 aircraft, development of one identification technique for continuing in-house use at NAVAIRDEVCEEN, and the establishment of a carefully and completely documented file of flight data to be made available to anyone pursuing parameter identification technique development. Although not part of the original objectives, the most significant result of this current work may be the development of NAVAIRDEVCEEN expertise (in data acquisition and use of identification techniques) which will be essential in the current effort on development of high angle of attack (stall/post-stall/spin) parameter identification processes.

It should be emphasized that no attempt was planned or made to originate new identification techniques or even substantially modify existing ones. Rather, existing techniques were used, modified only slightly for adaptation to this particular application. In recent years, the opinion that the low angle of attack aircraft identification problem had been "solved" has been expressed by numerous investigators in various forums. Thus there seemed to be no need to attempt to develop any new identification techniques for this program.

Since a portion of the program objective was the establishment of an in-house identification capability for the future, the existing telemetry and data recording equipment at NAVAIRDEVCEEN was used for the project, although this equipment was by no means state-of-the-art. This constraint conflicted with the desire of producing carefully controlled, low noise level flight data - a type of flight data which has been essentially unavailable to many investigators in the parameter identification field. The most significant problem with generally available flight data in the past, however, has been a lack of documentation. For this project all relevant information pertaining to flight circumstances and instrumentation has been recorded.

The need for an in-house capability in parameter identification perhaps merits further comment. Although it has not been active in in-house experimental flight dynamics research programs prior to the effort reported here, NAVAIRDEVCEEN is designated (reference (b)) as the lead laboratory for flight dynamics research and development work in the Navy. Consequently, it would be appropriate and desirable for NAVAIRDEVCEEN to have a capability for in-house experimental flight dynamics work, and parameter identification would probably be required in such work.

In particular, NAVAIRDEVCON has planned to construct a variable stability research aircraft and prototype trainer based on the T-2. A parameter identification capability is necessary for the calibration and verification of such a simulator. A consensus set of T-2 stability derivatives as a function of flight condition would be necessary for the programming of the variable stability control system, so two portions of the results of this work have application to the variable stability project.

Volume I of this report concerns the acquisition of the flight data and the in-house identification effort, while Volume II reports on the contractor identification efforts.

#### S E L E C T I O N   O F   I D E N T I F I C A T I O N T E C H N I Q U E S

It is generally recognized that modern, digital computer, identification techniques can be divided into two types: maximum likelihood and Kalman filtering. Reference (c) provided an explanation of this division. Within these two broad divisions there exist many techniques which are somewhat different in specifics although similar in principle, and in fact there are numerous techniques which are quite similar although referred to by different names. All these techniques are "output error" types; equation of motion error techniques and non-digital (i.e., analog matching) techniques were not considered in this study.

Probably the most popular of the digital techniques today is the modified Newton-Raphson technique, which is a member of the maximum likelihood "family", and in fact becomes a maximum likelihood method if a properly calculated weighting matrix is used. Considering the relatively straightforward nature and the wide acceptance of the modified Newton-Raphson technique, it was decided to use this technique in-house at NAVAIRDEVCON.

Processing of the data by the most advanced identification technique at NASA-Ames Research Center, NASA-Langley Research Center, and NASA-Flight Research Center was considered highly desirable, but pressures of other work and limited manpower, and delays in the gathering of the data by NAVAIRDEVCON, made NASA participation uncertain. To ensure that at least three different identification techniques would be used, two contractors were selected to perform analysis concurrently with the in-house effort.

Systems Control, Inc., of Palo Alto, California, was contracted to use their version of maximum likelihood (reference (d)); Calspan Corp. of Buffalo, New York, was paid to apply their Kalman filtering/smoothing (reference (e)) method to the data.

It was decided that the in-house analysis effort would have a different philosophy than the contracted efforts. In-house, the data would be run through the identification procedure without any substantial operator interface - the program would simply be "on its own". The contractors, however, would be free to make minor modifications to their programs as they desired,

and to use any level of human involvement which they felt appropriate. Major modifications to the programs were rendered impossible by cost and time constraints, in addition to being contrary to the philosophy of the program.

## EXPERIMENTAL EQUIPMENT AND CONDITIONS

### THE AIRCRAFT

The flight data used in this report were obtained with YT-2B BuNo 144218, shown in Figures 1 and 2. The aircraft was constructed by Rockwell International, Columbus Division (formerly North American), as a prototype of the model T-2B, and is essentially identical to the T-2B and T-2C with respect to aerodynamics. The geometric parameters of the aircraft are given in Table I.

The most significant features of the aircraft configuration are the straight, mid-fuselage wing and the conventional elevator mounted on a fixed cruciform tail. The flaps are semi-Fowler single-slotted.

Naval Air Facility, Warminster, was the base of the aircraft throughout the flight program, and the majority of flights were conducted in the southeastern Pennsylvania and southern New Jersey areas.

### INSTRUMENTATION

A complete set of motion transducers was installed in the YT-2B for the sole purpose of obtaining flight time histories for parameter identification analysis. The locations and serial numbers of the transducers, as originally installed, are given in Table II. The measurement ranges of the transducers are presented in Table III. As of 10 May 1973, the changes listed in Table IV became effective.

In addition to the transducers listed in the tables, the aircraft was equipped for the measurement of airspeed, altitude, angle of attack, sideslip, and control positions. For the purposes of this project, the YT-2B was re-equipped with the noseboom constructed by North American at the time of the original flight testing. The boom included a pitot-static system and  $\alpha$  and  $\beta$  vanes.

The pressure altitude transducer was intended to measure perturbation altitudes  $\pm 1200$  feet about a reference altitude, which was "locked in" when the pilot selected the "altitude reference engage" control. The transducer malfunctioned, however, and would measure only  $+1200$ ,  $-600$  feet from reference. A reference-and-climb procedure was used to make the effective range  $\pm 900$  feet.

Airspeed was also calculated from the dynamic pressure transducer at the tip of the noseboom. Two independent transducers were used for "coarse" and "fine" measurements. Coarse airspeed had a range of 0-500 kt, while 0-50 kt was the range for fine airspeed which was automatically reset to zero at each 50 kt upper limit, thus describing a "sawtooth" function. This resetting

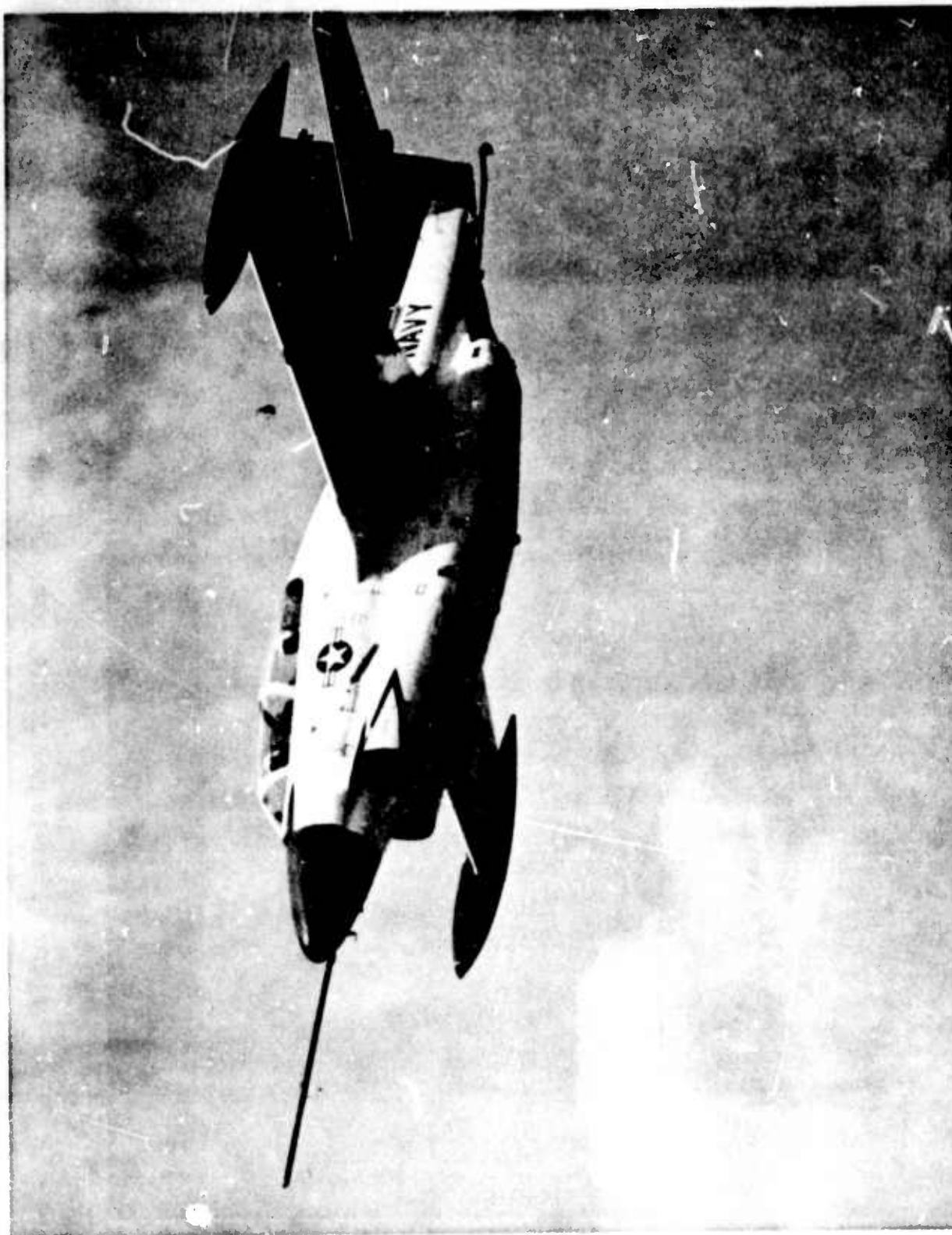


FIGURE 1. YF-12 BuNo 144218, CLEAN CONFIGURATION



FIGURE 2. YF-2B BuNo 144218, POWER APPROACH CONFIGURATION

TABLE I  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

WING

|             |                                                                                   |                                                                  |
|-------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------|
| $S_w$       | Total area (includes flap, aileron and 39.39 ft <sup>2</sup> covered by fuselage) | 254.86 ft <sup>2</sup>                                           |
| $A_w$       | Net surface area (wetted)                                                         | 424.85 ft <sup>2</sup>                                           |
| $b_w$       | Span (perpendicular to plane of symmetry) including tiptanks                      | 38.13 ft                                                         |
| $AR_w$      | Aspect Ratio                                                                      | 5.07                                                             |
| $\lambda_w$ | Taper Ratio                                                                       | .496                                                             |
| $\Gamma_w$  | Dihedral Angle                                                                    | +3°                                                              |
|             | Chord (in streamline direction)                                                   |                                                                  |
| $c_r$       | Root (Wing Sta. 0)                                                                | 114.20 in                                                        |
| $c_t$       | Tip Chord (Wing Sta. 214.242)                                                     | 56.63 in                                                         |
|             | (Equivalent)                                                                      |                                                                  |
| $\bar{c}_w$ | Mean aerodynamic chord                                                            | 88.88 in                                                         |
|             | (Wing Sta. 95.078)                                                                |                                                                  |
|             | Location of 25% MAC                                                               | F.S. 219.697                                                     |
| $\Lambda_w$ | Sweepback of 25% element                                                          | 2°17'                                                            |
| $i_w$       | Incidence angle                                                                   |                                                                  |
|             | Root Chord                                                                        | 2°                                                               |
|             | Tip Chord                                                                         | -1°                                                              |
|             | Airfoil Section (root and tip in streamline direction)                            | NASA641A212<br>a = .8*(MOD)<br>(flaps and ailerons rigged 3° up) |
|             | *NAA Modified                                                                     |                                                                  |

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

|            |               |        |
|------------|---------------|--------|
| $\Omega_w$ | Rate of Taper | 0.2671 |
|------------|---------------|--------|

FLAP (Data for One)

|                            |                                                   |                       |
|----------------------------|---------------------------------------------------|-----------------------|
|                            | Type                                              | Single Slotted        |
| $S_f$                      | Area                                              | 22.78 ft <sup>2</sup> |
| $b_f$                      | Span (perpendicular to plane of symmetry)         | 101.75 in             |
| $c_i$                      | Inboard chord (Wing Sta. 27.09)                   | 39.39 in              |
| $c_o$                      | Outboard chord (Wing Sta. 127.54)                 | 29.63 in              |
| $c_f/c_w$                  | Ratio flap chord to wing chord (avg.)             | .37                   |
| $b_f/b_w$<br>$\frac{1}{2}$ | Ratio flap span to wing semi-span                 | .475                  |
| $\delta_f$                 | Flap deflection, maximum (from uprigged position) | 33°                   |
|                            | Flap in neutral position                          | 3° Up                 |

AILERON

|                            |                                              |                     |
|----------------------------|----------------------------------------------|---------------------|
|                            | Type                                         | Straight Sided      |
| $S_a$                      | Area (aft of hinge line and including tab)   | 9.5 ft <sup>2</sup> |
| $b_a$                      | Span (perpendicular to plane of symmetry)    | 79.57 in            |
| $c_i$                      | Inboard chord (Wing Sta. 128.69)             | 20 in               |
| $c_o$                      | Outboard chord (Wing Sta. 208.26)            | 14.66 in            |
| $c_a/c_w$                  | Ratio aileron chord (aft H.L.) to wing chord | .25                 |
| $b_a/b_w$<br>$\frac{1}{2}$ | Ratio aileron span to wing semi-span         | .374                |

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

|           |                                                                 |                         |
|-----------|-----------------------------------------------------------------|-------------------------|
| $c_a$     | Aileron deflection, maximum (from neutral position)             | -12° Up, +13° Dn        |
|           | Aileron in neutral position                                     | 3° Up                   |
|           | Aerodynamic Balance                                             | Sealed paddle balance   |
| $S_b$     | Balance area forward of the H.L. (including 50% of fabric seal) | 4.45 ft <sup>2</sup>    |
| $c_b/c_a$ | Ratio balance chord to aileron chord                            | .42                     |
|           | Static balance                                                  | Weighted paddle balance |
|           | Irreversible full power system                                  | Hydraulic               |

AILERON TRIM TAB

Ground adjustable fixed tab on each aileron

|       |             |                     |
|-------|-------------|---------------------|
| $S_a$ | Area (each) | .07 ft <sup>2</sup> |
|-------|-------------|---------------------|

HORIZONTAL TAIL\*

|             |                                                                                 |                        |
|-------------|---------------------------------------------------------------------------------|------------------------|
| $S_h$       | Total area (includes 3.07 ft <sup>2</sup> covered by vertical tail and fairing) | 72.29 ft <sup>2</sup>  |
| $S_{net_h}$ | Net area                                                                        | 146.38 ft <sup>2</sup> |
| $A_h$       | Net surface area (wetted)                                                       | 146.38 ft <sup>2</sup> |
| $b_h$       | Span                                                                            | 17.91 ft               |
| $AR_h$      | Aspect Ratio                                                                    | 4.42                   |
| $\lambda_h$ | Taper Ratio                                                                     | 0.50                   |
| $\Gamma_h$  | Dihedral angle                                                                  | 0°                     |
| $\Lambda_h$ | Sweepback of 25% element                                                        | 15°                    |

\*Percent lines base on horizontal prior to addition of trailing edge extension.

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

Chord (in streamline direction)

|             |                                                        |             |
|-------------|--------------------------------------------------------|-------------|
| $c_r$       | Root (H.T. Sta. 0)                                     | 64.61 in    |
| $c_t$       | Equivalent tip chord<br>(H.T. Sta. 106.483)            | 33.05 in    |
| $\bar{c}_h$ | Mean aerodynamic chord<br>(H.T. Sta. 47.78)            | 50.447 in   |
| $i_h$       | Incidence angle                                        | 0°          |
|             | Airfoil section (root and tip in streamline direction) | NASA 65A012 |
| $l_h$       | Tail length (.25 $\bar{c}_w$ to .25 $\bar{c}_h$ )      | 202.58 in   |

HORIZONTAL STABILIZER

|       |                            |                      |
|-------|----------------------------|----------------------|
| $S_s$ | Area stabilizer, total     | 42.5 ft <sup>2</sup> |
| $i_s$ | Stabilizer incidence angle | 0°                   |

ELEVATOR

|           |                                                               |                       |
|-----------|---------------------------------------------------------------|-----------------------|
| $S_e$     | Total area (excluding balance area forward of the hinge line) | 21.00 ft <sup>2</sup> |
| $b_e$     | Span (between equivalent chords)<br>(one elevator only)       | 101.97 in             |
| $c_i$     | Inboard chord (B.P. 3.906)                                    | 18.85 in              |
| $c_o$     | Outboard chord (B.P. 105.877)                                 | 10.52 in              |
| $c_e/c_h$ | Ratio elevator chord (aft H.L.) to horizontal tail chord      | .310                  |
| $b_e/b_h$ | Ratio elevator span to horizontal tail span                   | 0.936                 |

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

|            |                                                                |                       |
|------------|----------------------------------------------------------------|-----------------------|
| $\delta_e$ | Elevator deflection maximum                                    | 27° Up, 15° Dn        |
|            | Boost: Push force 2.95:1                                       | Hydraulic             |
|            | Pull force 2.95:1 to 8 lbs                                     |                       |
|            | then 6.0:1                                                     |                       |
|            | Static balance                                                 | Weighted Leading Edge |
|            | Aerodynamic balance                                            | Overhang              |
| $S_b$      | Balance area forward of hinge line                             | 5.72 ft <sup>2</sup>  |
| $c_b/c_e$  | Ratio balance chord to elevator chord                          | 0.322                 |
|            | Nose factor                                                    | 0.60                  |
|            | Point of tangency for nose factor is<br>at elevator hinge line |                       |

ELEVATOR TRIM TAB

|            |                                       |                                                 |
|------------|---------------------------------------|-------------------------------------------------|
| $S_t$      | Area (each)                           | 2.36 ft <sup>2</sup>                            |
| $b_t$      | Span, Equivalent (B.P. 8.93 to 54.53) | 46.10 in                                        |
| $c_t$      | Chord, constant                       | 6.5 in                                          |
| $b_t/b_e$  | Ratio tab span to elevator span       | 0.462 in                                        |
| $\delta_t$ | Tab deflection                        | L.H. 10° Up,<br>13° Dn<br>R.H. 0° Up,<br>13° Dn |

VERTICAL TAIL

|            |                                                                                                                               |                       |
|------------|-------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| $S_v$      | Total area (includes 4.38 ft <sup>2</sup> blanketed<br>by fuselage plus 2.14 ft <sup>2</sup> blanketed by<br>horizontal tail) | 40.33 ft <sup>2</sup> |
| $S_{nctv}$ | Net area                                                                                                                      | 33.86 ft <sup>2</sup> |

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

|                     |                                                                                             |                       |
|---------------------|---------------------------------------------------------------------------------------------|-----------------------|
| $A_v$               | Net surface area (wetted)                                                                   | 79.18 ft <sup>2</sup> |
| $A_d$               | Net surface area of dorsal fin (wetted)                                                     | 18.12 ft <sup>2</sup> |
| $b_v$               | Span, unblanketed                                                                           | 8.04 ft               |
| $AR_v$              | Aspect ratio                                                                                | 1.80                  |
| $\lambda_v$         | Taper ratio                                                                                 | .375                  |
| $c_r$               | Chord (in streamline direction)                                                             |                       |
|                     | Root (W.P. + 33.000)                                                                        | 78.14 in              |
| $c_t$               | Equivalent Tip Chord (W.P. + 129.41)                                                        | 29.38 in              |
| $\bar{c}_v$         | Mean aerodynamic chord (W.P. + 73.92)                                                       | 58.47 in              |
| $\Lambda_v$         | Sweepback (25% chord)                                                                       | 30°                   |
|                     | Airfoil Section                                                                             | NASA 63A012           |
| $l_v$               | Tail length (.25 $\bar{c}_w$ to .25 $\bar{c}_v$ )                                           | 194.05 in             |
| <u>VERTICAL FIN</u> |                                                                                             |                       |
| $S_f$               | Area (including 2.14 ft <sup>2</sup> blanketed by horizontal tail and excluding dorsal fin) | 29.87                 |
| $i_f$               | Angle with respect to airplane plane of symmetry                                            | 0°                    |
| <u>RUDDER</u>       |                                                                                             |                       |
| $S_r$               | Total area                                                                                  | 9.13 ft <sup>2</sup>  |
|                     | $S_{r_u}$ Upper surface                                                                     | 3.23 ft <sup>2</sup>  |
|                     | $S_{r_l}$ Lower surface                                                                     | 5.90 ft <sup>2</sup>  |

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

|            |                                                           |                       |
|------------|-----------------------------------------------------------|-----------------------|
| $b_r$      | Span, equivalent                                          |                       |
|            | $b_{ru}$ Upper surface                                    | 31.94 in              |
|            | $b_{rl}$ Lower surface                                    | 42.99 in              |
| $c_{ru}$   | Upper chord (W.P. 96.00)                                  | 12.59 in              |
| $c_{rl}$   | Lower chord (W.P. + 9.91)                                 | 22.45 in              |
| $c_r/c_v$  | Ratio rudder chord (aft H.L.) to vertical tail chord      |                       |
|            | $c_r/c_v$ Upper surface @ W.P. 96.00                      | .266                  |
|            | $c_r/c_v$ Lower surface                                   | .250                  |
| $\delta_r$ | Rudder deflection, maximum                                | 25° Rt, 25° Lt        |
|            | Boost                                                     | None                  |
|            | Aerodynamic balance                                       | Overhang              |
| $S_b$      | Balance area forward of hinge line                        | 2.41 ft <sup>2</sup>  |
| $c_b/c_r$  | Ratio balance chord to rudder chord                       |                       |
|            | $c_b/c_{ru}$ Upper surface @ W.P. 96.00                   | .234                  |
|            | $c_b/c_r$ Lower surface                                   | .24                   |
|            | Static balance                                            | Weighted leading edge |
|            | Nose factor                                               | 0.40                  |
|            | Point of tangency for nose factor is at rudder hinge line |                       |

RUDDER TRIM TAB

|       |      |                      |
|-------|------|----------------------|
| $S_t$ | Area | 1.60 ft <sup>2</sup> |
|-------|------|----------------------|

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

|            |                                             |              |
|------------|---------------------------------------------|--------------|
| $b_t$      | Span, equivalent (W.P. 14.94 to W.P. 53.00) | 38.06 in     |
| $c_t$      | Chord, constant                             | 6.0 in       |
| $b_t/b_r$  | Ratio tab span to rudder span               | .508         |
| $\delta_t$ | Tab deflection, maximum                     | 7° Rt, 7° Lt |

FUSELAGE

|       |                                         |                        |
|-------|-----------------------------------------|------------------------|
| $l_f$ | Length (actual)                         | 34.58 ft               |
| $F_f$ | Maximum frontal area (basic fuselage)   | 15.75 ft <sup>2</sup>  |
| $w_f$ | Maximum width (basic fuselage) F.S. 169 | 54 in                  |
| $h_f$ | Maximum depth                           |                        |
|       | Basic fuselage over canopy (F.S. 169)   | 88.1 in                |
|       | Including ducts (F.S. 214)              | 73.9 in                |
| $A_f$ | Net surface area                        | 221.11 ft <sup>2</sup> |
| $L/D$ | Fineness ratio (actual)                 | 5.91                   |

CANOPY

|         |                         |                       |
|---------|-------------------------|-----------------------|
| $l_c$   | Length (actual)         | 19.75 ft              |
| $F_c$   | Maximum frontal area    | 3.70 ft <sup>2</sup>  |
| $A_c$   | Net surface area        | 73.10 ft <sup>2</sup> |
| $L/D_c$ | Fineness ratio (actual) | 8.8                   |

NACELLE

|       |                      |                       |
|-------|----------------------|-----------------------|
| $l_n$ | Length (actual)      | 23.71 ft              |
| $F_n$ | Maximum frontal area | 10.50 ft <sup>2</sup> |

TABLE I (CON'T)  
GEOMETRIC PARAMETERS OF FULL-SCALE T-2  
(from reference (f))

|                                             |                                     |                       |
|---------------------------------------------|-------------------------------------|-----------------------|
| $A_n$                                       | Net surface area                    | 206.0 ft <sup>2</sup> |
|                                             | Inlet area (includes gutters)       | 3.1 ft <sup>2</sup>   |
| $L/D_n$                                     | Fineness ratio (actual)             | 5.025                 |
| <u>SPEED BRAKE</u> (Data for one side only) |                                     |                       |
|                                             | Type                                | One Piece             |
|                                             | Location                            | Side of Aft Fuselage  |
|                                             | Number                              | Two                   |
| $S_j$                                       | Area (Planform)                     | 8.00 ft <sup>2</sup>  |
| $F_j$                                       | Area (frontal)                      | 4.24 ft <sup>2</sup>  |
| $\delta_j$                                  | Maximum deflection                  | 32°*                  |
| <u>TIP TANK</u> (Data for one tank only)    |                                     |                       |
| $l_{tt}$                                    | Overall length                      | 142.75 in             |
| $d_{tt}$                                    | Maximum diameter (Tank Sta. 61.875) | 20.00 in              |
| $L/D$                                       | Fineness ratio                      | 7.14                  |
| $S_{s_{tt}}$                                | Side area (projected)               | 14.1 ft <sup>2</sup>  |
| $S_{p_{tt}}$                                | Planform area (projected)           | 14.2 ft <sup>2</sup>  |
|                                             | Volume                              | 15.3 ft <sup>3</sup>  |
| $A_{tt}$                                    | Total Surface Area                  | 44.30 ft <sup>2</sup> |
| $A_{net_{tt}}$                              | Net Surface Area (wetted)           | 42.40 ft <sup>2</sup> |

\*Note: Manufacturers specification is 32°. By actual measurement, test A/C maximum speedbrake deflection is 50°. Reference (g) states that AFC 103 ordered extension of speed brake deflection to 50° for production T-2 aircraft.

TABLE II  
INSTRUMENT LOCATIONS ON YT-2B FOR AIRFRAME DYNAMICS IDENTIFICATION PROGRAM  
(prior to 10 May 73)

| Function                        | Name                                  | Fuselage Station | Wing Station | Water Line |
|---------------------------------|---------------------------------------|------------------|--------------|------------|
| $n_x$                           | Greenleaf Serial<br>1655000-A #674    | 37.              | -4.          | -11.       |
| $n_z$ (c.g.)                    | Giannini #1816<br>24117P-3.5-20       | 207.             | -1.          | -21.       |
| $n_z$ nose (for $\dot{q}$ )     | Giannini #1819<br>24117P-3.5-20       | 34.              | -6.          | -11.       |
| $n_z$ tail (for $\dot{q}$ )     | Giannini #1837<br>24117P-3.5-20       | 366.5            | 0            | +9.        |
| $\dot{q}$                       | Staham Ang. Acc.<br>AA196-8-350       | 230.             | 0            | -23.5      |
| $\theta$                        | Giannini Model<br>Serial 5812 3416    | 56.              | 0            | 5.         |
| $\alpha$                        | Giannini Model<br>Serial 3812 3416    | 56.              | 0            | 5.         |
| $r$                             | Gyro Dynamics<br>Serial #62           | 47.              | 0            | 3.5        |
| $p$                             | Norden RG 228<br>Serial #185          | 52.              | 0            | 2.5        |
| $q$                             | Norden RG 228<br>Serial #183          | 196.             | 0            | -22.5      |
| $n_y$ nose (for $\dot{r}$ )     | Edelcliff Model 7-30<br>Serial #367   | 31.5             | -6.          | -11.       |
| $n_y$ tail (for $\dot{r}$ )     | Edelcliff Model 7-30<br>Serial #366.5 | 366.5            | 0            | +9.        |
| $n_y$ (c.g.)                    | Edelcliff Model 7-30<br>Serial #4444  | 204.             | -1.5         | -19.       |
| $n_z$ wing tip (for $\dot{p}$ ) | Giannini #1685<br>24117P-3.5-20       | 249.             | 206.5        | 15.        |
| $n_z$ wing tip (for $\dot{p}$ ) | Giannini #1860<br>24117P-3.5-20       | 249.             | -206.5       | 15.        |

NOTE: Negative wing stations are toward left wing. Negative water line positions are below fuselage reference line.

TABLE III  
MEASUREMENT RANGES FOR YT-2B TRANSDUCERS

| Measurement | Range                                        |
|-------------|----------------------------------------------|
| $n_z$       | $\pm 3.5g$                                   |
| $n_x$       | $\pm 1.0g$                                   |
| $n_y$       | $\pm 1.0g$                                   |
| $q$         | $\pm 20 \text{ deg/sec}$                     |
| $\theta$    | $\pm 15 \text{ deg}$                         |
| $r$         | $\pm 20 \text{ deg/sec}$                     |
| $\dot{q}$   | $\pm 450 \text{ deg/sec}^2$                  |
| $\phi$      | $\pm 90 \text{ deg}$                         |
| $p$         | $\pm 20 \text{ deg/sec (prior to 5/10/73)}$  |
|             | $\pm 45 \text{ deg/sec (effective 5/10/73)}$ |

TABLE IV  
YT-2B INSTRUMENTATION CHANGES EFFECTIVE 10 MAY 1973

| Measurement                    | Transducer<br>Removed                     | Transducer<br>Substituted      |
|--------------------------------|-------------------------------------------|--------------------------------|
| p                              | Norden RG 228<br>SN 185                   | Humphrey G20-1021-00<br>SN 328 |
| r                              | Gyro Dynamics<br>SN 62                    | Norden RG 228<br>SN 185        |
| n <sub>z</sub> (port wing tip) | ----Giannini 24117-3.5-20-----<br>SN 1860 | -----<br>SN 1681               |

function developed problems, however, and caused some noise in the velocity signal at the switching points. A position error correction for the airspeed measurement was supplied by the manufacturer in reference (h).

The angle of attack and sideslip vanes were located 23.1 feet and 23.4 feet, respectively, forward of the nominal center-of-gravity. The ranges of the measurements from these vanes were adjustable, but were set at  $\pm 10^\circ$  for both vanes throughout this flight program.

While all gyros and accelerometers were aligned with respect to the fuselage reference line indicated by the aircraft manufacturer, the  $\alpha$  vane was referenced to the noseboom. It was calculated that the noseboom itself was inclined  $-4.0^\circ$  relative to the wing chord line, from which true angle of attack should be measured.

Aileron, rudder, elevator, flap, and speedbrake positions were measured via potentiometers covering the full range of available movement.

Note that pitch angular acceleration was measured twice: once directly with the Statham angular accelerometer and once via differential normal acceleration between nose-mounted and tail-mounted normal accelerometers.

#### TELEMETRY, RECORDING, AND DATA REDUCTION

Transducer signals were simultaneously recorded onboard the aircraft and broadcast to the ground station. The telemetry system was of the FM-FM type and the onboard recorder was an Astro-Science Corporation MARS 2000. Since only 12 discrete IRIG-standard subcarrier frequencies were available, many of the channels had to be assigned to a pulse amplitude modulation system and then sampled at 30 samples/sec by a commutator, with the commutator output modulated on the 70 KHZ subcarrier. Table V lists channel assignments. The various subcarrier signals were then modulated together and recorded as a single channel on the tape.

Demodulation and analog-to-digital conversion could not be accomplished at NAVAIRDEVCON without procurement of additional equipment, so these operations were performed at Naval Air Test Center. The digital data tapes were then provided as input to the NAVAIRDEVCON digital computer facility.

A digital computer program for data reduction purposes was developed. This program transformed the digital information into CDC 6600 format, corrected for aircraft instrumentation offsets, decalibrated the data into physical units, and referenced all motion variables to trim values. A printout of this program, configured for a typical run, is given as Appendix A.

The calibration constants used in this process for the gyros and accelerometers were developed from tests at NAVAIRDEVCON using rate tables and similar equipment. Every transducer was tested independently. Control surfaces and  $\alpha$  and  $\beta$  vanes were calibrated using an inclinometer. Airspeed and altitude transducers were calibrated in accordance with procedures recommended by manufacturers using pressurized air sources.

TABLE V  
CHANNEL ASSIGNMENTS FOR YT-2B TELEMETRY AND RECORDING

| Channel    | Assigned Variable                       |
|------------|-----------------------------------------|
| FM 1.3KHZ  | angle of attack                         |
| FM 1.7KHZ  | sideslip angle                          |
| FM 2.3KHZ  | heading                                 |
| FM 3.0KHZ  | pitch angle                             |
| FM 3.9KHZ  | pitch rate                              |
| FM 5.4KHZ  | roll rate                               |
| FM 7.35KHZ | roll angle                              |
| FM 10.5KHZ | normal acceleration (port wingtip)      |
| FM 14.5KHZ | pitch angular acceleration              |
| FM 22.0KHZ | normal acceleration (starboard wingtip) |
| FM 40.0KHZ | aileron position                        |
| FM 70.0KHZ | PAM                                     |
| PAM1       | zero reference                          |
| PAM2       | full scale reference                    |
| PAM3       | flap position                           |
| PAM4       | speed brake position                    |
| PAM5       | flight path acceleration                |
| PAM6       | side acceleration (cg)                  |
| PAM7       | normal acceleration (cg)                |
| PAM8       | normal acceleration (nose)              |
| PAM9       | normal acceleration (tail)              |
| PAM10      | side acceleration (nose)                |
| PAM11      | side acceleration (tail)                |
| PAM12      | airspeed (coarse)                       |
| PAM13      | airspeed (fine)                         |
| PAM14      | altitude                                |
| PAM15      | elevator position                       |
| PAM16      | -                                       |
| PAM17      | rudder position                         |
| PAM18      | yaw rate                                |

All of the calibrations mentioned above were static in nature, except that the angular accelerometer was exposed to a sinusoidal input because no practical method of providing steady-state angular acceleration was available. A byproduct of this calibration method was the capability of measuring phase shift. It was assumed that the oscillation table itself contributed no lag, so that all phase shift from input command to accelerometer signal can be attributed to the accelerometer. The results are shown in Figure 3. The transducer apparently develops significant phase lags at high frequencies, but the phase shift is only  $10^\circ$  to  $15^\circ$  in the highest frequency region of interest. The phase lead at very low frequencies is difficult to explain. Either the indication of phase lead is an error, or the transfer function for the transducer is considerably more complex than the simple lag usually assumed. If the data found in these tests are accurate, it must be concluded that the unit has been designed well, since the phase shift is zero in the frequency region of greatest interest.

One rate gyro was selected at random to be tested for phase shift in the manner described above. Results are shown in Figure 4. Again, zero phase shift seems to occur in the frequency range of most-interest, and a phase lead of as much as  $10^\circ$  exists at low frequencies. Thus phase shift on rate gyros should not cause any serious problems.

#### FLIGHT DATA CHARACTERISTICS

Flight data were collected for a wide variety of pilot control inputs for eight flight conditions. For the purposes of the current parameter identification effort, however, 17 sets of time histories, including only the two most significant flight conditions, were selected. A list of the characteristics of each time history set (referred to by "Data Run Number") is given in Table VI. A detailed discussion of elevator control inputs is given elsewhere in this report. Furthermore, the pilot's record of the circumstances of each flight (from which data were taken) are presented in Table VII. The details of the two flight conditions are listed in Table VIII.

The trim angle of attack was calculated by first calibrating the vane relative to the boom, and then measuring the angle between the noseboom and the wing chord line (in the vicinity of the mean aerodynamic chord). Trim angles of attack referenced to wing chord line cannot have negative values for the T-2, yet negative values are shown in Table VI. It seems, therefore, that an error exists in the angle of attack reference. Such an error should not affect the perturbation angle of attack measurement significantly.

#### PILOT CONTROL INPUTS

It is generally recognized (see, for example, reference (j)) that system identification is impossible if the test input does not excite the principal natural modes of system response. Moreover, several investigators (see references (k) and (l)) have determined that an input can be found which will improve identification performance substantially relative to traditional flight test inputs.

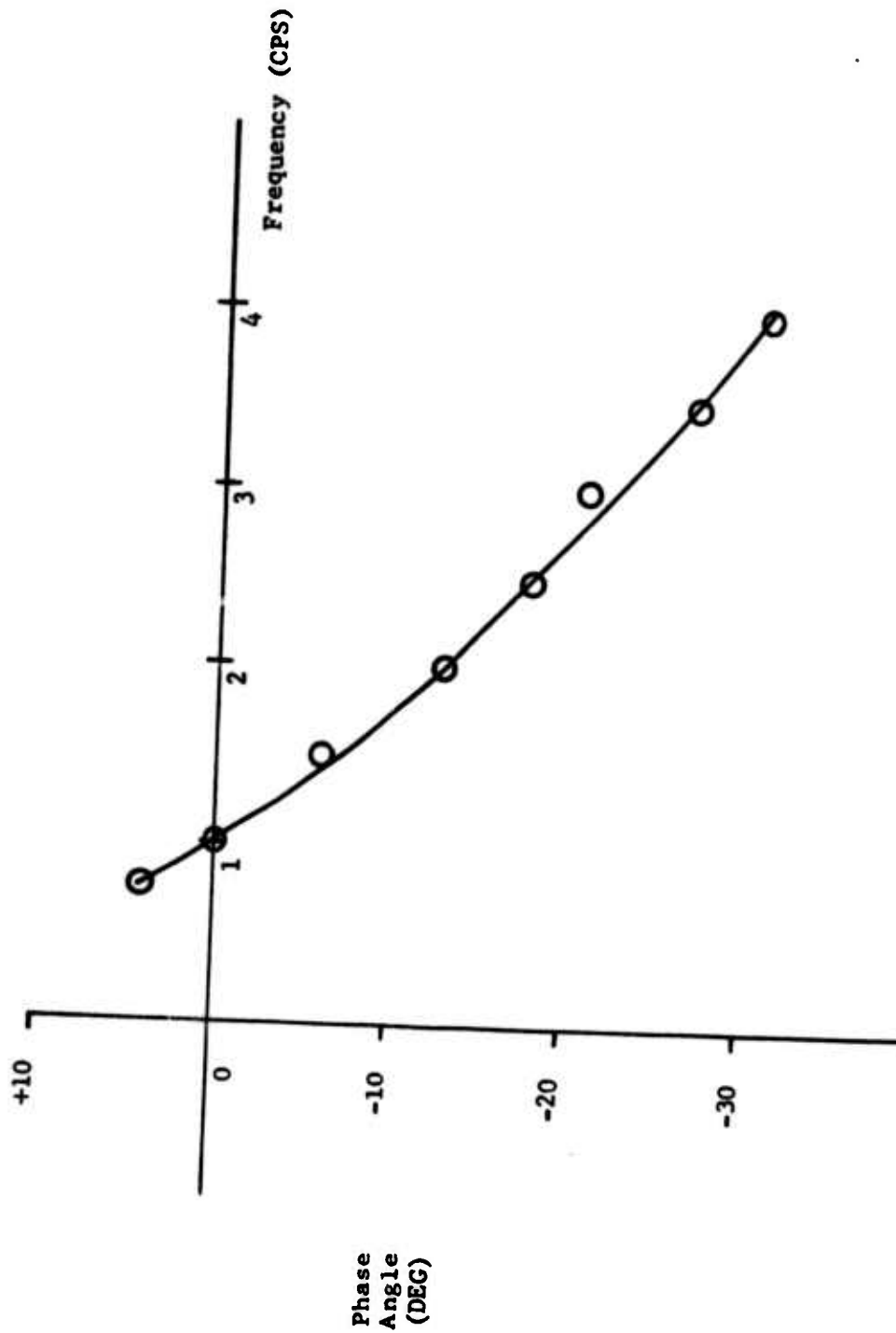


FIGURE 3. PHASE SHIFT TESTS OF STATHAM ANGULAR ACCELEROMETER (AA196-8-350)

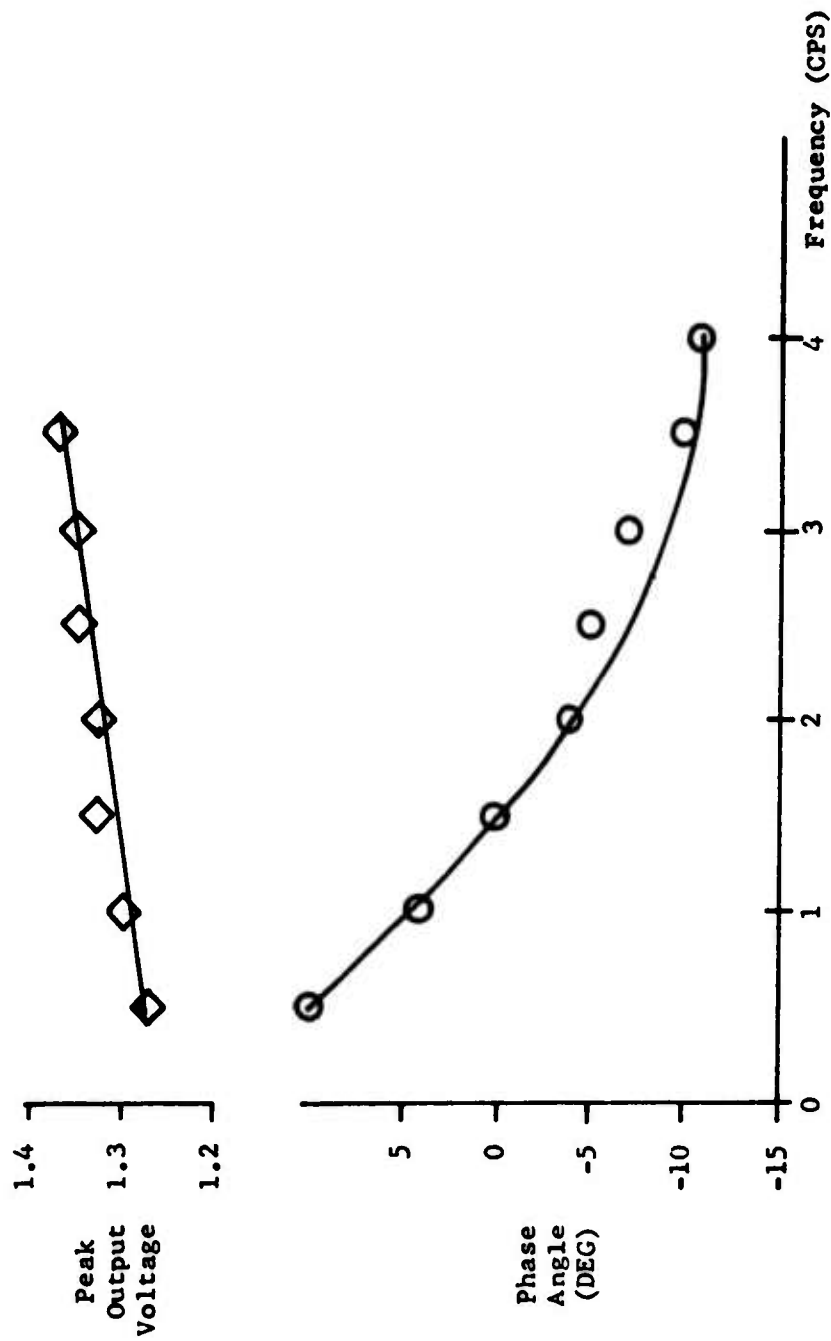


FIGURE 4. RATE GYRO FREQUENCY RESPONSE, NORDEN RATE GYRO MODEL RG228, SERIAL NO. 183

TABLE VI  
FLIGHT DATA CHARACTERISTICS

| Data Run Number | Date    | Flight Condition | Trim Velocity (ft/sec) | Trim Angle-of-Attack (deg) | Elevator Input                             |
|-----------------|---------|------------------|------------------------|----------------------------|--------------------------------------------|
| 2               | 3/14/73 | 1                | 266.5                  | 5.8                        | (2-cycle sine wave short period frequency) |
| 3               | 3/14/73 | 1                | 246.7                  | 7.1                        | pulse                                      |
| 4               | 3/21/73 | 1                | 253.2                  | 6.0                        | (1-cycle sine wave short period frequency) |
| 5               | 3/21/73 | 1                | 255.7                  | 5.2                        | (2-cycle sine wave short period frequency) |
| 6               | 3/21/73 | 1                | 251.6                  | 5.9                        | pulse                                      |
| 7               | 3/23/73 | 2                | 685.7                  | 0.1                        | (1-cycle sine wave short period frequency) |
| 8               | 3/23/73 | 2                | 685.5                  | 0.1                        | (3-cycle sine wave short period frequency) |
| 9               | 5/10/73 | 2                | 699.3                  | 0.3                        | pulse                                      |
| 10              | 5/10/73 | 2                | 683.7                  | 0.3                        | pulse                                      |
| 11              | 5/10/73 | 2                | 679.2                  | 0.1                        | pulse                                      |
| 12              | 5/10/73 | 2                | 669.9                  | 0.2                        | step                                       |
| 13              | 5/10/73 | 2                | 680.8                  | 0.1                        | SCI optimum                                |
| 14              | 5/10/73 | 2                | 687.2                  | -0.1                       | SCI optimum                                |
| 16              | 5/16/73 | 2                | 683.9                  | -0.6                       | step                                       |
| 17              | 5/16/73 | 2                | 689.6                  | -0.7                       | step                                       |
| 18              | 5/16/73 | 2                | 682.8                  | -0.7                       | SCI optimum                                |
| 19              | 5/16/73 | 2                | 690.0                  | -0.8                       | white noise                                |

TABLE VII  
PILOT'S RECORD OF FLIGHT CIRCUMSTANCES

| Date                        | 3/14/73             | 3/21/73            | 3/23/73       | 5/10/73            | 5/16/73            |
|-----------------------------|---------------------|--------------------|---------------|--------------------|--------------------|
| Calibrated<br>Airspeed (kt) | 140                 | 140                | 351           | 351                | 351                |
| Power Setting (%)           | 78-79               | 78-79              | 90            | 93                 | 93                 |
| Pressure<br>Altitude (ft)   | 1500                | 1500               | 10,000        | 10,000             | 10,000             |
| Clouds                      | 10,000'<br>Overcast | 3000'<br>scattered | None          | 3500'<br>scattered | 3500'<br>scattered |
| Turbulence                  | Light               | None               | None          | None               | None               |
| Altimeter<br>Setting        | 30.02               | 30.00              | 30.12         | 29.85              | 30.03              |
| Fuel Level (lb)             | 2200-1300           | 2100-1800          | 2200-1000     | 2400-600           | 2300-600           |
| Wind Velocity (kt)          | 5                   | 8                  | 2             | 4                  | 27                 |
| Time<br>Out/Back            | 1005/<br>1115       | 0710/<br>0824      | 1015/<br>1118 | 1450/<br>1550      | 1335/<br>1435      |
| Temperature (°F)            | 52                  | 32                 | 48            | 78                 | 57                 |
| Gear                        | Down                | Down               | Stowed        | Stowed             | Stowed             |
| Flaps                       | 50%                 | 50%                | Up            | Up                 | Up                 |

TABLE VIII  
SELECTED YT-2B FLIGHT CONDITIONS

| Flight Condition Number                   | 1      | 2      |
|-------------------------------------------|--------|--------|
| Nominal Mach Number                       | 0.212  | 0.63   |
| Nominal True Airspeed (ft/sec)            | 236    | 679    |
| Nominal Pressure Altitude (ft)            | 0      | 10,000 |
| Gear Position                             | down   | up     |
| Flap Position (deg)                       | 16     | 0      |
| Speed Brake Position                      | closed | closed |
| Approximate Weight (lb)                   | 11,000 | 11,000 |
| Approximate CG Position (% $\bar{c}$ )    | 20     | 20     |
| Approximate $I_y$ (slug-ft <sup>2</sup> ) | 14,600 | 14,600 |
| Approximate $I_x$ (slug-ft <sup>2</sup> ) | 9,000  | 9,000  |
| Approximate $I_z$ (slug-ft <sup>2</sup> ) | 19,000 | 19,000 |
| Estimated Trim Angle-of-Attack (deg)      | 4.7    | 1.2    |

NOTE: Weight and moment of inertia approximations were based on reference (1).

To maximize the identifiability of the aircraft from the current flight data and to provide a basis for the determination of the effects of input type on identification performance, it was decided that a variety of pilot inputs would be used. The classic step, pulse, and doublet inputs were included. The frequencies of the principal longitudinal modes of motion (short period and phugoid) were estimated, and sine waves at those frequencies were used also. The number of cycles of the sine waves was also varied.

Systems Control, Inc., calculated inputs which they believed to be optimum for identification of parameters which have significant effect on the short period mode. These inputs are shown in Figures 5 and 6. The shape of such inputs is dependent upon the flight condition and the estimated short period characteristics. On the theory that all possible frequencies should be represented in the input, a pseudo-white noise input was also selected.

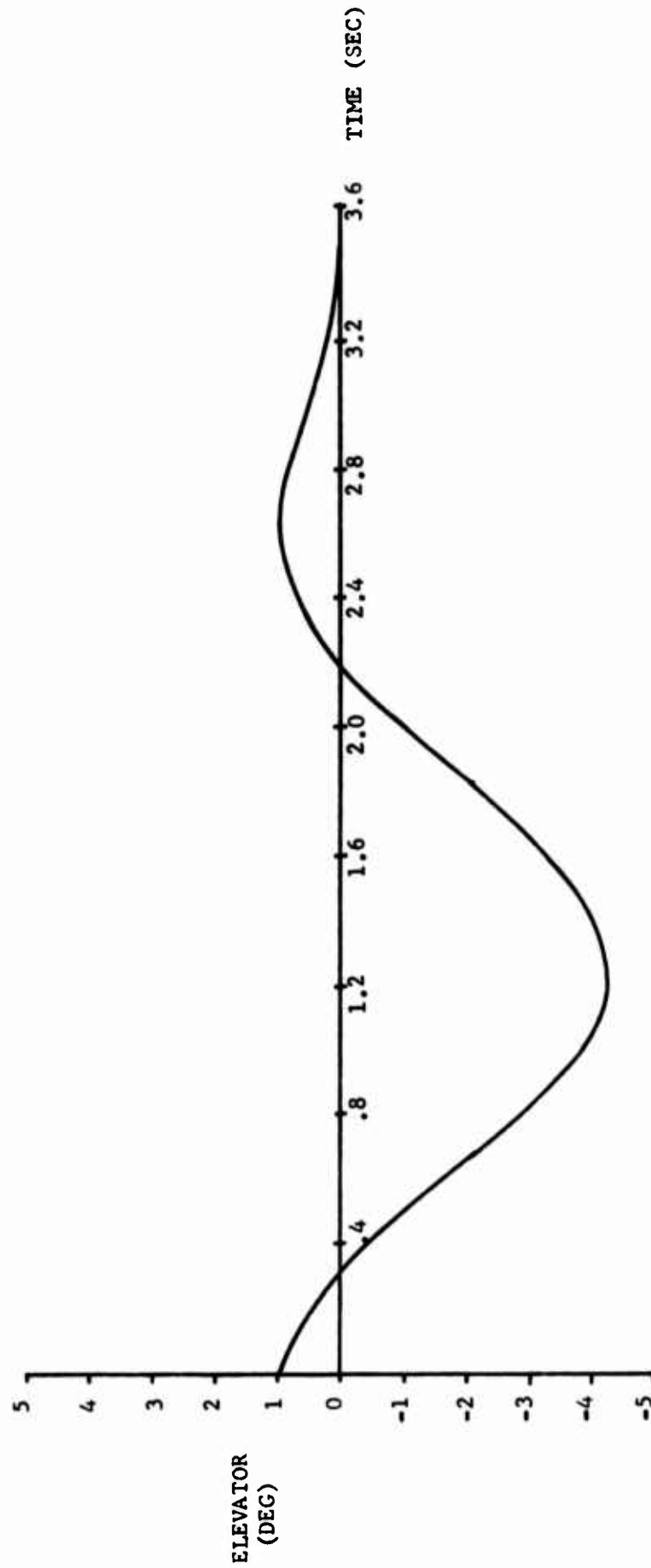


FIGURE 5. SCI OPTIMAL INPUT FOR T-2 SHORT PERIOD, FLIGHT CONDITION #1

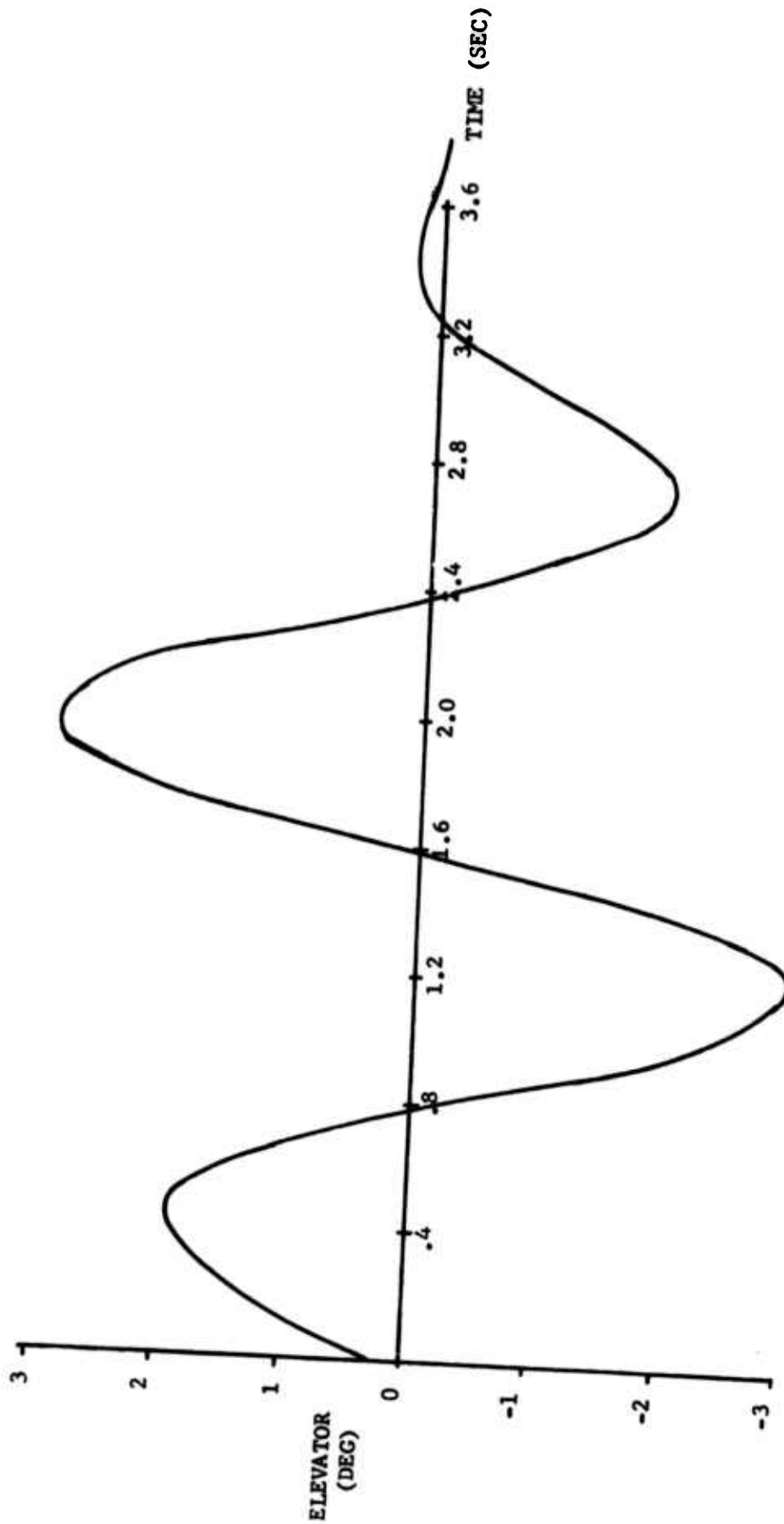


FIGURE 6. SCI OPTIMAL INPUT FOR T-2 SHORT PERIOD, FLIGHT CONDITION #2

The actual shape of the pilot input was, of course, not always identical to the requested command since no automatic equipment was available to aid the pilot in making these relatively complex stick movements. After some practice, however, the pilots (who were not test pilots) developed a high degree of skill in executing the planned inputs. Whenever the real-time telemetry system was in operation, the pilot inputs could be observed at the ground station in graphical form and corrections could be dictated to the pilot immediately. This iterative process would quickly converge to an acceptable approximation of the requested input.

The amplitudes of the inputs were also determined iteratively. Acceptable amplitudes were difficult to obtain in some cases. The goal in the selection of input size was to force all significant output variables to be large enough for a reasonable signal-to-noise ratio while remaining small enough to permit the use of the linear approximations to the equations of motion and to remain within the ranges of the transducers. An additional problem existed at flight condition #1, since the pilots were reluctant to permit significant altitude variations while in proximity to the ground. Unfortunately, altitude variations are inherent in the phugoid mode, and it was therefore difficult to find any input which would generate a phugoid output without exceeding any of the constraints placed on the tests.

The rapid doublet input was eventually abandoned since too large an elevator deflection was required for sufficient excitation of aircraft response. The SCI optimum input was never successfully generated in flight condition #1, and cannot be evaluated.

#### SOURCES OF NOISE

The scope of this effort did not permit any attempt at quantitative analysis of noise contributions from various sources, nor of the sensitivity of identification performance to levels of noise of different types. It is possible, however, to list the known sources of noise and evaluate their importance subjectively based on the experiences of the investigators.

It is generally recognized that noise can be broadly divided into two types: process noise and measurement noise. In theory, the modified Newton-Raphson identification technique used in this in-house investigation is more affected by process noise. Given sufficient quantities of data, this algorithm will produce unbiased estimates even in the presence of measurement noise, but the technique does not tolerate significant process noise. The theoretical sensitivity of various types of identification techniques to different noise types has been discussed many times (see, for instance, reference (m)), and will not be discussed in this report.

Process noise can be further subdivided into turbulence and modeling error. Atmospheric turbulence was not noticeable on any flight at flight condition #2, but was present for the low altitude flight condition #1. Every effort was made to fly early in the day to minimize turbulence. As can be seen in Table VII, the flight of 3/21/73 occurred rather early in the day and the turbulence level was such that the pilot termed it "none", given

a choice of "none", "light", "moderate", and "heavy". On 3/14/73 the flight did not occur until late morning and turbulence was "light". Several additional flights were launched at 0700 or earlier, but data from these flights was found unacceptable for reasons other than turbulence considerations. Turbulence, then, should not be a factor in analysis of flight condition #2 data, but might have a degrading influence on identification at condition #1.

The mathematical model (equations of motion) used in this analysis is discussed elsewhere in this report. Substantial errors in the longitudinal equations per se are unlikely, but one must consider the validity of the assumption that the longitudinal and lateral-directional motions are independent. Although the lateral-directional motions occurring during the longitudinal maneuvering are not large, there are noticeable excursions in sideslip. It would have been possible to include in the model some sideslip effects and consider the sideslip as an external input (i.e., an additional control), but this work was judged to be outside the scope of the current program. In summary, the investigators suspect that process noise is present, but not in sufficient degree to impede the identification process, in spite of the theoretical sensitivity of the identification technique to process noise.

In theory, every change in the nature or the format of the flight motion data introduces some measurement noise. It is clearly desirable to minimize the number of transformations in the process of changing physical aircraft motions into digital computer identification program inputs. However, it was necessary that already available NAVAIRDEVCON equipment be used in this investigation, and the number of data transformations became rather large. The recording and data reduction procedures have been described in a previous section of this report, and the various transformations will only be summarized here. The physical motions were sensed by transducers, which output electrical signals in analog form. These signals were frequency modulated and multiplexed for single channel recording. They were then demultiplexed, demodulated, sampled (at 20 samples/second), and recorded as digital information. These digital data were read from tape, re-organized to a form compatible with the NAVAIRDEVCON CDC 6600 computer, decalibrated (converted to physical units), transformed to the stability axis system, and written onto a disk file to be available for input to identification programs. Based on the investigators' observations of the data throughout the processes outlined above, it seems that substantial noise was introduced by these repeated transformations.

Specifically, "bad points" arose in the data both from the commutator and the analog/digital conversion. These saturated data points had to be deleted, and their places occupied by interpolated information. Zero and full-scale reference values for both modulation and analog/digital conversion were subject to drifting. Each recording/playback process introduced noise from the recording device.

Although no transducer is perfect, only three of the longitudinal flight motion transducers in the YT-2B caused noticeable problems: elevator position, airspeed, and angle of attack. Every transducer selection involves some coarse/fine trade-off. In the case of elevator position, it was determined that the entire range of deflection would have to be included, so a potentiometer

was installed on the actuator and calibrated for the entire  $-27^{\circ}$  to  $+15^{\circ}$  deflection range. At high dynamic pressure flight conditions, however, the elevator movement about its trim position was quite small (on the order of magnitude of  $1^{\circ}$ ), and the resulting signal-to-noise ratio for the data was rather poor. No straightforward solution was found to this problem because the elevator trim position varied considerably with flight condition. The noise level in elevator data was high even for flight conditions in which large elevator deflections were used, indicating that sources of noise other than resolution difficulties are also contributing.

Airspeed measurement presented a problem analogous to the elevator position measurement problem: small perturbations about a large trim value. For airspeed measurement, however, two sensors were used - a 0-500 kt coarse transducer and a 0-50 kt resetting fine transducer. This system worked well except that the fine transducer was "undecided" about resetting between 48 and 50 knots. At, and just below, any multiple of 50 knots airspeed, the airspeed measurement becomes useless as the transducer continuously switches between full scale and zero readings. This problem is strictly a hardware phenomenon, but no other hardware was available.

A filter on the velocity signal was used to process some of the data. This digital filter simply eliminated velocity values which were excessively different from a previous data point, and reset the excessive value to equal the previous data point. Thus the bursts of sharp peaks in the signal were reduced to constant value "flap spots". For the in-house identification effort, however, this filter was applied only to the worst data cases because extensive use would have compromised the principle of minimizing the engineering interaction with the details of the identification process.

Angle of attack was measured by a vane mounted on a noseboom. The vane mounting position was sufficiently forward of the wing for upwash effects to be negligible. However, the vane appeared to have dynamic characteristics which varied from day to day as the friction on the pivot changed with weather, time, etc. Unfortunately, no means of dynamic calibration for the vane was available.

In summary, the investigators suspect that most of the noise in the flight data was measurement noise. It is especially significant that measurement noise was considerable in the control input, since theoretical parameter identification studies generally consider the input as a noise-free measurement.

#### SELECTION OF MATHEMATICAL MODEL

The general equations of motion for aircraft flight are quite complex, but numerous assumptions are often made to justify simplification of the equations for a particular application. Two simplifying assumptions were implicit in the definition of this project: (1) longitudinal equations may be decoupled from lateral-directional equations, and (2) small perturbation theory and small angle approximations are applicable to the flight motions. Equations based on these assumptions are developed in many texts, but reference (n) was used for this project.

The modified Newton-Raphson computer program (and most other identification schemes) requires that the model be in the state vector form

$$\dot{x} = Fx + Gu$$

where  $x$  is the vector of the motion states,  $u$  is the control vector,  $F$  is the matrix of stability derivatives, and  $G$  is the matrix of control derivatives. The equations of motion are not usually written in such a form when used for dynamics analysis, but they can be manipulated to the proper form. The resulting equations are listed in Table IX.

During the identification process, the equations were simplified even further, as  $Z_{\dot{\alpha}}$ ,  $Z_q$ ,  $X\delta_e$ , and  $\gamma_o$  were all taken to be zero. The quantities  $\dot{u}$  and  $\dot{v}$  were not measured, but were calculated from  $a_x$  and  $a_z$  using auxiliary equations.

With the equations of motion in the state vector form, it is clear that no straightforward solution for  $M_{\dot{\gamma}}$  is possible. Various schemes were considered, including the use of the auxiliary relationship  $M_{\delta_e} = \text{tail length} \times Z_{\delta_e}$  and obtaining data at large  $\gamma_o$ , to permit separation of  $M_{\dot{\gamma}}$  from the lumped parameters, but all were eventually discarded as grossly inaccurate or impractical. To separate the identified derivatives for comparison to estimates, either the  $M_{\dot{\gamma}}$  estimate can be assumed correct or the estimates can be combined into lumped parameters and the comparisons done with those quantities.

#### DEVELOPMENT OF A PRIORI PARAMETER SET

Despite occasional claims that various parameter identification techniques will function without any a priori or start-up parameter estimates, it is generally agreed that the use of such estimates substantially increases the chances of success. A priori parameter estimates which merit a high level of confidence may also serve as a basis of comparison for results, but should never be considered the "right answers". Indeed, if a priori estimates were to be considered the "right answers", then there would be no need for parameter identification from flight data.

A priori parameter estimates for the T-2 for the flight conditions of current interest were developed from information in references (f), (i), and (o). The methods used by the aircraft manufacturer to generate this original information are not known, but a reasonable level of confidence would seem appropriate for any information released to the public by the aircraft design team.

The estimated parameters are given in Table X in several forms. Only one set of information is presented, but several formats were used as a convenience to the user. This information has been supplied to all parties receiving the flight data.

TABLE IX  
T-2 LONGITUDINAL EQUATIONS OF MOTION IN STATE VECTOR FORMAT

$$\dot{z} = \left[ \frac{Z_u}{U_0 - Z_{\dot{z}}} \right] u + \left[ \frac{Z_{\alpha}}{U_0 - Z_{\dot{z}}} \right] \alpha + \left[ \frac{U_0 + Z_q}{U_0 - Z_{\dot{z}}} \right] q - \left[ \frac{g \sin \gamma_0}{U_0 - Z_{\dot{z}}} \right] \eta + \left[ \frac{Z_{\delta_e}}{U_0 - Z_{\dot{z}}} \right] \delta_e$$

$$\dot{u} = X_u u + X_{\alpha} \alpha - (g \cos \gamma_0) \eta + X_{\delta_e} \delta_e$$

$$\begin{aligned} \dot{q} = & \left[ M_u + \frac{M_{\dot{z}} Z_u}{U_0 - Z_{\dot{z}}} \right] u + \left[ M_{\alpha} + \frac{M_{\dot{z}} Z_{\alpha}}{U_0 - Z_{\dot{z}}} \right] \alpha \\ & + \left[ M_q + M_{\dot{z}} \left[ \frac{U_0 + Z_q}{U_0 - Z_{\dot{z}}} \right] \right] q - \left[ \frac{M_{\dot{z}} g \sin \gamma_0}{U_0 - Z_{\dot{z}}} \right] \eta \\ & + \left[ M_{\delta_e} + \frac{M_{\dot{z}} Z_{\delta_e}}{U_0 - Z_{\dot{z}}} \right] \delta_e \end{aligned}$$

$$\dot{\eta} = q$$

**TABLE X**  
**A PRIORI VALUES FOR YT-2B AERODYNAMIC PARAMETERS**

| Parameter                             | Dimensions                  | Flight Condition |          |
|---------------------------------------|-----------------------------|------------------|----------|
|                                       |                             | 1                | 2        |
| $C_L$                                 | -                           | 0.642            | 0.106    |
| $C_D$                                 | -                           | 0.110            | 0.018    |
| $C_{L\dot{v}}$                        | -                           | 4.62             | 5.50     |
| $C_{D\dot{v}}$                        | -                           | 0.172            | 0.228    |
| $C_{L\delta_e}$                       | 1/rad                       | 1.049            | -        |
| $C_{L\delta_e}$                       | 1/rad                       | 0.486            | 0.401    |
| $C_{L\dot{u}}$                        | -                           | 0                | 0.031    |
| $C_{D\dot{u}}$                        | -                           | 0                | 0        |
| $C_{m\dot{u}}$                        | -                           | 0                | 0.011    |
| $C_{m\dot{v}}$                        | -                           | -0.597           | -0.429   |
| $C_{m\dot{v}}$                        | -                           | -3.95            | -5.50    |
| $C_{mq}$                              | -                           | -10.59           | -11.86   |
| $C_{m\delta_e}$                       | 1/rad                       | -1.13            | -0.994   |
| $X_u$                                 | 1/sec                       | -0.046           | -0.016   |
| $X_{\dot{v}}$                         | ft/(sec <sup>2</sup> - rad) | -23.23           | -36.91   |
| $Z_u$                                 | 1/sec                       | -0.269           | -0.122   |
| $Z_{\dot{v}}$                         | ft/(sec <sup>2</sup> - rad) | -233.75          | -1669.24 |
| $Z_{\delta_e}$                        | ft/(sec <sup>2</sup> - rad) | -24.02           | -121.30  |
| $M_u$                                 | 1/(ft - sec)                | 0                | 0.0017   |
| $M_{\dot{v}}$                         | 1/(sec <sup>2</sup> - rad)  | -5.11            | -22.50   |
| $M_{\dot{v}}$                         | 1/(sec - rad)               | -0.53            | -1.57    |
| $M_q$                                 | 1/(sec - rad)               | -1.42            | -3.39    |
| $M_{\delta_e}$                        | 1/(sec <sup>2</sup> - rad)  | -9.68            | -52.12   |
| $-g (\cos \nu_0)/U_0$                 | 1/sec                       | -0.134           | -0.047   |
| $Z_u U_0/(U_0 - Z_{\dot{v}})$         | 1/sec                       | -0.27            | -0.12    |
| $Z_{\dot{v}}/(U_0 - Z_{\dot{v}})$     | 1/sec                       | -0.974           | -2.46    |
| $(U_0 + Z_q)/(U_0 - Z_{\dot{v}})$     | -                           | 1.0              | 1.0      |
| $-g (\sin \nu_0)/(U_0 - Z_{\dot{v}})$ | 1/sec                       | 0                | 0        |

TABLE X (CON'T)  
A PRIORI VALUES FOR YT-2B AERODYNAMIC PARAMETERS

| Parameter                                                                         | Dimensions         | Flight Condition |        |
|-----------------------------------------------------------------------------------|--------------------|------------------|--------|
|                                                                                   |                    | 1                | 2      |
| $X_{\dot{\gamma}}/U_o$                                                            | 1/sec              | -0.097           | -0.054 |
| $X_{\delta_e}/U_o$                                                                | 1/sec              | 0                | 0      |
| $(U_o (\dot{M}_u + M_{\dot{\gamma}} Z_u/U_o - Z_{\dot{\gamma}}))$                 | 1/sec <sup>2</sup> | 1.43             | 1.34   |
| $M_{\dot{\gamma}} + (M_{\dot{\gamma}} Z_{\dot{\gamma}}/(U_o - Z_{\dot{\gamma}}))$ | 1/sec <sup>2</sup> | -4.59            | -18.6  |
| $M_q + M_{\dot{\alpha}} ((U_o + Z_q)/(U_o - Z_{\dot{\alpha}}))$                   | 1/sec              | -1.95            | -4.96  |
| $-(M_{\dot{\gamma}} g \sin \gamma_o)/(U_o - Z_{\dot{\gamma}})$                    | 1/sec <sup>2</sup> | 0                | 0      |
| $Z_{\delta_e}/(U_o - Z_{\dot{\gamma}})$                                           | 1/sec              | -0.102           | -0.18  |
| $M_{\delta_e} + (Z_{\delta_e} M_{\dot{\gamma}}/(U_o - Z_{\dot{\gamma}}))$         | 1/sec <sup>2</sup> | -9.63            | -51.8  |

The conditions of each actual data run are, of course, slightly different from each other and from the nominal flight condition. For the in-house identification analysis, a separate set of combined start-up parameters was generated for each run reflecting the differences in trim velocity.

## I N - H O U S E   I D E N T I F I C A T I O N C O M P U T E R   P R O G R A M

### ACQUISITION

The identification technique used in this effort was a modified Newton-Raphson algorithm. The computer program was provided (informally) by Mr. Larry Taylor of NASA-Langley Research Center. The rationale of the program and an example of its application are given in reference (p). Reference (q) is a "user's guide" for the program. In fact, the computer program has been documented so thoroughly that it would be redundant to discuss it in this report. Minor changes were made to the program in accordance with references (r) and (s), and some modifications had to be made to adapt the program to the current NAVAIRDEVCON CDC 6600 computer operating system.

### VERIFICATION

At the time of its acquisition by NAVAIRDEVCON, the computer program had been configured for analysis of lateral-directional dynamics. To minimize the number of immediate programming changes, it was decided that the program would first be applied to lateral-directional "flight data" generated by a digital computer simulation of the T-2, and then the program would be tried on longitudinal data. Results of the first run on lateral-directional data are shown in Table XI. Since the data are theoretically noiseless and the same equations of motion were used in both the simulation and identification computer programs, the identification should be perfect if all controls are used. Both aileron and rudder were applied in the simulation program.

Run 1 results indicate that the parameter identification was excellent, but not perfect. Small errors existed in almost all parameters, and  $N_p$ ,  $Y_p$ , and  $Y_{\delta_a}$  were not identified at all. It is customary to neglect  $Y_{\delta_a}$  and  $Y_p$  in most applications, and  $N_p$  was very small in this case, although  $N_p$  can be an important derivative in some cases. It is clear, then, that some noise was present after all. The investigators suspect that the source of the noise was an incompatibility in the integration schemes used in the digital computer programs for identification and flight simulation. Any quantification error resulting from integration algorithm mismatch was a phenomenon unique to application of the identification method to digitally simulated flight data, so that the problem should not exist in applications of the program to true flight data, and no further investigation was made.

Several types of gusts were added to the flight data to test the reaction of the identification program to process noise. The characteristics of runs 2 through 5 are given in Table XII. It can be seen from the results, given

TABLE XI  
RESULTS OF  
IDENTIFICATION OF COMPUTER-GENERATED  
LATERAL-DIRECTIONAL T-2 DATA

| Actual<br>Parameter<br>Value | Run Number |          |          |          |          |          |          |
|------------------------------|------------|----------|----------|----------|----------|----------|----------|
|                              | <u>1</u>   | <u>2</u> | <u>3</u> | <u>4</u> | <u>5</u> | <u>6</u> | <u>7</u> |
| L <sub>p</sub>               | -6.69      | -6.66    | -6.79    | -7.35    | -7.43    | -6.71    | -6.40    |
| L <sub>r</sub>               | 1.38       | 1.41     | 1.44     | .64      | .60      | 1.70     | 1.59     |
| L <sub>q</sub>               | -46.2      | -45.5    | -46.9    | -48.1    | -48.9    | -46.4    | -44.6    |
| L <sub>δa</sub>              | -82.3      | -82.9    | -83.8    | -85.8    | -86.8    | -82.3    | -80.4    |
| L <sub>δr</sub>              | 8.1        | 8.2      | 7.3      | 7.4      | 7.8      | 8.1      | 8.3      |
| N <sub>p</sub>               | -.0087     | -.0026   | .036     | .37      | .42      | .015     | -.07     |
| N <sub>r</sub>               | -.931      | -.946    | -.937    | -.474    | -.473    | -1.10    | -.867    |
| N <sub>q</sub>               | 24.9       | 24.7     | 25.2     | 26.3     | 26.6     | 25.0     | 24.5     |
| N <sub>δa</sub>              | -1.78      | -1.30    | -1.12    | .40      | .99      | -1.70    | -1.94    |
| N <sub>δr</sub>              | -13.9      | -14.0    | -13.4    | -13.7    | -13.8    | -13.9    | -13.9    |
| Y <sub>p</sub>               | -.679      | -8.1     | -7.4     | -3.9     | 1.26     | 1.93     | -9.9     |
| Y <sub>q</sub>               | -266.6     | -296.8   | -254.7   | -383.7   | -353.9   | -134.6   | -381.    |
| Y <sub>r</sub>               | 4.116      | -6.43    | 2.62     | -4.08    | 3.47     | 4.41     | -.17     |
| Y <sub>δa</sub>              | 0          | -63.2    | -155.0   | -26.6    | 27.8     | 27.7     | -106.    |
| Y <sub>δr</sub>              | 41.6       | 43.6     | 2.6      | 122.9    | 124.     | -24.5    | 75.9     |

TABLE XII  
NOISE CHARACTERISTICS OF COMPUTER-GENERATED  
T-2 FLIGHT TIME HISTORIES

| <u>Run No.</u> | <u>Characteristics</u>                                                                                                                                              |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.             | Noiseless. Should be perfect identification. Used as reference.                                                                                                     |
| 2.             | Low amplitude, low frequency, sinusoidal $\beta$ and r gusts. No p gusts.                                                                                           |
| 3.             | Moderate amplitude, moderate frequency, sinusoidal $\beta$ and r gusts; and low amplitude, high frequency p gusts.                                                  |
| 4.             | Amplitude and spectral characteristics of $\beta$ gusts per MIL-F-8785B. No r or p gusts.                                                                           |
| 5.             | Amplitude and spectral characteristics of $\beta$ and r gusts per MIL-F-8785B. No p gusts.                                                                          |
| 6.             | No gusts. Lag with .098 second time constant introduced in $\beta$ vane.                                                                                            |
| 7.             | No gusts. Pseudo-random noise in all measurements. Noise amplitudes selected on basis of Cornell Aeronautical Laboratory experience in X-22 identification program. |

in Table XI, that the the quality of the identification process deteriorates rapidly as gust intensity is increased. The presence of turbulence, having the characteristics set forth in section 3.7 of military specification MIL-F-8785B (ASG) for ambient atmospheric turbulence, is sufficient to seriously degrade the performance of the identification method. The results obtained by the computer program from flight data acquired under such turbulence conditions could be used only to specify  $\pm 10\%$  estimates of  $L_a$ ,  $L_{\delta_a}$ ,  $L_{\delta_r}$ ,  $N_{\delta}$ , and  $N_{\delta_r}$ , a  $\pm 15^\circ$  estimate of  $L_p$ , and no estimates of the other parameters.

These poor results are not unexpected, since the modified Newton-Raphson algorithm is known to give biased results in the presence of process noise. Whenever a consistent set of turbulence characteristics of a particular level (e.g., light turbulence, moderate turbulence, MIL-F-8785 ambient turbulence) is present, the  $\beta$  gusts are far more damaging to identification quality than  $r$  or  $p$  gusts.

Run 6 was made to evaluate the effect of a lag in the  $\beta$ -vane, and all other noise was temporarily deleted to isolate this effect. The presence of this small uncompensated time lag in the sideslip vane seriously corrupts estimation of  $Y_{\beta}$ ,  $Y_{\delta_r}$ ,  $N_r$ , and  $L_r$ , and has a lesser effect on the other derivatives. This result is curious, since the four listed derivatives are not those which one would expect to be affected most, but the important conclusion is that the existence of the lag is sufficient to seriously disrupt the identification process.

In theory, the operation of the modified Newton-Raphson algorithm is not biased by the presence of zero mean white Gaussian measurement noise. While the results from the application of the identification method to any individual set of time histories may be corrupted by the presence of measurement noise, the mean value of the parameter estimates will approach the true parameter values during repeated analysis of different sets of time histories for the same flight condition. No source of truly white noise was available for data generation, so a zero-mean approximation was developed. The noise amplitudes were selected on the basis of Calspan Corporation experience with flight testing of the X-22 aircraft in reference (e).

The results from the identification program operating in the presence of such pseudo-random measurement noise may be described as fair. The  $L_p$ ,  $L_{\beta}$ ,  $L_{\delta_a}$ ,  $L_{\delta_r}$ ,  $N_r$ ,  $N_{\beta}$ ,  $N_{\delta_a}$ , and  $N_{\delta_r}$  parameters are estimated within  $\pm 10\%$  error. These results are presented as run 7 in Table XI.

The longitudinal form of the identification program was also tested, albeit briefly. When the initial parameter values are identical to the correct results, the first iteration of the program has a very low fit error. If the program is allowed to continue to iterate, a slightly smaller fit error is obtained with a set of stability derivatives somewhat different from the correct value. Presumably, this problem is analogous to the slight disparities found in the lateral-directional data identification.

It must be noted that the weighting matrix in the identification program was not used during these applications of the program. These experiments were performed immediately after acquisition of the program, and it was felt at that time that use of the weighting matrix would be difficult and would violate the concept of an "off-the-shelf" program to be used in "cookbook" fashion. Later experiences, described elsewhere in this report, revealed that the weighting matrix could be used easily and in straightforward manner, and that its use would substantially improve the performance of the program on noisy data.

#### IN - HOUSE IDENTIFICATION PROCEDURES

A number of "data runs" were selected from the original flight data. These runs were processed by program MESSAGE (see listing, Appendix A) to a reduced form. The runs were then analyzed individually by program NEWTON (see listing, Appendix B). In most cases 350 data points were extracted from the input data file for each identification run. The time location of these points was selected to place the control input several seconds from the beginning. For some runs, less than 350 points were available (data run 6, for instance, only had 200 data points before occurrence of excessive noise). At 20 data points per second, these 350 point data sets were 17.5 seconds in length. In an attempt to extract velocity derivatives from longer data runs, a mechanism was provided in the program for reading only every second, or third, or fourth data point, so that 350 data points were still used, but the time interval was multiplied.

A bad point filter was used in the identification program, which substituted a reasonable value (calculated by extrapolation from previous points) for any data point which was completely off scale. A somewhat more restrictive filter was applied to airspeed in those instances where spikes existed from transducer switching. This filter also operated with the substitution/extrapolation method. These were the only filters used on the flight condition #1 data - there was no general, lowpass filtering done during A/D conversion.

The very low signal/noise ratios in the elevator flight data for flight condition #2 led to the use of several relatively extreme measures. The elevator signal was treated with a weighted average smoothing routine. Only a three point width smoothing interval was used to prevent excessive loss of high frequency signal content, and the signal was smoothed either once or twice. The suppression of the elevator signal to zero following the significant portion of the control input was also done for the data sets containing "spikes". The smoothing was done after the suppression to maintain a smooth transition.

The identification program contained a weighting matrix which weighted the importance of the time history matches in the parameter update iteration process. The program printout lists the weighted contributions to the overall time history fit error, and the diagonal elements of the weighting matrix should each be the inverse of the corresponding weighted fit error term. This process of adjusting the weighting matrix thus became an outer iterative loop - the inner loop being the parameter determination with a fixed weighting matrix.

The weighting matrix was updated manually, and after two or three iterations the weighted fit error terms would usually all be nearly equal to 1 (between 0.9 and 1.1), which of course was a terminal condition since further inversion would yield no changes. The process of correcting the weighting matrix clearly could be included in the program itself if one wished to make the necessary effort. The effect of the weighting matrix was to compensate for the dimensional differences in the time histories (in effect a normalization) and to proportion the significance of each time history inversely with its noise level.

In most cases, all the identifiable derivatives were left as variables, but on the longer time (such as 52.5 seconds) runs, the short period derivatives were held constant at the values determined for those derivatives by analysis of the first 17.5 seconds of the same data run.

The variables read into the identification program from the data message program were  $\hat{a}_e$ ,  $\omega$ ,  $\theta$ ,  $q$ ,  $\dot{q}$  (calculated from linear accelerations),  $\dot{q}_2$  (measured directly),  $u$ ,  $a_x$ ,  $a_z$ ,  $h$ ,  $\hat{a}_b$ . Of these variables,  $\dot{q}$ ,  $h$ , and  $\hat{a}_b$  were not usually used by the identification program. The  $\dot{q}$  signal appeared far more noisy than the  $\dot{q}_2$  signal and therefore was abandoned. The mechanization of the computer program had no provision for use of altitude information, and speed brakes simply were not used by the pilot during any of the selected data runs.

Since the equations of motion in the program are in state variable format,  $a_x$  and  $a_z$  were used to calculate, respectively,  $\dot{u}$  and  $\dot{\omega}$ , which were the matched variables along with  $\omega$ ,  $u$ ,  $\theta$ ,  $q$ , and  $\dot{q}$ .

According to reference (q), the output from the computer program includes "the approximate standard deviation if the inverse of the noise covariance matrix is used" for the weighting matrix. The investigators on this project felt, however, that the method of calculation of this "approximate standard deviation" was not necessarily valid. It was decided not to attempt to use this quantity as a measure of estimation quality, and no other confidence level indicator was developed.

## IN - HOUSE IDENTIFICATION RESULTS

### SUMMARY OF FLIGHT CONDITION NO. 1

Flight condition #1 time history data included data runs 2 through 6. A tabular summary of the stability derivatives obtained from the various modified Newton-Raphson identification attempts with these data is given in Appendix C. A tabular summary of the results of significant runs, reduced with respect to velocity and reduced with an assumed  $M_\infty$  and  $Z_\infty$ , is given in Table XIII. The reduced form will be used for most discussions because it is more universal and more easily compared to estimates, even though some inaccuracy is clearly introduced by the assumption of a known  $M_\infty$ . Although

TABLE XIII  
FLIGHT CONDITION #1 FINAL RESULTS

| Run               | $X_u$  | $X_\alpha$ | $Z_u$  | $Z_\alpha$ | $M_u$  | $M_\alpha$ | $M_q$ | $Z_{\delta e}$ | $M_{\delta e}$ |
|-------------------|--------|------------|--------|------------|--------|------------|-------|----------------|----------------|
| A Priori          | -0.046 | -23.23     | -0.27  | -233.8     | 0      | -5.11      | -1.42 | -24.           | -9.68          |
| <u>Data Run 3</u> |        |            |        |            |        |            |       |                |                |
| 1W2               | -0.046 | -5.7       | -0.28  | -235.3     | -0.001 | -4.97      | -1.22 | -21.7          | -7.20          |
| 1W1DEZ            | -0.044 | +0.4       | -0.22  | -198.3     | +0.003 | -5.11      | -1.50 | -22.7          | -7.71          |
| 2W2               | -0.047 | -7.4       | -0.37  | -201.6     | -0.003 | -4.77      | -1.66 | -22.0          | -7.15          |
| U2W1              | -0.054 | -5.7       | -0.41  | -235.3     | -0.004 | -4.97      | -1.22 | -22.2          | -7.20          |
| U3W2              | -0.046 | -5.7       | -0.39  | -235.3     | -0.004 | -4.97      | -1.22 | -22.2          | -7.20          |
| <u>Data Run 2</u> |        |            |        |            |        |            |       |                |                |
| 1W3               | -0.076 | -10.92     | + .069 | -311.8     | +0.002 | -5.64      | -1.24 | -21.6          | -9.32          |
| <u>Data Run 4</u> |        |            |        |            |        |            |       |                |                |
| 1W4               | -0.036 | -10.63     | -0.22  | -222.6     | -0.004 | -4.69      | -1.28 | -23.0          | -8.26          |
| <u>Data Run 5</u> |        |            |        |            |        |            |       |                |                |
| 1W3               | +0.034 | +5.11      | -0.35  | -240.6     | +0.004 | -5.36      | -1.32 | -26.3          | -8.65          |
| <u>Data Run 6</u> |        |            |        |            |        |            |       |                |                |
| 1W3SH             | 0      | -8.55      | -0.24  | -233.2     | +0.001 | -4.90      | -1.33 | -21.6          | -8.15          |

the trim velocity has been eliminated as a direct effect on the identified derivatives, it is still true that velocity varies significantly among the five data runs, and some variation in the dimensional stability derivatives is to be expected with variation in trim velocity. Time history matches for all of the runs included in Table XIII, as well as some other matches from preliminary runs, are shown in Figures 7 through 16.

#### EFFECT OF WEIGHTING MATRIX AND START-UP VALUES

The first identification attempt was made on data run 3 with an identity weighting matrix and all zero start-up values, but only a divergence was obtained. A converging run was eventually obtained using a set of start-up values which were the "best guess" a priori stability derivatives, based on the trim velocity of data run 2 (which had also been tried with zero start-up values but diverged). Under these circumstances, the program converged, but the stability derivatives were virtually unchanged from the start-up values and the time history matches (see Figure 7) showed significant problems. Also visible in Figure 7 are the poor signal-to-noise ratio for the elevator input and a typical unfiltered velocity transducer switching problem. This first identification run, however, did provide sufficient information to calculate a weighting matrix. The next run (Figure 8) showed significant improvement, and a second iteration (Figure 9) brought about a respectable time history match and a series of weighted fit error contributions nearly equal to one.

#### EFFECT OF ZEROED CONTROL INPUT

In an effort to assess the damage caused to the identification process by the noisy elevator input, a run was made with  $\delta_e$  set to zero after the pilot control input was clearly completed. Unfortunately, an overzealous velocity filter set questionable velocity data to zero as well, rather than simply smoothing. This distortion of the velocity time history was felt to be relatively insignificant, however. The time history matches (see Figure 10) are quite similar, but comparison of run DR3-1W2 and run DR3-1WDEZ results in Table XIII shows that noticeable changes occur in the identified derivatives, so control noise clearly was a factor.

One identification run was accidentally made with the control input zeroed for the entire time history with the time histories of the other variables intact. Such an exercise is only of academic interest, of course, but the results do reveal some interesting aspects of the operation of the identification algorithm. The program returned values for the control derivatives which were equal to the a priori values, rather than calculating very large numbers or refusing to find a solution. The implication is clearly that the algorithm tends to retain the a priori parameter values when given insufficient information to estimate the parameters. This behavior may explain the phenomenon of reasonable estimation of the speed derivatives from short data records with little or no speed variation.

# KEY TO TIME HISTORY COMPARISONS

Solid lines are flight data. Dotted lines are calculated responses. For elevator time history, solid line is measured input data while dotted line is smoothed version actually used as input for identification program.

DE = elevator deflection, degrees, positive trailing edge up

A = angle of attack, degrees, positive for airplane nose up

U = airspeed, ft/sec

TH = pitch angle, degrees, positive for airplane nose up

Q = pitch rate, radians/seconds, positive clockwise viewed from port side of aircraft

AX = longitudinal acceleration,  $\text{ft/sec}^2$ , positive forward

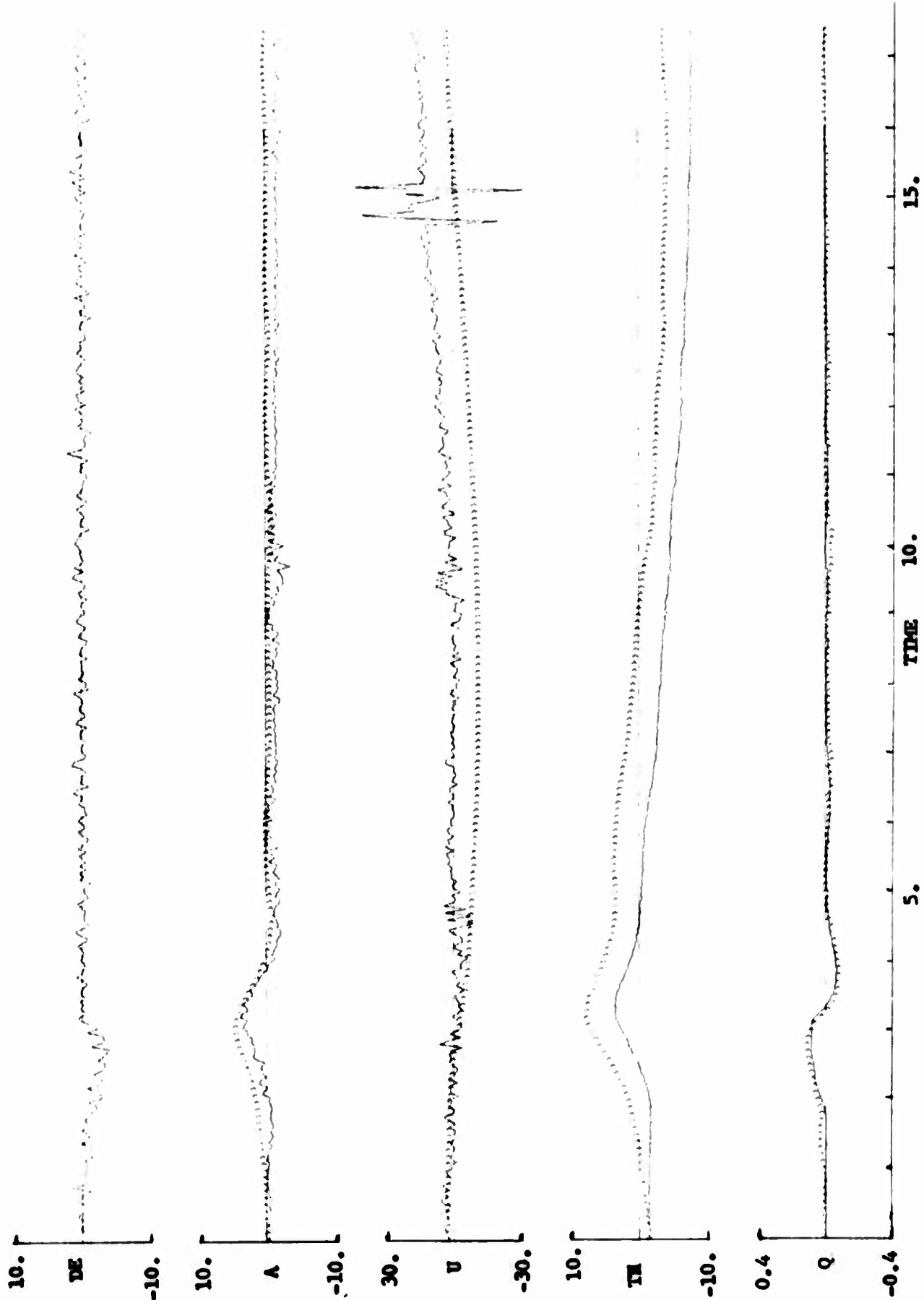
AZ = normal acceleration,  $\text{ft/sec}^2$ , positive down

QD = pitch acceleration,  $\text{radians/sec}^2$ , positive clockwise viewed from port side of aircraft

TIME = elapsed time, seconds

Run number coding:

1. Digit after "DR" is data run number.
2. "U" after hyphen indicates that only speed derivatives were variables.
3. First digit is time length in multiples of 17.5 seconds.
4. Digit after "W" is number of iterations to obtain satisfactory weighting matrix.
5. Digit after "S" is number of times smoothing applied to input data.
6. Absence of "W" or "S" indicates absence of weighting or smoothing, respectively.
7. "DEZ" indicates elevator set to zero following significant control input.



5. TIME 10. 15.  
FIGURE 7. TIME HISTORY COMPARISON DR3-1



5. TIME 10. 15.  
FIGURE 8. TIME HISTORY COMPARISON DR3-1W1

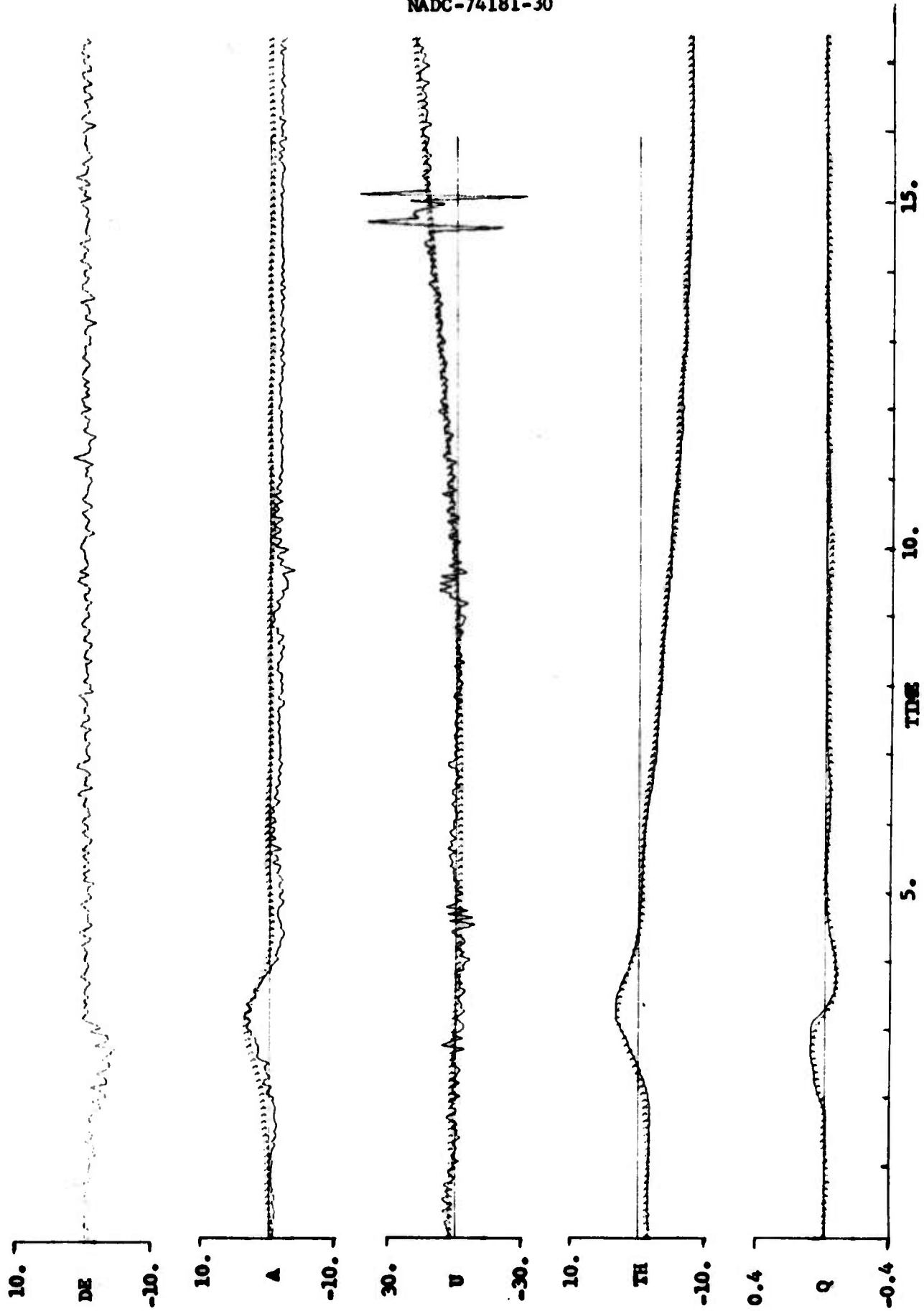


FIGURE 9. TIME HISTORY COMPARISON DR3-IW2

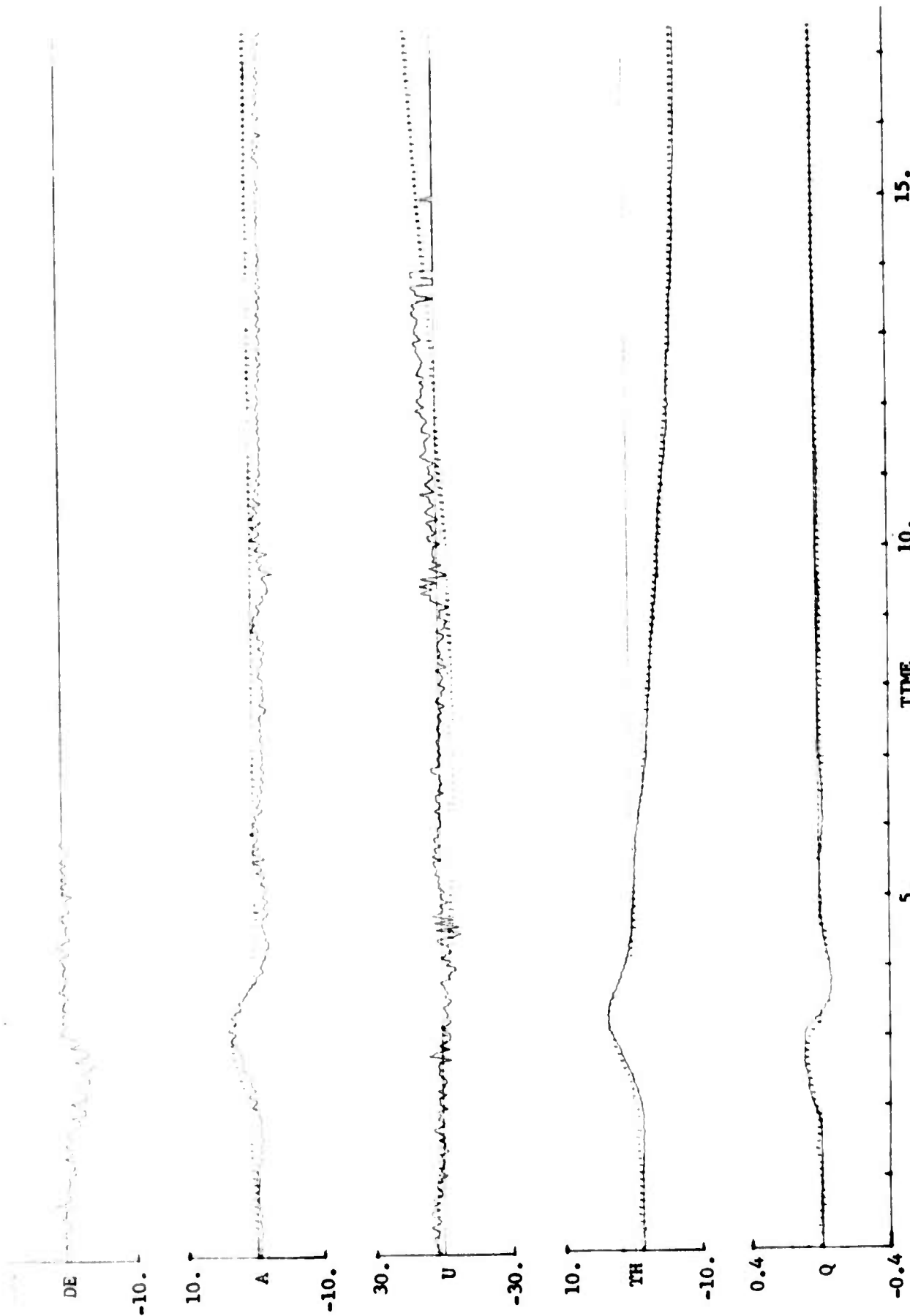


FIGURE 10. TIME HISTORY COMPARISON DR3-IWIDEZ

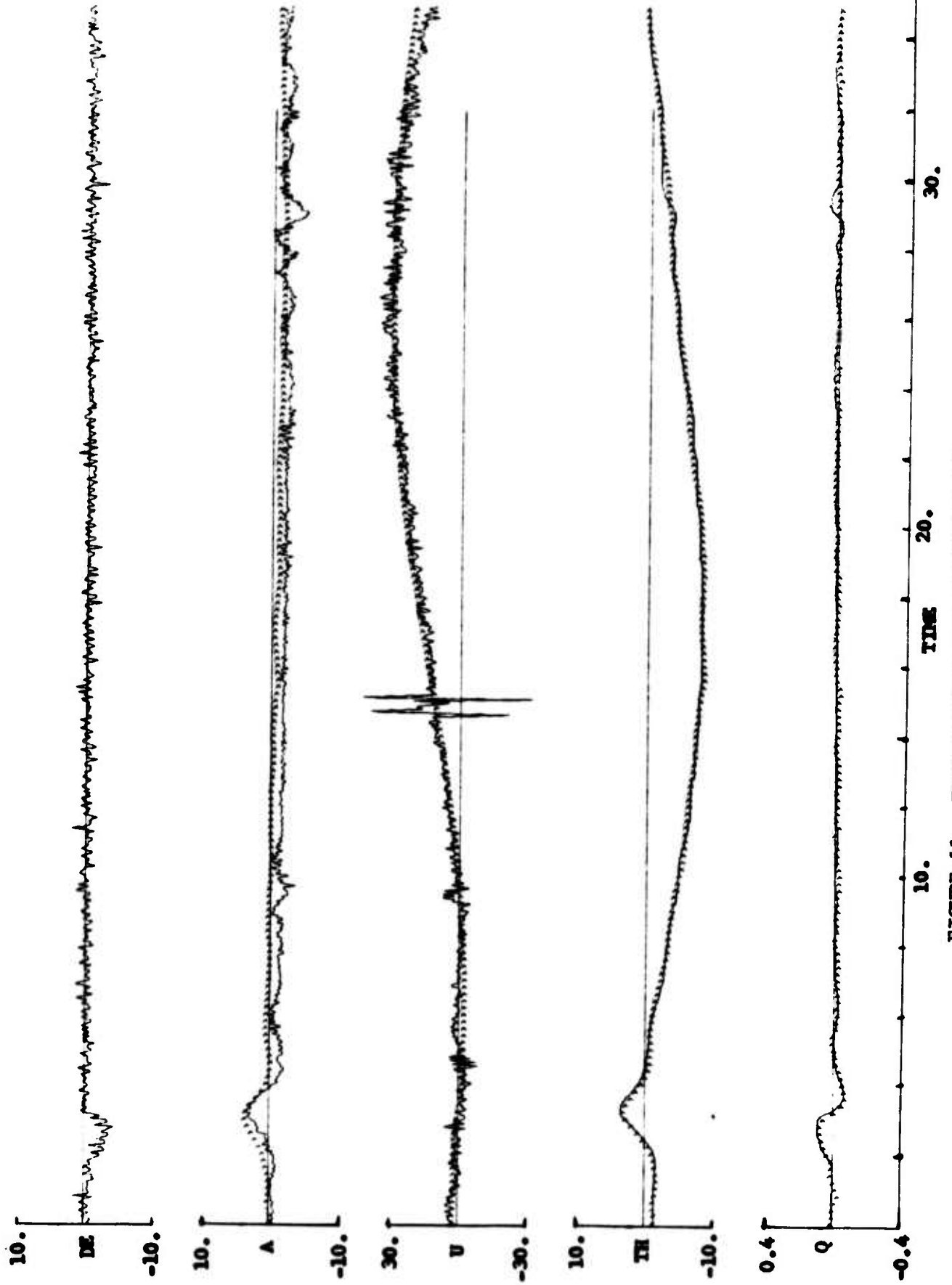


FIGURE 11. TIME HISTORY COMPARISON DR3-2W2

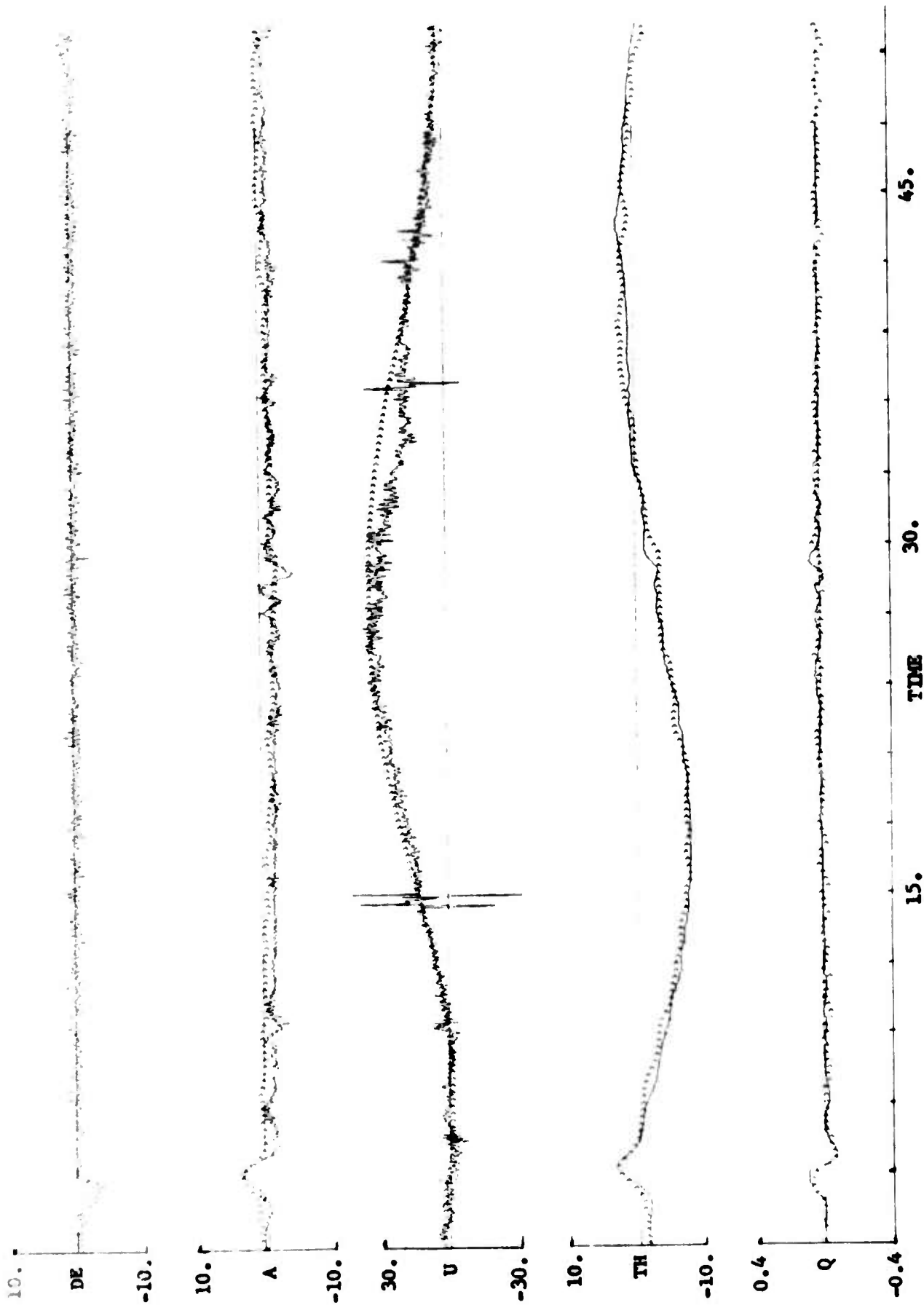


FIGURE 12. TIME HISTORY COMPARISON DR3-U3W2

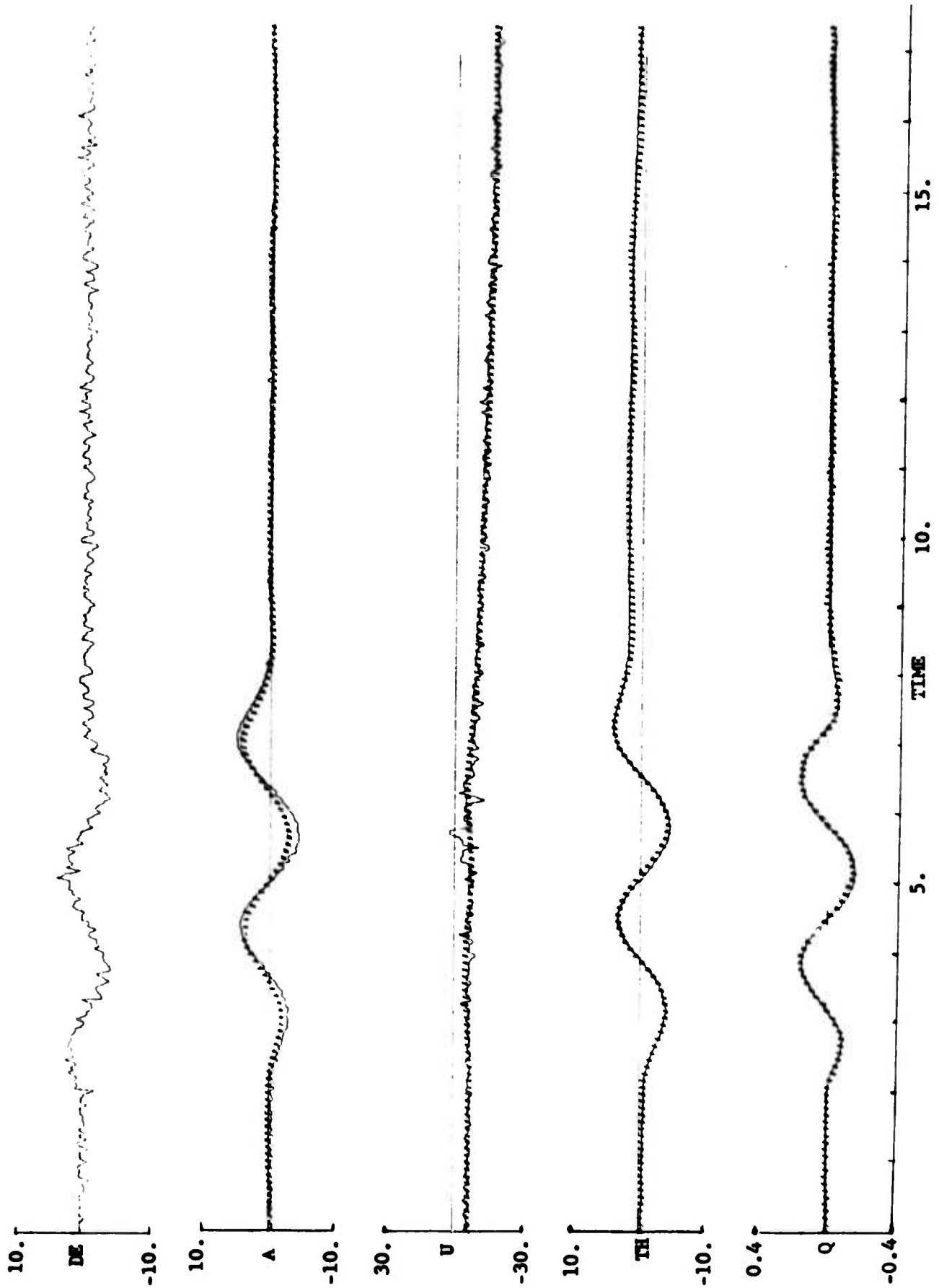


FIGURE 13. TIME HISTORY COMPARISON DR2-1W3

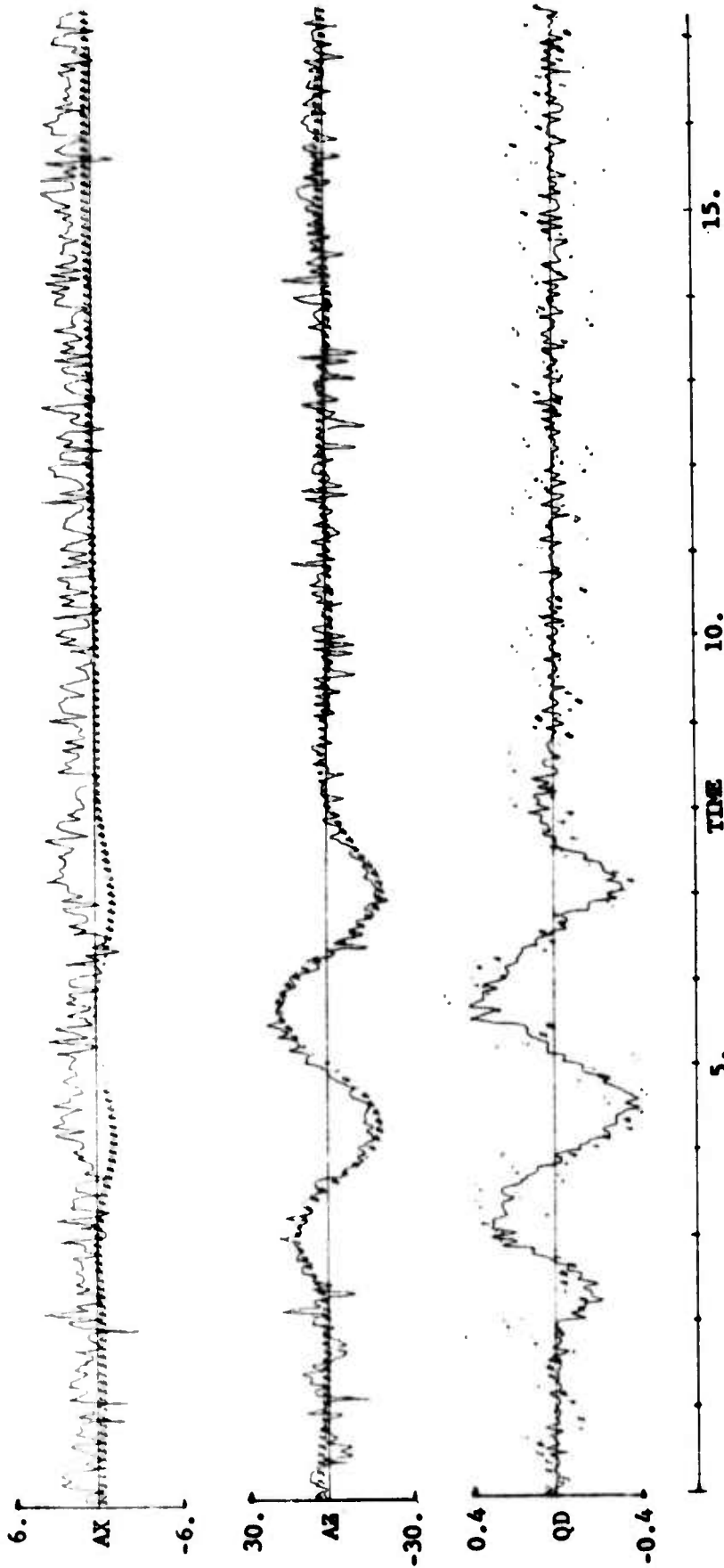


FIGURE 13 (CONT). TIME HISTORY COMPARISON DR2-1W3

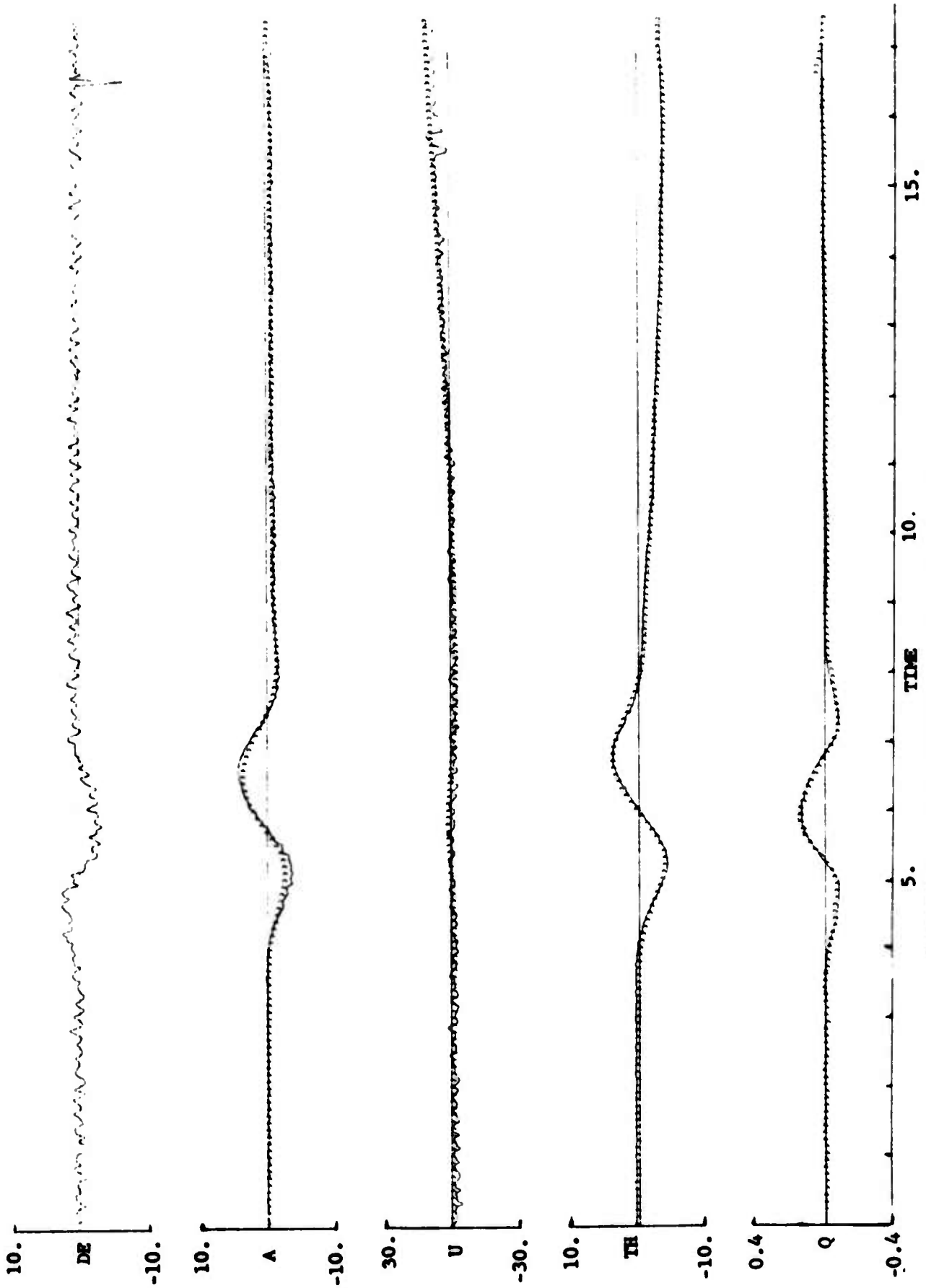


FIGURE 14. TIME HISTORY COMPARISON DR4-1W4

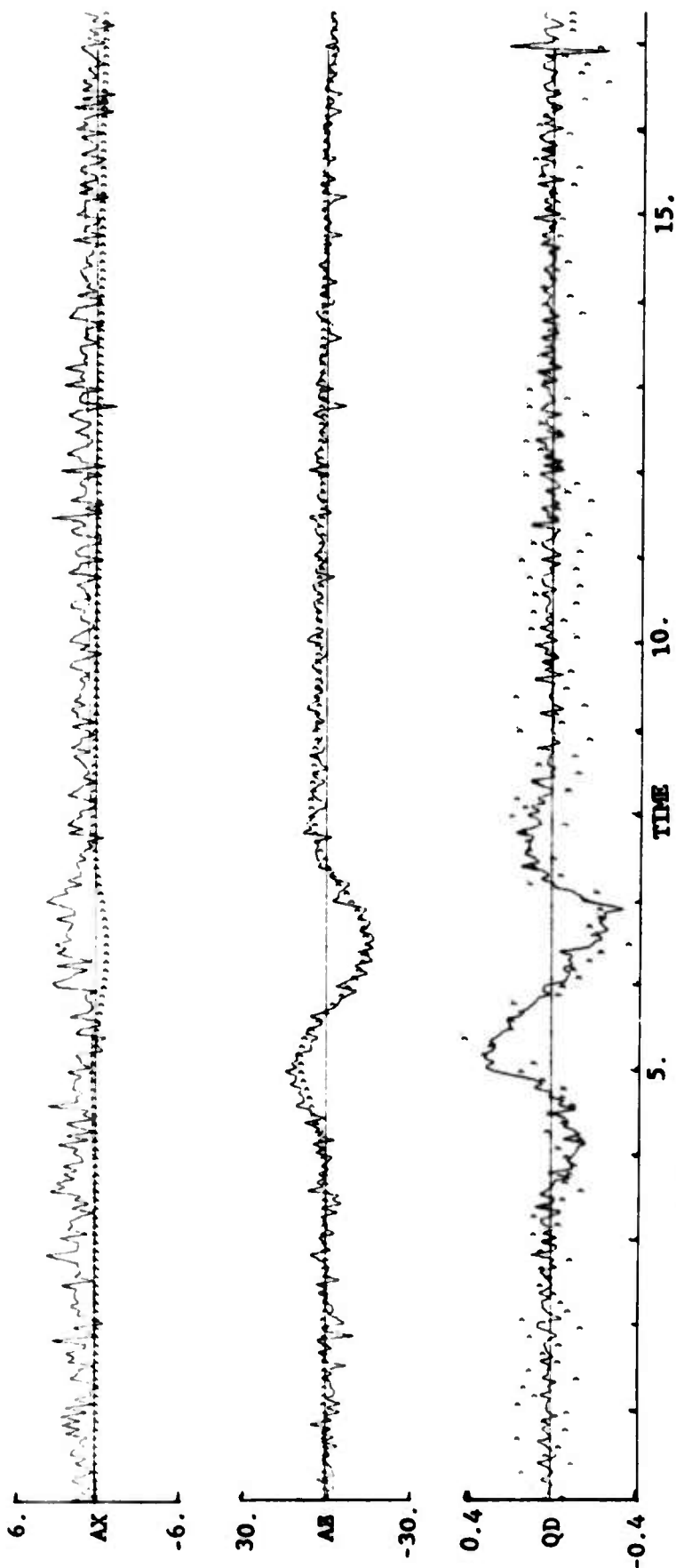
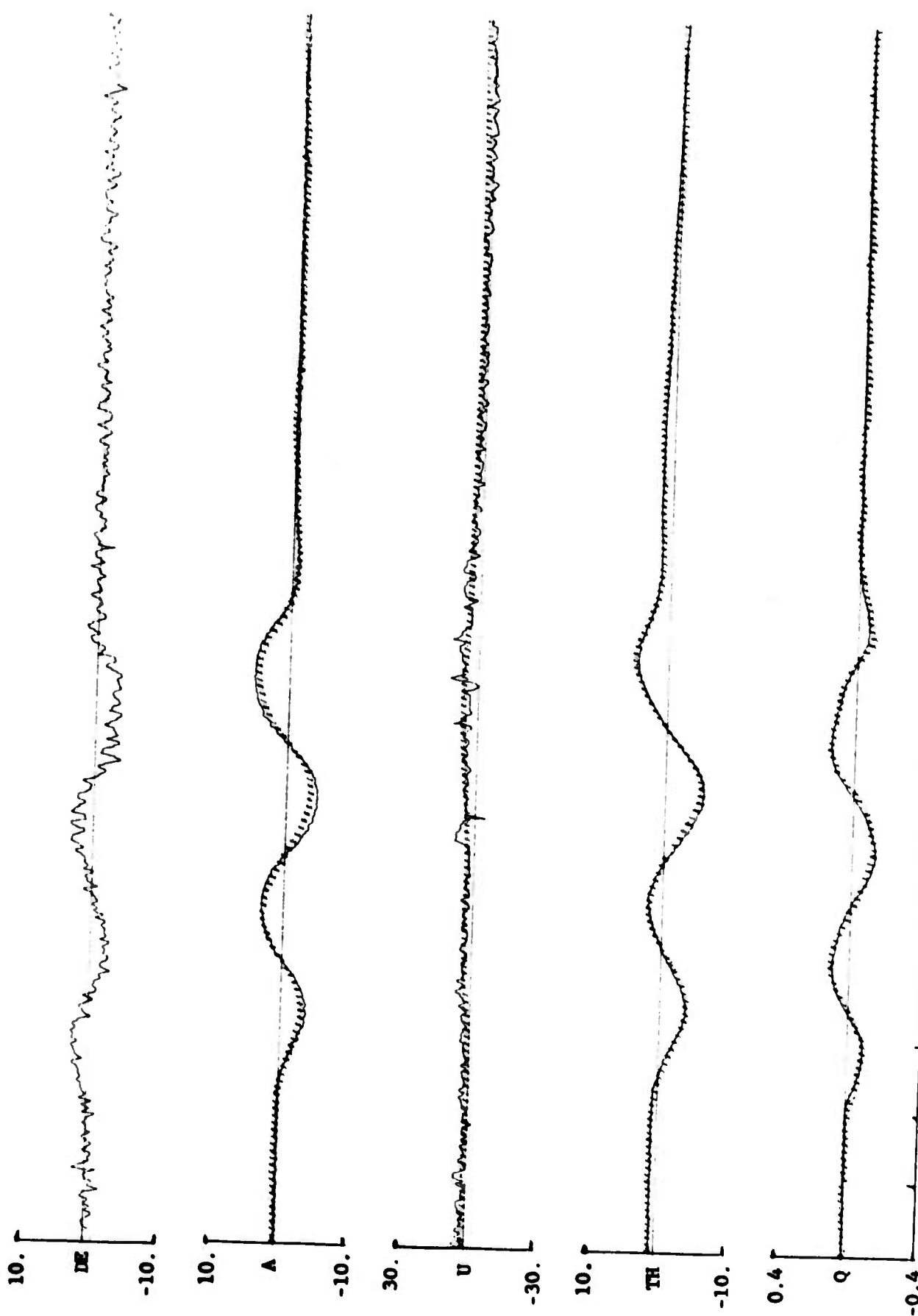


FIGURE 14 (CONT). TIME HISTORY COMPARISON DR4-1W4



5. TIME 10. 15.

FIGURE 15. TIME HISTORY COMPARISON DR5-1W3

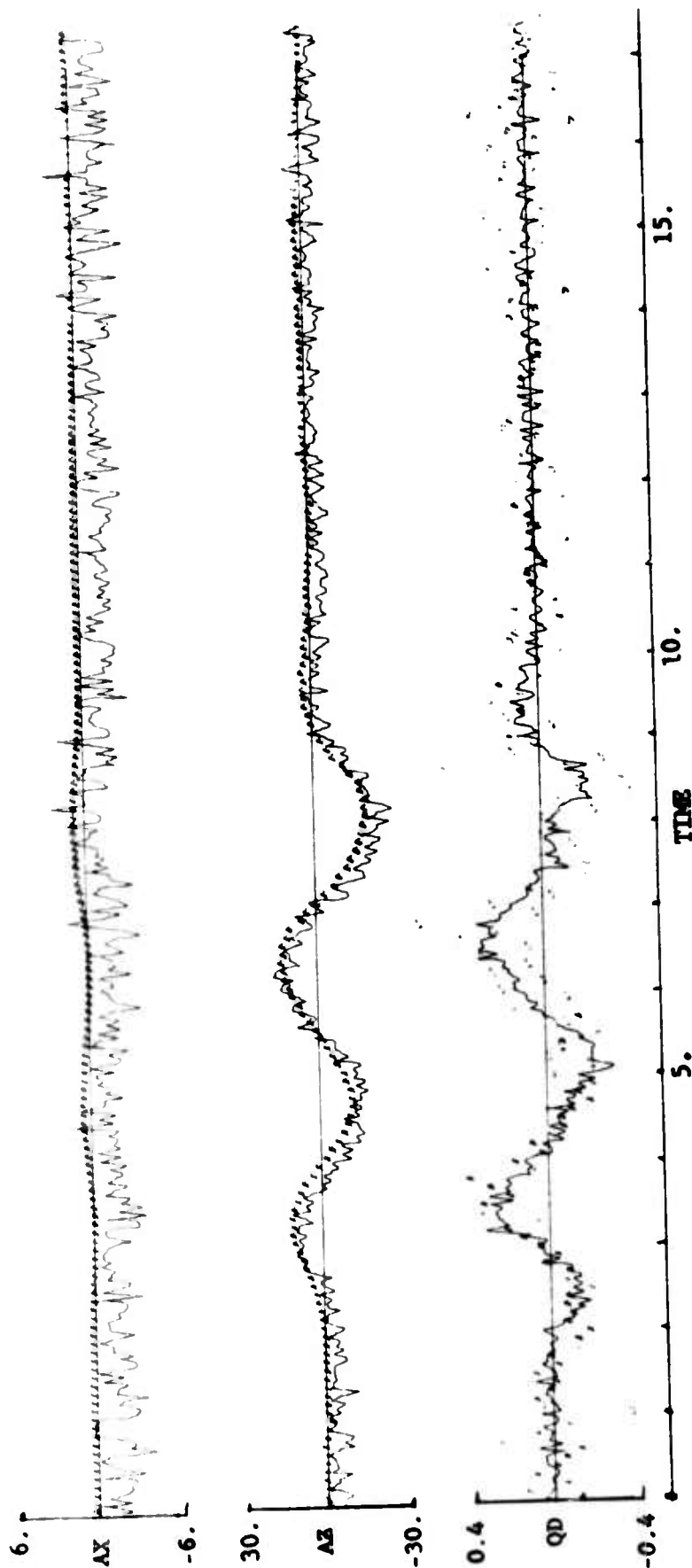


FIGURE 15 (CONT). TIME HISTORY COMPARISON DR5-1W3

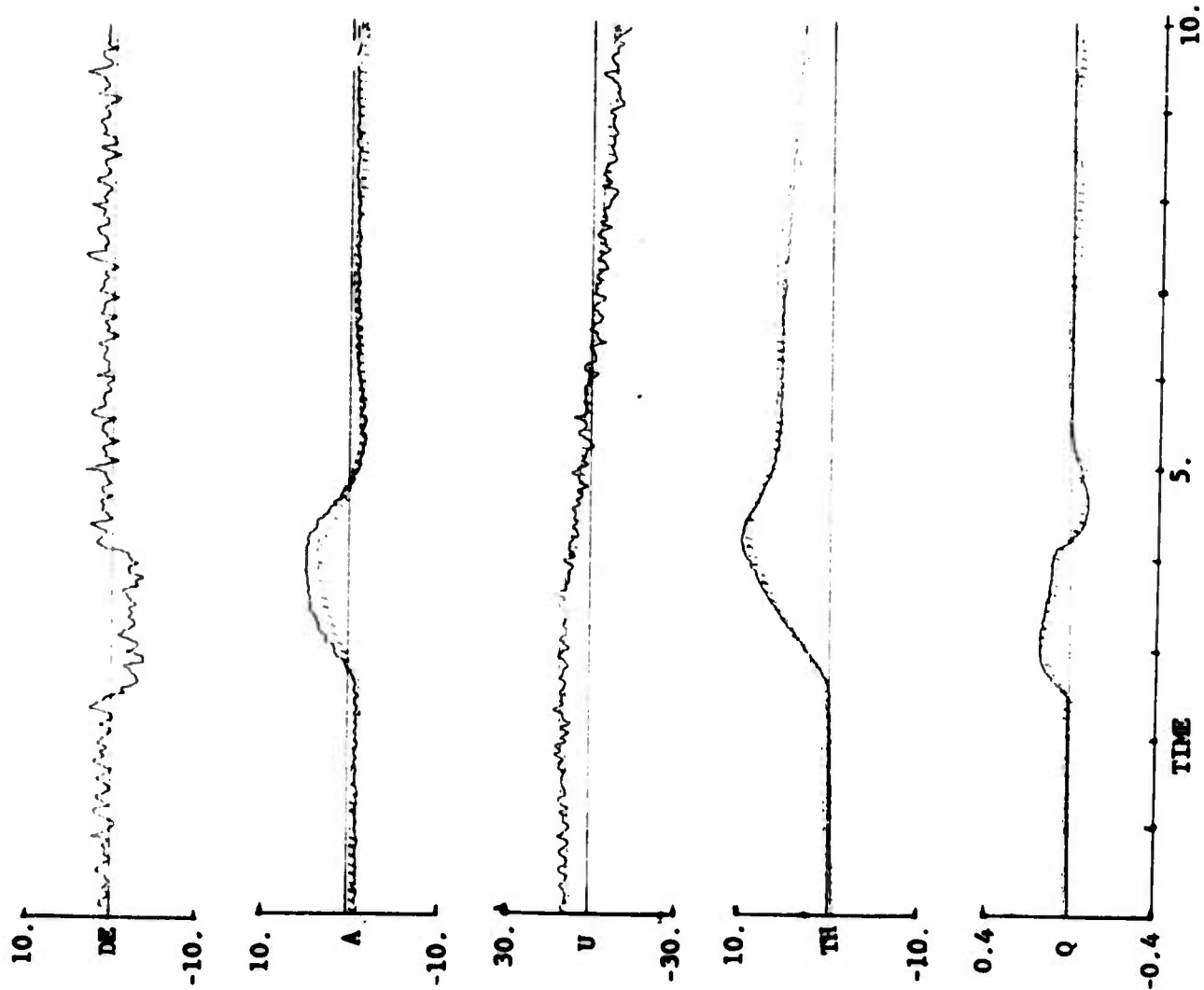


FIGURE 16. TIDE HISTORY COMPARISON DR6-1W3SH

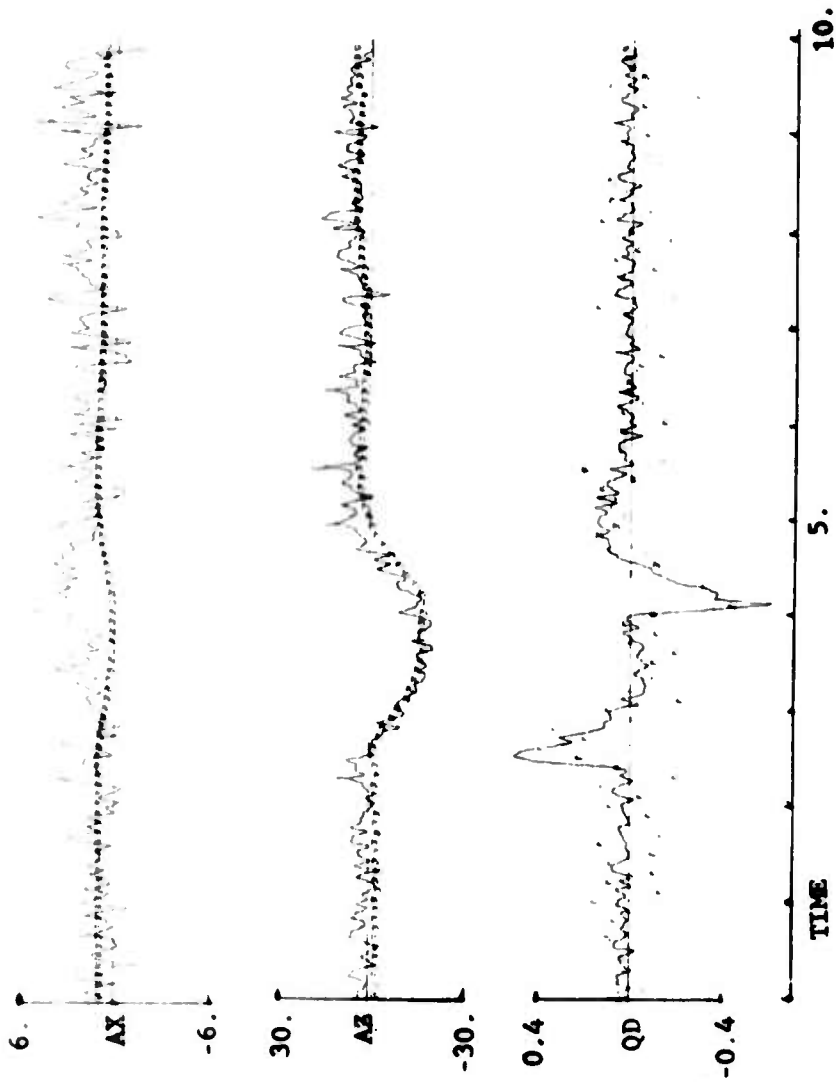


FIGURE 16 (CONT). TIME HISTORY COMPARISON DR6-1W3SH

If the algorithm does tend to keep parameters at their a priori values when faced with insufficient data, then parameter results would be a strong function of their start-up values if the flight data were incomplete or inappropriate. This theory was not tested because all radical changes in start-up values lead to divergence.

#### EFFECT OF HOLDING SHORT-PERIOD DERIVATIVES CONSTANT

Utilizing a 35 second section of data run 3, two different identification procedures were used. One run (DR3-2W2) had all derivatives as variables while the other (DR3-U2W1) had short period derivatives held fixed at the values determined by the best 17.5 second run (DR3-1W2) and only the speed derivatives variable.

Only  $M_q$  was significantly different in the two sets of results. As can be seen in Table XIII, the speed derivatives were essentially identical. The time history match (Figure 11) is for run DR3-2W2, but an identical plot was generated for DR3-U2W1. Both time history matches were disturbed by apparent atmospheric turbulence. At approximately 10 seconds and 28 seconds significant variations in angle of attack occur without any visible change in  $\delta_e$ . Pitch rate and pitch angle also change at this time, but not as severely as angle of attack. On the 52.5 second run with the same data (see Figure 12) even more turbulence is obvious, and a large disturbance in velocity is visible lagging significantly behind angle of attack. The model equations of motion have neither gust inputs nor nonlinear terms, so the model insists on creating smooth time histories. The velocity time history, for instance, rejoins the flight data after the gust disturbance.

#### DATA RUN #3

Several identification attempts using data run 3 have already been discussed for other purposes, but it remains necessary to take an overall look at data run 3 results. The principal results (DR3-1W2) agree well with the a priori values except for  $X_{\alpha}$ , which is negative but much smaller, and  $M_{\delta_e}$ , which is about 25% below the a priori value. The other runs (DR3-1WDEZ and DR3-2W2) which had variable short period derivatives had a similarly low  $M_{\delta_e}$ , and  $M_q$  higher than the a priori value (and about 25% higher than DR3-1W2), and a widely varying  $X_{\alpha}$ . The speed derivatives are surprisingly consistent from the short runs to the long runs, and also similar to the a priori values.

The time history match (Figure 9) for angle of attack seems to be both slightly out of phase and offset somewhat. The offset may be due to a poorly defined trim condition on angle of attack due to the atmospheric turbulence. The time history matches for the other variables are quite good except for the previously discussed areas of turbulence.

## DATA RUN #2

As can be seen from Table XIII, the results from data run 2 are significantly different from the other data runs. Specifically,  $Z_u$  has an incorrect sign (although it would be foolish to expect to estimate speed derivatives from a short data record),  $Z_w$  and  $M_w$  are unusually large, and  $M_{\dot{\alpha}}$ , although smaller than the a priori value, is much larger than that obtained from any other runs. Run 2 has a higher trim velocity than any other data run, but this factor alone is not enough to explain the difference. Considering  $C_{L_w}$  as independent of trim velocity, for instance,  $Z_w$  for data run 2 should be -275.6 (based on a value of -235.3 for  $Z_w$  from data run 3) but was estimated at -311.8.

Figure 13 shows the time history matches for data run 2, including  $a_x$ ,  $a_z$ , and  $\dot{q}$  in addition to the  $\dot{\alpha}$ ,  $w$ ,  $u$ ,  $\theta$ , and  $q$  shown for data run 3. The angle of attack time history match is far from perfect. Some phase shift seems to exist, with the modeling leading the flight data, and the model response is smaller in amplitude than the flight data. The flight data is nearly symmetric with respect to positive and negative excursions in angle of attack; the model response has smaller negative excursions than positive, creating a noticeable fit error.

The  $a_x$  time history match is not a match at all - the model response has a large lead relative to the flight data and the principal response is in the opposite direction. As stated previously, the program performs a match on  $\dot{u}$ , not on  $a_x$  itself, and  $\dot{u}$  contains a  $g^n$  term which in this case is much larger in magnitude than  $a_x$ . Thus the  $\dot{u}$  match is largely a repeat of the  $\theta$  match for this data set. The opposite sign trend in the response nevertheless motivated a thorough investigation of sign convention relative to  $a_x$ , but no mistakes were found.

The  $a_z$  situation is similar to the  $a_x$  problem mentioned above, in that the  $\dot{\alpha}$  match is partially a repeat of the  $q$  match rather than  $a_z$  alone, but the  $a_z$  time history match is really quite good. Of course the level of excitation is quite different -  $a_z$  is approximately  $\pm 30$  ft/sec<sup>2</sup> while  $a_x$  is  $\pm 2$  ft/sec<sup>2</sup>.

The  $\dot{q}$  time history comparison is quite unusual, since the model response is much noisier than the flight data. The flight data for  $\dot{q}$  are taken from the angular accelerometer, which was less noisy than expected. The other  $\dot{q}$  measurement, calculated from nose and tail linear accelerometers, was far too noisy to be of any use. The model response, which is directly proportional to elevator deflection, is quite noisy since the elevator deflection is so noisy. Although the measured fit error is quite large for this time history pair, the trends are clearly correct and it seems fair to judge that  $\dot{q}$  is matched.

## DATA RUN #4

The stability derivatives extracted from data run 4 are quite similar to the a priori values (and hence to data run 3 results). The widely varying  $X_{\dot{w}}$  has essentially the same value here as for data run 2.  $M_{\dot{w}}$  is unusually small for data run 4, however, being 8% below the a priori value. The value of  $M_{\dot{q}}$  is noticeably (10%) below the a priori value, but it is very close to the results from previous data runs. The  $M_{\dot{\delta}_e}$  extracted for this run is a compromise, almost evenly spaced between the results of run 3 and run 2. The extracted derivatives are listed in Table XIII.

Time history comparisons for data run 4 are shown in Figure 14. The comments made for data run 2 (above) apply almost exactly to data run 4 as well. Angle of attack time shift and amplitude, a time shift and direction of excursion, and  $\dot{q}$  model response noise were still problems.

## DATA RUN #5

The control input for data run 5 was similar to that of data run 2, except that the former was somewhat lower in frequency and amplitude than the latter. The trim airspeed for data run 5 is 11 ft/sec less than data run 2, which could lead to some differences in parameter values, but the data run 5 trim airspeed is essentially in the center of the range of trim airspeeds covered by the data, so overall comparisons of results without consideration of airspeed should be possible.

The most obvious feature of the results for data run 5 is that both  $X_u$  and  $X_{\dot{w}}$  are estimated to be positive, while all other estimates for these derivatives were negative. The estimate for  $M_{\dot{w}}$  is somewhat large, but not as large as the estimate from data run 2. The  $M_{\dot{\delta}_e}$  estimate falls near the center of the range defined by previous estimates.

The time history matches for data run 5, shown in Figure 15, appear to be slightly different from those for previous runs. The angle of attack phase and amplitude problems are slightly smaller than for the runs, but the  $a_z$  fit has deteriorated noticeably. The  $a_x$  flight data seems to have a steady-state offset, but the model and flight data excursions seem to be approximately equal in magnitude, identical in direction, and nearly in phase.

## DATA RUN #6

Excessive noise rendered the latter portion of data run 6 useless, so only 200 data points were used. The results for the shortened run 6 are given in Table XIII. A reasonable value for  $X_{\dot{w}}$  was obtained, while  $X_u$  was exactly zero. The remainder of the stability derivatives were very similar to the results from previous runs. Although it may seem unlikely that the speed derivatives could be estimated from a 10 second data run, the magnitude of the velocity

perturbation is actually larger (about 20 ft/sec) in data run 6 than in several other data runs.

Time history comparisons for data run 6 are shown in Figure 16. The angle of attack time history match is in phase, but a serious amplitude error exists. The model response is approximately 75% of the in-flight response. The  $a_z$  match is good. The  $a_x$  model response leads the flight data slightly and the excursion is once again in the opposite direction.

#### INTERPRETATION OF $X_{\alpha}$ RESULTS

Two stability derivatives,  $X_{\alpha}$  and  $M_{\delta_e}$ , vary more widely than anticipated in the results discussed above, and it would be desirable to identify reasons for this behavior. Although this report generally deals in dimensional derivatives, which are considered more meaningful, an examination of the nondimensional forms may be useful.

According to reference (n),  $X_{\alpha} = \frac{\rho S U^2}{2m} (C_L - C_{D_{\alpha}})$ . For flight condition #1,  $\frac{\rho S}{2m} = 8.469 \times 10^{-4}$ . Some uncertainty exists in the determination of trim  $C_L$  due to previously discussed difficulties with angle of attack reference, but  $(C_L)_{\text{trim}} = \frac{2mg}{\rho U^2 S}$  is probably sufficient for the purposes of this portion of the investigation. Table XIV lists  $X_{\alpha}$  reduced to nondimensional form, and  $C_{D_{\alpha}}$  extracted from the combined form, for all "final" runs of short time length. Unfortunately, it seems clear that neither  $(C_L - C_{D_{\alpha}})$  nor  $C_{D_{\alpha}}$  are much closer to being consistent than  $X_{\alpha}$  itself. Nor is  $C_{D_{\alpha}}$  a consistent function of  $(C_L)_{\text{trim}}$ .

Reference (t) found that a  $(C_L)_{\text{trim}}$  of 0.6 corresponds to an  $(\alpha)_{\text{trim}}$  of approximately  $6^\circ$ , and that a  $C_{D_{\alpha}}$  of 0.287 was indicated for this condition (without consideration of drag due to elevator required for trim). This value of  $C_{D_{\alpha}}$  is considerably smaller than those determined by the identification program. Reference (t) does indicate that  $C_{D_{\alpha}}$  increases rapidly with increasing  $(\alpha)_{\text{trim}}$ , having a value of 0.573 at  $(\alpha)_{\text{trim}} = 10^\circ$ , and 1.123 at  $(\alpha)_{\text{trim}} = 12.5^\circ$ .

#### INTERPRETATION OF $M_{\delta_e}$ RESULTS

The equation (reference (n))  $M_{\delta_e} = \frac{\rho S c U^2}{2I_y} C_{m_{\delta_e}}$  can be used to find the  $C_{m_{\delta_e}}$  equivalents of the identified  $M_{\delta_e}$  values. Table XV lists the results of these calculations.

TABLE XIV  
FLIGHT CONDITION #1 RESULTS FOR  $C_{D\alpha}$

| Run        | $X_{\alpha}$ | $(C_L - C_{D\alpha})$ | $(C_L)_{trim}$ | $C_{D\alpha}$ |
|------------|--------------|-----------------------|----------------|---------------|
| A Priori   | -23.23       | -0.492                | 0.683          | 1.175         |
| DR3-1W2    | -5.7         | -0.111                | 0.625          | 0.736         |
| DR3-1W1DEZ | +0.4         | +0.008                | 0.625          | 0.617         |
| DR2-1W3    | -10.92       | -0.182                | 0.535          | 0.717         |
| DR4-1W4    | -10.63       | -0.196                | 0.593          | 0.789         |
| DR5-1W3    | +5.11        | +0.092                | 0.582          | 0.490         |
| DR6-1W3S   | -8.55        | -0.159                | 0.601          | 0.760         |

TABLE XV  
FLIGHT CONDITION #1 RESULTS FOR  $C_{m\delta_e}$

| Run      | $M_{\delta_e}$ | $C_{m\delta_e}$ |
|----------|----------------|-----------------|
| A Priori | -9.68          | -1.18           |
| DR3-1W2  | -7.20          | -0.803          |
| DR2-1W3  | -9.32          | -0.891          |
| DR4-1W4  | -8.26          | -0.875          |
| DR5-1W3  | -8.65          | -0.899          |
| DR6-1W3S | -8.15          | -0.875          |

Reduction to nondimensional forms tends to reduce the differences between the identified parameters. The smallest  $C_{m\alpha_e}$  is only an 11% reduction from the largest identified  $C_{m\alpha_e}$ , while the smallest  $M_{\alpha_e}$  was a 23% decrease from the largest identified  $M_{\alpha_e}$ . However, observation of the  $C_{m\alpha_e}$  results reveals that the identified results are all quite different from the a priori value. The  $C_{m\alpha_e}$  determined by the wind tunnel tests reported in reference (t) is 1.29 for  $\alpha_e$  between  $-10^\circ$  and  $-15^\circ$ , which is slightly higher than the a priori value and much different from the identified parameters. However, the wind tunnel tests also indicate that elevator effectiveness drops off rapidly with increasingly negative  $\alpha_e$  beyond  $\alpha_e = -15^\circ$ , suggesting that a linear  $C_{m\alpha_e}$  might not be appropriate. Yet the reference (t) wind tunnel data are for a no-flaps configuration, while the flight data were taken for a half-flaps configuration. The deflection of the flaps certainly could change the elevator effectiveness and the elevator angle at which effectiveness decreases. Thus, the comparison of the reference (t) data and the flight results may not be meaningful, but the a priori information was generated for the half-flap case and no simple explanation exists for the discrepancy between this value and the flight results.

#### SUMMARY OF FLIGHT CONDITION #2

Identification results for flight condition #2, reduced with respect to an assumed known  $M_0$ , are given in Table XVI. In general, the results are consistent within themselves, although not necessarily in agreement with the a priori values. Unreduced results are given in Appendix C.

#### DATA RUN 19

Data run 19 featured a pseudo-white noise elevator input with approximately zero mean. The continuous reversal movements of the control allowed the control deflection magnitude to be relatively large without causing any motion variables to exceed the range for which linear dynamics may reasonably be considered. Thus the signal to noise ratio for the elevator signal was high enough to permit processing without first smoothing the control data. The resultant time history matches are shown in Figure 17. General agreement seems evident although the matches are by no means perfect. The largest discrepancy occurs due to an elevator noise spike at approximately four seconds. The angle of attack match has a persistent offset problem, however, and the normal acceleration response of the model seems to consistently lag the flight data. The pitch acceleration response of the model is too noisy to permit any conclusions.

#### DATA RUN 10

The time history matches for data run 10 are shown in Figure 18. The signal/noise ratio for the elevator data (solid line) is clearly poor. Shown dotted on the elevator trace is the smoothed elevator time history actually used as input to the identification program. The time history match is rather good, but the maneuver is so small that it would seem dangerous to place too much weight on the results.

TABLE XVI  
FLIGHT CONDITION #2 FINAL RESULTS

Assuming  $Z_\alpha = 0$ ,  $M_\alpha = -1.57$

| Run #                                | $X_u$            | $X_\alpha$     | $Z_u$           | $Z_\alpha$         | $M_u$            | $M_\alpha$     | $M_q$          | $Z_{\delta_e}$   | $\delta_e$       |
|--------------------------------------|------------------|----------------|-----------------|--------------------|------------------|----------------|----------------|------------------|------------------|
| A Priori                             | -0.016           | -36.91         | -0.122          | -1669.2            | 0.0017           | -22.5          | -3.39          | -121.3           | -52.12           |
| Data Run 10<br>1W2S2                 | 0.001            | 6.84           | 0.155           | -1381.1            | -0.0006          | -22.2          | -6.47          | -129.9           | -50.10           |
| Data Run 11<br>1W2S2DEZ<br>U4W2S2DEZ | -0.006<br>-0.099 | 11.55<br>11.55 | 0.175<br>-0.011 | -1358.4<br>-1358.4 | 0.0008<br>0.0016 | -22.4<br>-22.4 | -7.12<br>-7.12 | -135.8<br>-135.8 | -49.61<br>-49.61 |
| Data Run 12<br>U5W3S2DEZ             | -0.038           | 11.39          | -0.233          | -1339.8            | 0.0018           | -22.4          | -7.12          | -134.0           | -49.61           |
| Data Run 14<br>1W3S2SH               | 0.053            | 28.17          | -0.021          | -1656.2            | 0.0013           | -23.0          | -8.08          | -123.7           | -49.00           |
| Data Run 18<br>1W3S2                 | 0.024            | 32.77          | 0.005           | -1119.8            | 0.0015           | -21.9          | -7.05          | -143.4           | -49.73           |
| Data Run 19<br>1W2                   | -0.075           | 24.84          | -0.013          | -1366.2            | 0.0004           | -22.7          | -7.94          | -138.0           | -48.51           |
| Data Run 13<br>1W2S2                 | -0.027           | 19.06          | 0.093           | -1348.0            | 0.0012           | -22.5          | -7.72          | -136.2           | -48.91           |

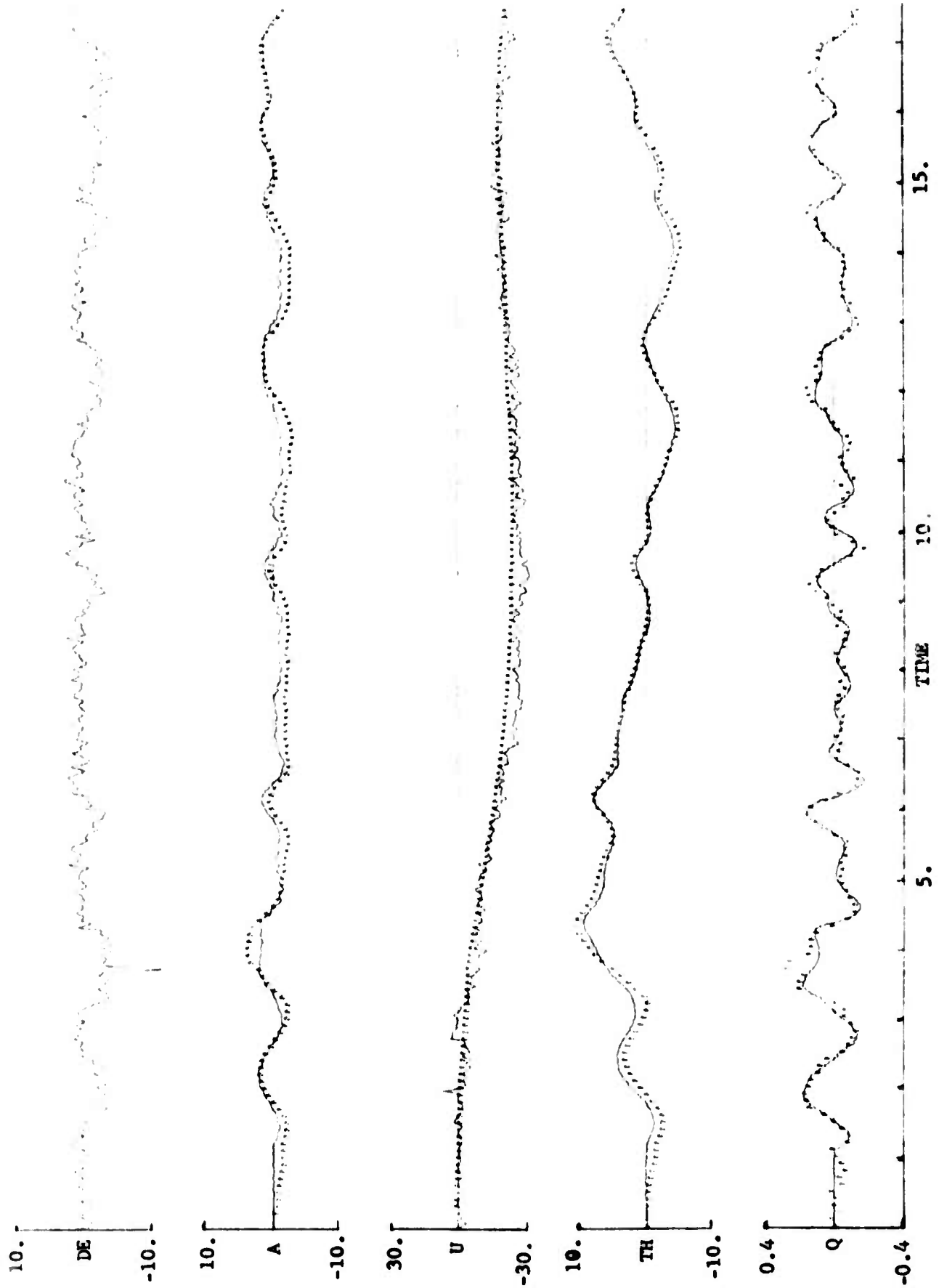


FIGURE 17. TIME HISTORY COMPARISON DR19-1W2

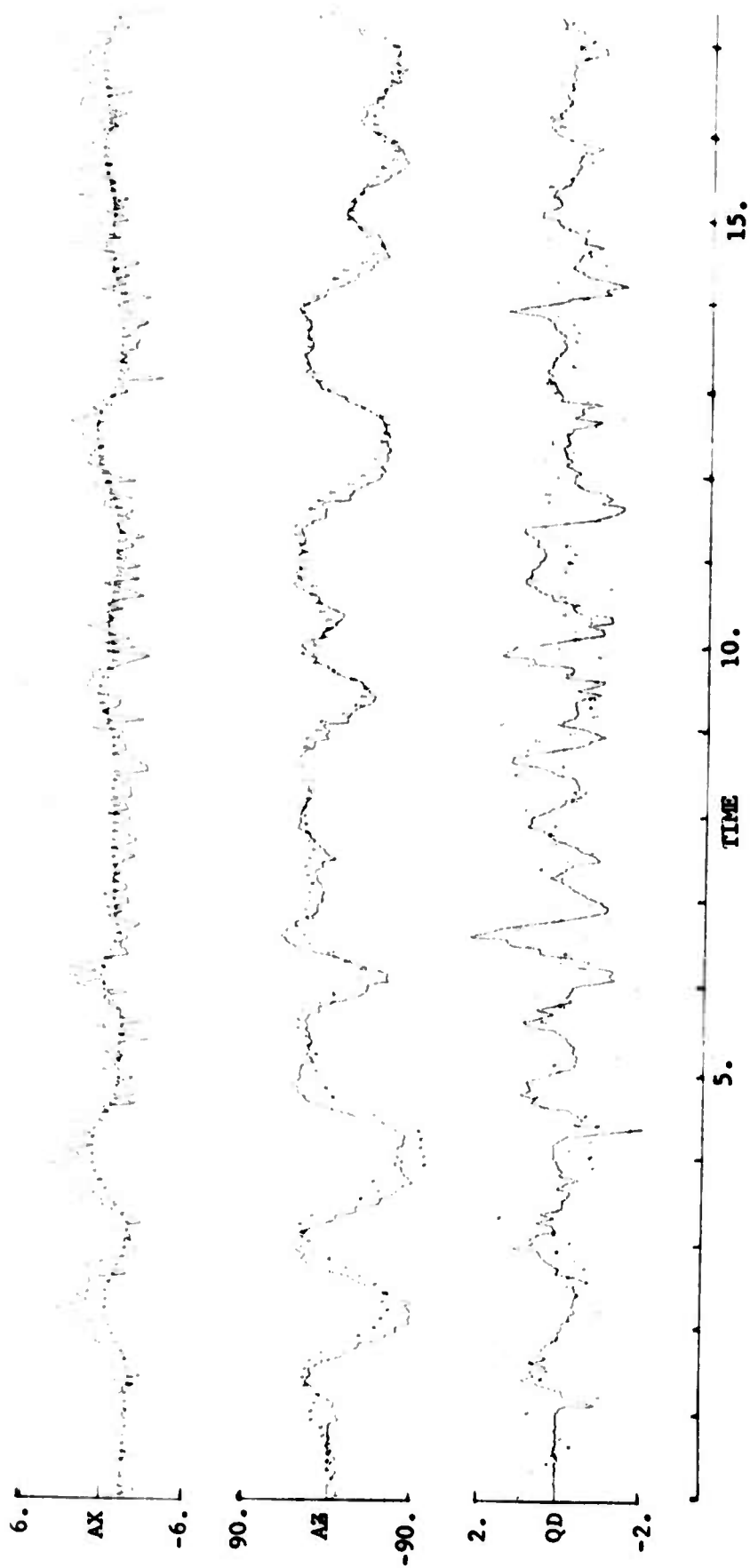


FIGURE 17 (CONT). TIME HISTORY COMPARISON DR19-1W2

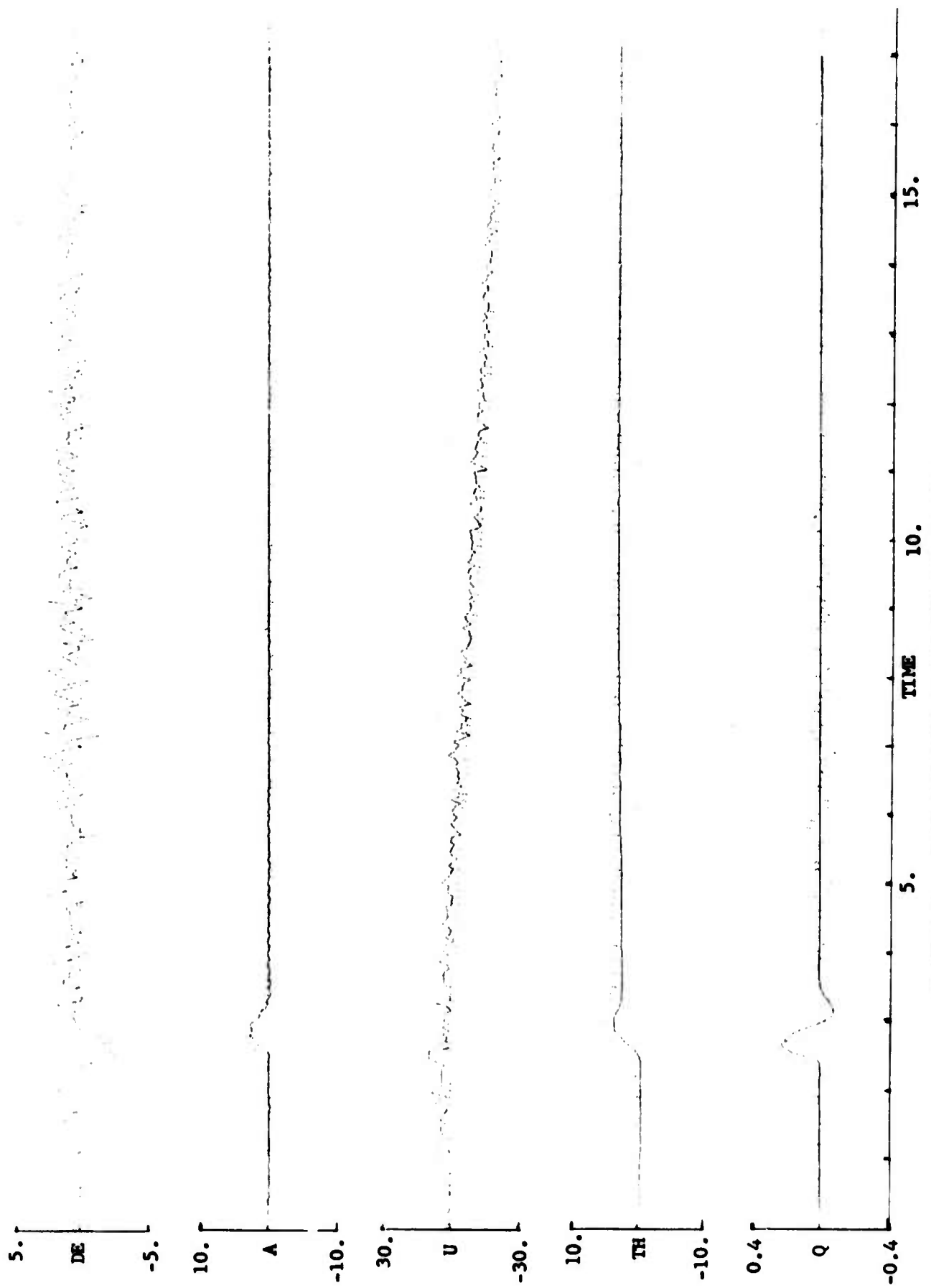


FIGURE 18. TIME HISTORY COMPARISON DR10-IW2S1

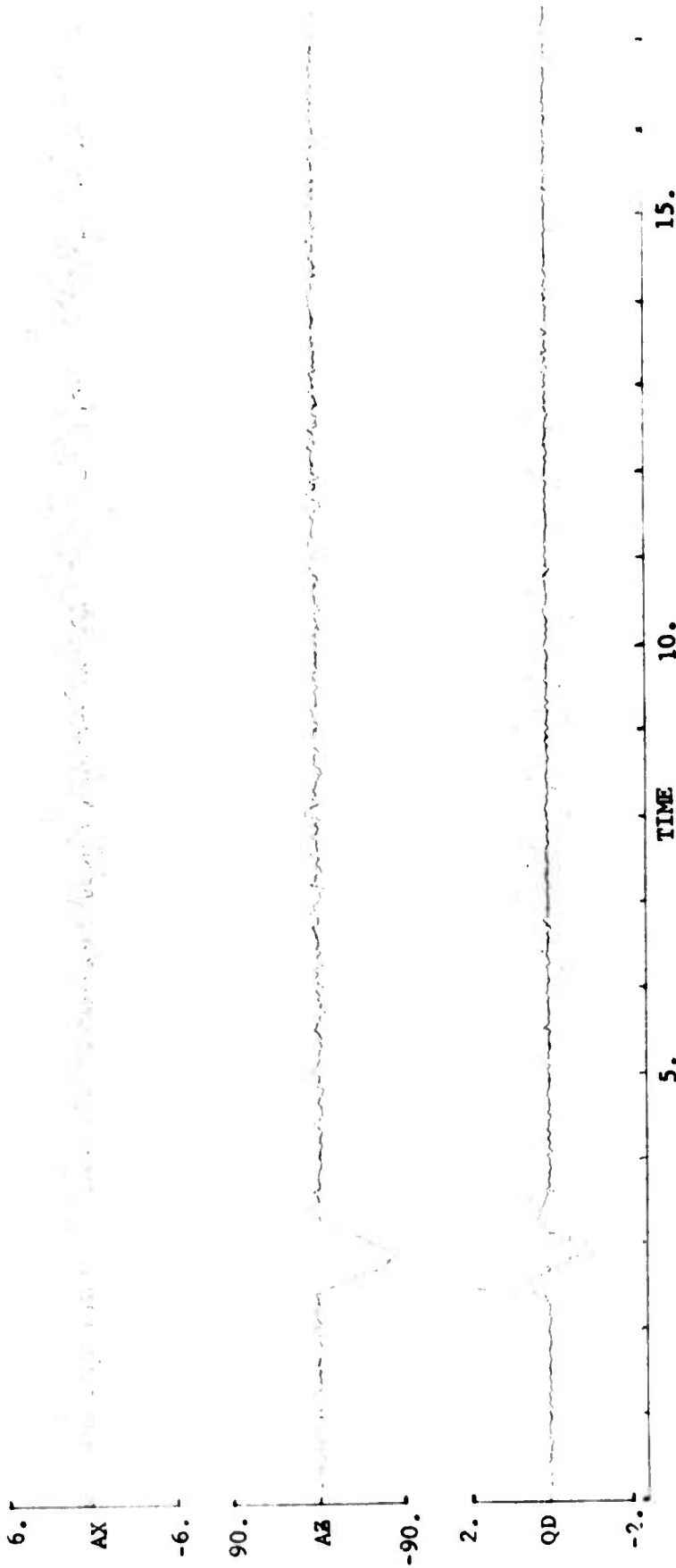


FIGURE 18 (CONT). TIME HISTORY COMPARISON DR10-1W2S1

## DATA RUN 14

Only 15 seconds of data were available in data run 14. The time history matches obtained for the shortened run are shown in Figure 19. The magnitudes of the peaks of the angle of attack and pitch angle responses in their positive directions are significantly larger for the model than for the flight data. Also, the model normal acceleration response again seems to lag the flight data.

Although the results for individual stability derivatives will be discussed in later sections, it is worth noting here that the largest values of  $Z_{\dot{\alpha}}$ ,  $M_{\dot{\alpha}}$ , and  $M_{\dot{q}}$ , and the smallest value of  $Z_{\delta_e}$ , were obtained from this data run. In particular, the  $Z_{\dot{\alpha}}$  value of -1656. is the only identified result approaching the a priori  $Z_{\dot{\alpha}}$  value of -1669.

## DATA RUN 13

The control input shape, and the errors in the resulting time history match, for data run 13 are nearly identical to data run 14. Yet the identified  $Z_{\dot{\alpha}}$  for data run 13 is 19% lower than that obtained from data run 14, and  $X_{\dot{\alpha}}$ ,  $M_{\dot{\alpha}}$ , and  $M_{\dot{q}}$  are also lower. The time history comparisons for data run 13 are shown in Figure 20.

## DATA RUN 18

Time history comparisons for data run 18 are shown in Figure 21. The model responses for angle of attack and pitch angle are roughly correct in shape but have a substantial bias in the direction of positive response. This phenomenon is not a simple shift of the entire response curves, because the model response curves and the flight data are similar at both the beginning and end of the data run. The normal acceleration shows that the model response lags the flight data and the amplitude of the model response is insufficient in the positive direction to match the flight data.

The  $a_x$  time history comparison in this data run, as well as all the previously discussed data runs for flight condition #2, contains little information because of the high noise level in the  $a_x$  flight data and the relatively low level of excitation. It is quite significant, however, that the model and flight responses are in the same direction. It should be recalled that the responses tended to be in opposite directions in flight condition #1 time history comparisons, leading to speculation that a sign error existed in either the model or the measurement system. The somewhat larger  $a_x$  excitations in the data runs of flight condition #2 reveal that the signs are correct in general, although the  $a_x$  matching problems in flight condition #1 may indicate a deficiency in the model for that configuration.

The results from data run 18 feature the smallest  $Z_{\dot{\alpha}}$ ,  $M_{\dot{\alpha}}$ , and  $M_{\dot{q}}$ , and the largest value of  $Z_{\delta_e}$ , of any flight condition #2 data run. This situation is exactly opposite that of data run 14.

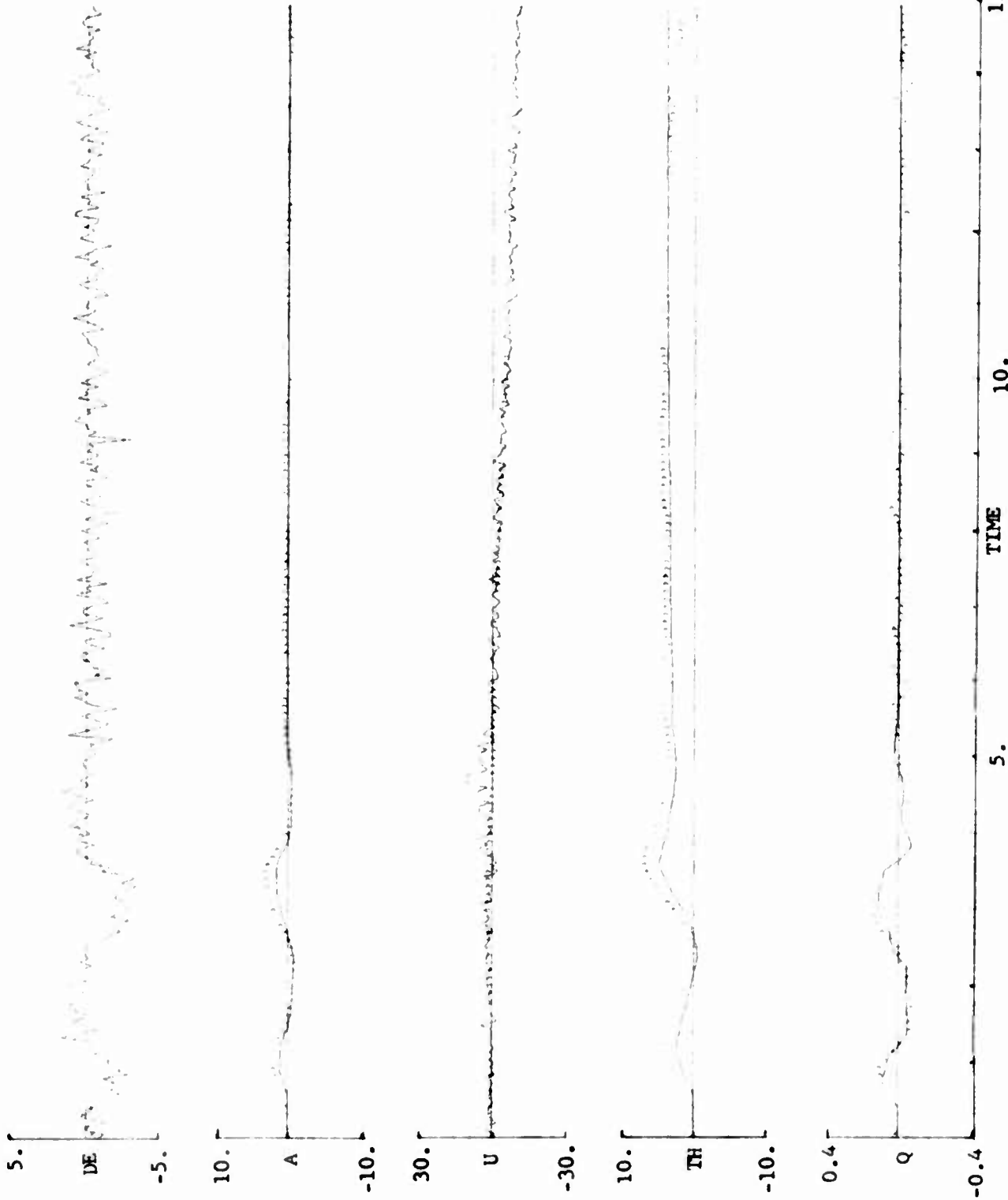


FIGURE 19. TIME HISTORY COMPARISON DR14-1W3S2SH

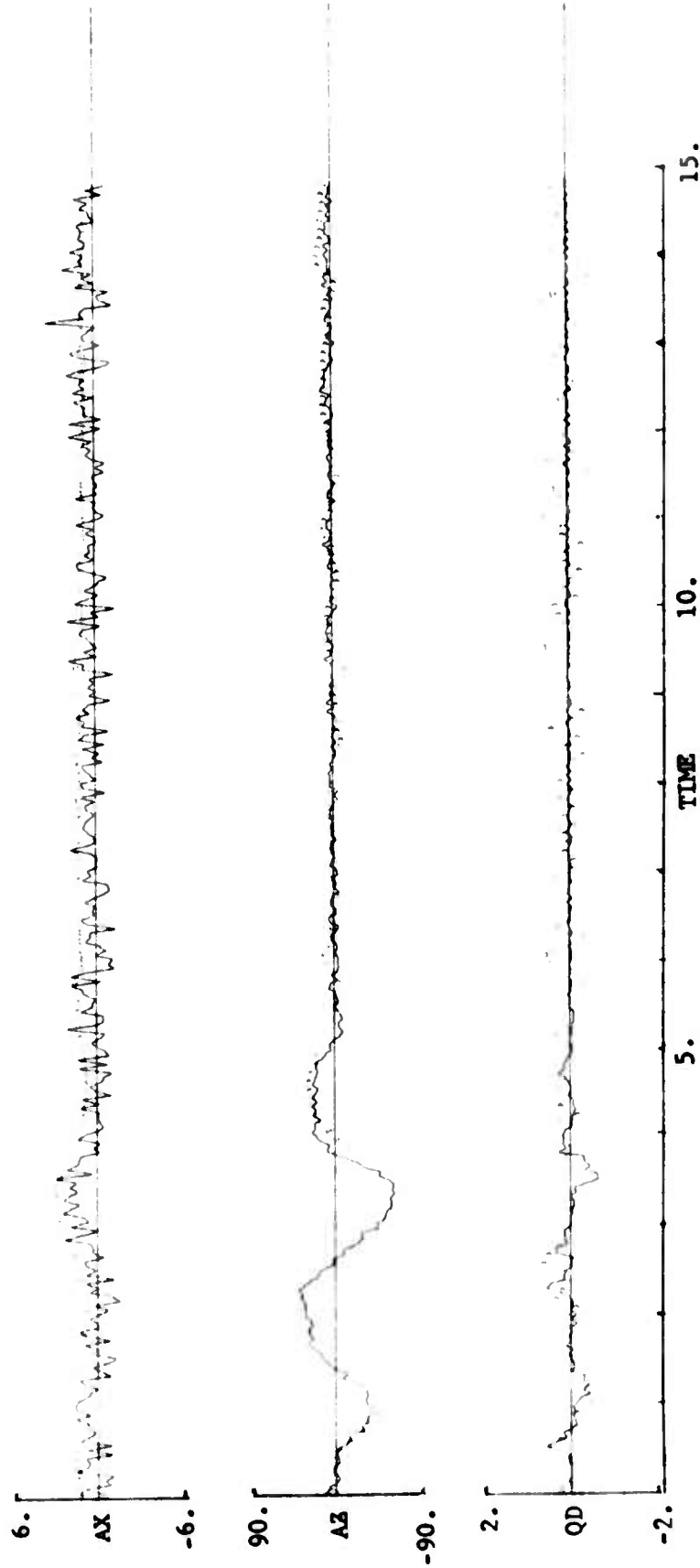


FIGURE 19 (CONT). TIME HISTORY COMPARISON DR14-1W3S2SH

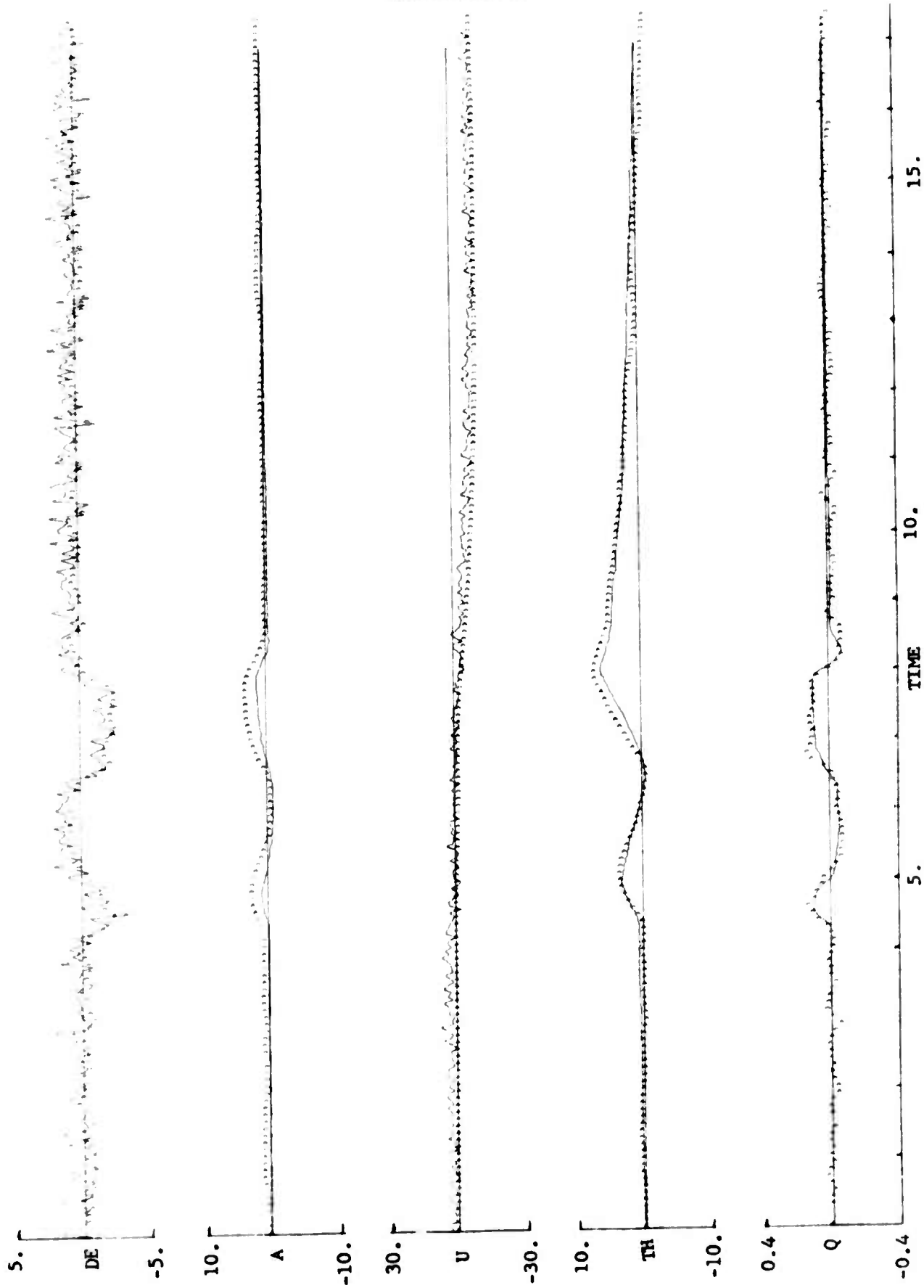


FIGURE 20. TIME HISTORY COMPARISON DR13-1W2S2

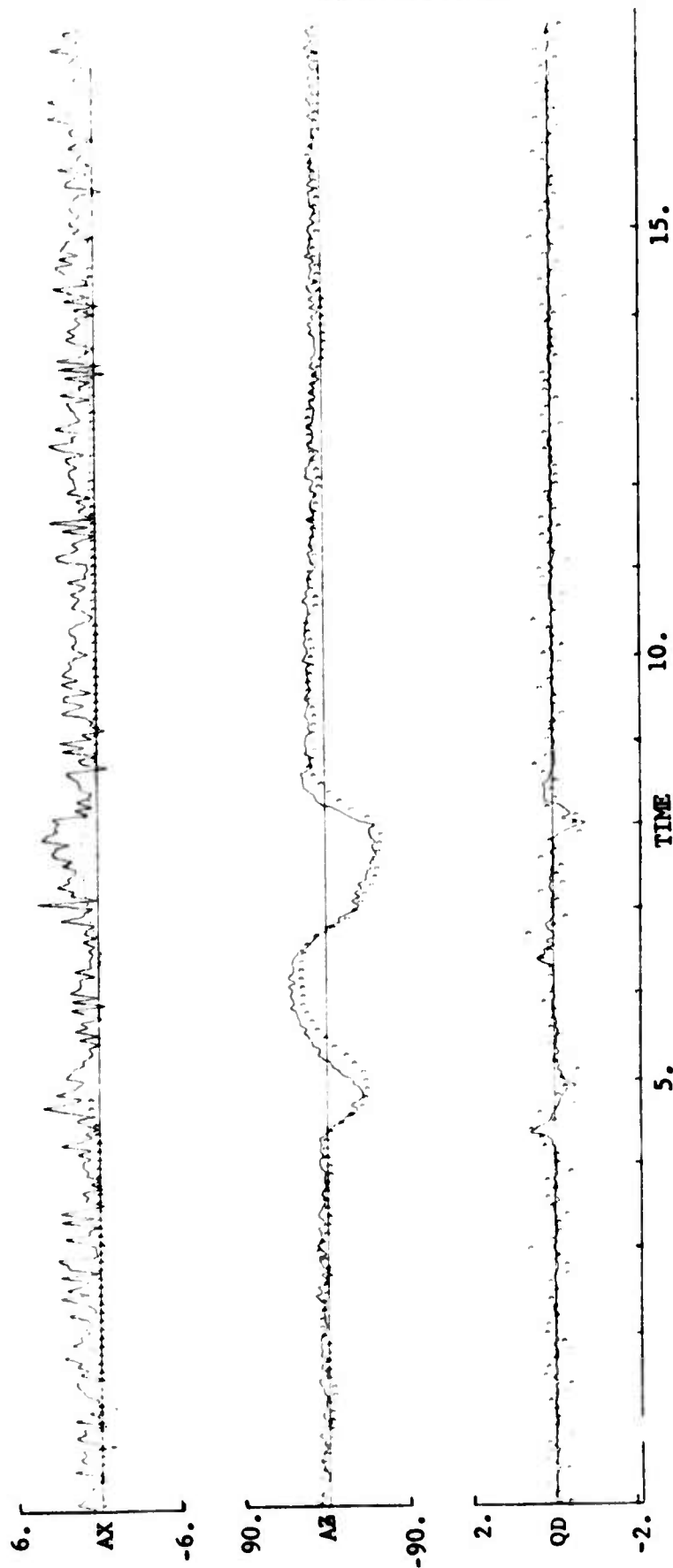


FIGURE 20 (CONT). TIME HISTORY COMPARISON DR13-IW2S2

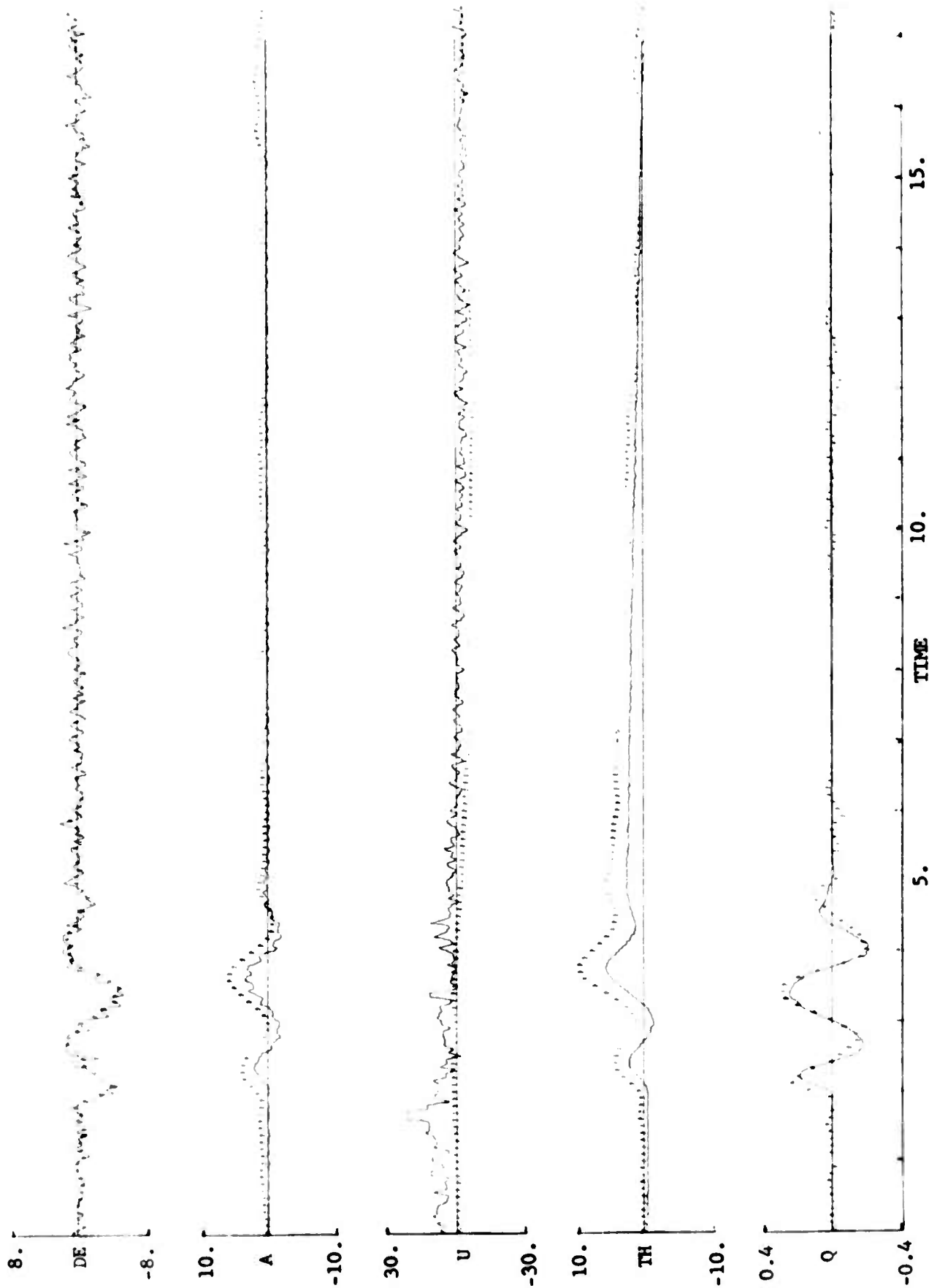


FIGURE 21. TIME HISTORY COMPARISON DR18-1W3S2

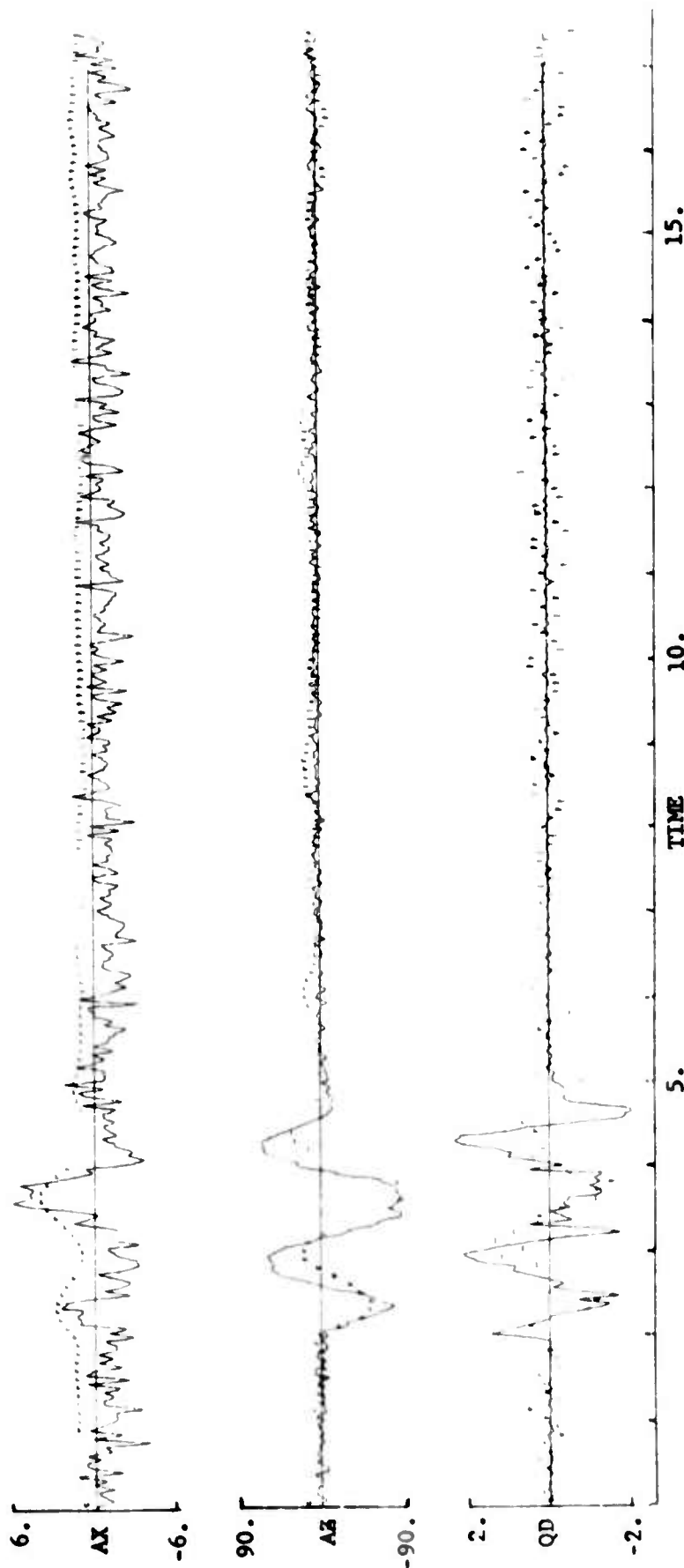


FIGURE 21 (CONT). TIME HISTORY COMPARISON DR18-1W3S2

## DATA RUN 11

Figure 22 is a time history comparison for data run 11. Note that even with two iterations of smoothing, the elevator noise spikes cause considerable model response which is not present in the flight data. Figure 23 is a similar comparison for data run 11 with elevator set to zero following the significant input. Once again the angle of attack, pitch angle, and normal acceleration model responses overshoot the flight data in the time immediately following the input. The identification attempts not including elevator zeroing were not considered "final", and the results were not used. The time history comparison plots were shown to illustrate the severity of the elevator noise problem.

Unfortunately, a plot of the 70 second identification processing of data run 11 was not available due to computer malfunction. Airspeed, the quantity of particular interest, varied to -25 ft/sec and returned to approximately the original trim value during the data run. The stability derivative results (with all but the speed derivatives held at the values obtained in DR11-1W2S2DEZ) are shown in Table XVI.

## DATA RUN 12

The pilot input for this data run was insufficient to cause motions large enough to permit identification of the stability derivatives principally involved in the short period motion. The intent of the input was the generation of phugoid motions, in which it succeeded. An 87.5 second record length segment of data run 12 contained  $1\frac{1}{2}$  cycles of phugoid motions, including velocity variations between +41 ft/sec and -30 ft/sec.

Once again, a plot of the time history comparison was unavailable, but the stability derivative results are shown in Table XVI. Start-up values for DR12-U5W3S2DEZ were not the usual a priori values, but the final results of DR11-U4W2S2DEZ.

## STABILITY DERIVATIVE RESULTS

The variation in identified stability derivatives from run-to-run, and with respect to their a priori values, was similar to flight condition #1 with certain exceptions. As shown in Table XVI, results for  $X_\alpha$  were somewhat more consistent, but still covered a wide range. Both  $(C_L)_{trim}$  and  $C_{Dv}$  would be expected to be quite small for flight condition #2, and any measurement of the differences between them could certainly be subject to considerable error. The a priori value, which is larger in magnitude than any identified  $C_{Dv}$  and opposite in sign to all of the identified  $X_\alpha$  results, could also be subject to error for the same reason. Calculation of the a priori value required the measurement of the slope of a very shallow  $C_D$  vs.  $\alpha$  curve.

The results for  $M_{\delta_e}$  were remarkably consistent. This phenomenon may indicate that the  $M_{\delta_e}$  identification problems were unique to flight condition

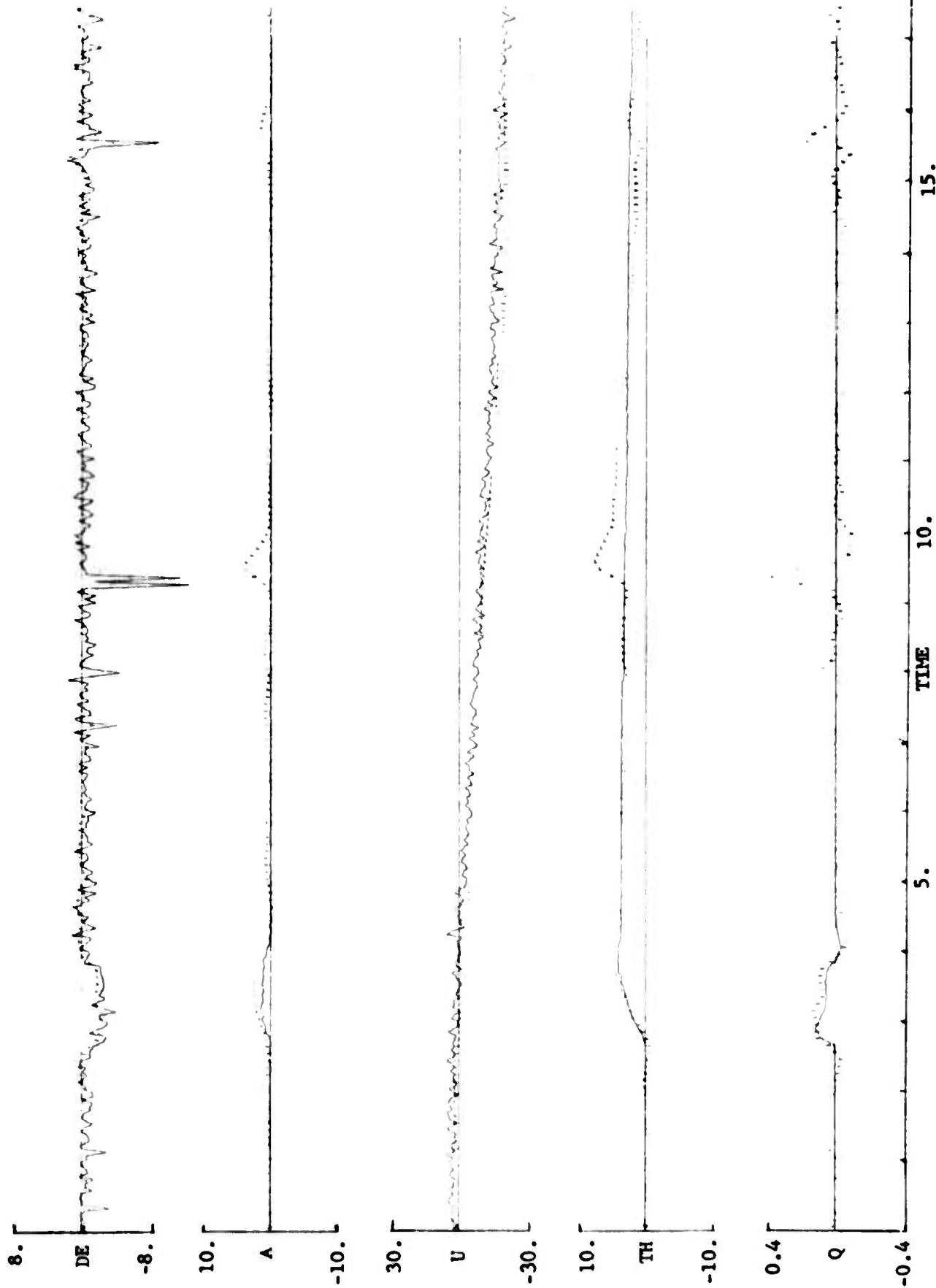


FIGURE 22. TIME HISTORY COMPARISON DR11-IW2S2

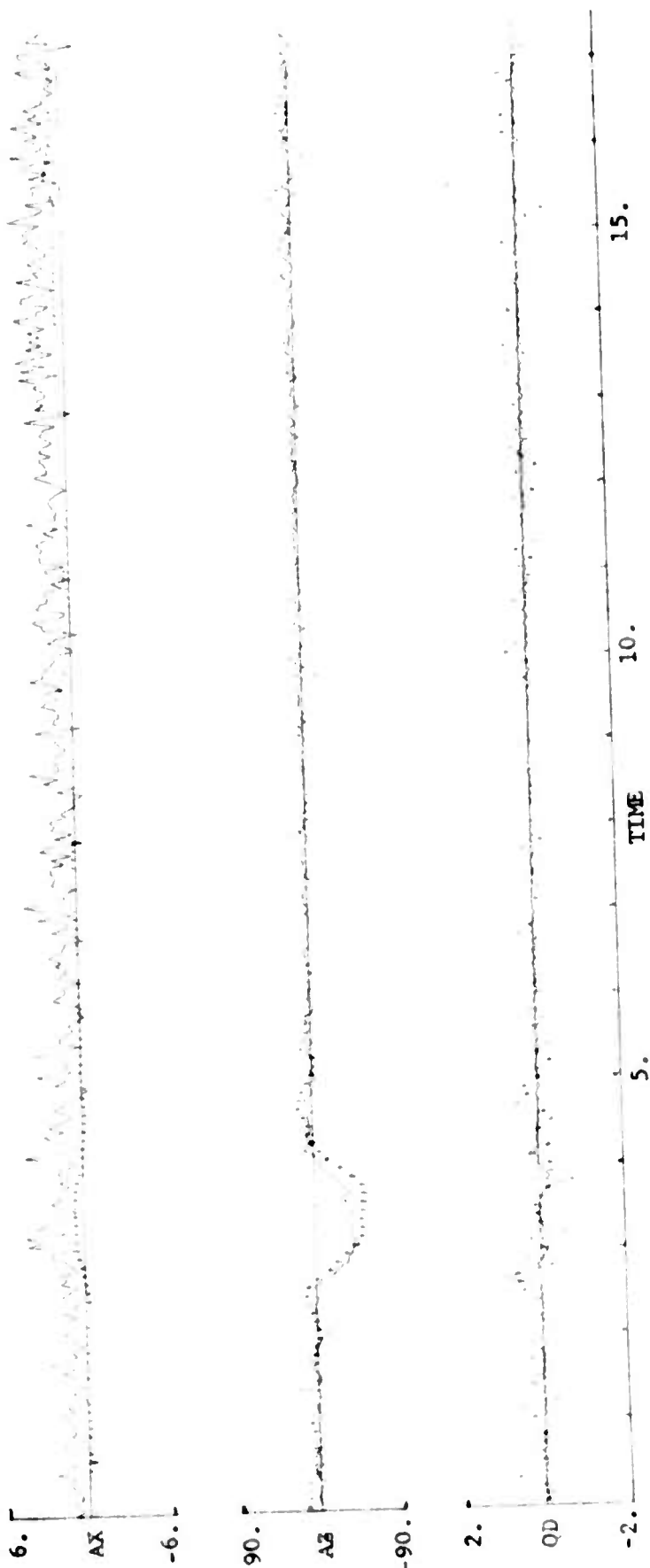


FIGURE 22 (CONT). TIME HISTORY COMPARISON DR11-1W2S2

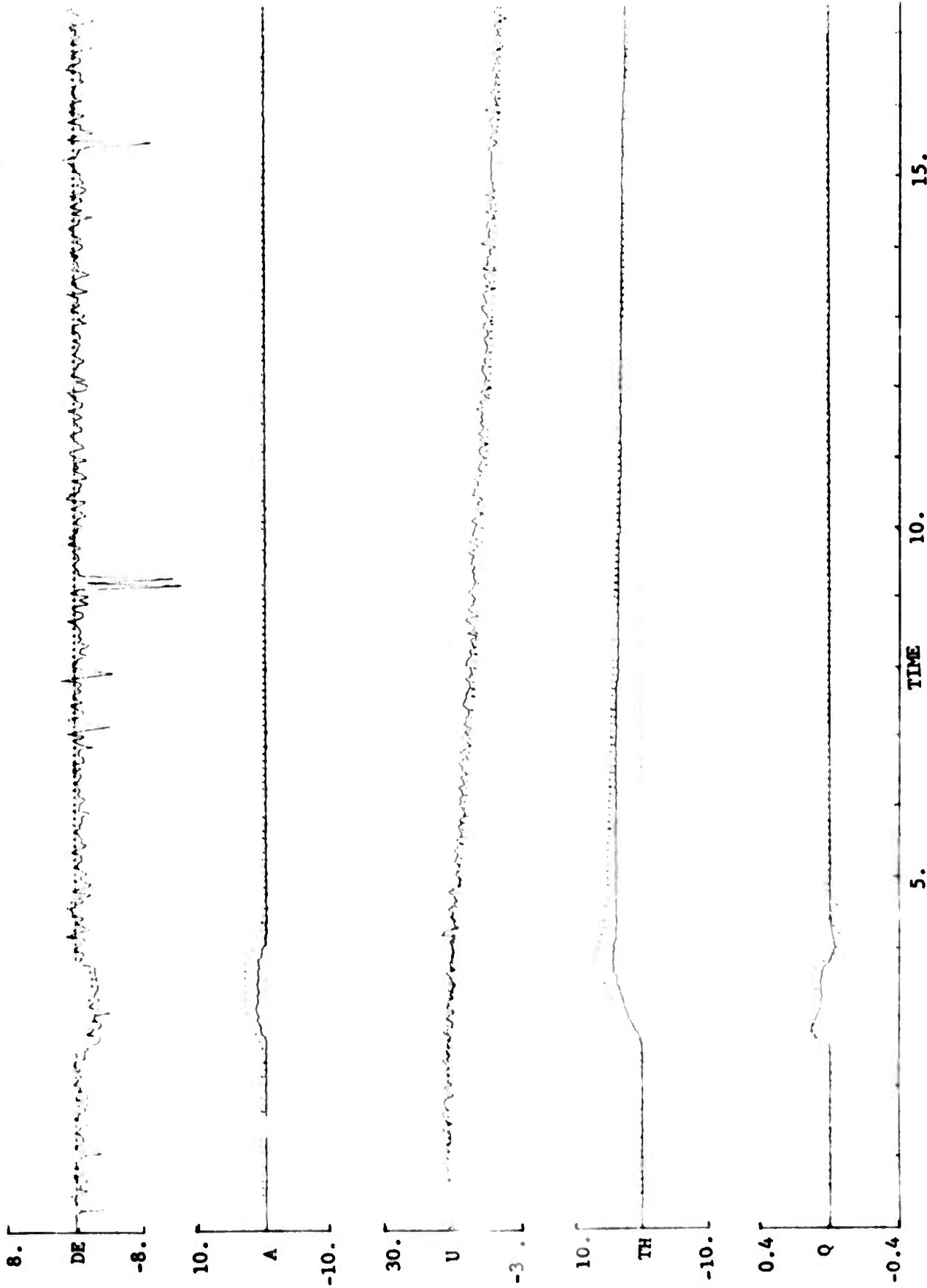


FIGURE 23. TIME HISTORY COMPARISON DR11-1W2S2DEZ

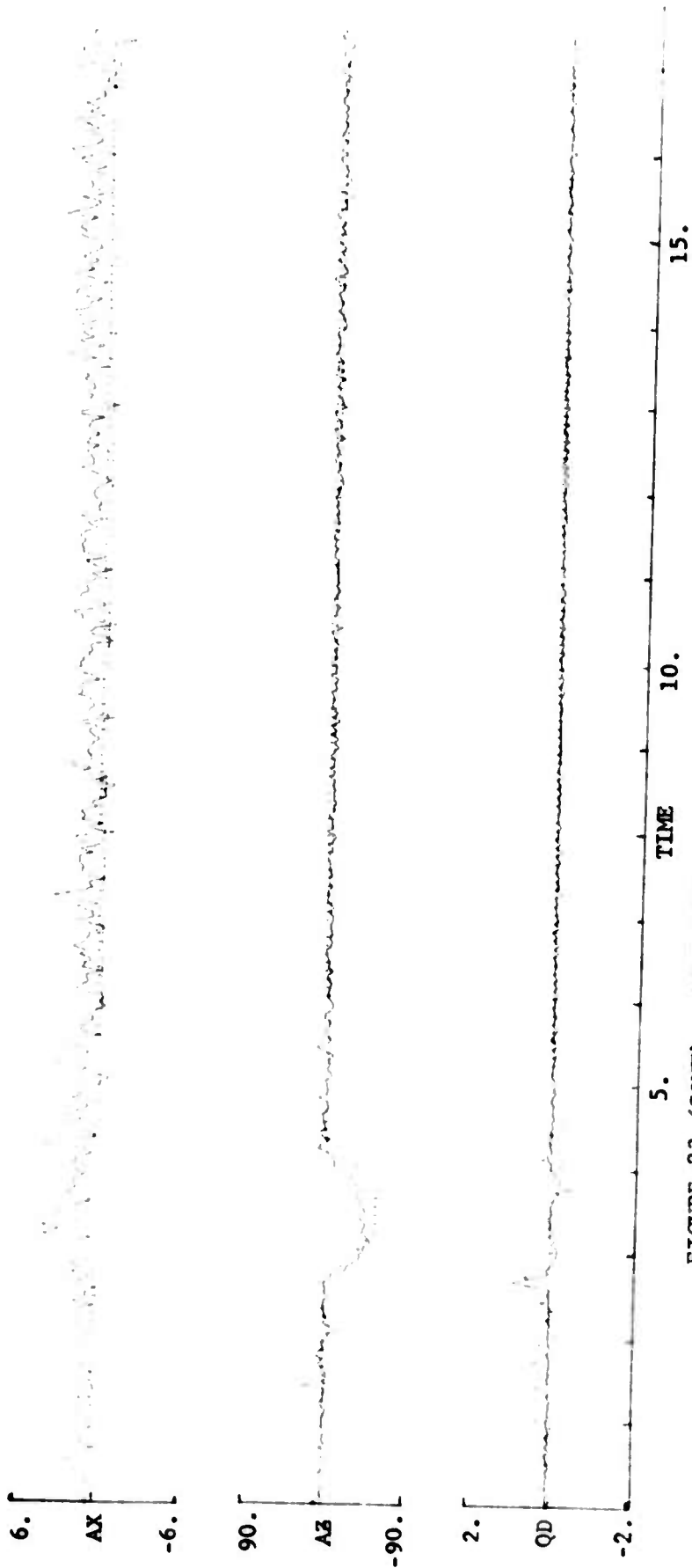


FIGURE 23 (CONT). TIME HISTORY COMPARISON DR11-IW2S2DEZ

#1, or just the opposite could be true if the algorithm were in fact simply retaining the a priori value due to a lack of sufficient information.

The  $M_q$  identification results are rather consistent, but quite different from the a priori value, the latter only having about half the magnitude of the former.

## CONCLUSIONS

### GENERAL

1. A modified Newton-Raphson parameter identification technique was acquired. This technique was shown to extract nearly perfect sets of stability derivatives from computer-generated data.
2. Carefully documented sets of flight data have been collected and provided to several contractors and agencies for the purpose of parameter identification. These data are especially suitable for parameter identification in the sense of the completeness of the measurements and the variety of selected pilot inputs. However, the signal-to-noise ratios for many of the measured quantities are not high enough for the data to be suitable as a test case for unproven identification techniques or for automatic identification without human involvement. The most serious problem is the high noise level on the control input measurement.
3. The measurement and recording systems currently available at NAVAIRDEVCON for the acquisition of flight data for parameter identification are barely adequate for the purpose.
4. A great deal of valuable experience has been gained, and expertise developed at NAVAIRDEVCON, in the acquisition of flight data for parameter identification purposes and in the use of parameter identification techniques.
5. No significant, consistent trends in results were observed as a function of pilot input type. Without any type of quantitative indication of identification accuracy, it is not possible to reach any conclusions from the current analysis concerning the effect of input type on identification performance.
6. Measurement of pitch angular acceleration directly with a Statham angular accelerometer is a far superior method to the calculation of pitch acceleration based on nose and tail normal acceleration measurements.

### FLIGHT CONDITION #1

1. Due to problems with the performance of the airspeed transducers, filtering of the airspeed measurement was necessary.
2. Proper use of the weighting matrix in the identification program, causing the weighted contributions to the fit error by the various time history matches to be equal, was essential to the performance of the identification technique.

3. Setting the value of the control input to zero following the significant pilot control input has a significant effect on the identified results, but it is not certain that this technique produces valid results, since information is destroyed as well as noise.
4. The algorithm would not converge unless the a priori stability derivatives were reasonable estimates. In the absence of sufficient information in the time histories, the identified results are heavily dependent upon the a priori values.
5. Only one data run (#3) was sufficiently long to permit a reasonable attempt at identification of the speed derivatives. Unfortunately, these data included significant atmospheric turbulence, which was not included in the model and therefore must have had an adverse effect on the identification process.
6. Based on identification results, the best estimate of  $X_u$  is -0.046, which agrees with the a priori value.
7. The stability derivative  $X_\alpha$  was not consistently identifiable. Reduction of results to  $C_{D_{\alpha}}$  still does not reveal any single value or function of  $(C_{L_{\alpha}})_{trim}$ . All identified  $C_{D_{\alpha}}$  values were substantially smaller than the a priori value.
8. The best estimate of  $Z_u$  is -0.39, while the a priori value was -0.27.
9. Based on best results from data run segments of 17.5 seconds or less, the mean estimate for  $Z_\alpha$  was -240.3 (compared to an a priori value of -233.8) and the standard deviation among the six numbers was 38.1.
10. The best estimate of  $M_u$  is -0.004, compared to the a priori value of zero.
11. The mean estimate, based on appropriate results, for  $M_\alpha$  was -5.11, exactly identical to the a priori value, with a standard deviation of 0.34.
12. For  $M_q$ , the mean estimate was -1.32 and the standard deviation was 0.1. The a priori value of  $M_q$  was -1.42.
13. The mean estimate of  $Z_{\delta_e}$  was -22.8 and the standard deviation was 1.81. The a priori value was -24.
14. The mean estimate of  $M_{\delta_e}$  was -8.22, with a standard deviation of 0.74. The a priori estimate was -9.68. Although there was less scatter in the  $M_{\delta_e}$  estimates than, for instance,  $Z_\alpha$  estimates, the large discrepancy between the mean estimate and the a priori value was a source of concern. Reduction of the results to the nondimensional form  $C_{m_{\delta_e}}$ , however, led to an increase in the consistency of the identified results and an increase in the difference between the mean estimate and the a priori value.

15. The time history matches were generally good. The most serious matching problems occurred in the angle of attack time histories.

#### FLIGHT CONDITION #2

1. The conclusions reached for flight condition #1 concerning airspeed signal filtering, use of weighting matrix, and zeroing of control input signal are also applicable to flight condition #2.
2. The signal to noise ratio in the elevator signal was so low that a smoothing process was required before the elevator signal could reasonably be used in the identification program.
3. A priori value of  $X_u$  was -0.016. Only two estimates were obtained, -0.038 and -0.099, and insufficient agreement exists for selection of a best estimate.
4. A priori value of  $Z_u$  was -0.122. Estimates were -0.011 and -0.233, again insufficient for selection of a reasonable estimate.
5. Estimates of  $M_u$  were 0.0016 and 0.0018, which agree very well with an a priori value of 0.0017.
6. The mean estimate of  $X_w$  was 20.5, with a standard deviation of 9.97 (49% of the mean), indicating that little confidence should be placed in this estimate. The a priori value of -36.9 is in strong disagreement with the identified results.
7. The mean estimate of  $Z_w$  was -1371.6, in contrast with an a priori value of -1669.2. This discrepancy seems large for a derivative which should be easily identifiable. The standard deviation among the six appropriate estimates of  $Z_w$  was 170.4 (12% of the mean).
8. The mean estimate of  $M_w$  was -22.4, which agrees very well with the a priori value of -22.5. The standard deviation was less than 2% of the mean, indicating very consistent identification.
9. The mean estimate of  $M_q$  was -7.33, and the standard deviation of the run-to-run values was 0.67, or 9% of the mean, indicating fairly consistent results. Yet the a priori value was only -3.39 and would seem to be seriously in error.
10. The mean estimate of  $Z_{\dot{\alpha}_e}$  was -134.5, in contrast to the a priori value of -121.3. The standard deviation was 6.8 (5% of the mean).
11. The mean estimate of  $M_{\dot{\alpha}_e}$  was -49.3 and the standard deviation was only 0.6, or about 1%. This remarkably consistent set of identified results is in reasonable agreement with the a priori value of -52.1.

12. The time history matches were only fair. A particular pattern of excessive amplitude in the model response for angle of attack, pitch angle, and normal acceleration was obtained several times.

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APPENDIX A  
LISTING OF PROGRAM MESSAGE

```

PROGRAM MESSAGE (INPJ1,OUTPJ1,TAPE1,TAPE2,TAPE3,PUNCH)
COMMON THOUR,TMIN,TSEC,DATA(30),IFILE,IREFC,IFPAME,IPAR,INDAT(240)
C*****
DATA ICOUNT,ISTRT/2,0/
C*****
READ 40,CG
PRINT 40,CG
PRINT 140
READ 1030,IFILER,IREFR,IFPAMER,IFILER,IRECE,IFRAMEE
1000 FORMAT(6I5)
X1=(CG-37.)/12
X2=(CG-34.)/12
X3=(CG-207.)/12
X4=(CG-366.5)/12
X5=(CG-249.)/12
X6=X5
X7=(CG-203.)/12
X8=(CG-56.)/12
X9=X8
X10=(CG-52.)/12
X11=(CG-196.)/12
X12=(CG-47.)/12
X13=(CG-31.5)/12
X14=(CG-204.)/12
X15=X4
Y1=-.33
Y2=-.5
Y3=-.083
Y4=0
Y5=-17.2
Y6=+17.2
Y7=0
Y8=0
Y9=0
Y10=0
Y11=0
Y12=0
Y13=-.5
Y14=-.125
Y15=0

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```

21=.917
22=.21
23=1.75
24=-.75
25=-1.23
26=.75
27=1.96
28=-.42
29=.28
30=-.21
31=1.83
32=-.29
33=.71
34=1.51
35=-.75
36) FORMAT (F10.2)
37) FORMAT (1X,12E10.4)
38) FORMAT (F10.4,5X,I1,9X,I2,7X,I5,2X,8F10.4)
39) FORMAT (5F10.4)
40) FORMAT (1X,9E10.4)
41) FORMAT (10F10.4)
42) FORMAT (90HXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX)
22) CALL INPT
IF (IFILE.EQ. IFILER.AND. IREC.EQ. IREC.AND. IFRAME.EQ. IFRAME) ISTR1=1
IF (ISTR1) 235, 220
235 IF (IFILE.EQ. IFILER.AND. IREC.EQ. IREC.AND. IFRAME.EQ. IFRAME) ISTR1=2
I=I+IN*60.+TSEC
IP=(ICOUNT-2)*.05
VCON=(DATA(13)-DATA(12)).5.
V25=(DATA(14)-DATA(12))/VCON
IF (V25.LT.-.5.OR.V25.GT.5.) 50 TO 130
V24=(DATA(15)-DATA(12))/VCON
IF (V24.LT.-.5.OR.V24.GT.5.) 50 TO 140
V1=(DATA(16)-DATA(12))/VCON
IF (V1.LT.-.5.OR.V1.GT.5.) 50 TO 150
V14=(DATA(17)-DATA(12))/VCON
IF (V14.LT.-.5.OR.V14.GT.5.) 50 TO 160
V3=(DATA(18)-DATA(12))/VCON
IF (V3.LT.-.5

```

```

V2 =(DATA(19)-DATA(12))/VCON
IF(V2 .LT.-.5.OR.V2 .GT.5.5) GO TO 180
V4 =(DATA(20)-DATA(12))/VCON
IF(V4 .LT.-.5.OR.V4 .GT.5.5) GO TO 190
V13=(DATA(21)-DATA(12))/VCON
IF(V13.LT.-.5.OR.V13.GT.5.5) GO TO 180
V15=(DATA(22)-DATA(12))/VCON
IF(V15.LT.-.5.OR.V15.GT.5.5) GO TO 190
V17=(DATA(23)-DATA(12))/VCON
IF(V17.LT.-.5.OR.V17.GT.5.5) GO TO 180
V18=(DATA(24)-DATA(12))/VCON
IF(V18.LT.-.5.OR.V18.GT.5.5) GO TO 190
V16=(DATA(25)-DATA(12))/VCON
IF(V16.LT.-.5.OR.V16.GT.5.5) GO TO 190
V21=(DATA(26)-DATA(12))/VCON
IF(V21.LT.-.5.OR.V21.GT.5.5) GO TO 190
V23=(DATA(28)-DATA(12))/VCON
IF(V23.LT.-.5.OR.V23.GT.5.5) GO TO 180
V12=(DATA(29)-DATA(12))/VCON
IF(V12.LT.-.5.OR.V12.GT.5.5) GO TO 180
V19=((DATA(1)+13.)*.001323)+2.5
IF(V19.LT.-.5.OR.V19.GT.5.5) GO TO 190
V20=((DATA(2)+13.)*.001327)+2.5
IF(V20.LT.-.5.OR.V20.GT.5.5) GO TO 180
V27=((DATA(3)+21.)*.00133)+2.5
IF(V27.LT.-.5.OR.V27.GT.5.5) GO TO 190
V8=((DATA(4)+60.)*.00133)+2.5
IF(V8.LT.-.5.OR.V8.GT.5.5) GO TO 190
V11=((DATA(5)+29.)*.001342)+2.5
IF(V11.LT.-.5.OR.V11.GT.5.5) GO TO 190
V10=((DATA(6)+75.)*.001346)+2.5
IF(V10.LT.-.5.OR.V10.GT.5.5) GO TO 190
V9=((DATA(7)+10.)*.00133)+2.5
IF(V9.LT.-.5.OR.V9.GT.5.5) GO TO 190
V5=((DATA(8)+13.)*.001333)+2.5
IF(V5.LT.-.5.OR.V5.GT.5.5) GO TO 190
V7=((DATA(9)+23.)*.001334)+2.5
IF(V7.LT.-.5.OR.V7.GT.5.5) GO TO 190
V5=((DATA(10)+40.)*.001338)+2.5
IF(V5.LT.-.5.OR.V5.GT.5.5) GO TO 190

```

```

V22=((0.171*(11.611)*0.1323)*0.130
IF (V22.LT.-5.02)*22.55,5.54 0 190
P1= 13.5*(V1-2.45)
P4=-47.0*(V4-2.45)
P13=-4.183*(V19-2.5)
P11= .151*(V11-2.5)
P16= 500.0*(V16-2.4)
ASC=100.0*V17
K=2.0*V17
PK=K
ASF1=50.0*RK+10.0*V17
ASF2=ASF1+50.
ASF3=ASF1-50.
)IF1=A3S(ASF1-ASC)
)IF2=A8S(ASF2-ASC)
)IF3=A8S(ASF3-ASC)
IF (DIF1.LE.DIF2.AND. DIF1.LE.DIF3) P18=ASF1
IF (DIF2.LE.DIF1.AND. DIF2.LE.DIF3) P18=ASF2
IF (DIF3.LE.DIF2.AND. DIF3.LE.DIF1) P18=ASF3
IF (IFILE-4) 190,200,200
190 P5=+7.7*(V5-2.55)
P12=+.138*(V12-2.5)
P11=+.145*(V10-2.48)
GO TO 210
200 P5=+30.11*(V5-2.55)
P12=+.146*(V12-2.48)
P10=+.3216*(V10-2.53)
210 P6=+49.5*(V6-2.55)
P9=+6.65*(V9-2.5)
P13=+15.05*(V13-2.5)
P14=+12.03*(V14-2.5)
P15=+13.8*(V15-2.5)
P20=-4.183*(V20-2.55)
P22=+7.7*(V22-3.02)
P23=+14.61*(V13-2.64)
P7=-3.27*(V7-2.5)
P8= 5.39*(V8-2.55)
P21= 9.97*(V21-4.77)
P2=-4.4*(V2-2.4)
P3=-47.8*(V3-2.4)

```

```

24=-9.053*(V24-4.22)
25=((P5-P6)*(X4-X2))-((22-P4)*(Y5-Y6))/((Y5-Y6)*(X4-X2))-
1 (X6-X5)
26=(22-P4-P0*(Y2-Y4))/(X4-X2)
27=(213-P15-P0*(Z15-Z13))/(X13-X15)

202=P7
2=P10
2=P11
2=P12
2A=P22
2HI=P9
2H=P9
A=213+4.0
H=P16
3=P20
2R=P23
2E=P21
2B=P24
IF (IFILE-3) 50,50,63
50 V=(P18+4)*1.688
60 TO 80
60 V=(P18+8)*1.923
70 TO 80
70 V=(P18+6.5)*2.609
80 A=A+1323.6*Q/V
9=9+1340.8*R/V
IF (IP) 30,20
20 E=A/57.3
30 AZ=(23-((SIN(E)/COS(E))*(21-Z1*QD+Y1*RD))+X3*QD-Y3*PD)/
1 ((SIN(E))*2)/COS(E))+COS(E)
AX=(21+AZ*SIN(E)-Z1*QD+Y1*P)/COS(E)
A=A-E*57.3
AV=P14-X14*RD+Z14*PD
IF (IP) 100,90
90 201=20
202T=Q02
21=Q
201=20
201=20
21=2

```

```

RT=R
AYT=AY
PHIT=PHI
DAT=DA
DRT=DR
RT=R
THT=TH
AZT=AZ
AXT=AX
DET=DE
VPRIME=0.
VT=V
DRT=DR
HT=H
100 D02=D02-Q02T
D03=D03-Q03T
V=V-VT
H=H-HT
Q=Q-QT
TH=TH-THT
AZ=AZ-AZT
AX=AX-AXT
DE=DE-DET
D0=D0-Q0T
R=R-RT
D0=D0-P0T
D0=D0-R0T
P=P-P0T
R=R-RT
AY=AY-AYT
DA=DA-DAT
PHI=PHI-PHIT
DR=DR-DRT
IF (IP) 180,170
170 F=3.37.3
PRINT 160, IP, F, THT, QT, D0T, D02T, AZT, AXT, DET, DRT, VT, HT
180 PRINT 160, IP, A, TH, Q, D0, Q02, AZ, AX, DE, DB, V, H
IPN=2
JNCH 103, IP, A, TH, Q, D02, AZ, AX, DE, V, H, IRN
103 FORMAT(F6.2,9F8.3,I2)

```

```

WRITE(3)      TP,A,TH,Q,QD,QD2,AZ,AX,DE,D3,V,M
COUNT=ICOUNT+1
IF(ISTRT.EQ.2) GOTO 130
DO TO 220
130 CONTINUE
STOP
END

```

```

SUBROUTINE INPT
  INPUT DATA FROM TAPE, FLOAT IT AND STORE IN COMMON.  INPT IS
  CALLED ONCE FOR EACH FRAME OF DATA.
  ENTRY NONE
  EXIT
    THOUR.EQ.VALUE OF HOURS FIELD FLOATED
    TMIN .EQ.VALUE OF MINUTES FLOATED
    TSEC .EQ.VALUE OF SECONDS FIELD F.OATED
    DATA .EQ.VALUE OF CHANNEL DATA FLOATED
    IFILE.EQ.CURRENT FILE NO.
    IREC .EQ.CURRENT RECORD NO. WITHIN FILE
    IFRAME.EQ.CURRENT FRAME NO. WITHIN RECORD
    IPAR .EQ. 0, IF NO PARITY ERR.
    IPAR .EQ. 1, IF PARITY ERR
  JSES INDAT
  CALLS MXRBYT
  COMMON THOUR,TMIN,TSEC,DATA(30),IFILE,IREC,IFRAME,IPAR,INDAT(240)
  DATA IFLG/1/
  BRANCH 1 - FIRST TIME ENTERED
        2 - TAPE READ REQUIRED
        3 - FRAME ALREADY IN CORE
  GO TO (90,40,80),IFLG
  HERE FOR FIRST TIME
  NOFL=6
  IFILE=1
  IREC=0
  IFRAME=0
  IFLG=2
  HERE IF TAPE READ NEEDED
  BUFFER IN(1,1)(INDAT(1),INDAT(240))
  IF(UNIT(1))10,20,30

```

```

* *
* *
10  IPAR=0
50  IREC=IREC+1
    IFRAME=0
    IFLG=3
* *
* *
* *
40  HERE IF FRAME ALREADY IN CORE
    IFRAME=IFRAME+1
    NPOS=(IFRAME-1)*7
* *
* *
* *
    GET TIME VALUES
    NDAT=INDAT(NPOS+1)
    I40JR=10*MXRBYT(33,2,NDAT)
    1  +MXRBYT(31,4,NDAT)
    I41N=10*MXRBYT(27,3,NDAT)
    1  +MXRBYT(24,4,NDAT)
    I44=1000*MXRBYT(20,4,NDAT)
    1  +1009*MXRBYT(15,4,NDAT)
    2  +100*MXRBYT(12,4,NDAT)
    3  +10*MXRBYT(8,4,NDAT)
    +MXRBYT(4,4,NDAT)
    TSEC=TEM/1000.
* *
* *
    GET CHANNEL DATA
    DO 50 I=1,6
    DO 70 J=1,5
    ITEM =MXRBYT(60-(J-1)*12,12,INDAT(NPOS+I+1))
    IF (ITEM.GE.2048) ITEM=-(ITEM-2048)
    DATA(I-1)*5+J)=ITEM
    CONTINUE
    CONTINUE
70
60
* *
* *
* *
    SET IFLG FOR NEXT ENTRY.
    IF(IFRAME.EQ.34) IFLG=2
    RETURN

```

```

*
*
*
20  HERE WHEN EOF FOUND
    IFILE=IFILE+1
    IF(IFILE.EQ.NOFL+1) STOP1
    IPEC=0
    GO TO 40.
*
*
*
    HERE WHEN PARITY ERR. FOUND
30  PRINT 100,IFILE ,IPEC,IFRAME
100  FORMAT(1X,*,FILE*,I3,*,X,*,RECORD*,I10,4X,*,*,NAME*,I3,*,CONTAINS PARITY
    1 ERROR*)
    IPAR=1
    GO TO 50
    END

```

APPENDIX B  
LISTING OF PROGRAM NEWTON

**B-3**

```

MU = B(2) + .01
MX = A(2) + .01
MZ = OIS(2) + .01
MXP1 = 4X + 1
IB = OIS(1) + .01
IF(IU-1) 78,79,78
78 CALL SET(J1, 1,MZ)
IJ = 4 - MZ
DO 80 I = 1,MZ
  IJ = IJ + MZ + 1
80 OI(I+4) = OIS(IJ)
  GO TO 81
79 CALL MAKE(OI, DIS)
81 CALL SPII(OI, 2HD1)
AU = 1.0/E NN

CALL AUU(AU, OI, O., OI, OI)
CALL AUJ(AU, OIS, O., OIS, DIS)
PRINT 1002
JKM = 1
DO 9 NP = 1,100
  READ 111, (IP(NP,I), I = 1,4), (AP(NP,J), J = 1,3)
  PRINT 111, (IP(NP,I), I = 1,4), (AP(NP,J), J = 1,3)
  AP(NP,4) = AP(NP,1)
  AP(NP,5) = 0.
  IF(IP(NP,1)) 6,5,5
5 JKM = JKM + IP(NP,1)
0 CONTINUE
  JKMM1 = JKM - 1
  NPM = NP - 1
  PRINT 1003, JKM, NPM
  IT = - 4H
  PRINT 1004, MU, MZ
  DO 62 I=1,NSKIP
  READ(1)(JUU(J),J=1,12)
  IF(100H=U(1)) 62,62
62 CONTINUE
  ICOUNT=NINTVL
  I=0
500 IF(I.GE.NN)GO TO 501
  IF(ICOUNT-NINTVL) 65,66

```

**B-5**

[illegible]

[illegible]

[illegible]

```
CALL MU-T(MPHI, DUJ, DJM)
CALL AU(1.0,X2,1.0,DUM,X2)
DO 2 J = 1,MX
    2 Y(J+4) = X2(J+4) + DZN(J+4)
C-----SSSSSSSSSSSSSSSSSSSSS.....COMPUTE STATE (END).....$
CEEEEEEEEEE.....SET UP SYSTEM OF EQUATIONS.....$
    41 CALL TRUCK(XJ), DI5, SUM)
CTTTTTTTTITTTTTTTTTTTTTTTTTT.....TIME LOOP (END).....$
    LLM1 = 'L-1'
PRINT 1005, SUM(JKM*JKM+4),L.M1
CALL SPIT(EZ,4HEE*Q)
DO 60 I = 1,MZ
    60 EE(I+4) = SQRT((EE(I+4)/(DI(I+4)*ENN))/SZ(I+4))
CALL SPIT(EE, 3HRMS)
CUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUU...MULT DIAG BY 1.0005 TO CONDUTION.$
    CALL SET(DUM, 1, JKM)
DO 1 J = 1,JKM
    JJ = JKM*J + 4
    IJ = (J-1)*JKM + J + 4
    DUM(J+4) = SUM(IJ)
        1 SUM(IJ) = SUM(IJ)*1.0005
    CALL SPIT(DUM, 4HGRAD)
    531 FORMAT('55H WOULD YOU BELIEVE.....')
    PRINT 531
C-----SSSSSSSSSSSSSSSSSSSSS.....SOLVE SYSTEM OF EQUATIONS.....$
CALL AU(FINK, SUM, 0., SUM, SUM)
IF(LL-IIR)74,73,74
73 CALL MINR(SUM, JKM, JKMI, XJI)
CALL SET(UUJ, JKMM1, 1)
JJ = 4
DO 75 J = 1,JKMM1
    JJ = JJ + JKM
75 UUJ(J+4) = SUM(JJ)
74 CALL SOLVE(SUM, DC)
    CALL SPIT(CG, 2HUC)
CUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUU...UPDATE COEFFICIENTS (START).....$
    JK = 0
DO 12 NP = 1,NPM
    IG = IP(NP,2)
    II = IP(NP,3)
```

[illegible]

```

      IF(IP(NP,1)-1)50,77,50
77 JK = JK + 1
      IJ = (JK-1)*JKMM1 + JK + 4
      AP(NP,5) = SQR(SUM(IJ)/FINK)
50 PRINT 111, (IP(NP,J), J = 1,4), (AP(NP,J), J = 1,5)
      STOP
      ENJ

```

```

SUBROUTINE ADD(P, A, Q, B, C)
VECTOR FORMAT
  DIMENSION A(1), B(1), C(1)
  N = A(3) + 4.01
  DO 1 I = 5, N
    1 C(1) = 3*A(I) + Q*B(I)
    C(1) = A(1)
    C(2) = A(2)
    C(3) = A(3)
    C(4) = A(4)
  RETURN
END

```

```

C      SUBROUTINE EAT(A, I, PHI, APHI, A2, A3)
      VECTOR FORMAT
      DIMENSION A(1), PHI(1), APHI(1), A2(1), A3(1)
123  FORMAT(55H MATRIX IS NOT SQUARE FOR EAT, STUPID.....
      II = A(1) + .01
      JJ = A(2) + .01
      IF(II-JJ)4,3,4
      3  CALL SET(PHI, II, II)
      CALL SET(APHI, II, II)
      DO 1 I = 1, II
      1  IJ = (I-1)*II + I + 4
      1  PHI(IJ) = 1.0
      CALL MAKE(A2, PHI)
      G = 1.0
      DO 2 I = 1, 6
      2  BB = I
      G = G*T/BB
      CALL ADJ(1.0, APHI, G, A2, A*PHI)
      CALL MULTI(A, A2, A3)
      CALL MAKE(A2, A3)
      CALL ADJ(1., PHI, G, A2, P*PHI)
      2  CONTINUE
      GO TO 5
      4  PRINT 123
      5  RETURN
      END

```

```

C      SUBROUTINE INVR(A, B)
C      VECTOR FORMAT, DIAGONAL ELEMENTS MUST BE NON-ZERO.
      DIMENSION A(1), B(1)
101  FORMAT(15.7)
      N = A(1) + .01
      CALL SET(B, N, N)
      DO 6 I = 1, N
        IJ = (I-1)*N + I + 4
        B(IJ) = 1.0
        DELTA = 1.0
        DO 3 K = 1, N
          KP1 = K + 1
          KK = (K-1)*N + K + 4
          AKK1 = 1.0/A(KK)
          DELTA = DELTA*A(KK)
          DO 5 J = 1, N
            IJ = (K-1)*N + J + 4
            B(IJ) = B(IJ)*AKK1
          DO 1 J = K, N
            IJ = (K-1)*N + J + 4
            A(IJ) = A(IJ)*AKK1
          DO 2 KI = 1, N
            IF(K - KI) 7, 2, 7
          7  KIK = (KI-1)*N + K + 4
            AKIK = A(KIK)
            DO 4 L = 1, N
              KL = (K-1)*N + L + 4
              KIL = (KI-1)*N + L + 4
              B(KIL) = B(KIL) - AKIK*B(KL)
            4  CONTINUE
          IF(K-N) 8, 3, 8
          8  DO 10 L = KP1, N
            KL = (K-1)*N + L + 4
            KIL = (KI-1)*N + L + 4
            A(KIL) = A(KIL) - AKIK*A(KL)
          10  CONTINUE
        9  CONTINUE
      2  CONTINUE
      3  CONTINUE
      PRINT 101, DELTA
      RETURN
      END

```

```

SUBROUTINE LUADU(A, B, C, D)
  VECTOR FORMAT
  DIMENSION A(1), B(1), C(1), D(1)
  CALL LOUE(A)
  IF(M-1)8,8,2
  2 CALL LOUE(B)
  IF(M-2)8,8,4
  4 CALL LOUE(C)
  IF(M-3)8,8,6
  6 CALL LOUE(D)
  8 RETURN
  END

```

```

SUBROUTINE LOUE(A)
  VECTOR FORMAT
  DIMENSION A(1)
  700 FORMAT(7F10.3)
  444 FORMAT(7X,I3,7X,I3)
  READ 444, II, JJ
  A(1) = II
  A(2) = JJ
  A(3) = II*JJ
  A(4) = 0.
  IF(A(3))2,3,2
  2 CONTINUE
  L = 4 - JJ
  DO 1 I = 1,II
  L = L + JJ
  1 READ 700,(A(L+J), J = 1, JJ)
  3 CONTINUE
  RETURN
  END

```

```

C      SUBROUTINE MINR(A, I, J, B)
      VECTOR FORMAT
      DIMENSION A(1), B(1)
      M = A(1) + .01
      N = A(2) + .01
      IF(I) 11, 10, 11
10  I = 99999
      MM1 = M
      GO TO 12
11  MM1 = M - 1
12  IF(J) 13, 14, 13
14  J = 99999
      NM1 = N
      GO TO 3
13  NM1 = N - 1
      DO 1 K = 1, M
      DO 1 L = 1, N
      IF(I-K) 2, 3, 3
2  II = K - 1
      GO TO 4
3  II = K
4  IF(J-L) 5, 3, 6
5  JJ = L - 1
      GO TO 7
6  JJ = L
7  B(II*NM1 + JJ - NM1 + 4) = 1(K*N + L - N + 4)
8  CONTINUE
9  CONTINUE
      B(1) = 4M1
      B(2) = NM1
      B(3) = MM1*NM1
      B(4) = J.
      RETURN
      ENJ

```

```

SUBROUTINE MAKE(A, B)
VECTOR FORMAT
DIMENSION A(1), B(1)
N = 4(1)*3(2) + 4.01
DO 1 I = 1,N
1 A(I) = B(I)
RETURN
END

```

```

SUBROUTINE MULT(A, B, C)
VECTOR FORMAT - NEITHER A NOR B CAN BE EQUIVALENT TO C
DIMENSION A(1), B(1), C(1)
II = A(1) + .01
JJ = B(2) + .01
KK = A(2) + .01
LL = B(1) + .01
CALL SET(C, II, JJ)
IF(KK - LL)12,11,12
12 PRINT 123
123 FORMAT(55H MATRICES INCOMPATIBLE FOR MULTI, DUM-UUM....
11 DO 1 I = 1,II
DO 1 J = 1,JJ
DO 1 K = 1,KK
IJ = (I-1)*JJ + J + 4
IK = (I-1)*KK + K + 4
NJ = (K-1)*JJ + J + 4
1 C(IJ) = C(IJ) + A(IK)*B(KJ)
C(1) = A(1)
C(2) = B(2)
C(3) = II*JJ
C(4) = 0.
RETURN
END

```

```

SUBROUTINE SOLVE(A, C)
  VECTOR FORMAT
  DIMENSION A(1), C(1)
101 FORMAT(=15.7)
  N = A(1) - .99
  NM1 = N - 1
  NP1 = N + 1
  NP3 = N - 3
  DO 6 K = 1, NM1
    AKK1 = 1./A(K*NP1 + K - NP3)
    K1 = K + 1
    DO 6 KI = K1, N
      AKIK = A(K1*NP1 + K - NP3)*A(K1
    DO 6 L = K1, NP1
      KIL = KI*NP1 + L - NP3
6 A(KIL) = A(KIL) - AKIK*A(K*NP1 + L - NP3)
    DELTA = A(5)
    C(NP4) = A(NP1*NP1 - NP3)/A(V*NP1 + 3)
    DO 16 I = 2, N
      NI1 = N - I + 1
      C(NI1 + 4) = A(NI1*NP1 + 4)
      NI2 = NI1 + 1
    DO 8 J = NI2, N
      C(NI1+4) = C(NI1+4) - C(J+4)*A(NI1*NP1 + J - NP3)
      C(NI1+4) = C(NI1+4)/A(NI1*NP1 + NI1 - NP3)
16 JCTA = JCTA*A(I*NP1 + 1 - VP3)
  PRINT 101, DELTA
  C(1) = 1.0
  C(2) = A(1) - 1.0
  C(3) = C(2)
  C(4) = 0.0
  RETURN
END

```

```

SUBROUTINE SPIT(A, B)
  VECTOR FORMAT
  DIMENSION A(1)
  505 FORMAT(5E12.4)
  321 FORMAT(6H MATRIX ,A5,4H HAS ,I4,10H ROWS AND ,I4,8H COLUMNS)
  II = A(1) + .01
  JJ = A(2) + .01
  PRINT 321, B, II, JJ
  L = 4 - JJ
  IF(II)3,3,2
  2 DO 1 L = 1,II
  L = L + JJ
  1 PRINT 505, (A(L+J), J = 1,JJ)
  3 RETURN
  END

```

```

SUBROUTINE SET(A, II, JJ)
  VECTOR FORMAT
  DIMENSION A(1)
  A(1) = II
  A(2) = JJ
  A(3) = II*JJ
  A(4) = 0.
  N = II*JJ + 4
  DO 1 I = 5,N
  1 A(I) = 0.0
  RETURN
  END

```

```

C
SUBROUTINE TRICK(A, B, C)
  VECTOR FORMAT
  DIMENSION A(1), B(1), C(1)
  IB = B(1) + .01
  JB = B(2) + .01
  II = A(1) + .01
  JJ = A(2) + .01
  IF((IB-1)*(JB-1))3,4,3
  4 CONTINUE
  DO 1 J = 1,II
  DO 1 I = 1,J
  IJ = (I-1)*II + J + 4
  DO 2 K = 1,JJ
  2 C(IJ) = C(IJ) + A(1*JJ+K-JJ++)*A(J*JJ+K-JJ++)*B(K++)
  1 C(J*II + I - II + 4) = C(IJ)
  RETURN
  3 CONTINUE
  DO 11 J = 1,II
  DO 11 I = 1,J
  IJ = (I-1)*II + J + 4
  DO 12 K = 1,JJ
  12 C(IJ) = C(IJ) + A(IK)*B(KL)*C(JL)
  11 C(J*II + I - II + 4) = C(IJ)
  RETURN
  END

```

**APPENDIX C**  
**IDENTIFICATION RESULTS (UNREDUCED)**

## Unreduced Derivatives:

$$X_{\sim}' = \frac{X_{\sim}}{U}$$

$$Z_{\sim}' = \frac{Z_{\sim}}{U_0 - Z_{\sim}}$$

$$M_u' = M_u + \frac{M_{\sim} Z_u}{U_0 - Z_{\sim}}$$

$$M_{\sim}' = M_{\sim} + \frac{M_{\sim} Z_{\sim}}{U_0 - Z_{\sim}}$$

$$M_q' = M_q + M_{\sim} \left[ \frac{U_0 + Z_q}{U_0 - Z_{\sim}} \right]$$

$$Z_{\lambda_e}' = \frac{Z_{\lambda_e}}{U_0 - Z_{\sim}}$$

$$M_{\lambda_e}' = M_{\lambda_e} + \frac{M_{\sim} Z_{\lambda_e}}{U_0 - Z_{\sim}}$$

Initial Conditions:  $X_0, Z_0, M_0$

For run number coding refer to page 52.

Preceding page blank

TABLE C-I  
IDENTIFICATION RESULTS (FLIGHT CONDITION #1)

| <u>Derivative<br/>Name</u> | <u>Start-<br/>Up</u> | <u>Run No.</u>       |                      |                      |
|----------------------------|----------------------|----------------------|----------------------|----------------------|
|                            |                      | <u>DR2-1W1</u>       | <u>DR2-1W2</u>       | <u>DR2-1W3</u>       |
| $X_u$                      | -.046                | -.066                | -.074                | -.076                |
| $X'_u$                     | -.087                | -.049                | -.046                | -.041                |
| $Z_u$                      | -.27                 | .040                 | .062                 | .069                 |
| $Z'_u$                     | -.877                | -1.142               | -1.16                | -1.17                |
| $M_u$                      | 1.59                 | .28                  | .23                  | .21                  |
| $M'_u$                     | -4.59                | -4.95                | -4.99                | -5.02                |
| $M'_q$                     | -1.95                | -1.74                | -1.76                | -1.77                |
| $Z'_{h_e}$                 | -.092                | -.090                | -.082                | -.081                |
| $M'_{h_e}$                 | -9.63                | -9.16                | -9.24                | -9.28                |
| $X_o$                      | -                    | $-.2 \times 10^{-2}$ | $-.3 \times 10^{-2}$ | $-.3 \times 10^{-2}$ |
| $Z_o$                      | -                    | $.8 \times 10^{-2}$  | $1. \times 10^{-2}$  | $.1 \times 10^{-1}$  |
| $M_o$                      | -                    | $-.2 \times 10^{-1}$ | $-.2 \times 10^{-1}$ | $-.2 \times 10^{-1}$ |
| Run Time                   | -                    | 17.5                 | 17.5                 | 17.5                 |
| Trim<br>Velocity           | -                    | 266.5                | 266.5                | 266.5                |

TABLE C-I (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #1)

| Derivative<br>Name | Start-<br>Up | Run No.               |                       |                       |
|--------------------|--------------|-----------------------|-----------------------|-----------------------|
|                    |              | <u>DR3-1</u>          | <u>DR3-1W1</u>        | <u>DR3-1W2</u>        |
| $X_u$              | -.046        | -.046                 | -.028                 | -.046                 |
| $X'_u$             | -.087        | -.087                 | -.047                 | -.023                 |
| $Z_u$              | -.27         | -.27                  | -.26                  | -.28                  |
| $Z'_u$             | -.877        | -.877                 | -.903                 | -.954                 |
| $M_u$              | 1.59         | 1.60                  | .935                  | -.020                 |
| $M'_u$             | -4.59        | -4.59                 | -4.54                 | -4.46                 |
| $M'_q$             | -1.95        | -1.95                 | -1.97                 | -1.75                 |
| $Z'_{h_e}$         | -.092        | -.092                 | -.089                 | -.088                 |
| $M'_{h_e}$         | -9.63        | -9.61                 | -7.56                 | -7.15                 |
| $X_o$              | -            | $-0.8 \times 10^{-3}$ | $-0.3 \times 10^{-2}$ | $-0.2 \times 10^{-2}$ |
| $Z_o$              | -            | $0.4 \times 10^{-3}$  | $0.1 \times 10^{-1}$  | $0.2 \times 10^{-1}$  |
| $M_o$              | -            | $-0.6 \times 10^{-4}$ | $-0.2 \times 10^{-1}$ | $-0.2 \times 10^{-1}$ |
| Run Time           | -            | 17.5                  | 17.5                  | 17.5                  |
| Trim<br>Velocity   | -            | 246.7                 | 246.7                 | 246.7                 |

TABLE C-I (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #1)

| Derivative<br>Name | Start-<br>Up | Run No.               |                       |                       |
|--------------------|--------------|-----------------------|-----------------------|-----------------------|
|                    |              | <u>DR3-2W</u>         | <u>DR3-2W2</u>        | <u>DR3-U2W1</u>       |
| $X_u$              | -.046        | -.046                 | -.047                 | -.054                 |
| $X'_w$             | -.087        | -.048                 | -.030                 | -.023                 |
| $Z_u$              | -.27         | -.356                 | -.373                 | -.414                 |
| $Z'_w$             | -.877        | -.831                 | -.817                 | -.954                 |
| $M'_u$             | 1.59         | -.57                  | -.61                  | -.73                  |
| $M'_w$             | -4.59        | -4.45                 | -4.34                 | -4.46                 |
| $M'_q$             | -1.95        | -2.13                 | -2.19                 | -1.75                 |
| $Z'_{\delta_e}$    | -.092        | -.090                 | -.089                 | -.090                 |
| $M'_{\delta_e}$    | -9.63        | -7.07                 | -7.10                 | -7.15                 |
| $X_o$              | -            | $-0.2 \times 10^{-2}$ | $-0.3 \times 10^{-2}$ | $-0.2 \times 10^{-2}$ |
| $Z_o$              | -            | $0.2 \times 10^{-1}$  | $0.2 \times 10^{-1}$  | $0.2 \times 10^{-1}$  |
| $M_o$              | -            | $-0.1 \times 10^{-1}$ | $-0.2 \times 10^{-1}$ | $-0.2 \times 10^{-1}$ |
| Run Time           | -            | 35                    | 35                    | 35                    |
| Trim<br>Velocity   | -            | 246.7                 | 246.7                 | 246.7                 |

TABLE C-I (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #1)

| <u>Derivative<br/>Name</u> | <u>Start-<br/>Up</u> | <u>Run No.</u>        |                       |                       |
|----------------------------|----------------------|-----------------------|-----------------------|-----------------------|
|                            |                      | <u>DR3-U3W1</u>       | <u>DR3-U3W2</u>       | <u>DR3-1W1DEZ</u>     |
| $X_u$                      | -.046                | -.046                 | -.046                 | -.044                 |
| $X'_v$                     | -.087                | -.023                 | -.023                 | +.002                 |
| $Z_u$                      | -.27                 | -.338                 | -.387                 | -.22                  |
| $Z'_v$                     | -.877                | -.954                 | -.954                 | -.804                 |
| $M'_u$                     | 1.59                 | -.62                  | -.84                  | .75                   |
| $M'_v$                     | -4.59                | -4.46                 | -4.46                 | -4.69                 |
| $M'_q$                     | -1.95                | -1.75                 | -1.75                 | -2.03                 |
| $Z'_{\delta_e}$            | -.092                | -.090                 | -.090                 | -.092                 |
| $M'_{\delta_e}$            | -9.63                | -7.15                 | -7.15                 | -7.66                 |
| $X_o$                      | -                    | $-0.2 \times 10^{-2}$ | $0.1 \times 10^{-2}$  | $-0.5 \times 10^{-2}$ |
| $Z_o$                      | -                    | $0.1 \times 10^{-1}$  | $0.2 \times 10^{-1}$  | $0.1 \times 10^{-1}$  |
| $M_o$                      | -                    | $-0.2 \times 10^{-1}$ | $-0.2 \times 10^{-1}$ | $-0.2 \times 10^{-1}$ |
| Run Time                   |                      | 52.5                  | 52.5                  | 17.5                  |
| Trim<br>Velocity           |                      | 246.7                 | 246.7                 | 246.7                 |

TABLE C-I (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #1)

| Derivative<br>Name | Start-<br>Up | Run No.              |                      |                      |                      |
|--------------------|--------------|----------------------|----------------------|----------------------|----------------------|
|                    |              | <u>DR4-1W1</u>       | <u>DR4-1W2</u>       | <u>DR4-1W3</u>       | <u>DR4-1W4</u>       |
| $X_u$              | -.046        | -.023                | -.014                | -.020                | -.036                |
| $X'_u$             | -.087        | -.057                | -.038                | -.043                | -.042                |
| $Z_u$              | -.27         | -.16                 | -.20                 | -.22                 | -.22                 |
| $Z'_u$             | -.877        | -.922                | -.904                | -.887                | -.879                |
| $M_u$              | 1.59         | -.67                 | -.83                 | -.93                 | -.96                 |
| $M'_u$             | -4.59        | -4.30                | -4.27                | -4.24                | -4.22                |
| $M'_q$             | -1.95        | -1.72                | -1.76                | -1.79                | -1.81                |
| $Z'_{\lambda_e}$   | -.092        | -.096                | -.088                | -.090                | -.091                |
| $M'_{\lambda_e}$   | -9.63        | -8.08                | -8.11                | -8.18                | -8.21                |
| $X_o$              | -            | $.2 \times 10^{-2}$  | $.9 \times 10^{-3}$  | $-.1 \times 10^{-3}$ | $-.7 \times 10^{-3}$ |
| $Z_o$              | -            | $-.4 \times 10^{-3}$ | $-1. \times 10^{-3}$ | $-.2 \times 10^{-2}$ | $-.2 \times 10^{-2}$ |
| $M_o$              | -            | $.6 \times 10^{-2}$  | $.3 \times 10^{-2}$  | $-.4 \times 10^{-3}$ | $-.3 \times 10^{-2}$ |
| Run Time           |              | 17.5                 | 17.5                 | 17.5                 | 17.5                 |
| Trim<br>Velocity   |              | 253.2                | 253.2                | 253.2                | 253.2                |

TABLE 7-1 (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #1)

| Derivative<br>Name | Start-<br>Up | Run No.              |                      |                      |
|--------------------|--------------|----------------------|----------------------|----------------------|
|                    |              | <u>DR5-1W1</u>       | <u>DR5-1W2</u>       | <u>DR5-1W3</u>       |
| $X_u$              | -.046        | .034                 | .035                 | .034                 |
| $X'_v$             | -.087        | .023                 | .024                 | .020                 |
| $Z_u$              | -.27         | -.35                 | -.36                 | -.35                 |
| $Z'_v$             | -.877        | -.919                | -.922                | -.941                |
| $M_u$              | 1.59         | 1.29                 | 1.29                 | 1.25                 |
| $M'_v$             | -4.59        | -4.80                | -4.81                | -4.86                |
| $M_q$              | -1.95        | -1.87                | -1.88                | -1.85                |
| $Z'_{\delta_e}$    | -.092        | -.113                | -.113                | -.103                |
| $M'_{\delta_e}$    | -9.63        | -8.66                | -8.67                | -8.60                |
| $X_o$              | -            | $.7 \times 10^{-3}$  | $.7 \times 10^{-3}$  | $.7 \times 10^{-3}$  |
| $Z_o$              | -            | $.60 \times 10^{-2}$ | $.6 \times 10^{-2}$  | $.6 \times 10^{-2}$  |
| $M_o$              | -            | $-1. \times 10^{-2}$ | $-1. \times 10^{-2}$ | $-.1 \times 10^{-1}$ |
| Run Time           | -            | 17.5                 | 17.5                 | 17.5                 |
| Trim<br>Velocity   | -            | 255.7                | 255.7                | 255.7                |

**TABLE C-1 (CONTINUED)**  
**IDENTIFICATION RESULTS (FLIGHT CONDITION #1)**

| Derivative<br>Name | Start-<br>Up | Run No.              |                      |                      |                      |
|--------------------|--------------|----------------------|----------------------|----------------------|----------------------|
|                    |              | <u>DR6-1W1</u>       | <u>DR6-1W2</u>       | <u>DR6-1W2SH</u>     | <u>DR6-1W3SH</u>     |
| $X_u$              | -.046        | .024                 | .025                 | .018                 | 0                    |
| $X'_w$             | -.087        | -.052                | -.055                | -.044                | -.034                |
| $Z_u$              | -.27         | -.38                 | -.38                 | -.25                 | -.24                 |
| $Z'_w$             | -.877        | -.941                | -.945                | -.937                | -.927                |
| $M'_u$             | 1.59         | .56                  | .54                  | .59                  | .47                  |
| $M'_w$             | -4.59        | -4.51                | -4.53                | -4.54                | -4.41                |
| $M'_q$             | -1.95        | -1.76                | -1.79                | -1.81                | -1.86                |
| $Z'_{\delta_e}$    | -.092        | -.094                | -.096                | -.089                | -.086                |
| $M'_{\delta_e}$    | -9.63        | -6.74                | -6.81                | -7.97                | -8.10                |
| $X_o$              | -            | $.2 \times 10^{-2}$  | $.2 \times 10^{-2}$  | $.2 \times 10^{-2}$  | $.2 \times 10^{-2}$  |
| $Z_o$              | -            | $-.1 \times 10^{-1}$ | $-.1 \times 10^{-1}$ | $-.1 \times 10^{-1}$ | $-.1 \times 10^{-1}$ |
| $M_o$              | -            | $.1 \times 10^{-1}$  | $.2 \times 10^{-1}$  | $.2 \times 10^{-1}$  | $.2 \times 10^{-1}$  |
| Run Time           |              | 17.5                 | 17.5                 | 10.0                 | 10.0                 |
| Trim<br>Velocity   |              | 251.6                | 251.6                | 251.6                | 251.6                |

TABLE C-II  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| <u>Derivative<br/>Name</u> | <u>Start-<br/>Up</u> | <u>Run No.</u>         |                        |                        |
|----------------------------|----------------------|------------------------|------------------------|------------------------|
|                            |                      | <u>DR10-1W1S1</u>      | <u>DR10-1W2S1</u>      | <u>DR10-1W2S2</u>      |
| $X_u$                      | -.016                | -.0034                 | .0017                  | .0010                  |
| $X'_u$                     | -.054                | .0065                  | .011                   | .010                   |
| $Z_u$                      | -.12                 | +.179                  | +.156                  | +.155                  |
| $Z'_u$                     | -2.46                | -1.89                  | -2.05                  | -2.06                  |
| $M'_u$                     | 1.34                 | -.375                  | -.63                   | -.63                   |
| $M'_\alpha$                | -18.6                | -19.07                 | -19.0                  | -19.0                  |
| $M'_q$                     | -4.96                | -8.59                  | -8.15                  | -8.04                  |
| $Z'_e$                     | -.18                 | -.19                   | -.19                   | -.19                   |
| $M'_e$                     | -51.8                | -49.0                  | -49.4                  | -49.8                  |
| $X_o$                      | -                    | .15 X 10 <sup>-3</sup> | .3 X 10 <sup>-3</sup>  | .3 X 10 <sup>-3</sup>  |
| $Z_o$                      | -                    | -.5 X 10 <sup>-2</sup> | -.5 X 10 <sup>-2</sup> | -.5 X 10 <sup>-2</sup> |
| $M_o$                      | -                    | .6 X 10 <sup>-3</sup>  | .5 X 10 <sup>-2</sup>  | .5 X 10 <sup>-2</sup>  |
| Run Time                   | -                    | 17.5                   | 17.5                   | 17.5                   |
| Trim<br>Velocity           | -                    | 683.7                  | 683.7                  | 683.7                  |

TABLE C-II (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| <u>Derivative<br/>Name</u> | <u>Start-<br/>Up</u> | <u>Run No.</u>       |                      |                      |
|----------------------------|----------------------|----------------------|----------------------|----------------------|
|                            |                      | <u>DR11-1W1S2</u>    | <u>DR11-1W2S2</u>    | <u>DR11-1W1S2DEZ</u> |
| $X_u$                      | -.016                | -.026                | -.038                | -.004                |
| $X'_u$                     | -.054                | .012                 | .028                 | .020                 |
| $Z_u$                      | -.12                 | .029                 | .092                 | .172                 |
| $Z'_u$                     | -2.46                | -2.28                | -2.13                | -1.80                |
| $M'_u$                     | 1.34                 | .78                  | .751                 | .32                  |
| $M'_u$                     | -18.6                | -19.0                | -19.1                | -19.1                |
| $M'_q$                     | -4.96                | -9.78                | -9.05                | -7.29                |
| $Z'_{A_e}$                 | -.18                 | -.18                 | -.19                 | -.20                 |
| $M'_{A_e}$                 | -51.8                | -48.8                | -49.1                | -50.3                |
| $X_o$                      | -                    | $-.2 \times 10^{-3}$ | $-.5 \times 10^{-3}$ | $.2 \times 10^{-3}$  |
| $Z_o$                      | -                    | $.2 \times 10^{-1}$  | $.2 \times 10^{-1}$  | $.1 \times 10^{-1}$  |
| $M_o$                      | -                    | $-.4 \times 10^{-2}$ | $-.7 \times 10^{-2}$ | $-.4 \times 10^{-2}$ |
| Run Time                   | -                    | 17.5                 | 17.5                 | 17.5                 |
| Trim<br>Velocity           | -                    | 679.2                | 679.2                | 679.2                |

TABLE C-II (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| Derivative<br>Name | Start-<br>Up | Run No.              |                       |                       |
|--------------------|--------------|----------------------|-----------------------|-----------------------|
|                    |              | <u>DR11-1W2S2DEZ</u> | <u>DR11-U4W1S2DEZ</u> | <u>DR11-U4W2S2DEZ</u> |
| $X_u$              | -.016        | -.006                | -.117                 | -.099                 |
| $X'_u$             | -.054        | .017                 | .017                  | .017                  |
| $Z_u$              | -.12         | .175                 | .158                  | -.011                 |
| $Z'_u$             | -2.46        | -2.00                | -2.00                 | -2.00                 |
| $M_u$              | 1.34         | .259                 | 1.07                  | 1.12                  |
| $M'_u$             | -18.6        | -19.3                | -19.3                 | -19.3                 |
| $M'_q$             | -4.96        | -8.69                | -8.69                 | -8.69                 |
| $Z'_{A_e}$         | -.18         | -.20                 | -.20                  | -.20                  |
| $M'_{A_e}$         | -51.8        | -49.3                | -49.3                 | -49.3                 |
| $X_o$              | -            | $.2 \times 10^{-3}$  | $-.5 \times 10^{-3}$  | $-.2 \times 10^{-3}$  |
| $Z_o$              | -            | $.1 \times 10^{-1}$  | $.5 \times 10^{-2}$   | $.87 \times 10^{-3}$  |
| $M_o$              | -            | $-.6 \times 10^{-2}$ | $-.1 \times 10^{-1}$  | $.6 \times 10^{-2}$   |
| Run Time           | -            | 17.5                 | 70                    | 70                    |
| Trim<br>Velocity   | -            | 679.2                | 679.2                 | 679.2                 |

TABLE C-II (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| Derivative<br>Name | Start-<br>Up | Run No.              |                      |                      |
|--------------------|--------------|----------------------|----------------------|----------------------|
|                    |              | DR12-U5W1S2DEZ       | DR12-U5W2S2DEZ       | DR12-U5W3S2DEZ       |
| $X_u$              | -.016        | -.038                | -.040                | -.038                |
| $X'_u$             | -.054        | -.054                | -.054                | .017                 |
| $Z_u$              | -.12         | -.207                | -.215                | -.233                |
| $Z'_u$             | -2.46        | -2.03                | -2.03                | -2.00                |
| $M_u$              | 1.34         | 1.40                 | 1.28                 | 1.57                 |
| $M'_u$             | -18.6        | -22.0                | -22.0                | -19.3                |
| $M'_q$             | -4.96        | -7.0                 | -7.0                 | -8.69                |
| $Z'_{Ae}$          | -.18         | -.2                  | -.2                  | -.20                 |
| $M'_{Ae}$          | -51.8        | -50.                 | -50.                 | -49.3                |
| $X_o$              | -            | $-.2 \times 10^{-2}$ | $-.2 \times 10^{-2}$ | $-.1 \times 10^{-2}$ |
| $Z_o$              | -            | $-.5 \times 10^{-2}$ | $-.5 \times 10^{-2}$ | $-.6 \times 10^{-2}$ |
| $M_o$              | -            | $.8 \times 10^{-2}$  | $.1 \times 10^{-2}$  | $.4 \times 10^{-2}$  |
| Run Time           | -            | 87.5                 | 87.5                 | 87.5                 |
| Trim<br>Velocity   | -            | 669.9                | 669.9                | 669.9                |

TABLE C-II (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| <u>Derivative<br/>Name</u> | <u>Start-<br/>Up</u> | <u>Run No.</u>       |                      |
|----------------------------|----------------------|----------------------|----------------------|
|                            |                      | <u>DR13-1W1S2</u>    | <u>DR13-1W2S2</u>    |
| $X_u$                      | -.016                | -.029                | -.027                |
| $X'_u$                     | -.054                | +.027                | +.028                |
| $Z_u$                      | -.12                 | +.106                | +.093                |
| $Z'_u$                     | -2.46                | -2.06                | -1.98                |
| $M'_u$                     | 1.34                 | +.91                 | +.70                 |
| $M'_u$                     | -18.6                | -19.7                | -19.4                |
| $M'_q$                     | -4.96                | -9.15                | -9.29                |
| $Z'_{\delta_e}$            | -.18                 | -.19                 | -.20                 |
| $M'_{\delta_e}$            | -51.8                | -48.3                | -48.6                |
| $X_o$                      | -                    | $-.3 \times 10^{-3}$ | $-.3 \times 10^{-3}$ |
| $Z_o$                      | -                    | $.2 \times 10^{-1}$  | $.2 \times 10^{-1}$  |
| $M_o$                      | -                    | $-.2 \times 10^{-1}$ | $-.9 \times 10^{-2}$ |
| Run Time                   | -                    | 17.5                 | 17.5                 |
| Trim<br>Velocity           | -                    | 680.8                | 680.8                |

TABLE C-II (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| Derivative<br>Name | Start-<br>Up | Run No.              |                      |                      |
|--------------------|--------------|----------------------|----------------------|----------------------|
|                    |              | <u>DR14-1W1S1SH</u>  | <u>DR14-1W2S2SH</u>  | <u>DR14-1W3S2SH</u>  |
| $X_u$              | -.016        | .044                 | .052                 | .053                 |
| $X'_u$             | -.054        | .043                 | .042                 | .041                 |
| $Z_u$              | -.12         | +.111                | +.021                | -.021                |
| $Z'_u$             | -2.46        | -2.02                | -2.28                | -2.41                |
| $M_u$              | 1.34         | .40                  | .73                  | .91                  |
| $M'_u$             | -18.6        | -19.5                | -19.3                | -19.2                |
| $M'_q$             | -4.96        | -10.36               | -9.78                | -9.65                |
| $Z'_e$             | -.18         | -.20                 | -.19                 | -.18                 |
| $M'_e$             | -51.8        | -47.7                | -48.6                | -48.7                |
| $X_o$              | -            | $.2 \times 10^{-2}$  | $.2 \times 10^{-2}$  | $.2 \times 10^{-2}$  |
| $Z_o$              | -            | $.1 \times 10^{-1}$  | $.1 \times 10^{-1}$  | $.1 \times 10^{-1}$  |
| $M_o$              | -            | $-.1 \times 10^{-1}$ | $-.1 \times 10^{-1}$ | $-.1 \times 10^{-1}$ |
| Run Time           | -            | 15.0                 | 15.0                 | 15.0                 |
| Trim<br>Velocity   | -            | 687.2                | 687.2                | 687.2                |

TABLE C-II (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| Derivative<br>Name  | Start-<br>Up | Run No.              |                      |                      |
|---------------------|--------------|----------------------|----------------------|----------------------|
|                     |              | <u>DR18-1W1S2</u>    | <u>DR18-1W2S2</u>    | <u>DR18-1W3S2</u>    |
| $X_u$               | -.016        | +0.044               | +0.036               | .024                 |
| $X'_u$              | -.054        | +0.050               | .050                 | .048                 |
| $Z_u$               | -.12         | +0.022               | -.021                | +0.005               |
| $Z'_u$              | -2.46        | -1.66                | -1.44                | -1.64                |
| $M_u$               | 1.34         | +1.94                | 1.29                 | 1.00                 |
| $M'_u$              | -18.6        | -21.0                | -19.7                | -19.3                |
| $M_q$               | -4.96        | -9.23                | -8.88                | -8.62                |
| $Z'_{\dot{\alpha}}$ | -.18         | -.21                 | -.21                 | -.21                 |
| $M'_{\dot{\alpha}}$ | -51.8        | -45.4                | -48.7                | -49.4                |
| $X_o$               | -            | $.8 \times 10^{-3}$  | $.6 \times 10^{-3}$  | $.9 \times 10^{-3}$  |
| $Z_o$               | -            | $.3 \times 10^{-1}$  | $.4 \times 10^{-1}$  | $.2 \times 10^{-1}$  |
| $M_o$               | -            | $-.3 \times 10^{-1}$ | $-.9 \times 10^{-2}$ | $-.5 \times 10^{-2}$ |
| Run Time            | -            | 17.5                 | 17.5                 | 17.5                 |
| Trim<br>Velocity    | -            | 682.8                | 682.8                | 682.8                |

TABLE C-II (CONTINUED)  
IDENTIFICATION RESULTS (FLIGHT CONDITION #2)

| <u>Derivative<br/>Name</u> | <u>Start-<br/>Up</u> | <u>Run No.</u>       |                      |
|----------------------------|----------------------|----------------------|----------------------|
|                            |                      | <u>DR19-1W</u>       | <u>DR19-1W2</u>      |
| $X_u$                      | -.016                | -.097                | -.075                |
| $X'_u$                     | -.054                | +.062                | +.036                |
| $Z_u$                      | -.12                 | -.116                | -.013                |
| $Z'_u$                     | -2.46                | -2.00                | -1.98                |
| $M_u$                      | 1.34                 | -.123                | +.276                |
| $M'_u$                     | -18.6                | -20.0                | -19.55               |
| $M'_q$                     | -4.96                | -9.91                | -9.51                |
| $Z'_{\delta_e}$            | -.18                 | -.19                 | -.20                 |
| $M'_{\delta_e}$            | -51.8                | -45.8                | -48.2                |
| $X_o$                      | -                    | $-.2 \times 10^{-2}$ | $-.2 \times 10^{-2}$ |
| $Z_o$                      | -                    | $-.2 \times 10^{-1}$ | $-.3 \times 10^{-1}$ |
| $M_o$                      | -                    | $+.2 \times 10^{-1}$ | $+.8 \times 10^{-2}$ |
| Run Time                   | -                    | 17.5                 | 17.5                 |
| Trim<br>Velocity           | -                    | 690.0                | 690.0                |

Note: "S" followed by digit indicates degree of  
smoothing for elevator signal